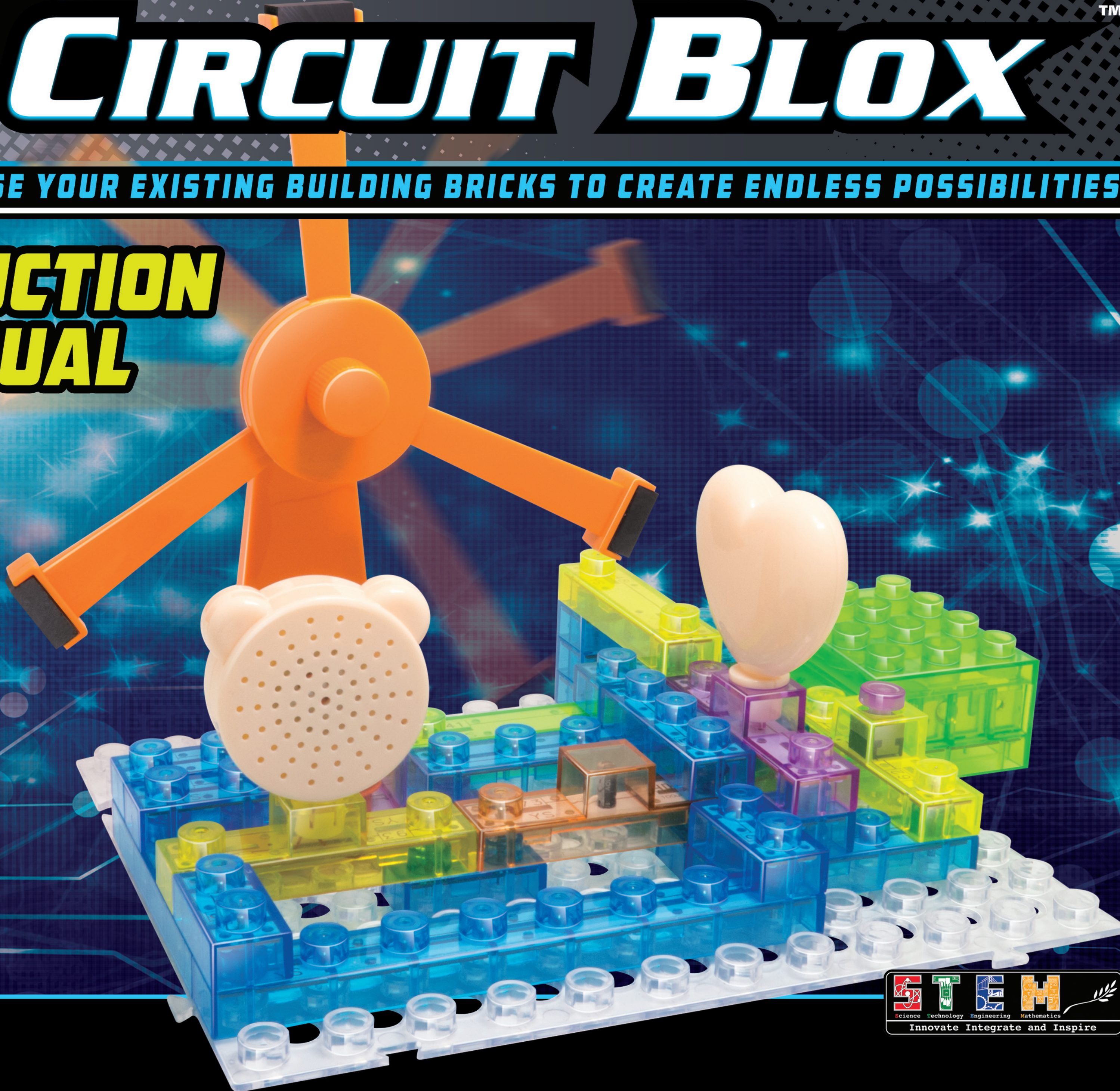
E-Blox®

# Circuit Blox™

USE YOUR EXISTING BUILDING BRICKS TO CREATE ENDLESS POSSIBILITIES!

## INSTRUCTION MANUAL



800 PROJECTS

STEM™
Science Technology Engineering Mathematics
Innovate Integrate and Inspire

# CIRCUIT BLOX™ 800

## WARNING: SHOCK HAZARD

Never connect E-Blox® Circuit Blox™ to the electrical outlets in your home in any way!

## WARNING:

Only use the battery holder with the cover securely in place.

## WARNING: CHOKING HAZARD

Small parts. Not for children under 3 years.

## WARNING: MOVING PARTS

Do not touch the fan while it is spinning.

**WARNING: Always check your wiring before turning on a circuit. Never leave a circuit unattended while the batteries are installed. Never connect additional batteries or any other power sources to your circuits. Discard any cracked or broken parts.**

**Adult Supervision:**

**Because children's abilities vary so much, even with age groups, adults should exercise discretion as to which experiments are suitable and safe (the instructions should enable supervising adults to establish the experiment's suitability for the child). Make sure your child reads and follows all of the relevant instructions and safety procedures, and keeps them at hand for reference.**

**This product is intended for use by adults and children who have attained sufficient maturity to read and follow directions and warnings.**

**Never modify your parts, as doing so may disable important safety features in them, and could put your child at risk of injury.**

**FCC Notice: Please note that changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.**

**NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:**
**• Reorient or relocate the receiving antenna. • Increase the separation between the equipment and receiver. • Connect the equipment into an outlet on a circuit different from that to which the receiver is connected. • Consult the dealer or an experienced radio/TV technician for help.**

## Batteries:

- Use only 1.5V "AA" type, alkaline batteries (not included).
- Insert batteries with correct polarity.
- Non-rechargeable batteries should not be recharged.
- Rechargeable batteries should only be charged under adult supervision, and should not be recharged while in the product.
- Do not mix old and new batteries.
- Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.
- Remove batteries when they are used up.
- Do not short circuit the battery terminals.
- Never throw batteries in a fire or attempt to open its outer casing.
- Batteries are harmful if swallowed, so keep away from small children.

# Basic Troubleshooting

1. Most circuit problems are due to incorrect assembly, always double-check that your circuit exactly matches the drawing for it.
2. Be sure that parts with positive/negative markings are positioned as per the drawing.
3. Be sure that all connections are securely made.
4. Try replacing the batteries. Note: Rechargeable batteries do not work as well as alkaline batteries.

**E-Blox® is not responsible for parts damaged due to incorrect wiring.**

**Note:** If you suspect you have damaged parts, you can follow the Advanced Troubleshooting procedure on page 15 to help determine which ones need replacing.

# About Electricity (Science)

## 1. What is Science?

Q: What do we mean when we say “Science”?

A: Science is defined as the intellectual and practical activity encompassing the systematic study of the structure and behavior of the physical and natural world through observation and experiment.

Early scientists were curious people that wondered what made lightning. They decided to experiment to see if they could understand lightning and even make their own somehow.

## 2. Who Discovered Electricity?

Q: Who was the first scientist to study electricity?

A: In ancient Greece, it was found that rubbing fur on amber produced an attraction between the two. This discovery is credited to the philosopher Thales of Miletus.

One day, when he was polishing his amber at home, he found that a piece of fur was attracted by the amber after he put it on the desk. Then he split them, but it happened again. So he made a record about the phenomenon.

It took many centuries before anyone was able to connect this phenomenon with electricity and a century before electrical current was put to practical use.

## 3. What Other Ways Does Science Help Us?

Q: What are some areas of Science?

A: A few major Sciences are Biology, Chemistry, Astronomy, and Physics.

**Biology** is the study of living things like plants & animals.

**Chemistry** is the study of substances & how they react when you combine them. Things like the plastic in your remote and the batteries that make it work.

**Astronomy** is the study of the universe.

**Physics** is the study of matter, energy, and forces that are on structures like a tall tower.

The science of **Electronics** is considered a branch of Physics.

## 4. Can Science Help Predict the Weather?

Q: What Sciences were used to help weather prediction?

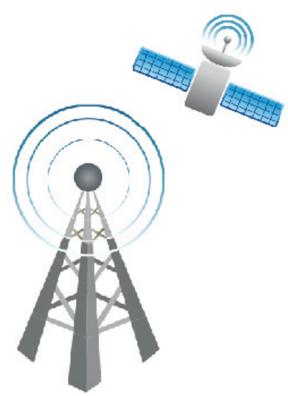
A: Putting a satellite into orbit that could monitor the weather required the use of almost all the Sciences.

**Astronomy** and **Physics** were needed to understand the forces of gravity and how objects stay in orbit.

**Chemistry** was needed to make materials that could withstand the heat and cold and to make fuels to get the satellite into orbit.

**Electronics** was used to study the weather and transmit it back to earth.

**Biology** was needed to study how repair people could work in orbit.



# About Electricity (Technology)

## 5. What is Technology?

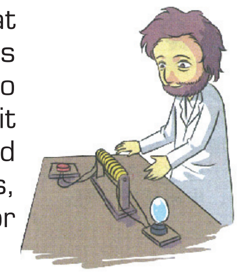
Q: What is technology and who used technology in the past?

A: Technology is the application of scientific knowledge for practical purposes. Dating back to the 18th century, Benjamin Franklin (a famous American) proved that lightning was caused by electricity by performing an experiment in which an electrical conductor would be used to extract power from a thundercloud. In the experiment, he flew a kite with a metal key attached to it into a suitable cloud. The precise historical details are unclear, but he may have then retrieved the key and discharged electricity from it. He later, in 1799, invented the lightning rod, a device that served a practical purpose.

## 6. Technical Terms

Q: What terms do electrical technicians need to know?

A: When technicians work on circuits and appliances there are some terms they need to know. Current is the movement of electrons and is measured in Amperes (Amps), which is named in honor of André-Marie Ampère. Resistance is the opposition of the flow of electric current and is measured in Ohms, which is named after George Ohm. Electro-Motive Force EMF that pushes the electrons through the resistance is measured in Volts, named after Alessandro Volta. Electrical Power is the rate, per unit time, at which electrical energy is transferred by an electric circuit and is measured in Watts, named after the famous technical inventor James Watt.



## 7. Technology in Everyday Life

Q: Where do we see Technology?

A: Since Technology is the application of scientific knowledge, we see it every day when we watch television, cook in an electric pot, ride on a train that is powered by electricity, and more. Repairmen that fix our furnaces or our air-conditioning units are technicians because knowledge of how the science was used to make things hot and cold helps us repair a broken device.

## 8. Is There an Age Requirement to be a Technician?

Q: How old do you have to be to become a Technician?

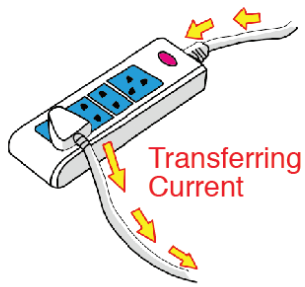
A: Let me tell you a story about a girl named Becky. She was only 10 years old when she was attempting to do her homework in her mom's car. As it got darker outside, she had the idea that there should be a way to make her paper easier to see in the dark. She began playing around with phosphorescent materials, which exhibited light without heat. She then used phosphorescent paint to cover an acrylic board and The Glo-Sheet was created. At the ripe old age of 12, Becky became the youngest woman to be approved for a U.S. patent for her Glo-Sheet invention.

# About Electricity (Engineering)

## 9. What is Engineering?

Q: What is Engineering? What do engineers do?

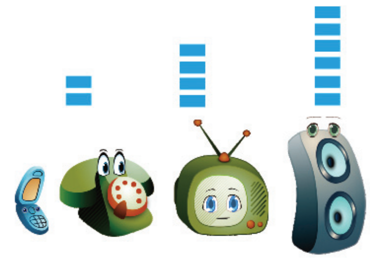
A: Engineering is the application of Science, Technology, and Mathematics to make products that are useful to people. Engineers are skillful in using their knowledge to make products. For example, surge protectors transfer current from the electrical wall outlet to the electrical appliances plugged into it while protecting the appliances from large spikes of electricity which could damage them. Some surge protectors have many sockets to plug computers and TVs into them, while others only have two. The design is an engineer's job.




## 10. Is Engineering only about Electronics?

Q: Besides Electronics what else do Engineers do?

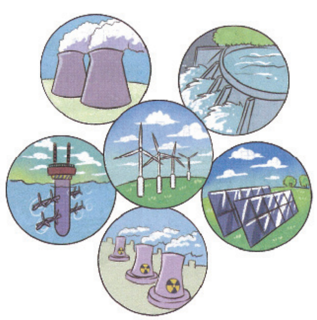
A: Engineers must design the products to be the most appealing at the best price. Product appearance helps marketing sell the product. Product performance is also important and engineers are given specifications by marketing to meet their requirements. Safety is always very important. An audio device should only be loud enough to serve the specifications. Production Engineers use electronic and magnetic sensors to automate production. Civil engineers design roads and bridges that are safe for everyone to use.



## 11. Engineering and Electricity Generation

Q: Do engineers help make electricity for daily use?

A: Yes! So far they have designed systems that use the seven fundamental methods of directly transforming other forms of energy into electrical energy: Fossil-fuel, biomass, hydro/tidal, wind, nuclear, mechanical power generation, and solar thermal energy. Certainly there will be more methods for electricity generation to be found, since the engineers, like artists, are always creating.



## 12. Environmental Engineering - Battery Recycling

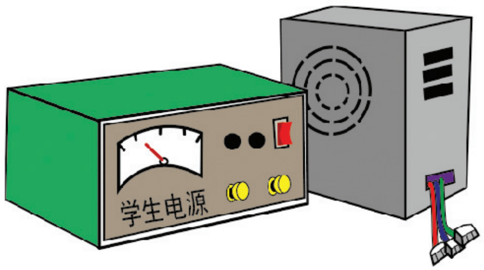
Q: How do Engineers help protect our environment?

A: Batteries contain a number of toxic chemicals and their improper disposal may cause soil contamination and water pollution. Engineers know that most typical kinds of batteries can be recycled, especially lead-acid automotive batteries which are nearly 90% recycled today. Nickel-cadmium (Ni-Cd), nickel metal hydride (Ni-MH), lithium-ion (Li-ion) and nickel zinc (Ni-Zn) can also be recycled. Engineers are always looking for ways to make products safe like integrating fuses into their designs to prevent overheating and fires.

# About Electricity (Mathematics)

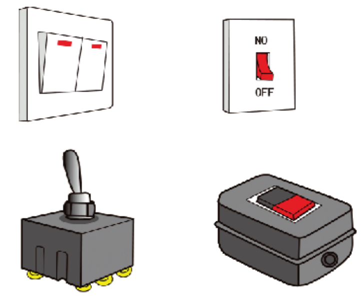
## 13. Ohm's Law

Ohms Law states that Voltage equals Current multiplied by Resistance. If V = Voltage, I = Current, and R = Resistance, then mathematically Ohms Law is V = I x R where "x" stands for "multiplied by". Since the law starts with Voltage, we need a voltage source or a Power Supply. There are both DC (direct current) and AC (alternating current) power supplies. Batteries are also a source of DC voltage. Using Algebra, any one unknown can be calculated if the other two variables are known. For example, if V =9 Volts and R=1000 Ohms, then I=0.009 Amp or 9 milliamps.




## 14. Switches and Power

A switch is a device that may control other components in the circuit. It is used for power connection and disconnection. A switch is a device that is either ON or OFF and used often in digital electronics. Power is the product of the current in a device multiplied by the voltage across it. Electronic Power is expressed in Watts. Mathematically this is expressed as W = V x I. If you have a 60 Watt light that is on a voltage of 120 Volts, then the current can be calculated to be 60 Watts divided by 120 Volts, which equals 1/2 Amp. Some switches are controlled by magnets and others by temperature.

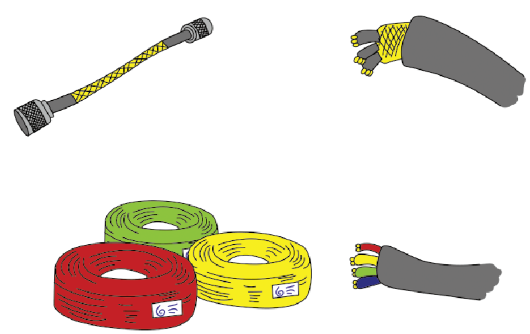



## 15. Using Mathematics to Calculate Fuses

Many different appliances can be connected to draw current from the outlets in your homes. If these outlets are all connected to one fuse, then the fuse must be able to handle the sum of all the currents being drawn. Fuses are used in the battery holder that comes with this product. Each current drawn from any outlet in your home will add up as the appliances are turned ON because they are all connected in parallel.

## 16. Calculating Resistance

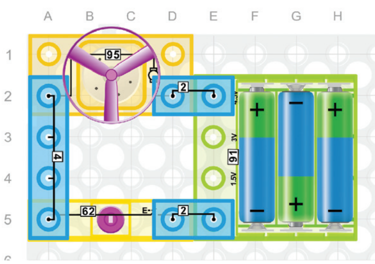
Conductive paths are used to connect circuits and transfer electricity. If the voltage on one end of the conductor is lower than on the other end when current is flowing, then the conductor has resistance. The voltage drop on the conductor divided by the current in the conductor is the Resistance of the conductor or wire. In Mathematical terms and from Ohms law, this would be stated as R = V/I. If the voltage drop is 2 Volts when 4 Amps is flowing, then the resistance of the conductor is 1/2 Ohm.



# About Electricity (STEM)

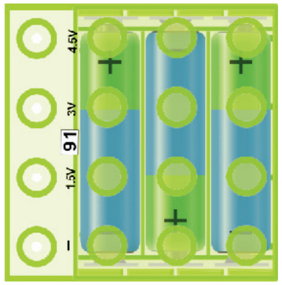
## 17. Circuit Blox™

For Circuit Blox™, the definition of an electrical circuit is: The complete path for an electric current flow, usually including the source of electric energy. The path shown in the circuit below is from the battery, through the blue 2-wire, through the motor under the fan, through the blue 4-wire, through the switch, through the blue 2-wire, and then back to the battery. If the switch in this circuit is closed, then current will flow from the battery through all the components and back to the battery. If enough current flows, the motor will spin and launch the fan. If the switch is open, nothing will happen since it is an open circuit with no current.




## 18. Short Circuits in Circuit Blox™

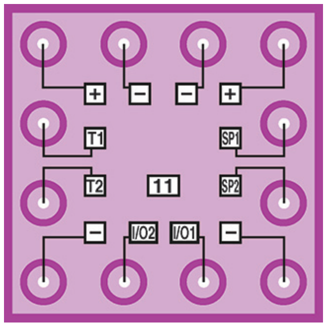
The battery holder that comes with your Circuit Blox™ Kit is fully protected. A short circuit indicator LED lights and a beeper sounds if any of the outputs are shorted or under a high current draw. It is important that you always use this battery holder in the circuits you build to protect the batteries and prevent damage to parts. Even shorts from one voltage output to another is protected by a patented circuit and will indicate an excessive current. This circuit uses resettable Positive Temperature Fuses (PTCs). Circuit Blox™ kits are always approved by independent safety laboratories to insure all users will be able to experiment without worry of harm to parts or themselves.




## 19. Sound and Light

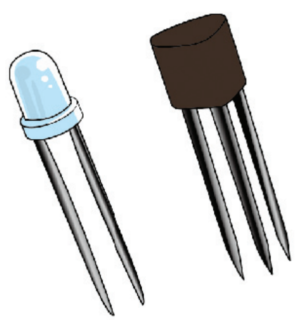
There are many modules in Circuit Blox™ that will produce different sounds and different light effects.

The Three-in-One module, for example, has two control inputs (T1, T2), a speaker connection (SP1, SP2), and music & space sound selects (I/O1, I/O2). By proper connection of parts with the Three-in-one module many special effects can be generated and triggered in different ways. This module will be used to simulate many of the different interesting problems in the fields of Sound Technicians, Medical Engineering, Communication Engineers, Home Security, and much more.



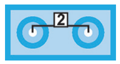
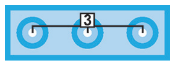
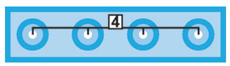
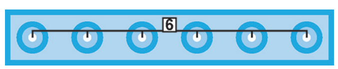
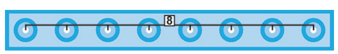
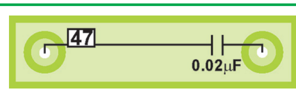

## 20. Semiconductors

Semiconductors have properties that can control current flowing through a conductor similar to a faucet controlling the flow of water in a pipe. A diode acts like a check valve in a water pipe by only letting current flow in one direction. A Light Emitting Diode (LED) produces light when very little current flows. Different colored LEDs are made and some LEDs can even produce Laser light similar to hand-held pointers or gun scopes. Transistors have three leads and one is used to control the current between the other two.



# Parts List (colors and styles may vary) Symbols and Numbers

**Important:** If any parts are missing or damaged, **DO NOT RETURN TO RETAILER.** Call toll-free (855) MY EBLOX (693-2569) or e-mail us at: support@myeblox.com. Customer Service: 880 Asbury Dr., Buffalo Grove, IL 60089 U.S.A.

| Qty. | Name | Symbol | Part # |
|---|---|---|---|
| 5 | 1-wire Block |  | 6EB2X01 |
| 12 | 2-wire Block |  | 6EB2X02 |
| 4 | 3-wire Block |  | 6EB2X03 |
| 5 | 4-wire Block |  | 6EB2X04 |
| 1 | 5-wire Block |  | 6EB2X05 |
| 1 | 6-wire Block |  | 6EB2X06 |
| 1 | 8-wire Block |  | 6EB2X08 |
| 1 | 100Ω Resistor |  | 6EB2X41 |
| 1 | 1kΩ Resistor |  | 6EB2X42 |
| 1 | 10kΩ Resistor |  | 6EB2X44 |
| 1 | 100kΩ Resistor |  | 6EB2X45 |
| 1 | 0.02μF Capacitor |  | 6EB2X47 |

| Qty. | Name | Symbol | Part # |
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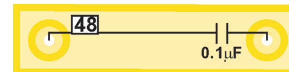
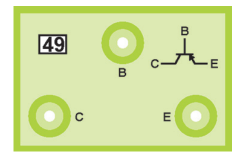
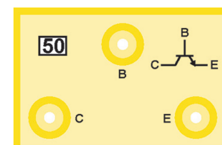
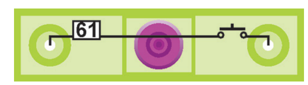
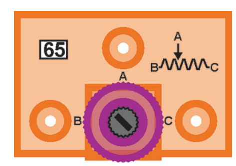
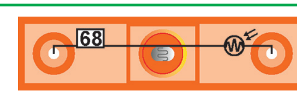
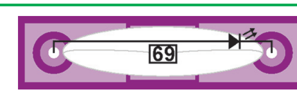
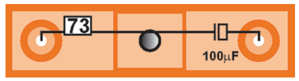
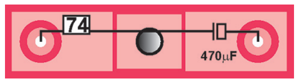
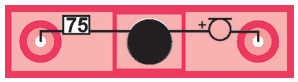
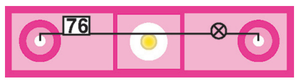
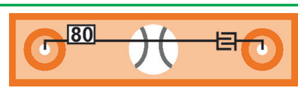
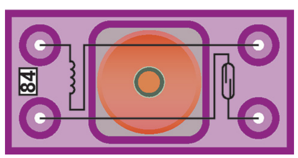
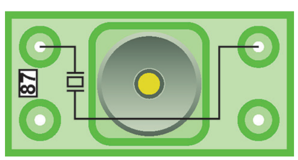
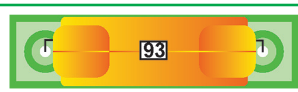
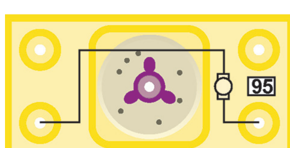
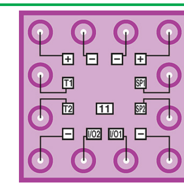
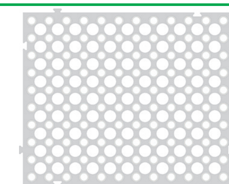
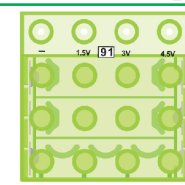
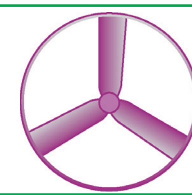
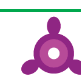
| 1 | 0.1μF Capacitor |  | 6EB2X48 |
| 1 | 10μF Capacitor |  | 6EB2X52 |
| 1 | PNP Transistor |  | 6EB2X49 |
| 1 | NPN Transistor |  | 6EB2X50 |
| 2 | Press Switch |  | 6EB2X61 |
| 1 | Switch |  | 6EB2X62 |
| 1 | Variable Resistor |  | 6EB2X65 |
| 1 | Photo Resistor |  | 6EB2X68 |
| 1 | Heart LED |  | 6EB2X69 |

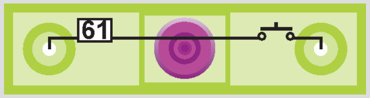
| Qty. | Name | Symbol | Part # |
|---|---|---|---|
| 1 | Star LED |  | 6EB2X70 |
| 1 | 100µF Capacitor |  | 6EB2X73 |
| 1 | 100µF Capacitor |  | 6EB2X74 |
| 1 | Microphone |  | 6EB2X75 |
| 1 | Lamp |  | 6EB2X76 |
| 1 | Touch Switch |  | 6EB2X80 |
| 1 | Reed Switch |  | 6EB2X83 |
| 1 | Inductor |  | 6EB2X84 |
| 1 | Buzzer |  | 6EB2X87 |
| 1 | Speaker |  | 6EB2X93 |
| 1 | Motor |  | 6EB2X95 |

| Qty. | Name | Symbol | Part # |
|---|---|---|---|
| 1 | Magnet |  | 6EB2X07 |
| 1 | Spring Wire |  | 6EB2X09 |
| 3<br>3 | 1&2 Level Block |  | 6EB2X100<br>6EB2X200 |
| 1 | Windmill Assembly |  | 6EB2X90 |
| 1 | 3-in-1 Module |  | 6EB2X11 |
| 1 | Base Grid |  | 6EB2X39 |
| 1<br>1 | Battery Holder<br>Battery Cover |  | 6EB2X91<br>6EB2X91C |
| 3 | Fan Blade |  | 6EB2X60 |
| 3 | Motor Shaft Cap |  | 6EB2X60A |
| 3 | Motor Top |  | 6EB2X64 |

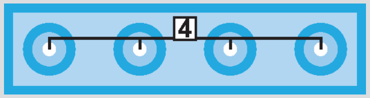
# How to Use Your E-Blox® Circuit Blox™ Set

E-Blox® Circuit Blox™ parts contain a PC board with connectors so you can build the different electrical and electronic circuits in the projects. Each block has a function: there are switch blocks, a light block, battery block, wire blocks, etc. These blocks are different colors and have numbers on them so that you can easily identify them.

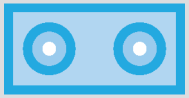
**For Example:**
This is the press switch, it is green and has the marking 61 on it. The part symbols in this booklet may not exactly match the appearance of the actual parts, but will clearly identify them.

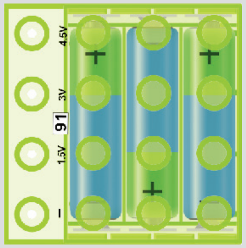



This is a wire block which comes in 5 different lengths. The part has the number 1, 2, 3, 4, 5, or 6 on it depending on the length of the wire connection required.




There are also 1-post and 2-post blocks that are used as a spacer or for interconnection between different layers.





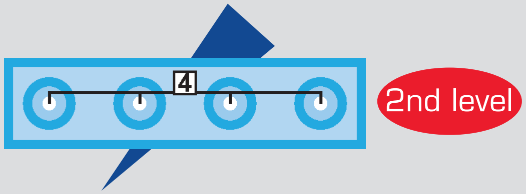
You need a power source to build each circuit. The part is marked 91 and requires three (3) 1.5V "AA" batteries (not included). The four connections are marked –, 1.5V, 3V, and 4.5V.

A short circuit indicator LED lights and beeper sounds if any of the outputs are shorted or under a high current draw.

Only use the battery holder when the cover is securely in place.

A large clear plastic base grid is included with this kit to help keep the circuit blocks properly spaced. You will see evenly spaced posts that the different blocks plug into.

Next to the assemble drawing may be a part with an arrow and red circle as shown below. This indicates that the part is installed below other parts and which level it is on.



# About Your E-Blox® Circuit Blox™ Parts

(Part designs are subject to change without notice).

The **base grid** functions like the printed circuit boards found in most electronic products. It is a platform for mounting parts and wire blocks (though the wires are usually "printed" on the board).

The blue **wire blocks** are just wires used to connect other components, they are used to transport electricity and do not affect circuit performance. They come in different lengths to allow orderly arrangement of connections on the base grid.

The **spring wire (9)** is two single blocks connected by a wire used to make unusual connections.

The **batteries (91)** produce an electrical voltage using a chemical reaction. This "voltage" can be thought of as electrical pressure, pushing electrical "current" through a circuit. This voltage is much lower and much safer than that used in your house wiring. Using more batteries increases the "pressure" and so more electricity flows.

The **switch (62)** connects (ON) or disconnects (OFF) the wires in a circuit.

The **press switch (61)** connects (pressed) or disconnects (not pressed) the wires in a circuit, just like the switch does.

The **4.5V lamp (76)** contains a special wire (filament) that glows bright when a large electric current passes through it. Voltages above the bulb's rating can burn out the wire.

A **reed switch (83)** is an electrical switch operated by an applied magnetic field. When exposed to a magnetic field, the switch closes (ON). When the magnetic field is removed the switch opens (OFF).

The **touch plate (80)** is a type of switch when both electrodes are touched together using your finger, shorts the two electrodes and a small amount of current flows, activating the circuit.

The blue **level blocks (100 & 200)** are non-conductive and just used as building blocks.

The **LEDs (69 & 70)** is a light emitting diode inside the star, and may be thought of as a special one-way light bulb. In the "forward" direction (indicated by the "arrow" in the symbol) electricity flows if the voltage exceeds a turn-on threshold (between 1.8V to 3.3V typically); brightness then increases. A high current will burn out the LED, so the current must be limited by other components in the circuit. LEDs block electricity in the "reverse" direction.

The **motor (95)** converts electricity into mechanical motion. Electricity is closely related to magnetism, and an electric current flowing in a wire has a magnetic field similar to that of a very, very tiny magnet.

Inside the motor are three coils of wire with many loops. If a large electric current flows through the loops, the magnetic effects become concentrated enough to move the coils. The motor has a magnet inside, so as the electricity moves the coils to align them with the permanent magnet, the shaft spins.

The **resistors (41, 42, 44, 45)** are used to add resistance to your circuits that limits the flow of current. Resistance is measured in Ohms which uses the symbol Ω, and higher resistance values will limit the flow of current more than lower resistance values.

The **variable resistor (65)** is used just like a resistor to limit current in your circuits, but can also be used as a voltage divider. As you turn the knob on the variable resistor clockwise, the resistance between the points marked A and B on the variable resistor increases and the resistance between the points marked A and C on the variable resistor decreases.

Conversely, as you turn the knob on the variable resistor counter-clockwise, the resistance between the points marked A and B on the variable resistor decreases and the resistance between the points marked A and C on the variable resistor increases.

In practice variable resistors are used to set voltage levels at the center tap (marked A) of the variable resistor.

# About Your E-Blox® Circuit Blox™ Parts

The **photoresistor (68)** is used just like a resistor to limit current in your circuits. But the resistance value of the photoresistor depends on the intensity of light that shines on the photoresistor. The photoresistor provides very low resistance when bright light is shining on it, and very high resistance when in the dark.

The **capacitors (47, 48, 52, 73, 74)** are used to introduce capacitance in your circuits by storing and releasing charge across two plates with a dielectric material between them. The time it takes to charge up the capacitor and for the capacitor to discharge depends on the capacitor value and the resistance in the circuit.

Capacitance is measured in Farads, and larger valued capacitors take longer to charge and discharge than smaller valued capacitors. In practice capacitors are used to block Direct Currents (DC current) and pass Alternating Currents (AC current).

The **microphone (75)** is used to convert sound to an electrical signal in your circuits.

The **inductor (84)** is used to provide inductance in your circuits by creating magnetic fields that vary as the current flowing through the inductor varies. An inductor typically consists of an insulated wire wound into a coil around a core.

The unit of measure for inductance is the Henry, and larger valued inductors create larger magnetic fields per Ampere of current than smaller valued inductors. In practice inductors are used to block Alternating Currents (AC current) and pass Direct Currents (DC current). Note that your inductor module also includes a reed switch across two of it's terminals, which is useful for windmill spinning projects.

The **buzzer (87)** is a high impedance speaker that is used to produce sound from the signals you send through it (e.g. the signals from the 3-in-1 module).

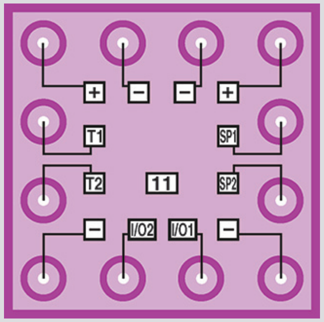
The **windmill (90)** has magnets on the ends of its spokes that enable it to gain acceleration when passing over the inductor module.

The **transistors (49, 50)** are used as switches and amplifiers in your circuits. The transistors have three terminals: the base, the collector and the emitter. For the NPN transistor, a little current into the base allows a large current to flow from collector to emitter. For the PNP transistor, a little current out of the base allows a large current to flow from emitter to collector. In practice, transistors are used for switching and amplification.

The **speaker (93)** converts electricity into sound. It does this by using the energy of a changing electrical signal to create mechanical vibrations (using a coil and magnet similar to that in the motor). These vibrations create variations in air pressure which travel across the room. You "hear" sound when your ears feel these air pressure variations.

Some types of electronic components can be super-miniaturized, allowing many thousands of parts to fit into an area smaller that your fingernail. These "integrated circuits" (ICs) are used in everything from simple electronic toys to the most advanced computers.

The **three-in-one (11)** modules contain specialized sound-generation ICs and other supporting components (resistors, capacitors, and transistors) that are always needed with them. This was done to simplify the connections you need to make to use them. The pin descriptions are given here for those interested, see the projects for connection examples:




**Three-in-One:**
T1, T2 - control inputs
SP1 - speaker – connection
SP2 - speaker + connection
I/O1 - music select
I/O2 - space sound select
(+) - power to batteries
(–) - power return to batteries

# DOs and DON'Ts of Building Circuits

After building the circuits given in this booklet, you may wish to experiment on your own. Use the projects in this booklet as a guide, as many important design concepts are introduced throughout them. Every circuit will include a power source (the batteries), a resistance (which might be an LED, lamp, motor, integrated circuit, etc.), and wiring paths between them and back. **You must be careful not to create "short circuits" (very low-resistance paths across the batteries, see examples below) as this will damage components and/or quickly drain your batteries.** Only connect the parts using configurations given in the projects, incorrectly doing so may damage them. **E-Blox® is not responsible for parts damaged due to incorrect wiring.**

## Here are some important guidelines:

***DO*** **USE EYE PROTECTION WHEN EXPERIMENTING ON YOUR OWN.**

***DO*** include at least one component that will limit the current through a circuit, such as the speaker, lamp, LED, integrated circuit (IC, which must be connected properly), or motor.

***DO*** disconnect your batteries immediately and check your wiring if something appears to be getting hot.

***DO*** check your wiring before turning on a circuit.

***DO*** connect the IC using configurations given in the projects or as per the connection descriptions for the part.

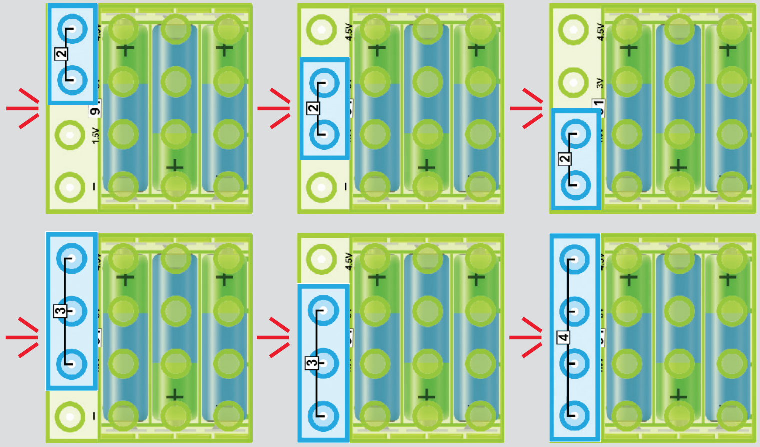
***DON'T*** connect to an electrical outlet in your home in any way.

***DON'T*** leave a circuit unattended when it is turned on.

***DON'T*** touch the motor when it is spinning at high speed.

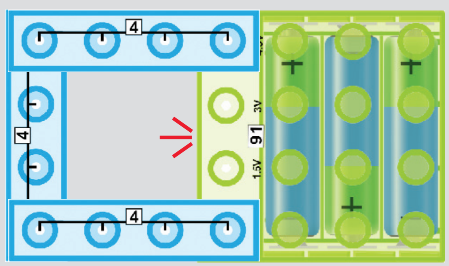
# Examples of SHORT CIRCUITS – NEVER DO THIS!

Placing a wire block directly across the battery holder is a SHORT CIRCUIT, indicated by a flashing LED in the battery holder.



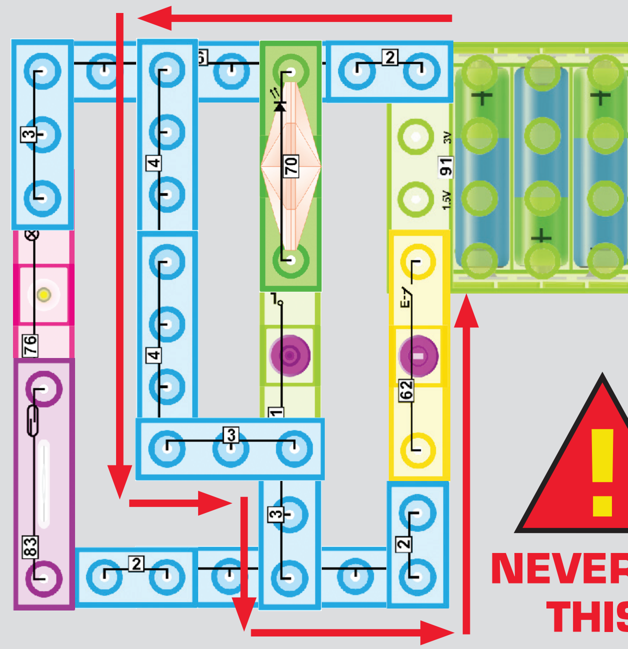
**NEVER DO THIS!**

**NEVER DO THIS!**



**NEVER DO THIS!**

When the switch (S1) is turned on, this large circuit has a SHORT CIRCUIT path (as shown by the arrows). The short circuit prevents any other portions of the circuit from ever working.



**NEVER DO THIS!**

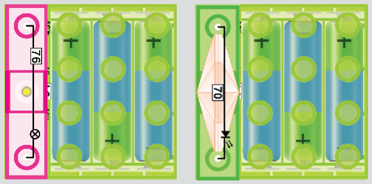
**WARNING: SHOCK HAZARD!** Never connect E-Blox® Circuit Blox™ to the electrical outlets in your home in any way!

# Advanced Troubleshooting (adult supervision recommended)

**E-Blox® is not responsible for parts damaged due to incorrect wiring.**

**If you suspect you have damaged parts, you can follow this procedure to systematically determine which ones need replacing:**

1. **Lamp (76), LEDs (69, 70), Battery Holder (91):** Place part directly across the battery holder as shown, it should light. If none work, then replace your batteries and repeat, if still bad then the battery holder is damaged. Make sure the LED is installed in the correct direction.

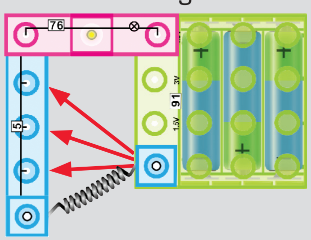


2. **Wire Blocks (1-6), Spring Wire (9), and Speaker (95):** Use this mini-circuit to test each of the Wire Blocks and Speaker (95), one at a time. The lamp (76) should light if the part is functioning properly. Follow the steps below:

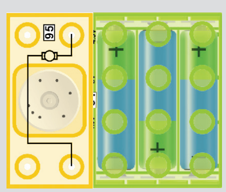
   Spring Wire test - Build the circuit shown below. The lamp (76) should light.

   Wire Block tests - Insert the Wire Blocks between the spring wire to lamp connection shown in the figure. The lamp should light.

   Speaker test - Insert the speaker (95) between the spring wire to lamp connection shown in the figure. The speaker will not sound, but the lamp will light.



3. **Motor (95):** Place the motor across the battery holder (95 at top) as shown; it should spin clockwise.

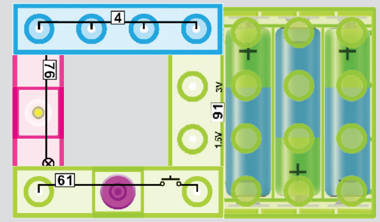


4. **Switch (62), Press switch (61), Reed Switch (83), Touch Plate (80):** Use this circuit to test each switch and the touch plate (80). The lamp (76) should light. If the lamp doesn't light, then the switch is bad.

   Switch - Up position the lamp off, Down position lamp on.

   Press - Light when switch is pressed.

   Reed - When you place the magnet on the switch the lamp should light.



   Touch Plate - Wet your finger; when you touch the contacts, the lamp should light.

5. **Three-in-One (11):** Siren - Build project #163, you should hear a siren sound from the speaker.

   Fire Siren - Build project #165, you should hear a fire siren from the speaker.

   Space Battle - Build project #166, you should hear a space battle sound from the speaker.

   Music - Build project #167, you should hear a music from the speaker.

   Machine Gun - Build project #164, you should hear machine gun sounds from the speaker.

**E-Blox®**
880 Asbury Dr., Buffalo Grove, IL 60089 U.S.A.
Phone / Fax: (855) MY EBLOX (693-2569)
e-mail: help@myeblox.com ● Website: www.myeblox.com

**You may order additional / replacement parts at: www.pickabrick.com**

# Project Listings

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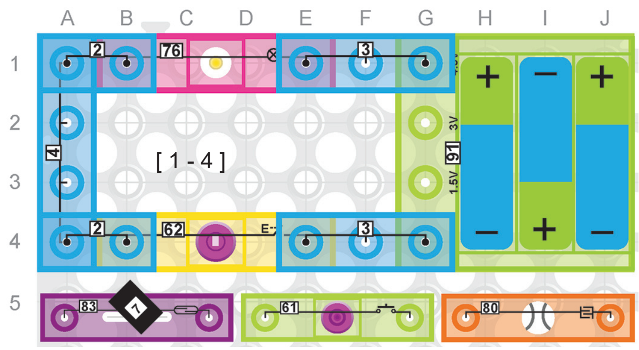
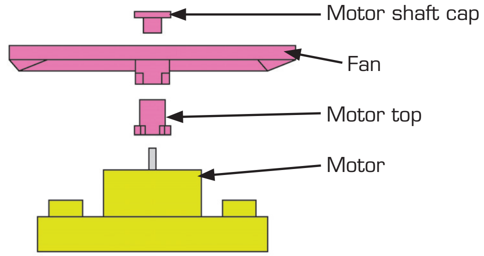
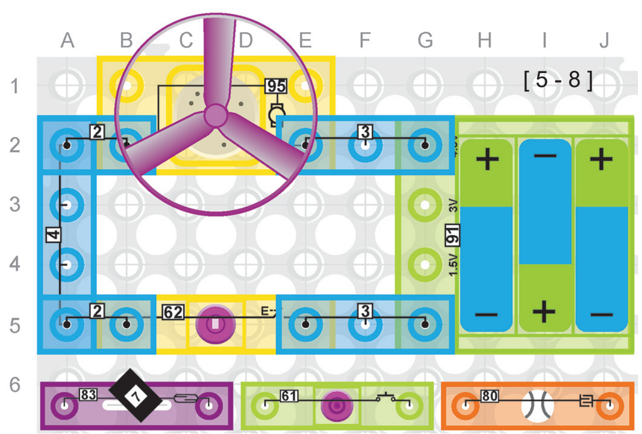



**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.

## 1. Closed Circuit

E-Blox® Circuit Blox™ uses electronic blocks that plug into a clear plastic grid to build different circuits. These blocks have different colors and numbers on them so that you can easily identify them.

Build the circuit shown on the left by placing all the parts that plug into the first layer base. Then, assemble the parts that connect to the secondary layer. Install three (3) "AA" batteries (not included) into the battery holder (91). **Secure the battery cover before using it.**

Pressing the switch (62) creates a closed circuit; the lamp (76) will turn on. Press it again to open the circuit and the lamp (76) will turn off.

## 2. Magnetic Switch

Replace the switch (62) with the reed switch (83). Put the magnet (7) near the reed switch (83) and the lamp (76) will turn on. Move the magnet (7) away and the lamp (76) will turn off. This is a "no touch" switch!

## 3. The 'Momentary' Switch

Replace the reed switch (83) with the press switch (61). Press and hold the press switch (61) and the lamp (76) will turn on. Release the press switch (61) and the lamp (76) will turn off. This type of switch is called a 'momentary' switch since it is only on when pressed.

## 4. The Touch Plate

Replace the press switch (61) with the touch plate (80). If you touch the touch plate (80), the lamp (76) will not turn on. This is because your finger is not a good enough conductor to allow enough current to flow through the circuit to light the lamp (76). Try pushing a metal object like a thick metal paper clip across the touch plate shiny area and you will see the lamp (76) light up. We will see later that there are certain types of circuits where your finger will be a good enough conductor to use the touch plate (80) as a switch, but this circuit is not one of them.

## 5. Electrical to Mechanical Energy

Assemble the fan (60) by following the assembly diagram shown on the left. Build the circuit to the left. Press the switch (62) and the fan (60) will spin as long as the switch (62) is pressed. Electrical energy from the batteries has been changed to mechanical energy by the motor (95).

## 6. Proximity Sensor

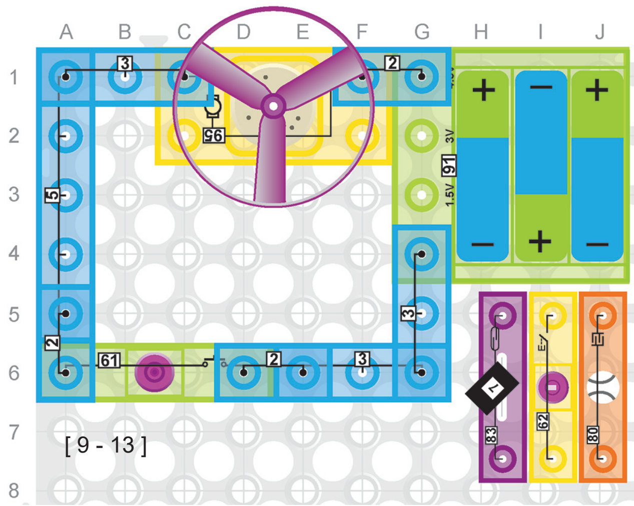
Replace the switch (62) with the reed switch (83), then move the magnet (7) near the reed switch (83) and the motor (95) will turn on. Move the magnet (7) away and the motor (95) will turn off. Proximity sensing like this is often used to control things like blow drying your car in a car wash.

## 7. Newton's First Law of Motion

Replace the reed switch (83) with the press switch (61), press and hold the press switch (61) and the fan (60) will start spinning. Release the press switch (61), the fan (60) will slow down and finally stop due to friction in the motor (95). This demonstrates Newton's First Law of Motion: An object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.

## 8. Good Conductors

Replace the press switch (61) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the fan (60) will start spinning. What makes metal such a good conductor? In order to allow current to flow, negatively charged particles (called electrons) or positively charged particles (called holes) need to be able to move freely. Metals generally have an abundance of delocalized electrons that make them good conductors when connected to a circuit like this one.




**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.

## 9. Newton's Second Law of Motion

Remove the cap (60A) that is on the fan blade (60). Hold the press switch (61) for ten seconds. Release the press switch (61) and the flying saucer should take off (Caution! Never let it fly near your face!). If the fan (60) does not fly, make sure the batteries are fresh, the motor (95) is in the correct direction and give the fan (60) a tap from underneath with the top of your fingernail. This circuit demonstrates Newton's Second Law of Motion: acceleration is produced when a force acts on a mass. In this case, air pressure under the fan blade (60) forces it to rise.

## 10. Magnet-controlled Flying Saucer

Replace the press switch (61) with the reed switch (83) and move the magnet (7) towards the reed switch (83). Wait for a few seconds then move the magnet (7) away to launch the saucer. A reed switch is typically made from two or more ferrous reeds encased within a small glass tube-like envelope, which become magnetized and move together or separate when a magnetic field is moved towards the switch.

## 11. Flying Saucer Design

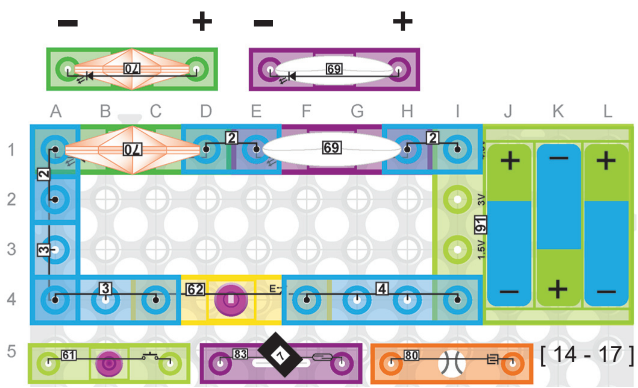
Replace the reed switch (83) with the switch (62). Press the switch (62) and wait ten seconds. Turn off the switch (62) and the flying saucer should take off. Newton's Law explains technically why the saucer launches, but look closely as the design of the saucer. You will see that the spokes of the saucer are tilted. This is what enables the air pressure to force the fan (60) upwards when it's spinning.

## 12. Helicopters

Replace the switch (62) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the fan (60) will start spinning. Remove the metal piece and the saucer should launch. Helicopters are designed with fan blades like the ones in your saucer, which is what enables helicopters to fly.

## 13. Reversing the Motor

Install the motor (95) in the reverse direction (i.e. so the 95 is near the top instead of near the bottom) and move the magnet (7) towards the reed switch (83). This time when you move the magnet (7) away the fan (60) does not launch. This is because by installing the motor (95) reversely, the motor (95) shaft spins in the opposite direction which makes the force on the fan blade (60) push the fan (60) in the downward direction.




## 14. LEDs in Series

Build the circuit shown on the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light (make sure both LED modules are in the circuit in the correct direction based on the markings show in the diagram), but they are both dim. This is because these LED modules have internal resistance built into them to protect from too much current going through the LED and burning it out. By placing the heart LED (69) and star LED (70) in series like in this circuit, there is only a single path for current to flow from the 4.5V terminal of the battery (91) to the "–" terminal of the battery (91), which is through both LED modules. Thus the current in this circuit is limited by the sum of the internal resistances of each LED module, which is why the LEDs are dim.

## 15. Disadvantage of Series Circuits

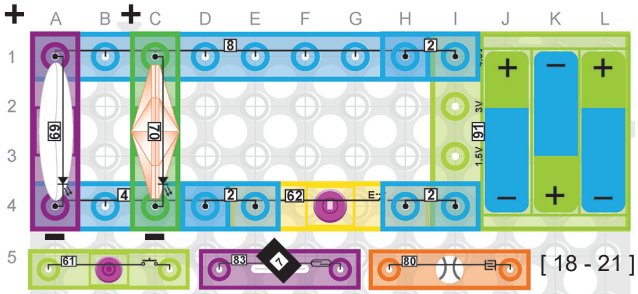
Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light dimly. Try disconnecting the heart LED (69) from the circuit and notice that the star LED (70) also goes off. This is one of the disadvantages of series circuits. Since there is only one current path running through both LEDs, removing one of these components creates an open circuit that disables current from flowing through the other component. Remember those old Christmas lights where one light going out made them all go out?

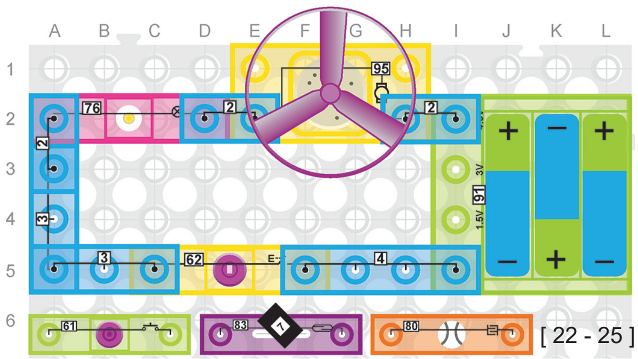
## 16. Advantage of Series Circuits

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and both the heart LED (69) and star LED (70) with light dimly. Although dim, the LED modules do still light and one of the benefits of this series circuit is that it is drawing less current so the batteries will not drain as quickly.

## 17. Overheating Benefits of Series Circuits

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and both the heart LED (69) and star LED (70) with light dimly. As discussed in projects #14 & #16, series circuits reduce the current flow through the circuit. Since lower current is flowing through each component, in this case the LEDs, it is less likely for these components to get hot and overheat.




**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.

## 18. LEDs in Parallel

Build the circuit shown on the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light, and this time they will both be bright. This is because these LED modules are in parallel in this circuit, which allows separate current paths to flow through each LED module. Each current path in this circuit is only limited by the internal resistances of the LED module in that path (i.e. the current flowing through the heart LED (69) is only limited by the internal resistance of the heart LED (69), and likewise for the star LED (70)), and thus each LED module is bright.

## 19. Advantage of Parallel Circuits (I)

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and both the heart LED (69) and star LED (70) with light brightly. Try disconnecting the heart LED (69) from the circuit and notice that the star LED (70) is still on.

This is one of the advantages of parallel circuits. Since there are separate current paths running through the heart LED (69) and the star LED (70), removing one of these components does not affect the current flowing through the other component. This is why the lights in your house use parallel circuits (when one light bulb burns out, you wouldn't want all the lights to go out in your house!).

## 20. Disadvantage of Parallel Circuits

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and both the heart LED (69) and star LED (70) with light brightly. Due to the parallel paths created by each LED module, more current is enabled to flow from the batteries in this circuit than when the LED modules are in series. Thus, one of the disadvantages of parallel circuits is that they drain the batteries more quickly.

## 21. Advantage of Parallel Circuits (II)

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and both the heart LED (69) and star LED (70) with light brightly.

Another benefit of parallel circuits vs. series circuits is that as you add components in parallel they don't affect the other components in the circuit (assuming there is enough battery power). Every time you add a component in series, it reduces the current flowing through the circuit which may affect the performance of the other components in series. But adding components in parallel just creates new paths for current to flow, minimally effecting the current flow through the other components.

## 22. Inertia

Build the circuit shown on the left, press the switch (62), and you will see the lamp (76) turn on dimly and the motor (95)/fan (60) spin at medium speed. Turn OFF the switch (62) and the motor (95)/fan (60) will keep spinning for a little while, but the lamp (76) will turn off immediately.

This circuit demonstrates the concept of Inertia: a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force. The motor (95)/fan (60) has inertia but the lamp (76) does not.

## 23. Motor at Medium Speed

Replace the switch (62) with the press switch (61). Press and hold the press switch (61) and you will see the lamp (76) is on dimly and the motor (95) spins at medium speed. Because the motor (95) is in series with the lamp (76), and the lamp (76) introduces resistance, there is less current that flows through the motor (95) in this circuit compared to projects #5-13, which is why the motor (95) spins slower in this project.

## 24. Reed Switch vs. Mechanical Switch

Replace the press switch (61) with the reed switch (83). Hold the magnet (7) near the reed switch (83) and you will see the lamp (76) turn on dimly and the motor (95) spin at medium speed.

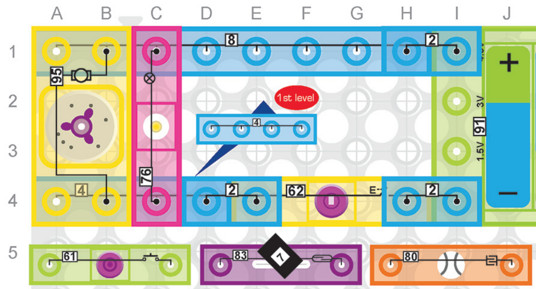
One of the benefits of reed switches over mechanical switches like the press switch (61) is reliability/lifetime. Mechanical switches can wear out more quickly as you use them, and some studies show that reed switches can be used 10,000 times more often than mechanical switches before they wear out.

## 25. Ohm's Law

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip you will see the lamp (76) turn on dimly and the motor (95) spin at medium speed. If you had a voltmeter and measured the voltage drop across each component, you would see that the voltage drop across the motor (95) is similar to the voltage drop across the lamp (76). According to Ohm's Law, $V = I*R$, where R stands for Resistance, V stands for Voltage, and I stands for Current. Since the lamp (76) and motor (95) are in series in this circuit, the same current runs through each. Ohm's law then tells us that the internal/equivalent resistance of the motor must be similar to that of the lamp (76) because the voltage drop across the motor (95) is similar to the voltage drop across the lamp (76).

## 26. Lamp and Motor in Parallel

Build the circuit to the left and turn on the switch (62). The lamp (76) will be bright and the motor (95) will spin at high speed. This demonstrates the advantage of parallel circuits. Since the motor (95) and lamp (76) are both directly connected to the battery terminals, they both see the full 4.5V and thus both perform without degradation.



[ 26 - 29 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 27. Power 'ON' Indicator

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the lamp (76) will light up brightly and the motor (95) will start running at high speed. Without the fan blade it is difficult to see if the motor is 'ON' when far from the circuit. With the lamp (76) in parallel with the motor (95), a visual indicator that the motor is 'ON' can be seen from a distance. Wasted "Watts" cost money and is bad for the environment.

## 28. Power

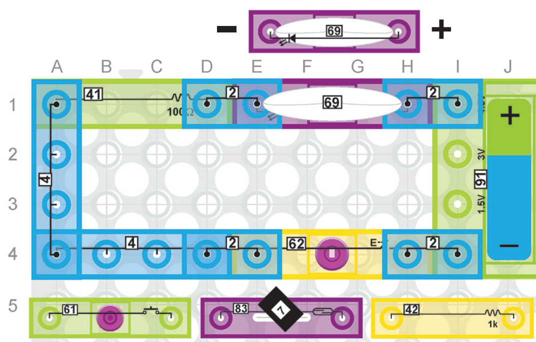
Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and the lamp (76) will light up brightly and the motor (95) will start running at high speed.

Power is defined as voltage times current and is measured in Watts. If you measured the internal/equivalent resistance of the motor (95) and the lamp (76) you would see that they are similar. Since the motor (95) and lamp (76) are in parallel in this circuit, they see the same voltage. If the internal Resistance (R) and Voltage (V) across each component are the similar, then Ohm's law (V = I*R) tells us that the Current (I) through each component is also similar. This shows that the power of each component (V*I) is also similar.

## 29. Light Power

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the lamp (76) will light up brightly and the motor (95) will start running at high speed.

Light power can be measured in Watts or Lumens. Watts refer to how much energy the bulb uses while Lumens are a measure of the bulb's light output intensity.



[ 30 - 33 ]

## 30. Adding Resistors in Series Circuit

Build the circuit shown on the left and turn on the switch (62). The heart LED (69) will light but be a little dimmer than in project #18.

To see this more easily, get in a dark room and place a 4-wire (4) across the grid points A1 to D1 in this circuit. You will see that the heart LED (69) gets brighter when you bypass the 100Ω resistor (41) with the 4-wire (4).

Resistors get their name because they are designed to resist the flow of current. This project shows that when you add resistors in series with components like the heart LED (69), the resistor (41) limits the current in the circuit and that seen by the heart LED (69), which is why the heart LED (69) gets dimmer.

## 31. Alarm Switches

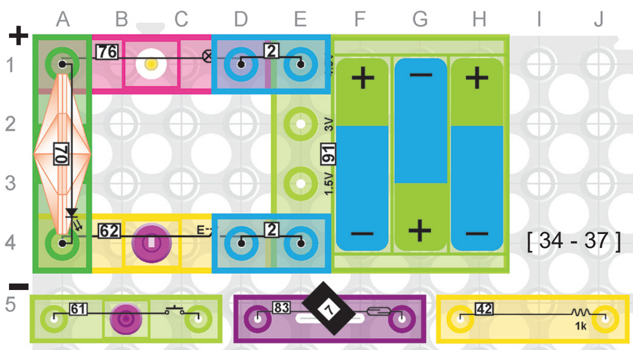
Replace the switch (62) with the reed switch (83), move the magnet (7) towards the reed switch (83), and the heart LED (69) will light. Move the magnet (7) away and the heart LED (69) will turn OFF. House alarms sometimes use reed switches to detect when a door or window is open.

## 32. LED Efficiency

Replace the reed switch (83) with the press switch (61), press and hold the press switch (61) and the heart LED (69) will light. An incandescent lamp converts about 9-10% of the energy fed to it into light, whereas LEDs convert at least 50% of that incoming energy they consume to light, the rest being lost to heat generation. So LEDs are much more efficient than incandescent lamps.

## 33. The 1k Ohm Resistor

Replace the 100Ω resistor (41) with the 1k Ohm resistor (42), press and hold the press switch (61) and the heart LED (69) will light dimly. The letter "k" in 1k Ohm stands for kilo, which is a prefix that stands for 1000. So 1k Ohm is equal to 1000 Ohms, which is 10 times greater than 100 Ohms, which is why the heart LED (69) gets dimmer when you replace the 100 Ohm resistor (41) with a 1k Ohm resistor (42).




## 34. Electronic Efficiency

Build the circuit shown on the left and turn on the switch (62). The star LED (70) will light but the lamp (76) will not light or will be very dim. Electronic Efficiency is defined as the Useful Power Output divided by the Total Power Input. There is resistance built into the star LED (70) to protect it (too much current could damage an LED), and this resistance is limiting the current in the circuit. Yet this circuit shows that the star LED (70) is more efficient than the lamp (76) because it still produces light (useful output power) even at the lower current.

## 35. Light Emitting Diode

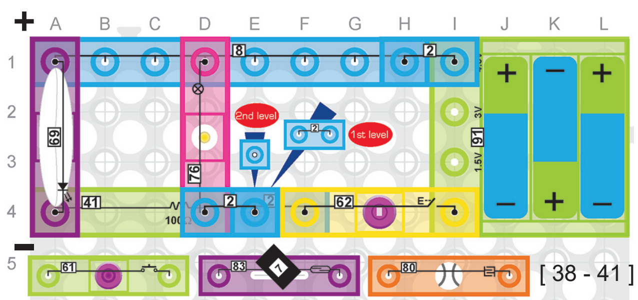
Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the star LED (70) will light but the lamp (76) will not light or will be very dim. LED stands for Light Emitting Diode. The Diode is the component that only allows the current to flow in one direction, but an LED is a special type of diode that emits light whenever the current does flow in the designed direction.

## 36. Detecting Fluid Levels

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and the star LED (70) will light but the lamp (76) will not light or will be very dim. Reed switch circuits like this can be used to detect fluid levels for coffee makers, dish washers, washing machines and water heaters. By putting a magnet on a float, which rises and falls with the liquid in the container, the magnet can trigger a reed switch circuit that turns on a warning light whenever the liquid, and by extension, the magnet, reach a certain level.

## 37. Toy Lights

Replace the 100Ω resistor (41) with the 1kΩ resistor (42) in project #35, press and hold the press switch (61) and the star LED (70) will light but the lamp (76) will not light or will be very dim. Circuits like this are used in lots of battery operated infant toys where lights go ON and OFF as the child presses certain buttons.




## 38. Ohms

Build the circuit to the left and turn on the switch (62). The heart LED (69) and the lamp (76) will light now because the they are in parallel in this circuit. The 100Ω resistor (41) in this circuit limits the current through the heart LED (69) but 100Ω is a relatively small resistance and thus only slightly dims the heart LED (69). Recall from project #25 that Ohm's law stated V = I*R. Solving for R yields R = V/I. This shows that 1 Ohm represents the resistance in a circuit that produces 1 Amp of current when subjected to a potential difference of 1 Volt.

## 39. History of LEDs

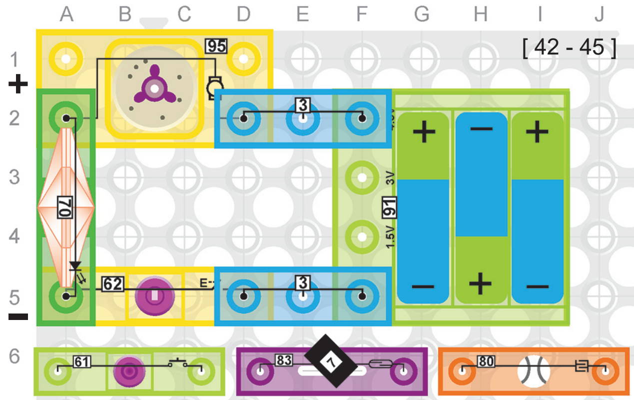
Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the heart LED (69) and the lamp (76) will light. The lighting industries as a whole are pushing LEDs to replace incandescent sources in a variety of applications, but the first time that LEDs actually did displace incandescent lamps was in vehicle brake lights, signal lights, and traffic lights back in 1987.

## 40. Battery Power

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and the heart LED (69) and the lamp (76) will light. Batteries have an anode (– side) and cathode (+ side) and are designed to have a build up of electrons in the anode. When you turn on the switch (62) in this circuit, it closes the circuit which allows the build up of electrons to flow out of the anode and into the cathode enabling current to flow through the circuit. Due to historical reasons however, conventional current (sometimes called "positive current") is actually said to flow from the cathode to the anode (the opposite direction that the "negative current" or electrons flow).

## 41. Ship to Ship Morse Code

Replace the reed switch (83) with the touch plate (80). When you touch the touch plate with a metal object like a thick metal paper clip, the heart LED (69) and lamp (76) will flash on. This can be used as a Morse code typing simulator. Morse code uses various sequences of long and short on-off tones, lights or clicks to represent letters, numbers and text. Since World War II, the process for sending messages using signal lamps has barely changed. It requires someone trained in Morse code to operate the lamp's shutter by hand, receiving, decoding, and replying to messages.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 42. Kirchhoff's Voltage Law

Build the circuit shown on the left, press the switch (62), and you will see the star LED (70) turn on and the motor (95) spin at slow speed. This is because the voltage across the star LED (70) reduces the voltage seen by the motor (95). Kirchhoff's voltage law states: The sum of the voltages around a closed network is zero. If a drop in voltage is considered as a negative voltage and a rise in voltage a positive voltage, then the following equation is a mathematical representation of Kirchhoff's voltage law:

$$V_{F5 \to F2} + V_{F2 \to A2} + V_{A2 \to A5} + V_{A5 \to F5} = 0$$

This shows that the voltage drop across the battery module (91) must equal the voltage drop across the motor (95) plus the voltage drop across the star LED (70). If you had a voltmeter and measured the voltage drop across the star LED (70) it would be around 3.5V, so Kirchhoff's voltage law says that's there's only about 1V across the motor (95) which is why it spins slowly.

## 43. Turn on Voltage of LED

Replace the switch (62) with the press switch (61). Press and hold the press switch (61) and you will see the star LED (70) turn on and the motor (95) spin at slow speed. Project #35 discussed that an LED has a special diode that emits light when current flows through it. In order for current to flow through it, about 1.8V to 3.3V is required to "turn on" the LED. This is why the voltage drop across the star LED (70) discussed in project #42 is so high (approx. 3V to turn on the actual LED and approx. 0.5 V across the resistor internal to the star LED (70) module).

## 44. Motors and Magnetic Fields

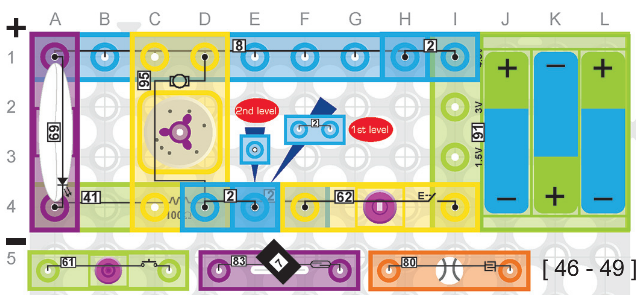
Replace the press switch (61) with the reed switch (83). Hold the magnet (7) near the reed switch (83) and you will see the star LED (70) turn on and the motor (95) spin at slow speed. Now put the magnet (7) near the motor (95). Note that the magnet (7) is attracted to the motor (95) at certain locations. This is because motors have magnets inside them that create a magnetic field. When a current flows through this magnetic field (the circuit is ON), it creates a force (look up Fleming's rule) that spins the motor shaft.

## 45. Kirchhoff's Current Law

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip you will see the star LED (70) turn on and the motor (95) spin at slow speed. Kirchhoff's current law states: At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node. Grid location A2 represents a node. If a positive current is coming into a node and a negative current is leaving a node, then:

$$I_{motor} + I_{star\ LED} = 0 \quad \text{or} \quad I_{motor} = -I_{star\ LED}$$

This shows that the current flowing into node A2 from the motor (95) must equal the current flowing out of node A2 to the star LED (70). Kirchhoff's Current Law proves that the current through each component in a series circuit is the same.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 46. ON-OFF Switch

Build the circuit above, press the switch (62), and you will see the heart LED (69) turn on and the motor (95) spin at high speed. This is because the voltage across the heart LED (69) and motor (95) are in parallel in this circuit, which enables them each to get the full 4.5V from the battery. The switch (62) is commonly called an on/off switch since it just turns the circuit on or off from one location. For that reason, it's also referred to as single location switch. Inside an on/off switch, there's a spring-loaded gate. When you change the switch to ON, that gate snaps closed. It closes the circuit and lets the power flow through the switch. When you change it to OFF, the gate snaps open. It opens the circuit and interrupts the flow of power.

## 47. Reversing a DC Motor

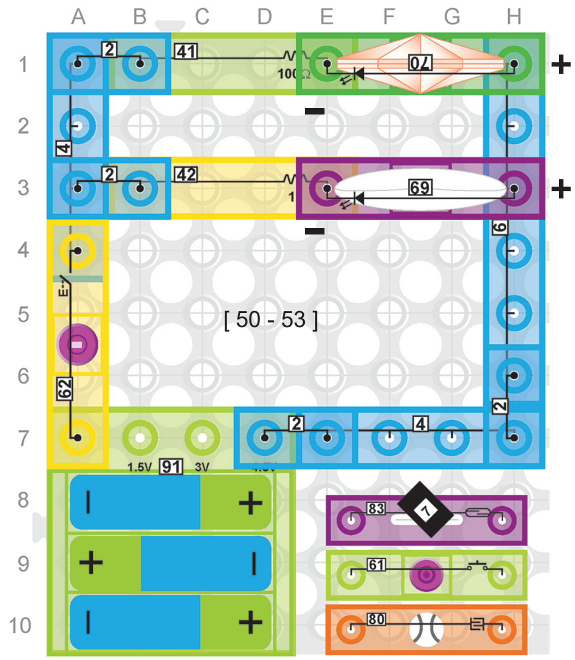
Replace the switch (62) with the press switch (61). Press and hold the press switch (61) and you will see the heart LED (69) turn on and the motor (95) spin at high speed. Release the press switch (61) and put the motor (95) in backwards reversing its direction. Press and hold the press switch (61) and the motor (95) now spins in the opposite direction. Notice that the direction the motor (95) spins is related to the direction the current flows through the motor (95). This is because the force created on the motor shaft is related to the direction that the current flows through the magnetic field in the motor (95). You can look up Fleming's left hand rule for more details on how the relationship between the current flow, magnetic field and force that creates motion.

## 48. First Electric Motor

Replace the press switch (61) with the reed switch (83). Hold the magnet (7) near the reed switch (83) and you will see the heart LED (69) turn on and the motor (95) spin at high speed. Did you know that Michael Faraday made the first electric motor using a nail, a wire, a spindle, a magnet, and a battery? Can you figure out how he did it?

## 49. The Dynamo and Generator

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip you will see the heart LED (69) turn on and the motor (95) spin at high speed. It was discussed in project #5 how the motor converts electrical energy to mechanical energy. On the other hand, a device that converts mechanical energy to electrical energy is called a dynamo or generator.




## 50. 100Ω vs. 1kΩ

Build the circuit to the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light but the heart LED (69) will be much dimmer. One of the reasons for this is because the 1kΩ resistor (42) in series with the heart LED (69) limits the current through the heart LED (69) more than the 100Ω resistor (41) limits the current through the star LED (70).

## 51. Voltage and Current in Parallel Circuits

Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light brightly. If you think about Kirchhoff's laws in projects #42 & #45, you can conclude that the voltage across components in parallel is the same, while the current through components in parallel are usually different.

## 52. LEDs are Less "Buggy"

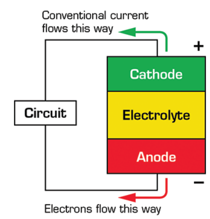
Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and both the heart LED (69) and star LED (70) with light brightly.

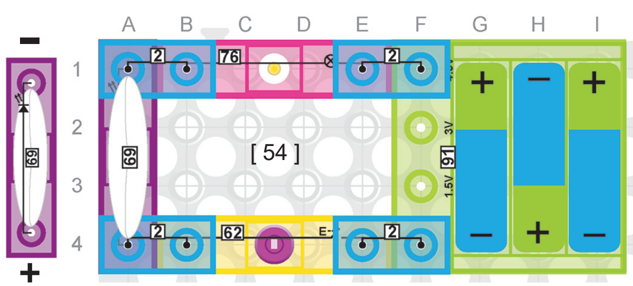
You may have noticed in the summertime at night, lots of bugs flying around your porch lights, especially if they are not LED lights but are incandescent lights. Try switching those incandescent lights to LED lights. LEDs don't attract as many insects as other traditional light sources as they have very little Ultra Violet (UV) content which bugs are attracted to.

## 53. Batteries

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and both the heart LED (69) and star LED (70) with light brightly.

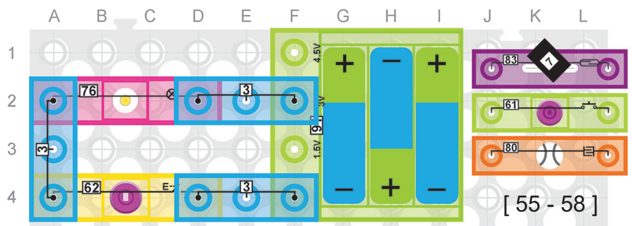
Ever wonder how the batteries in your circuit work? Batteries have three parts, an anode (–), a cathode (+), and the electrolyte, as shown in the figure below. When the cathode and anode are hooked up to an electrical circuit, a chemical reaction occurs in the battery causing a buildup of electrons at the anode, making the anode negatively charged, and a shortage of electrons (called holes) in the cathode, making the cathode positively charged. This results in an electrical difference between the anode and the cathode. The electrons want to rearrange themselves to get rid of this difference, but due to the properties of the Electrolyte, the electrons will not move through the Electrolyte region. So the only place for the excess of electrons to go is to the cathode, which causes current to flow in the circuit. When this happens, conventionally it is said that "positive" current is flowing from the cathode to the anode (while "negative" current or electrons flow from anode to cathode).




## 54. LED, the Check Valve Light

Build the circuit shown on the left, press the switch (62) and notice that the heart LED (69) will not light. The heart LED (69) does not light when in the circuit because it's in the circuit in the reverse direction. LEDs only allow current to flow in one direction (the direction of the little arrow on the module) as demonstrated in this circuit.




[ 55 - 58 ]

## 55. 3V Lamp

Build the circuit above and turn on the switch (62). Press the switch (62) and the lamp (76) will turn on but will not be as bright as it was in project #1. This is because the battery module is only providing 3V across the lamp (76) in this circuit. Lower voltage across the lamp (76) means lower current through the lamp (76) based on Ohm's law, which leads to the lamp (76) being more dim in this circuit.

## 56. Voltage Divider Circuit

Replace the switch (62) with the reed switch (83). Put the magnet (7) near the reed switch (83) and the lamp (76) will turn on. Move the magnet (7) away and the lamp (76) will turn off.

The way the battery module (91) provides 3V is by tapping into the point where the first two batteries are in series (each "AA" battery provides approximately 1.5V so two in series provide 3V). This is easy to do when you have multiple batteries with discrete voltage levels, but what if you only had a single 4.5V battery, but needed 3V? Voltage divider circuits can be used that can provide a fraction of the power supply or battery voltage.

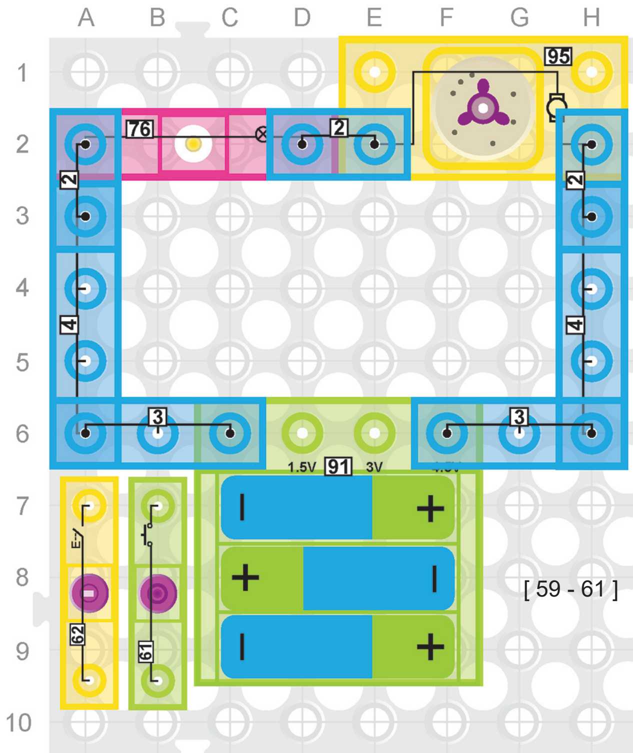
## 57. Details of Morse Code

Replace the reed switch (83) with the press switch (61). Press and release the press switch (61) and the lamp (76) will flash on and off. As discussed in project #41, this circuit could be used to send Morse code sequences. The International Morse Code is shown below where a dot represents a quick push of the press switch (61) and a dash represents holding the press switch (61) for a second. Try sending letters or a code to a friend and see if they can decode it by looking at the LEDs.

**Morse Code**

| | | |
|---|---|---|
| A ●– | J ●––– | S ●●● |
| B –●●● | K –●– | T – |
| C –●–● | L ●–●● | U ●●– |
| D –●● | M –– | V ●●●– |
| E ● | N –● | W ●–– |
| F ●●–● | O ––– | X –●●– |
| G ––● | P ●––● | Y –●–– |
| H ●●●● | Q ––●– | Z ––●● |
| I ●● | R ●–● | |

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

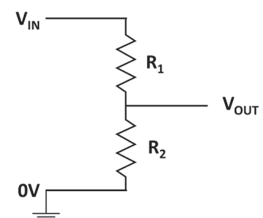



[ 59 - 61 ]

## 58. Sample Voltage Divider Circuit

Replace the press switch (61) with the touch plate (80). Press the touch plate (80) with a metal object like a thick metal paper clip across the touch plate shiny area and you will see the lamp (76) light up.

One way to provide a voltage divider circuit is using two resistors in series as shown on the right. Based on Kirchhoff's voltage law, we know that the voltage across the two resistors have to add up to the voltage across the battery ($V_{IN}$ in the diagram). So this means the voltage at the point between the two resistors, labeled $V_{OUT}$, provides a voltage somewhere between $V_{IN}$ and ground (0V), so the circuit is dividing the voltage across each resistor.




## 59. Lamp and Motor in Series

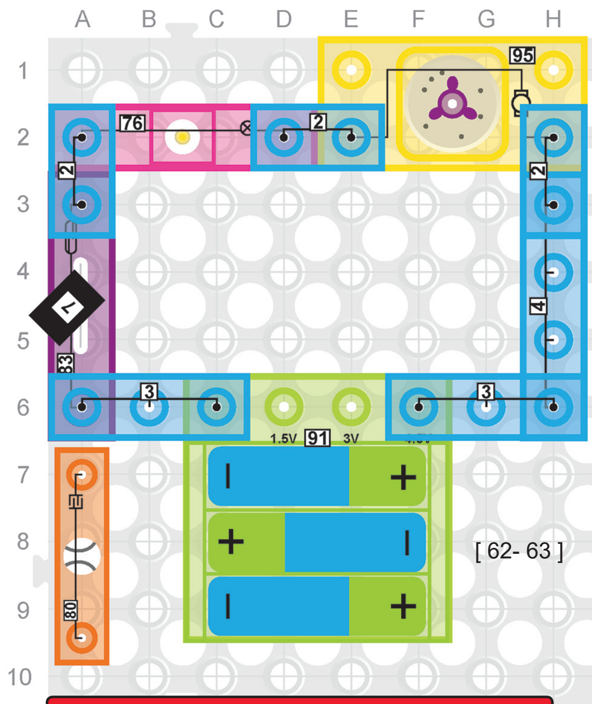
Build the circuit to the left. The lamp (76) will be dim and the motor (95) will spin at medium speed. This demonstrates the disadvantage of series circuits. Since the motor (95) and lamp (76) are in series, they divide the voltage, just like the voltage divider circuit in the previous project. In this case, since they each see less voltage, the lamp (76) is dim and the motor (95) spins at medium speed.

## 60. Uses of Motors

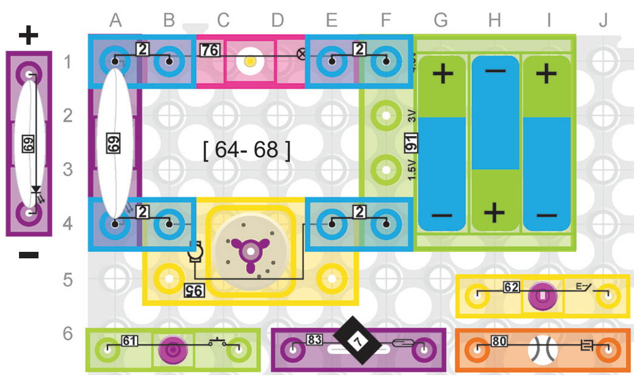
Replace the 4-wire (4) with the switch (62), turn on the switch (62), and the lamp (76) will light dimly and the motor (95) will start running at medium speed. If you look around your house you'll see that motors are used for many things. Fans, blenders, and sink dispose-all are just a few. Can you think of more?

## 61. Back Electromotive Force (EMF)

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the lamp (76) will light dimly and the motor (95) will start running at medium speed. You may have noticed that the lamp (76) starts out bright and then dims quickly. This is because initially the motor (95) is not moving and thus there is an "inrush" or burst of current that runs through the motor (95) and lamp (76) until the motor (95) starts spinning. Once the motor (95) starts spinning, then there is a voltage across the motor (95) created that opposes the change in current. This voltage is called back electromotive force, or back EMF. As the motor (95) spins faster, the back EMF created causes the current through the motor (95) to decrease, which in turn decreases the current through the lamp (76) which is why it dims quickly.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 62. Brushless Motors

Build the circuit shown on the left. Put the magnet (7) near the reed switch (83) and the lamp (76) will light up dimly and the motor (95) will start running at medium speed. Reed switches can actually be used to create what are called brushless motors.

## 63. Fleming's Left Hand Rule

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the lamp (76) will light up dimly and the motor (95) will start running at medium speed.

Fleming's left hand rule was mentioned in projects #44 and #47. The rule states: When current flows through a conducting wire, and an external magnetic field is applied across that flow, the conducting wire experiences a force perpendicular both to that field and to the direction of the current flow (i.e. they are mutually perpendicular).

You can use your left hand to implement this rule by pointing your index and middle fingers perpendicular to each other and pointing your thumb up in the air. If your index finger points in the direction of the magnetic field (internal to the motor) and your middle finger points in the direction of the current, then your thumb will point in the direction of the force. You can then see that if the current is reversed, Fleming's rule shows that the force will be in the opposite direction which will make the motor (95) spin in the opposite direction.

## 64. Motor, Lamp and Heart LED in Series

Build the circuit shown on the left. The heart LED (69) will light, the motor (95) will spin at slow speed, and the lamp (76) will not light. Since the heart LED (69), motor (95), and lamp (76) are all in series in this circuit, the 4.5V from the battery (91) is divided across them.

As discussed in project #43, the turn on voltage of the diode in the heart LED (69) requires about 1.8V before any current can flow in the circuit. This leaves only about 2.7V to distribute across the lamp (76), the motor (95) and the resistor internal to the heart LED (69). The internal resistance of the heart LED (69), which limits the current in this series circuit, is then the main reason why the motor (95) spins slowly and the lamp (76) does not light.

## 65. Internal Resistance of the Heart LED

Replace the lamp (76) with the switch (62), turn on the switch (62) and the heart LED (69) will light and the motor (95) will start running at slow speed.

If you have a voltmeter, you can measure the voltage across the heart LED (69) and motor (95) and see that about 3.3V is across the heart LED (69) and only about 1V is across the motor (95). The heart LED (69) module consists of an actual LED and a resistor in series to protect the actual LED from ever seeing too much current that could burn it out. Actual LEDs have very little resistance but do require a certain "turn on" voltage, as discussed in project #43, which is actually color dependent.

Red light is one of the easier colors to light and requires only about 1.8V to turn on the LED. So this means that the internal resistor will see about 1.5V of the 3.3V across the heart LED (69). If you had an Ammeter (device that measures current), you would see there is about 15 mA (or 0.015 Amps) of current running through this circuit. Ohm's law ($R = V/I$) then tells us that the internal resistance of the heart LED (69) is about 1.5/0.015 = 100Ω.

## 66. Red Light Wavelength

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the heart LED (69) will light and the motor (95) will start running at slow speed. LEDs can produce different colors by transmitting light waves with different wavelengths. Light waves cycle up and down and a wavelength is the distance between successive crests of the wave. Red light has a wavelength of around 665 nanometers. A nanometer is 1 billionth of a meter.

## 67. Voltage and Current in Series Circuits

Replace the press switch (61) with the reed switch (83). Put the magnet (7) near the reed switch (83) and the heart LED (69) will light and the motor (95) will start running at slow speed. If you think about Kirchhoff's laws in projects #42 & #45, you can conclude that the current through components in series is the same, while the voltage across components in series are usually different.

## 68. Red Light Frequency

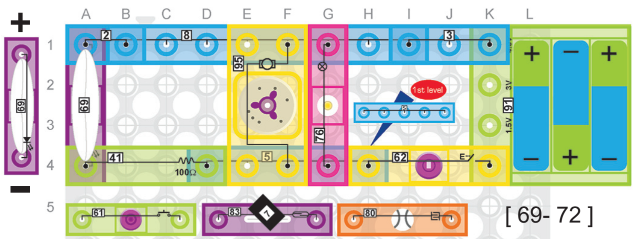
Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the heart LED (69) will light and the motor (95) will start running at slow speed. Project #66 discussed the wavelength of light. Light can also be characterized in frequency, which is inversely related of wavelength. Specifically,

**Frequency = (Speed of light)/Wavelength**

Light travels at a constant speed of 300 Million Meters/Second (that's fast!). So based on the wavelengths of red light discussed in project #66, we see that

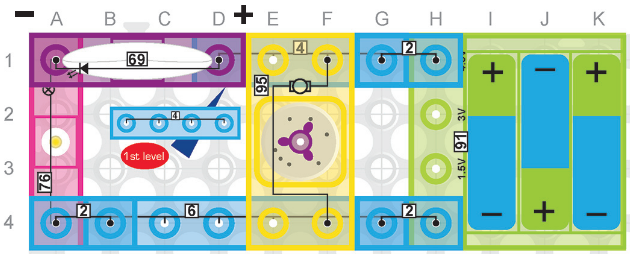
**Frequency of Red Light = $(3 \times 10^{8})/(665 \times 10^{-9})$ = ~451 THz.**

THz stands for TeraHertz which is $10^{12}$ Hertz. Hertz is the measure of frequency representing one cycle per second.



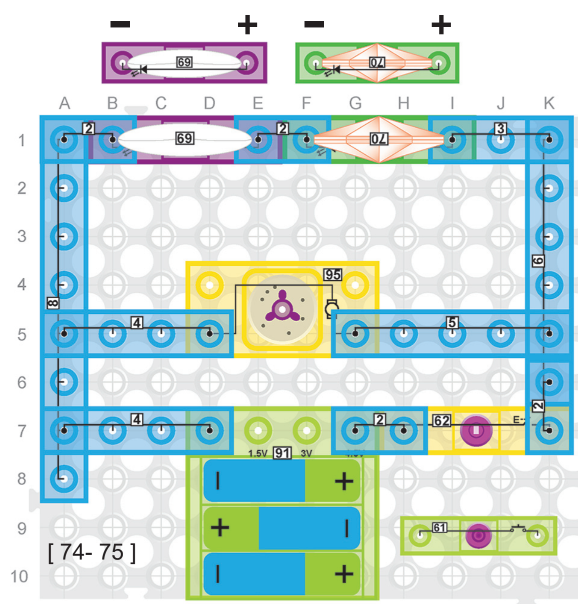
[ 69- 72 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



[ 73 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



[ 74- 75 ]

## 69. Motor, Lamp and Heart LED in Parallel

Build the circuit shown on the left, turn on the switch (62) and the heart LED (69) will light, the lamp (76) will light, and the motor (95) will start running at high speed.

This again demonstrates the benefits of parallel circuits as all components function well in this circuit. However, if you had an Ammeter and measured the current from the battery (91) in this circuit, you would see it's greater than 100 mA. This is more than 10 times the current that is drawn from the battery (91) in project #64 which demonstrates the disadvantage of parallel circuits (they draw more current which drains the batteries more quickly).

## 70. Applications of the Press Switch

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the heart LED (69) and lamp (76) will light and the motor (95) will start running at high speed. Some of the common applications of the press switch (61) are for doorbells, keys on your keyboard, and laser pointers.

## 71. Reed Switches for Speed Sensors

Replace the press switch (61) with the reed switch (83). Put the magnet (7) near the reed switch (83) and the heart LED (69) and lamp (76) will light and the motor (95) will start running at high speed.

Did you know that reed switches like the one in this circuit can be used to create speed sensors? The reed switch actuates briefly each time a magnet on the wheel passes the sensor, and this can be used to count the number of revolutions of the wheel per second which can then be converted to bicycle speed.

## 72. Direct Current and Alternating Current

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the heart LED (69) and lamp (76) will light and the motor (95) will start running at high speed.

The batteries in your battery module (91) are providing Direct Current (DC) to the circuit. DC provides a constant flow of current in one direction in the circuit. LEDs are generally driven by DC current, but the outlets in your house provide Alternating Current (AC). Alternating current changes the direction of the current like a sine wave. This is why you will usually see an AC to DC adaptor between your LED TV and the plug at the end of the cord for your LED TV. This adaptor coverts the AC current from your house outlets to DC current needed by the LEDs in your TV set.

## 73. Series-Parallel LEDs and Motor Circuit

Build the circuit shown on the left and the heart LED (69) will light and the motor (95) will spin, but the lamp (76) will not light. This is an example of a series-parallel circuit where some of the components are in series (the lamp (76) and the heart LED (69)), which are then in parallel with other components (the motor (95)). Since the motor (95) sees the full 4.5V from the battery (91), it spins at high speed. But since the 4.5V from the battery (91) is distributed across the heart LED (69) and lamp (76), and due to the 1.8V turn on voltage of the LED in the heart LED (69), the lamp (76) sees very low voltage which is why it does not turn on.

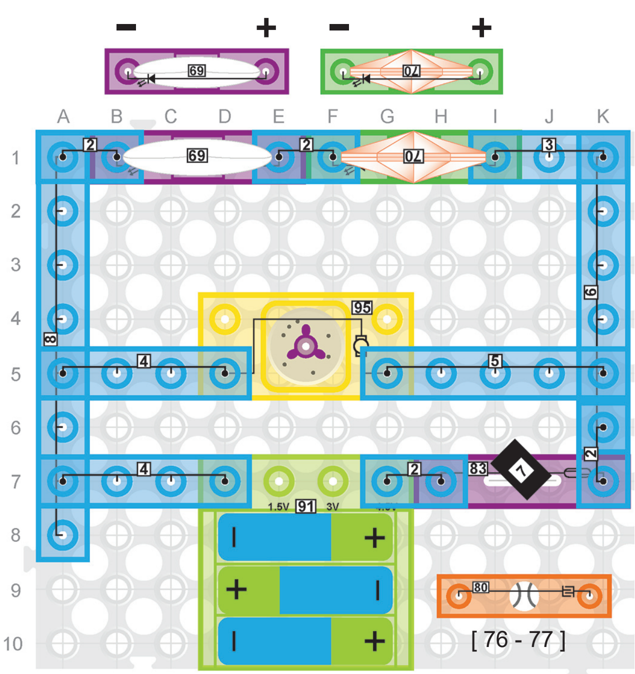
## 74. Instant ON

Build the circuit shown on the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light, but they are both dim because they are in series, while the motor (95) spins at high speed because it is in parallel. Due to the physics involved, LEDs have what we call Instant ON — unlike their incandescent counterparts. What this means is that you can switch an LED lamp on and you get the full brightness of that light instantly.

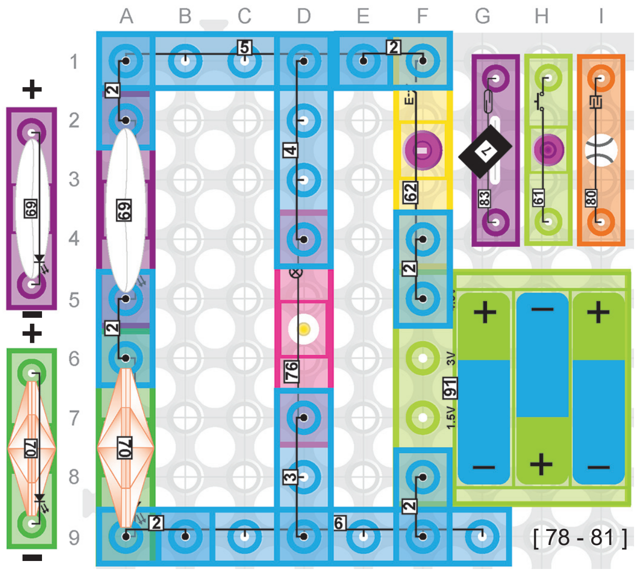
## 75. Measuring Current

Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light, but they are both dim, while the motor (95) spins at high speed.

If you wanted to know how much current is flowing in different parts of this circuit, you could use an Ammeter. An Ammeter is an instrument used to measure the Amps of current flowing in a circuit. If you hooked up an ammeter to the current path of the motor (95), you would see about 26mA (pronounced 26 milli-Amps, which represents 26 thousandths of an Amp) of current flowing when the press switch (61) is ON. If you hooked up an ammeter to the current path of the star LED (70) plus the heart LED (69), you would see less than 2 mA of current flowing when you press the press switch (61). Can you figure out why so much current flows through the motor (95)?




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




## 76. Reed Switches in Laptops

Build the circuit as shown on the left. Move the magnet (7) towards the reed switch (83), and the heart LED (69) and the star LED (70) will both light, but they are both dim, while the motor (95) spins at high speed. If you want to turn off the LEDs and motor (95), you need to move the magnet (7) away from the reed switch (83). Did you know that reed switches like the one in this circuit are used in some laptops to put the laptop in sleep/hibernation mode when the lid is closed?

## 77. Measuring Voltage

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the heart LED (69) and the star LED (70) will both light, but they are both dim, while the motor (95) spins at high speed. A Voltmeter is used to measure voltage. Since the LEDs in this circuit are in series, they each don't see the full 4.5V from the battery (91). If you used a voltmeter you would see that when the circuit is on, then the voltage across the heart LED (69) is about 1.9V and the voltage across the star LED (70) is about 2.6V. Note that these voltages sum to 4.5V (Kirchhoff's Voltage Law in action!).

## 78. Conservation of Energy

Build the circuit to the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light, but they are both dim because they are in series, while the lamp (76) lights brightly because it is in parallel. In physics, the law of Conservation of Energy states that the total energy of an isolated system remains constant — it is said to be conserved over time. This law means that energy can neither be created nor destroyed; rather, it can only be transformed from one form to another. In this circuit the energy being lost by the batteries is being converted mostly to light energy being emitted by the LEDs and lamp (76).

## 79. Different Color LED Turn On Voltages

Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light, but they are both dim, while the lamp (76) lights brightly. In project #68 we saw that the frequency of red light is ~451 THz. The table below shows the frequency and wavelength of all light colors. The table shows that Blue & Violet are the highest frequency light colors in the 600-790 THz range. White light is actually a combination of all light colors. There is a one-to-one correspondence between photons emitted from an LED and electrons that pass through the LED. Each electron, having a charge q, will fall through the voltage difference $\Delta V$ (pronounced Delta V), using up an amount of energy, $E = q*\Delta V$. Each electron emits one photon which has an energy $E = hf$, with f being the frequency of the light and h being Planck's constant equal to $6.626*10^{-34}$. Conservation of energy lets us say that the energy lost by the electron is equal to the energy of the emitted photon, so $q*\Delta V = hf$. So the Conservation of Energy tells us that for the same light intensity, higher frequencies require a larger $\Delta V$, which means that the star LED (70) producing white light (which contains all colors) requires a higher "turn on" voltage than the heart LED (69) producing red light.

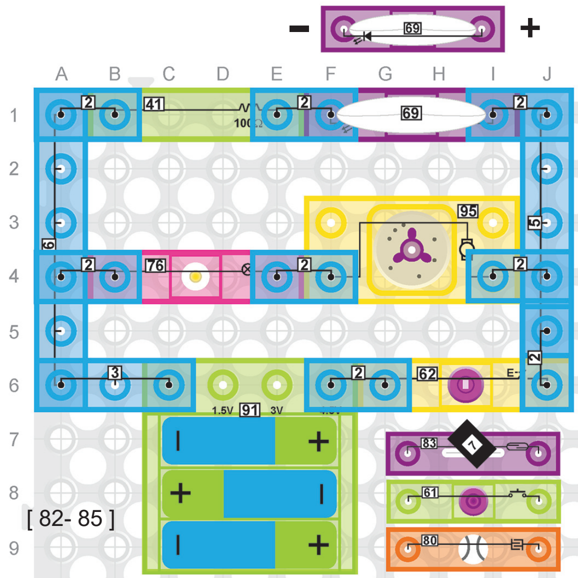
| Color | Wavelength | Frequency |
|---|---|---|
| Violet | ~380-450 nm | ~667-790 THz |
| Blue | ~450-500 nm | ~600-667 THz |
| Green | ~500-570 nm | ~526-600 THz |
| Yellow | ~570-590 nm | ~508-526 THz |
| Orange | ~590-625 nm | ~480-508 THz |
| Red | ~625-740 nm | ~405-480 THz |

## 80. Direction that Current Flows

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and the heart LED (69) and the star LED (70) will both light, but they are both dim, while the lamp (76) lights brightly. Based on the discussion on batteries in project #53, you could say that current is flowing from the "–" terminal of the battery to the "+" terminal of the battery since electrons are moving that direction. In fact, some in the industry will refer to this as "electron flow notation". However, the more conventional notation for current flow is based on "hole current". In electronics, a hole is an electric charge carrier with a positive charge, equal in magnitude but opposite in polarity to the charge on the electron. So instead of thinking about electrons moving from the "–" terminal to the "+" terminal of the battery, you can think of hole current as move from the "+" terminal to the "–" terminal of the battery. All discussions in this manual have used the more conventional hole current definition.

## 81. Forward & Reverse Bias

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the heart LED (69) and the star LED (70) will both light, but they are both dim, while the lamp (76) lights brightly. Note that the LEDs must be in the circuit in the direction shown in the diagram. If they are put in backwards they will not light. This is because they have to be "Forward Biased" to allow current to flow through them. LEDs are typically made of two types of semiconductor materials side-by-side. One material has an excess of electrons and the other material has a depletion of electrons (excess of holes). By doing this, even a small "forward bias" voltage can be applied in one direction and current will flow making the LED light. However, even large "reverse bias" voltages are note enough to enable current to flow in the other direction through the LED.




## 82. Series-Parallel Lamp, Motor and Heart LED Circuit

Build the circuit shown on the left and the heart LED (69) will light, the lamp (76) will light dimly, and the motor (95) will start running at medium speed.

The heart LED (69) and 100Ω resistor (41) are in parallel with the series connection of the motor (95) and lamp (76) in this circuit. The 100Ω resistor (41) only slightly limits the current through the heart LED (69), which is why the heart LED (69) is fairly bright. However the 4.5V from the battery is being distributed across the lamp (76) and motor (95) which is why the lamp (76) is dim and the motor (95) spins slower than in the previous project.

## 83. Revisiting Kirchhoff's Current Law

Replace the switch (62) with the press switch (61), press and hold the press switch (61) and the heart LED (69) will light, the lamp (76) will light dimly and the motor (95) will start running at medium speed.

If you had an ammeter, you would measure the current through the heart LED (69) to be about 13 mA and the current through the motor (95) and lamp (76) to be about 24 mA. Now If you hooked up the ammeter to the current path coming out of the battery (91), you would measure about 37 mA. This shows that the current being drawn from the battery (91) is equal to the sum of the currents through the heart LED (69) and the series connection of the motor (95) and lamp (76) (Kirchhoff's Current Law in action!).

## 84. Angular Light Intensity

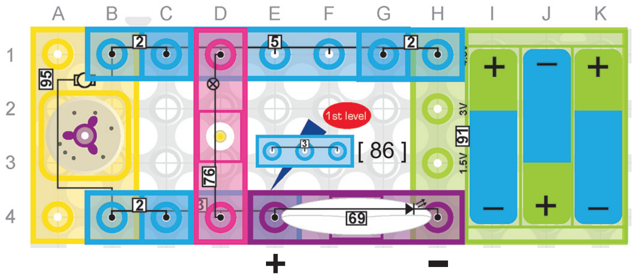
Replace the press switch (61) with the reed switch (83). Put the magnet (7) near the reed switch (83) and the heart LED (69) will light, the lamp (76) will light dimly and the motor (95) will start running at medium speed.

While it may appear that the heart LED (69) is not that bright, this is because LEDs have angular light intensity profiles such that a majority of the light emits straight out of the top of the LED. So the light you see is from the red LED in the heart LED (69) module reflecting off the plastic heart. If you were to remove the plastic heart and look straight down at the LED it would look much brighter.

## 85. 4-band Resistor

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and the heart LED (69) and lamp (76) will light and the motor (95) will start running at high speed.

Although the resistor values in your Circuit Blox™ 800 set are labeled (e.g. 100Ω in this project), physical resistors are often labeled through a color code. Below is a picture of a 4-band resistor. The first three bands on the left (brown, blue, and red in this case) define the resistance value of the resistor, while the last band on the right (silver in this case) defines the tolerance of the resistor.

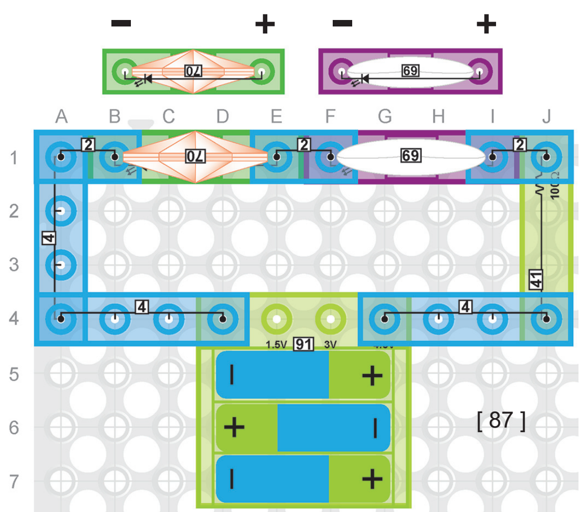



## 86. Effects of Components in Series-Parallel Circuits

Build the circuit shown on the left and the heart LED (69) will light, the lamp (76) will not light, and the motor (95) will not spin or spin very slowly.

While project #19 discussed that one of the benefits of parallel circuits is that component failures do not affect other components in parallel, this assumed there were no other components in series with the parallel connections of components. Try taking out the lamp (76) in this circuit. You will see that the motor (95) will start spinning faster, even though it was in parallel with the lamp (76). This is because with the lamp (76) in the circuit, more current flows through the heart LED (69).

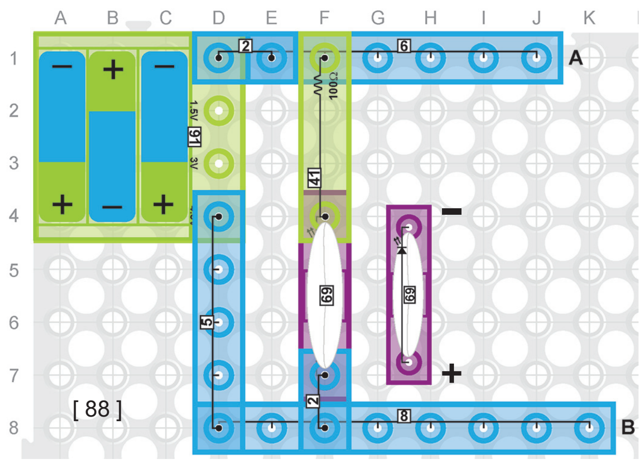
But more current through the heart LED (69) means a larger voltage drop across the resistor in the heart LED (69) due to Ohm's law. This ultimately means less voltage across the motor (95), which reduces the speed of the motor (95) or completely stops it from spinning. So having components in series with a parallel connection of components does impact the way the components do or do not effect each other.




## 87. Calculating Internal Resistance of the Star LED

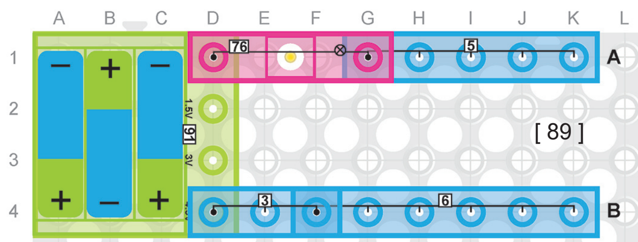
Build the circuit above and the heart LED (69) and star LED (70) will light. In project #77 we saw that the voltage across the heart LED (69) was about 1.9V and the voltage across the star LED (70) was about 2.6V.

We also saw in project #79 that white light requires a higher turn-on voltage than red light. If we assume the turn-on voltage for white light is around 2.5V, then that means that only about 0.1V is across the resistor in the star LED (70). If you had an ammeter you would measure that the current in this circuit is about 2.85 mA. Through Ohm's law, this means that the internal resistance in the star LED (70) is about 0.1/0.00285 = 35Ω.




## 88. Power Indicator

Build the circuit shown on the left. Pretend that an appliance with its own switch built into it in your house was connected to points A and B. Even if the appliance was turned off, the heart LED (69) in this circuit could act like a power indicator for your batteries.

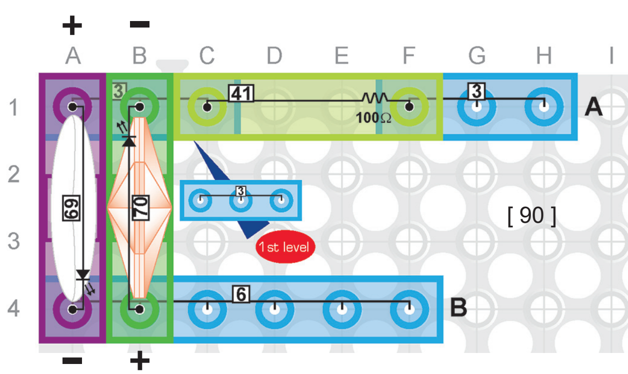



## 89. Conductivity Tester

Build the circuit shown on the left. Try connecting various objects across points A and B (they will have to be small objects that can touch the pins at points A and B like a paper clip). If the object is a very good conductor, then it will enable current to flow through it, lighting the lamp (76). If the object is a very poor conductor, then very little current will flow through it and the lamp (76) will be off.

## 90. Polarity Tester

Build the circuit shown on the lower left. If you connect the 4.5V terminal of the battery (91) to point A and the "–" terminal of the battery (91) to point B, you will see the heart LED (69) light. If you connect the "–" terminal of the battery (91) to point A and the 4.5V terminal of the battery (91) to point B (use the spring wire (9) to help you do this) then the star LED (70) with light. This circuit acts as a tester to see which side of a battery is the positive side and which is the negative side.




## 91. Calculating Equivalent Resistance

Build the circuit below and you will see the motor (95) spin and the two LEDs turn on at the same time. It is interesting that the motor (95) spins in this circuit but does not spin or at least slows down if you remove the star LED (70) from the circuit. This is because the equivalent resistance of the two LEDs in parallel is less than the resistance of either one alone. To prove this, assume the star LED (70) resistance is $R_{star}$ and the heart LED (69) resistance is $R_{heart}$. Then Ohm's Law states that:

$$I_{star} = V/R_{star} \text{ and } I_{heart} = V/R_{heart}$$

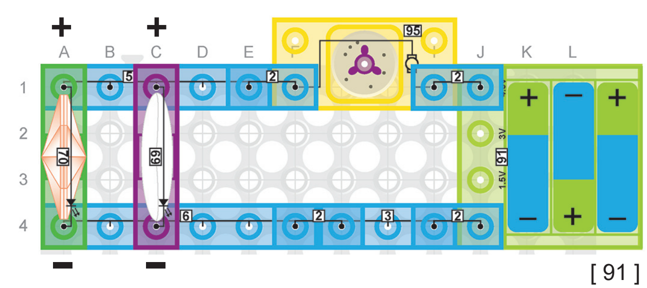
where V is the voltage across both the star LED (70) and heart LED (69), which is the same since they are connected in parallel. Thus, the total current can be written as:

$$\begin{aligned} I_{tot} &= I_{star} + I_{heart} = V/R_{star} + V/R_{heart} \\ &= (V{*}R_{heart} + V{*}R_{star})/R_{star}{*}R_{heart} \\ &= V{*}(R_{heart} + R_{star})/R_{star}{*}R_{heart} \end{aligned}$$

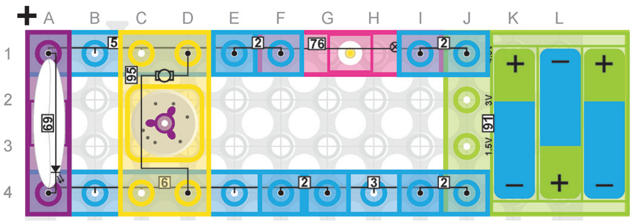
Solving for V yields:

$$V = I_{tot}{*}R_{star}{*}R_{heart}/(R_{heart}+R_{star})$$

This shows that the equivalent resistance through the parallel connection of the star LED (70) and heart LED (69) is $R_{star}{*}R_{heart}/(R_{heart}+R_{star})$. If for simplicity we were to assume that the internal resistance of the star LED (70) is the same as the internal resistance of the heart LED (69), and thus $R_{star} = R_{bdled} = R$, then the equivalent resistance of the parallel connection is R*R/(R+R) = R/2. Thus, the equivalent resistance of the parallel connection is half that compared to having the resistance from just the heart LED (69) in the circuit, which is why the motor (95) spins in this project.

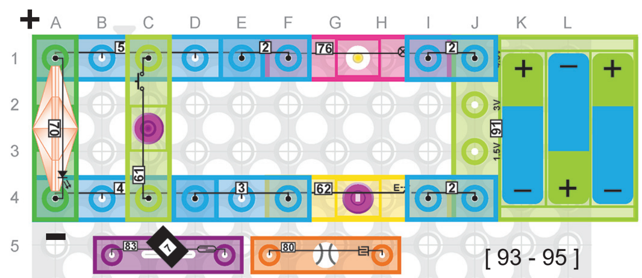



**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

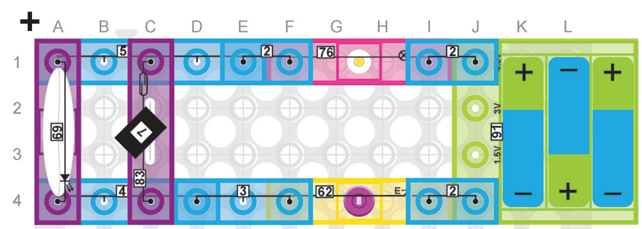


[ 92 ]

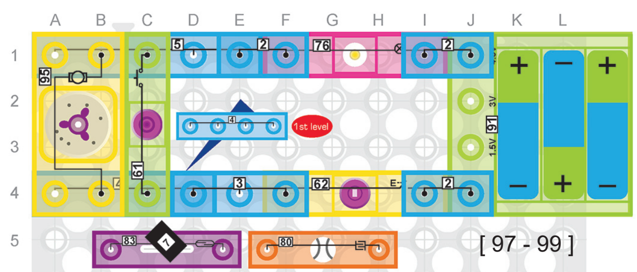
**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



[ 93 - 95 ]



[ 96 ]



[ 97 - 99 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 92. Equivalent Resistance of Motor and Heart LED in Parallel

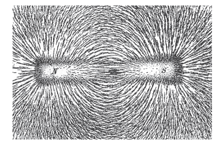
Build the circuit to the left and you will see the heart LED (69) and lamp (76) light while the motor (95) spins. It is interesting to note that the lamp (76) lights in this circuit, while it does not light when it's only in series with the heart LED (69) (like in project #73). This demonstrates that the equivalent resistance of the heart LED (69) and motor (95) in parallel is less than that of the heart LED (69) alone, which allows more current to flow through the lamp (76) and thus the lamp (76) lights in this project.

## 93. Simulating a Short Circuit

Build the circuit to the left and press the switch (62) to turn on the star LED (70), but the lamp (76) will be off or very dim. Press the press switch (61) and the star LED (70) will turn OFF and the lamp (76) will light. By pressing the press switch (61) you are simulating a short circuit that results in a much lower resistance path for current to flow (i.e. through the press switch (61) rather than through the star LED (70)) which causes the star LED (70) to stop working. Typically, short circuits occur due to unintended contacts of components that result in accidental diversion of the current.

## 94. Magnetic Field of a Magnet

Replace the press switch (61) with the reed switch (83). Turn on the switch (62) and the star LED (70) will light, but the lamp (76) will not light or be very dim. Put the magnet (7) near the reed switch (83) and the star LED (70) will turn off and the lamp (76) will turn on. Iron filings can be used to show magnetic fields created by magnets (such as in the picture below).



## 95. Active Elements

Replace the reed switch (83) with the touch plate (80). Turn on the switch (62) and the star LED (70) will light, but the lamp (76) will not light or be very dim. Touch the touch plate (80) with something metal like a thick metal paper clip and the star LED (70) will turn off and the lamp (76) will turn on. Active elements are elements that can source power. For example, a voltage or current source like a power supply or battery are active elements.

## 96. Passive Elements

Build the circuit shown on the left. Turn on the switch (62) and the heart LED (69) will light, but the lamp (76) will not. Put the magnet (7) near the reed switch (83) and the heart LED (69) will turn off and the lamp (76) will turn on. Passive elements are elements that do not provide a source of energy. For example, resistors, capacitors and diodes are passive elements.

## 97. Light Dimmer

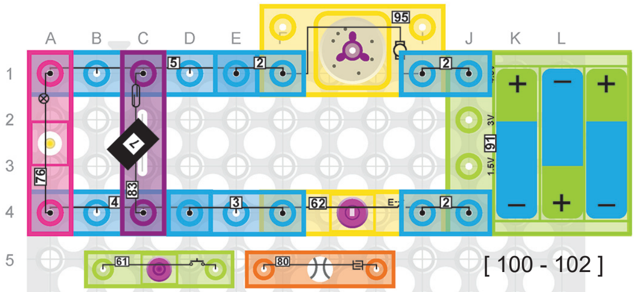
Build the circuit shown on the left, turn on the switch (62) and you will see the lamp (76) on dimly and the motor (95) spin at the same time. Now press the press switch (61) and the lamp (76) gets brighter while the motor (95) turns off. Pressing the press switch (61) removes the internal resistance of the motor (95) from the circuit so that more current flows through the lamp (76) making it brighter. This concept is used in light dimmer circuits.

## 98. Fused Motor

Replace the press switch (61) with the reed switch (83) and turn on the switch (62). Now you can control the brightness of the lamp by using the magnet (7). Also, the motor (95) goes off when you place the magnet (7) near the reed switch (83). Motors are designed with fuses to limit the current that can be seen by the motor to prevent fires. When you move the magnet (7) near the reed switch (83), you are simulating a motor fuse popping to protect the motor from too much current.

## 99. Electricity in Your Body

Replace the reed switch (83) with the touch plate (80). Turn on the switch (62) and you will see the lamp (76) on dimly and the motor (95) spin at the same time. Touch the touch plate (80) with something metal like a thick metal paper clip and the lamp (76) gets brighter and the motor (95) turns off. Did you know that electricity plays an important role in the way your heart functions? Muscle cells in the heart are contracted by electricity that runs through your body.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

### 100. Motor Speed Selection Circuit

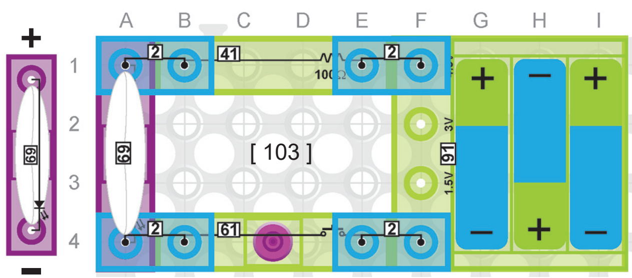
Build the circuit shown on the left. Turn on the switch (62) and the lamp (76) will light dimly and the motor (95) will spin at medium speed. Put the magnet (7) near the reed switch (83) and the lamp (76) will turn off and the motor (95) will spin faster. This circuit demonstrates how speeds of a remote control toy car can be controlled.

### 101. Motor Speed

Replace the reed switch (83) with the press switch (61). Turn on the switch (62) and the lamp (76) will light dimly and the motor (95) will spin at medium speed. Press the press switch (61) and the lamp (76) will go off and the motor (95) will spin faster. Motor speed is measured in Revolutions per Minute, or RPMs. How fast do you think your motor is spinning?

### 102. Motors in Cars

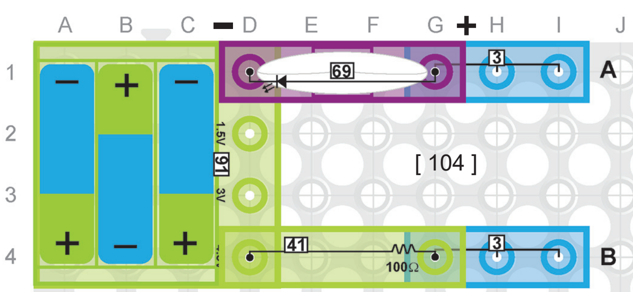
Replace the press switch (61) with the touch plate (80). Turn on the switch (62) and the lamp (76) will light dimly and the motor (95) will spin at medium speed. Touch the touch plate (80) with something metal like a thick metal paper clip and the lamp (76) will go off and the motor (95) will spin faster. Cars are a major consumer of motors. Did you know that an average car contains around 30 motors? See how many motors you can count in your car.




### 103. Help!

Build the circuit shown on the left, press the press switch (61) and you will see the heart LED (69) flash on and off. This circuit can be used for practicing telegraph typing. Try using this circuit as a Morse code generator (see project #57) and tap in the code below. This stands for S.O.S, or Save Our Souls. If you ever see this pattern then it means someone is in danger and calling for help.

●●● – – – ●●●
S O S

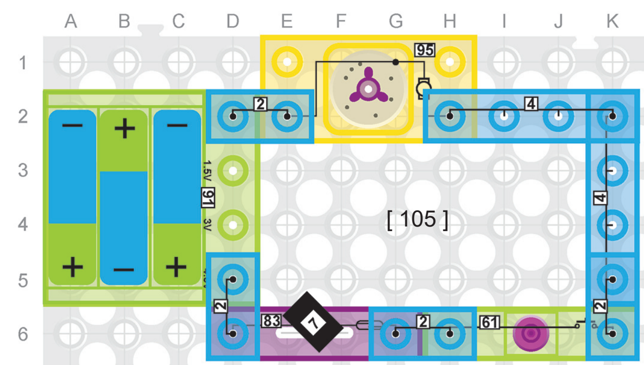



### 104. High Conductivity Tester

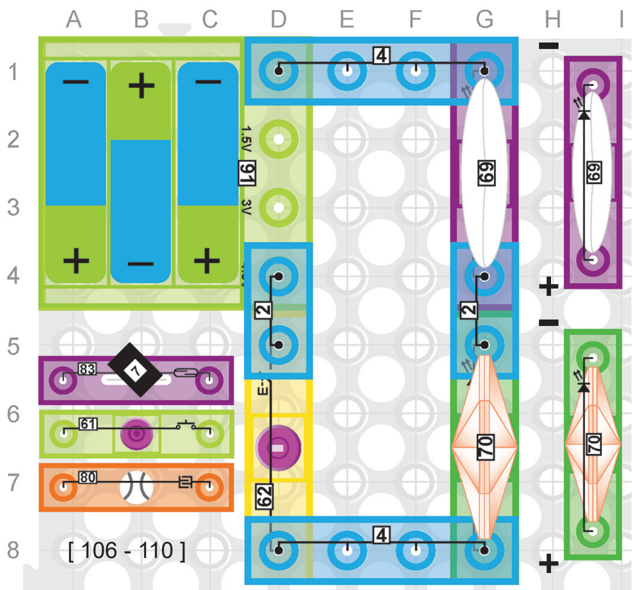
Build the circuit to the left. Try connecting various objects across points A and B (they will have to be small objects that can touch the pins at points A and B like a paper clip). Because of the added resistance of the 100Ω resistor (41) and internal resistance of the heart LED (69), the object will have to be a much better conductor to light the heart LED (69) than it would need to be to light the lamp (76) in project #89.

### 105. Safety Circuit

Build the circuit shown below, turn on the switch (62) and place the magnet (7) near the reed switch (83) and you will see the motor (95) spin. Sometimes, for safety reasons, it is required that two switches be ON before machinery will run.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




## 106. Alkaline Batteries

Build the circuit to the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light, but they are both dim. For long battery life, it's always recommended to use Alkaline batteries. Alkaline batteries have a higher energy density for the same voltage level than zinc-carbon batteries. This is accomplished using a different type of electrolyte. Zinc batteries are mostly composed of ammonium chloride while the alkaline batteries use potassium hydroxide.

## 107. Lithium Batteries

Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light dimly. While Alkaline batteries use manganese oxide to generate power, lithium batteries use lithium metal or compounds as their anode, which enable lithium batteries to last longer.

## 108. Storing Batteries in the Fridge

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and both the heart LED (69) and star LED (70) with light dimly.

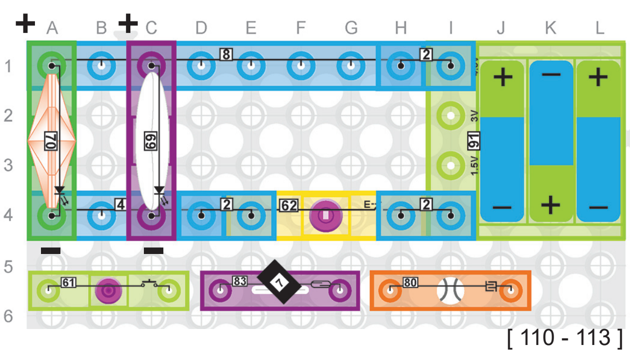
Does it help prolong battery life if you store your batteries in the fridge? Yes, but the benefits depend on the room temperature they would be stored in if you did not put them in the fridge. At a typical room temperature like 73 degrees Fahrenheit, batteries self-discharge very slowly (typically less than 2% per year). But if you live in a very hot climate and stored the batteries in a non-air-conditioned area, say 100 degrees Fahrenheit, then they would self-discharge much more quickly.

## 109. Rechargeable Batteries

Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and both the heart LED (69) and star LED (70) with light dimly. Project #53 discussed how batteries work. Rechargeable batteries work the same way, except that the reaction in the chemicals is reversible. When a voltage source is applied reversely on the rechargeable battery (e.g. "+" on the anode and "–" on the cathode), the electron flow that normally occurs during discharge is reversed, and the cell's charge is restored.

## 110. Ohms of Resistance

Build the circuit shown on the left, turn on the switch (62) and you will see the heart LED (69) and the star LED (70) will be on at the same time. You may notice that the heart LED (69) is dimmer than the star LED (70). This is because the heart LED (69) has an internal resistor of approximately 100 Ohms in series with the actual LED, while the star LED (70) has only an internal resistor of only approximately 35 Ohms in series with the actual LED. Larger resistors (higher Ohms) means more resistance, allowing less current to flow, while smaller resistors (lower Ohms) means less resistance allowing more current to flow.




## 111. Bi-directional LEDs

Replace the switch (62) with the press switch (61) and hold down the press switch (61). The heart LED (69) and the star LED (70) will both light. We saw in project #54 that both the heart LED (69) and star LED (70) are 1-way LEDs in that they only allow current to flow in one direction. Bi-directional LEDs, on the other hand, actually have two diodes in them in opposite directions so current can flow in both directions. But current is only flowing through one diode at a time, and a different color LED light can be used in each direction.

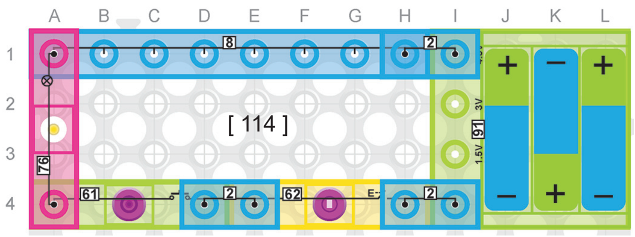
## 112. Bi-directional LED Sensor

Replace the press switch (61) with the reed switch (83), move the magnet (7) towards the reed switch (83) and both the heart LED (69) and star LED (70) with light. The previous project discussed bi-directional LEDs. Since a bi-directional LED can be made to light one color when current flows through it in one direction, and a different color when current flows through it in the opposite direction, a bi-directional LED could be used as a sensor that indicates which direction current is flowing.

## 113. Color Changing LEDs

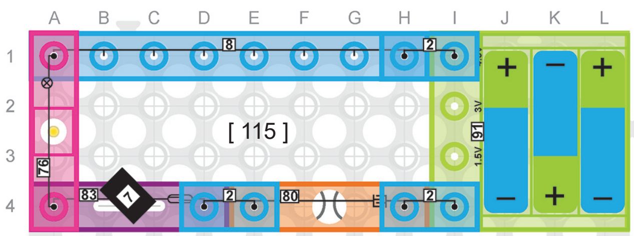
Replace the reed switch (83) with the touch plate (80). Touch the touch plate (80) with something metal like a thick metal paper clip and both the heart LED (69) and star LED (70) with light.

Color changing LEDs are similar to the heart LED (69) and star LED (70) except that they include three LEDs (one Red, one Green and one Blue) connected to a tiny Integrated Circuit (IC) that varies the percentage of time each LED is "ON". For instance, a color changing LED will look red if the red LED inside is ON 100% of the time and the green and blue LEDs are OFF 100% of the time. But if both red and green are on 100% of the time and the blue LED is OFF 100% of the time, then the color changing LED will look yellow. Similarly, red & blue ON will look magenta (purple) and green & blue ON will look cyan (light blue). In between colors can be formed by adjusting the percentage of time each LED is on between 0-100%.




## 114. Electronic 'AND' Gate

Build the circuit shown on the left. Note that the lamp (76) only turns on when both the switch (62) and press switch (61) are ON. In digital electronics there are seven logic gates: AND, OR, XOR, NOT, NAND, NOR, and XNOR. This circuit represents an AND gate. If ON = True and OFF = False then an AND gate is best defined as: The output is TRUE only when both inputs are True. Therefore, the two inputs represented by the press switch (61) and the switch (62) must both be ON (TRUE) in order for the output represented by the lamp (76) to be ON (TRUE).



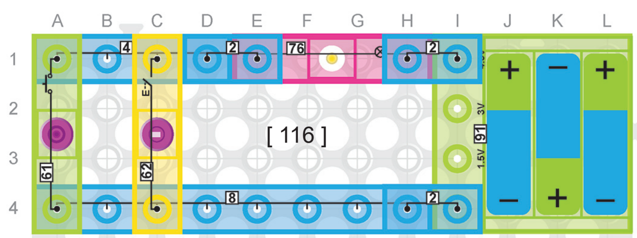

## 115. AND Gate Symbol and Logic

Build the circuit shown on the left. Note that the lamp (76) only turns on when both the magnet (7) is placed near the reed switch (83) AND the touch plate (80) is pressed with something metal like a thick metal paper clip.

The AND gate was discussed in the previous project. Because AND gates are used so often, the symbol and table below has been used to show an AND gate and describe it's logical function.

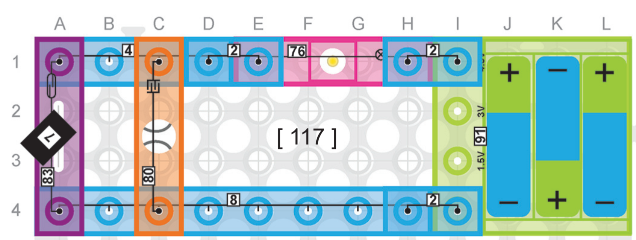
AND Gate


| Inputs | | Output |
|---|---|---|
| A | B | C |
| OFF | OFF | OFF |
| OFF | ON | OFF |
| ON | OFF | OFF |
| ON | ON | ON |




## 116. Electronic 'OR' Gate

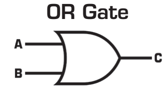
Build the circuit shown on the left. The lamp (76) will light if either the switch (62) or the press switch (61) is pressed. This circuit represents an OR gate. If ON = True and OFF = False then an OR gate is best defined as: The output is TRUE when any input is True and False only when all the inputs are False. In this circuit, the output represented by the lamp (76) is ON (True) if either input represented by the press switch (61) or the switch (62) or both is ON (TRUE). The lamp (76) is OFF (False) only when both switches are OFF (False).



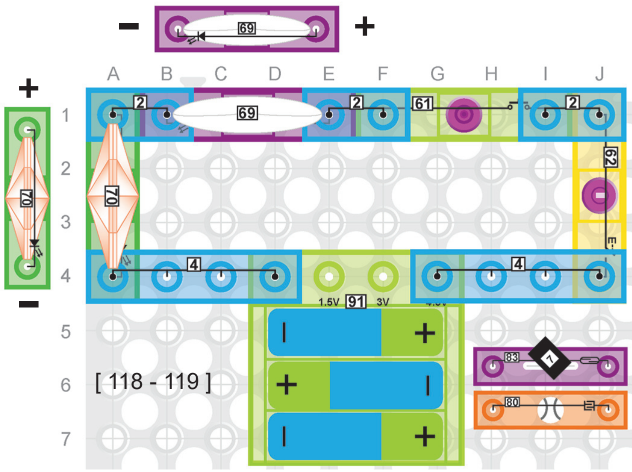

## 117. Symbol for 'OR' Gate

Build the circuit shown on the lower left. Note that the lamp (76) turns ON if either the magnet (7) is placed near the reed switch (83) OR the touch plate (80) is pressed with something metal like a thick metal paper clip. The OR gate was discussed in the previous project. Because OR gates are used so often, the symbol and table below has been used to show an OR gate and describe it's logical function.

OR Gate




| Inputs | | Output |
|---|---|---|
| A | B | C |
| OFF | OFF | OFF |
| OFF | ON | ON |
| ON | OFF | ON |
| ON | ON | ON |

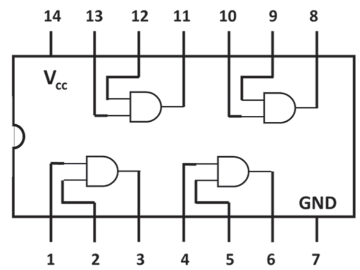


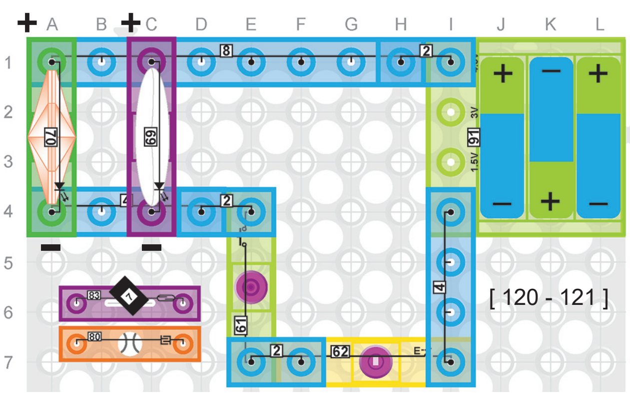

## 118. Integrated Circuits (ICs)

Build the circuit shown on the left. Note that the two LEDs only turn on when both the switch (62) and press switch (61) are ON. There is often the need to build simple as well as more complex circuits using AND, OR and other kinds of gates into very small devices (e.g. a garage door opener, a TV remote, etc.). Often this is done by making an Integrated Circuit (IC) board. ICs are small pieces of semiconducting material that is designed to provide the same circuit function as in this project or any other circuit. You can think of an IC circuit like a collection of resistors, capacitors, transistors, etc., all stuffed into a tiny chip and designed to provide the same circuit function as with actual physical resistors, capacitors and transistors.

## 119. AND Gate Devices

Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). Note that the two LEDs only turn on when both the magnet (7) is placed near the reed switch (83) AND the touch plate (80) is pressed with something metal like a thick metal paper clip. Did you know that you can buy Integrated Circuits (ICs) that implement AND-gate logic? Below is a picture of the pinout for one example IC that provides four AND-gates.



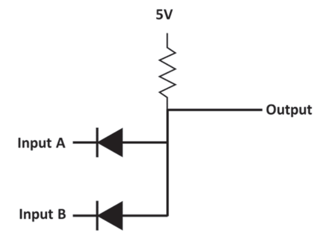



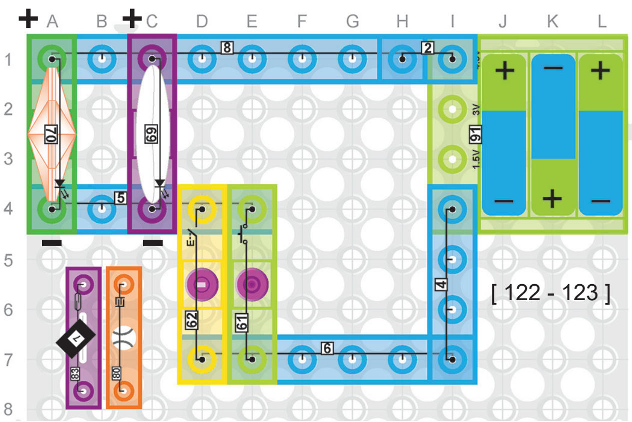

## 120. AND Gate Applications

Build the circuit shown on the left. Note that the two LEDs only turn on when both the switch (62) and press switch (61) are ON. One of the most common applications of AND gates are as enabling circuits like this. So for instance, the press switch (61) in the circuit could represent a stream of digital date going into your computer and the switch (62) is the ON-OFF switch on your computer. While the stream of data may always be present, for instance, at an Ethernet port on your computer, the data will only be processed by your computer when the switch (62) is ON. So an AND gate in your computer only allows the pass through of the Ethernet data when you power button is ON.

## 121. AND Gate Using Diodes

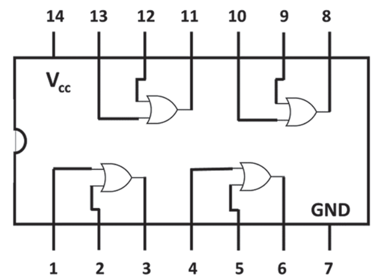
Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). Note that the two LEDs only turn on when both the magnet (7) is placed near the reed switch (83) AND the touch plate (80) is pressed with something metal like a thick metal paper clip. You can actually make an AND gate using diodes as shown in the figure below. If either input, A or B, is grounded (0V), then current can flow through the resistor which will bring the voltage at the output down close to ground (actually around 1.5V which is the turn on voltage of the diode). This is still considered a "Low" or "OFF" state. But if both inputs A and B are high (5V), then neither diode will turn on, no current will flow through the resistor, which means no voltage drop across the resistor, and thus the output will be 5V (high or ON).






## 122. OR Gate Devices

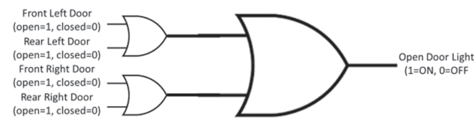
Build the circuit shown on the left. The two LEDs will light if either the switch (62) or the press switch (61) is pressed. OR gates can also be purchased in ICs. Below is a picture of the pinout for one example IC that provides four OR-gates.

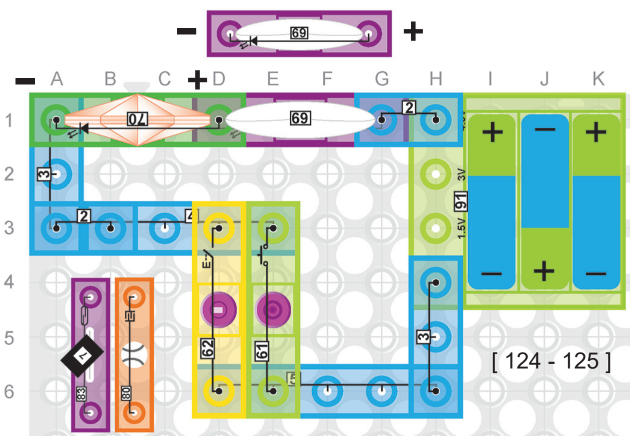



## 123. OR Gate Applications

Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). Note that the two LEDs turn on if either the magnet (7) is placed near the reed switch (83) OR the touch plate (80) is pressed with something metal like a thick metal paper clip.

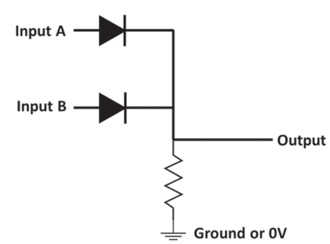
One application for OR gates would be the door open light in your car. Using a circuit like the one shown below, you can see that if any door is open (represented by a 1), then the output of the circuit produces a 1 (the door open light in dash comes on).




## 124. OR Gate Using Diodes

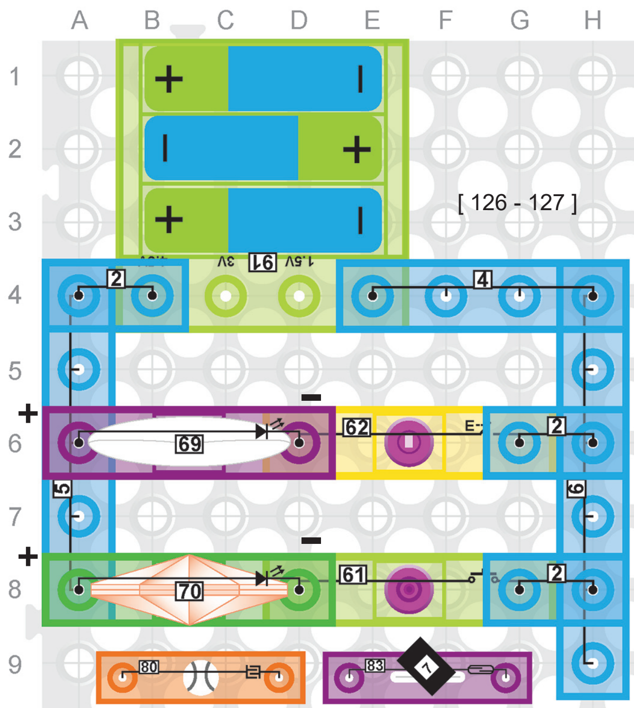
Build the circuit shown on the left. The two LEDs will light if either the switch (62) or the press switch (61) is pressed. You can actually make an OR gate using diodes as shown in the figure below. If either input, A or B, is high (5V), then current can flow through the resistor which will bring the voltage at the output close to 5V (actually around 3.5V which is 5V minus the turn on voltage of the diode). This is still considered a "High" or "ON" state. But if both inputs A and B are grounded (0V), then neither diode will turn on, no current will flow through the resistor, which means no voltage drop across the resistor, and thus the output will be at 0V (low or OFF).




## 125. Controlling Electrical Appliances

Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). If you want to turn on the LEDs you just need to place the magnet (7) near the reed switch (83) or press the touch plate (80) with a something metal like a thick metal paper clip. If you want to turn off the LEDs, you need to disconnect all the switches.

You might think this type of circuit could be used to have multiple switches in a room control the same device(s). However, this type of circuit is not ideal because the switches do not toggle with each other. In your house, if you turned on the reed switch (83) to turn ON your lights, then if you pressed the touch plate (80) with a metal paper clip you would want your lights to go OFF. Your house uses three-way switches to do this, and not the circuit on the left.



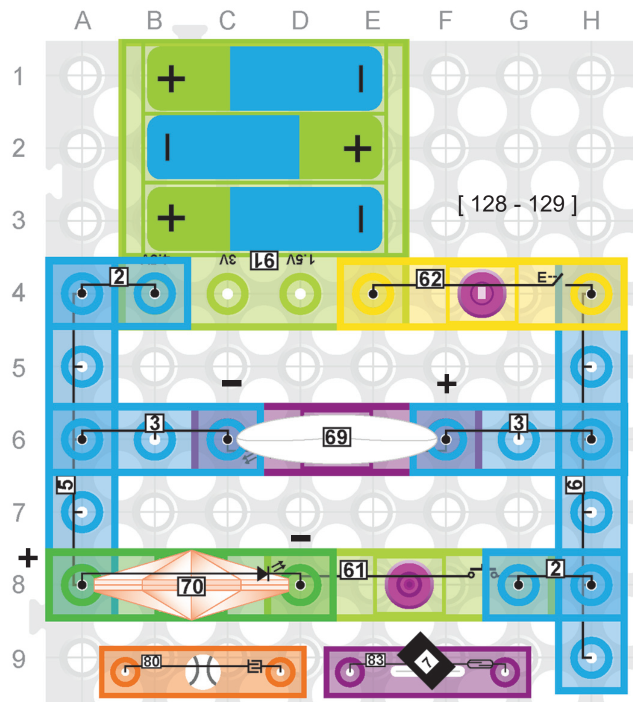

## 126. Individually Controlled Electrical Appliances

Build the circuit shown on the left. Press the switch (62) and you will see the heart LED (69) turn on. Press and hold the press switch (61) and you will see the star LED (70) turn on.

You might have a circuit in your family room like this where you have two switches on the wall where one switch turns on and off the lights in the room and one switch turns on and off the TV.

## 127. Ceiling Light & Fan

Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). Place the magnet (7) near the reed switch (83) and the heart LED (69) will turn on. Press the touch plate (80) with a something metal like a thick metal paper clip and the star LED (70) will turn on. This type of circuit could also be used to separately control the light and the fan in the ceiling in your bedroom.



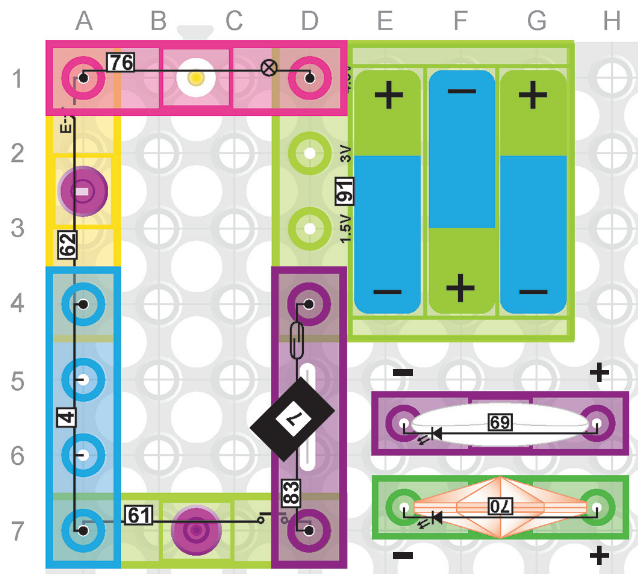

## 128. Switches on Appliances

Build the circuit, turn on the switch (62) and you will light up the heart LED (69). You then need press the press switch (61) for the star LED (70) to turn on. This type of circuit simulates how some appliances in your house may work. For instance, in your bed room there may be a switch that turns on the lights embedded in the ceiling, and it turns on certain outlets in the room. But you still need to flip the switch on lamp on your night stand that is connected to those outlets to turn it on.

## 129. ON-OFF Button on Appliances

Using the previous circuit, replace the press switch (61) with the reed switch (83) and replace the switch (62) with the touch plate (80). Place the magnet (7) near the reed switch (83) and you will light up the heart LED (69). You then need press the press the touch plate (80) with something metal like a thick metal paper clip for the star LED (70) to turn on.

This type of circuit is used in a lot of appliances because the reed switch (83) acts like the ON-OFF button on the appliance and the touch plate (80) acts like a selection button. For instance, your cable TV box has an ON-OFF button on it which you need to turn on before the other buttons like the channel select buttons or the menu button will work.



[ 130 - 132 ]

## 130. Triple Input 'AND' Gate

Build the circuit shown on the left. Turn the switch (62) ON, press and hold the press switch (61) to turn it ON, and move the magnet (7) towards the reed switch (83). Only when all three switches (INPUTS) are ON (True) will the lamp (76) (OUTPUT) be ON (True).

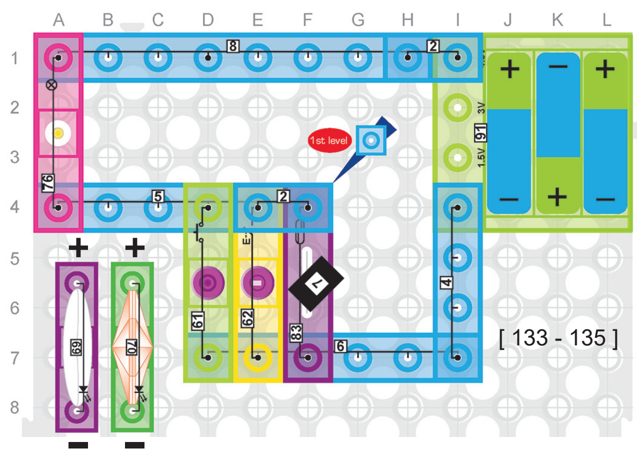
Electronic AND Gates can have two or more inputs but the function is still the same. All inputs must be True (ON) for the output to be True (ON).

## 131. Three-person Rocket Launch

Using the previous circuit, replace the lamp (76) with the heart LED (69). In this circuit, pretend the heart LED (69) is a rocket. To launch the rocket the switch (62) must be ON, AND the press switch (61) must be ON, AND the reed switch (83) must be turned ON with the magnet (7). Systems like this with the switches setup in three different rooms are used to prevent accidental rocket launching.

## 132. Circuit Breakers

Using the previous circuit, replace the heart LED (69) with the star LED (70). In this circuit, if you want to turn on the star LED (70), you need to turn on all the switches at the same time. This circuit could represent your house circuitry. Think of the reed switch (83) like the circuit breaker in your house, the switch (62) like a wall switch and the press switch (61) like the switch on an appliance plugged into the outlet controlled by the switch (62). Even if you turn on the wall switch and the switch on the appliance, if you trip a fuse in the circuit breaker for that room in your house (simulated by moving the magnet (7) away from the reed switch (83)) then the appliance will not turn on.



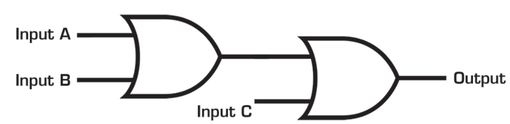
[ 133 - 135 ]

## 133. Triple Input OR Gate

Build the circuit to the left, making sure all switches are OFF. The lamp (76) should be OFF. Turn ON any one of the switches and the lamp (76) will be ON. To turn off the lamp (76), all of the switches must be OFF. Electronic OR Gates can have two or more inputs but the function is still the same. All inputs must be False (OFF) for output to be False (OFF).

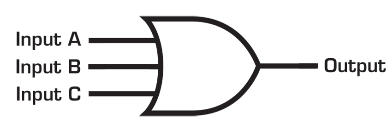
## 134. Triple Input OR Gate Logic

Using the previous circuit, replace the lamp (76) with the heart LED (69). The heart LED (69) should be OFF. Turn ON any one of the switches and the heart LED (69) will be ON. To turn off the heart LED (69), all of the switches must be OFF. One way to implement a triple input OR gate is by sending the output of a double input OR gate into the input of a second double input OR gate as shown below.

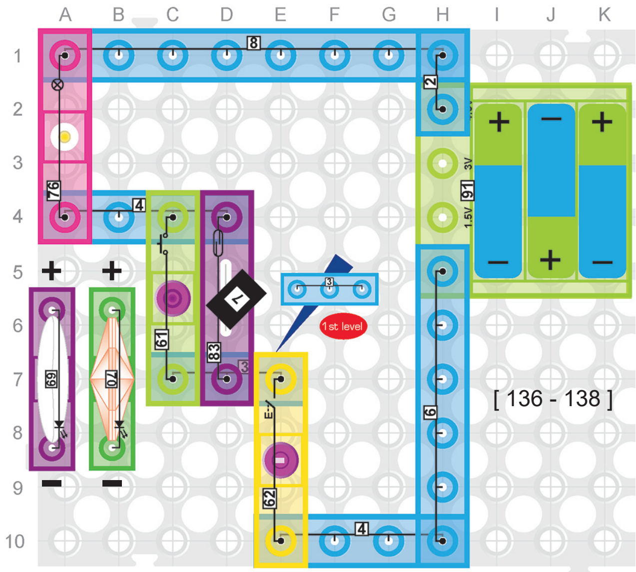



## 135. Triple Input OR Gate Diagram

Using the previous circuit, replace the heart LED (69) with the star LED (70). The star LED (70) should be OFF. Turn ON any one of the switches and the star LED (70) will be ON. To turn off the star LED (70), all of the switches must be OFF. The previous project showed how to implement a triple input OR gate, but for simplicity a triple input OR gate can be shown as below.



## 136. Series-Parallel Circuit Paths (I)




Build the circuit to the left. In this circuit, the lamp (76) that indicates current flow cannot turn on by just turning the switch (62) ON. If you turn the switch (62) ON and press and hold the press switch (61) then current will flow. Or if you turn the switch (62) ON and move the magnet (7) towards the reed switch (83) then current will flow. Since the switch (62) is in series with the other two switches that are in parallel, this makes a series-parallel circuit path for the lamp (76). This kind of circuit could be used in a hotel room where your key card must be inserted in a card holder near the door to enable a closed circuit, but you still need to turn on switches in the room to have certain lights or devices close the circuit and turn on.

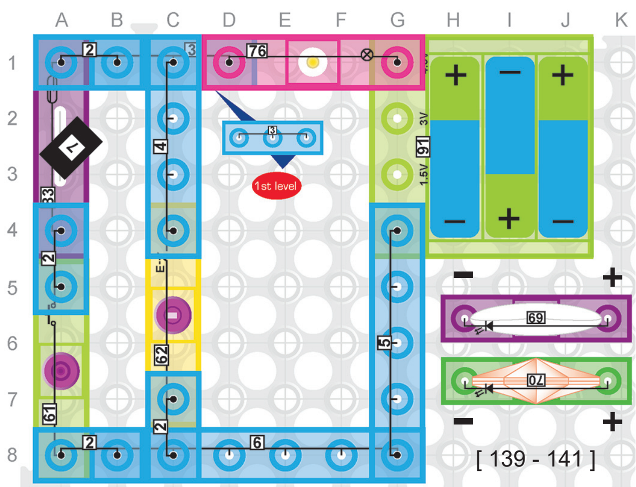
## 137. Garage Door Opening Circuit

Using the previous circuit, replace the lamp (76) with the heart LED (69). In this circuit, the heart LED (69) that indicates current flow cannot turn on by just turning the switch (62) ON. If you turn the switch (62) ON and press and hold the press switch (61) then current will flow. Or if you turn the switch (62) ON and move the magnet (7) towards the reed switch (83) then current will flow. Since the switch (62) is in series with the other two switches that are in parallel, this makes a series-parallel circuit path for the heart LED (69).  This type of circuit could be used where the heart LED (69) is your garage door, the press switch (61) is a button on the wall in your garage to open & close the garage door, the reed switch (83) is a remote control device you keep in your car to open and close your garage door, and the switch (62) is a circuit breaker in your house.

## 138. Power Strip

Using the previous circuit, replace the heart LED (69) with the star LED (70). In this circuit, the star LED (70) that indicates current flow cannot turn on by just turning the switch (62) ON. If you turn the switch (62) ON and press and hold the press switch (61) then current will flow. Or if you turn the switch (62) ON and move the magnet (7) towards the reed switch (83) then current will flow. Since the switch (62) is in series with the other two switches that are in parallel, this makes a series-parallel circuit path for the star LED (70). This type of circuit could be used where the star LED (70) is your TV, the press switch (61) is the ON-OFF button on your TV, the reed switch (83) is a remote control device for your TV, and the switch (62) is a power strip that your TV is plugged into. Power strips generally have ON-OFF switches too, and when they are OFF, then neither the buttons on your TV (press switch (61)) nor the TV remove (reed switch (83)) will turn on your TV, just like the star LED (70) in this circuit.

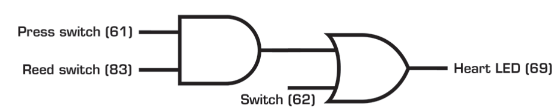
## 139. Series-Parallel Circuit Paths (II)




Build the circuit to the left. There are two ways to light the lamp (76) in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). Using the hotel analogy from project #136, the reed switch (83) could represent the key card holder and the press switch (61) could be a switch for a light in the room. But this room now has a master key card holder that only the employees (e.g. maids) at the hotel have keys for that turns on all the lights in the room regardless of what switches are turned on or off in the room.

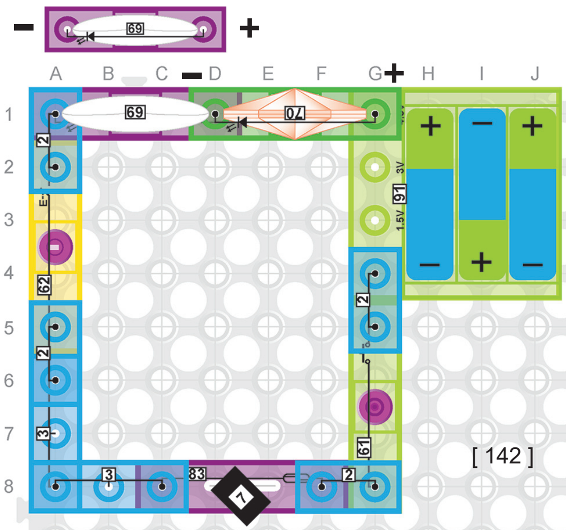
## 140. Logic Diagram for Series-Parallel Circuit Paths (II)

Using the previous circuit, replace the lamp (76) with the heart LED (69). There are two ways to light the heart LED (69) in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). The diagram below shows the logic diagram for this circuit.



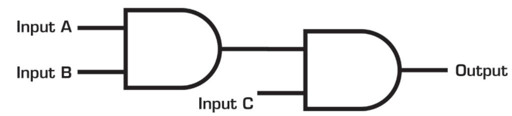

## 141. Boolean Operations

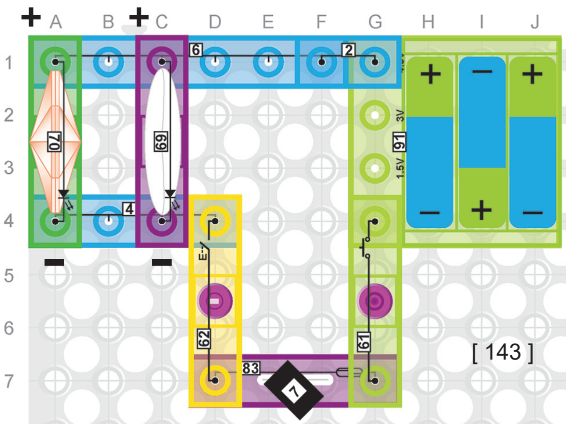
Build the circuit shown on the left. There are two ways to light the star LED (70) in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). Projects #134, #135, and #140 showed various logic diagrams for representing AND and OR gate circuits. The inputs and outputs to the logic symbols were all binary (either ON or OFF). These types of operations are called Boolean operations.




## 142. Triple Input AND Gate Logic

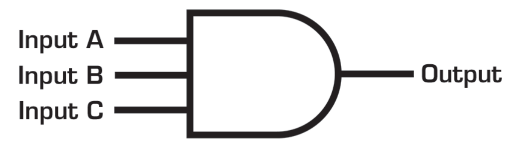
Build the circuit to the left, turn the switch (62) ON, press and hold the press switch (61) to turn it ON, and move the magnet (7) towards the reed switch (83). Only when all three switches (INPUTS) are ON (True) will the two LEDs (OUTPUT) be ON (True). The two LEDs are dim because they are in series as discussed in project #15. One way to implement a triple input AND gate is by sending the output of a double input AND gate into the input of a second double input AND gate as shown below.

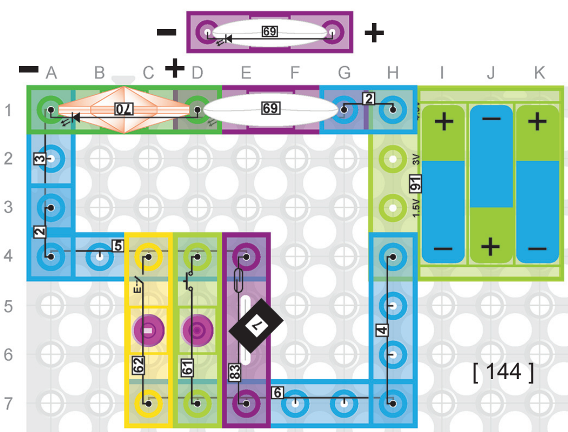



## 143. Triple Input AND Gate Diagram

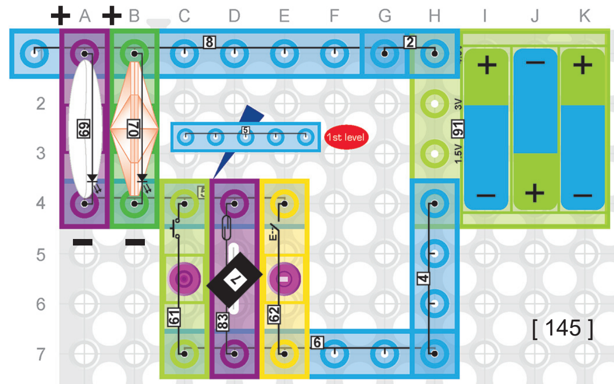
Build the circuit shown on the left, turn the switch (62) ON, press and hold the press switch (61) to turn it ON, and move the magnet (7) towards the reed switch (83). Only when all three switches (INPUTS) are ON (True) will the two LEDs (OUTPUT) be ON (True). The two LEDs are bright because they are in parallel as discussed in project #19. The previous project showed how to implement a triple input AND gate, but for simplicity a triple input AND gate can be shown as below.




## 144. Applications of Logic Gates

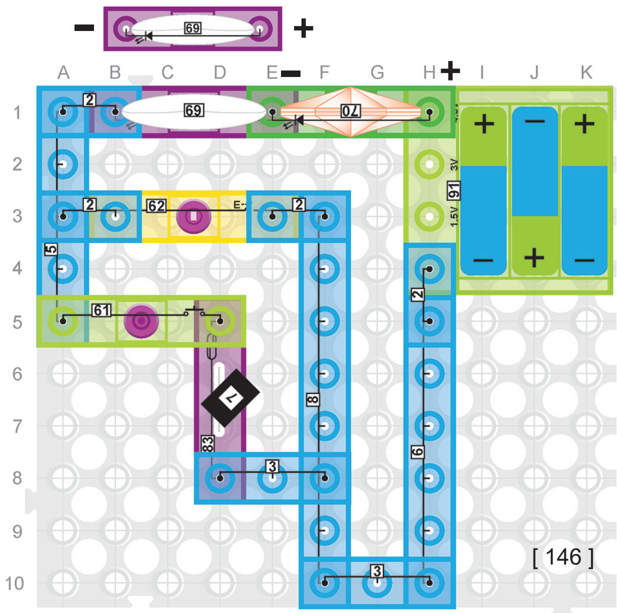
Build the circuit to the left. The two LEDs should be OFF. Turn ON any one of the switches and the two LEDs will be ON. The two LEDs are dim because they are in series as discussed in project #15. To turn off the two LEDs, all of the switches must be OFF. Logic gates are used in computers, cellphones and tablets, calculators and digital watches, just to name a few applications.




## 145. Boolean Algebra

Build the circuit shown on the left. The two LEDs should be OFF. Turn ON any one of the switches and the two LEDs will be ON. The two LEDs are bright because they are in parallel as discussed in project #19. To turn off the two LEDs, all of the switches must be OFF.

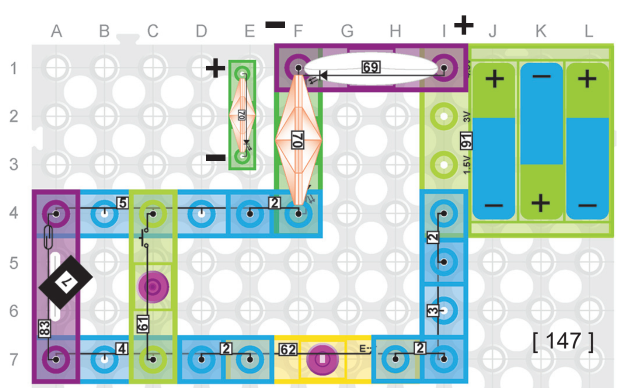
The logic tables, or often called truth tables, from projects #115 and #117 can be represented by Boolean Algebra. In Boolean Algebra, the "+" symbol is used to represent an OR function and the "*" symbol is used to represent an AND function. So in Boolean Algebra, 0+0 = 0 and 0+1 = 1, but 1+1 = 1. Also, 0*0 = 0, 0*1 = 0 and 1*1 = 1.




## 146. Boolean Algebra for Series-Parallel Circuit (II)

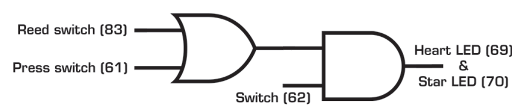
Build the circuit to the left. There are two ways to light the 2 LEDs in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). The two LEDs are dim because they are in series as discussed in project #15.

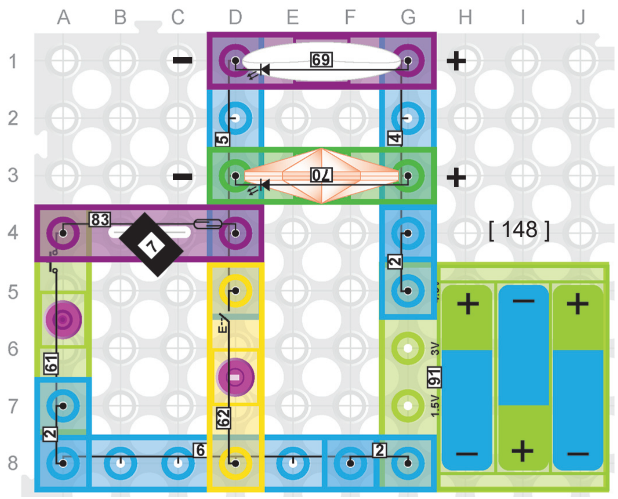
If you represent the switch (62) by the variable A, the press switch (61) by the variable B and the reed switch (83) by the variable C, then the output of this circuit (the two LEDs) can be represented in Boolean Algebra by the expression A + B*C. Based on the Boolean Algebra discussed in the previous project, this expression equals 1 (the LEDs ON) if either A is 1 (the switch (62) is ON) or if both B is 1 (the press switch (61) is ON) and C is 1 (the reed switch (83) is ON), or if A and B and C are all 1 (all the switches are on).




## 147. Series-Parallel Circuit Paths (III) – Logic Diagram

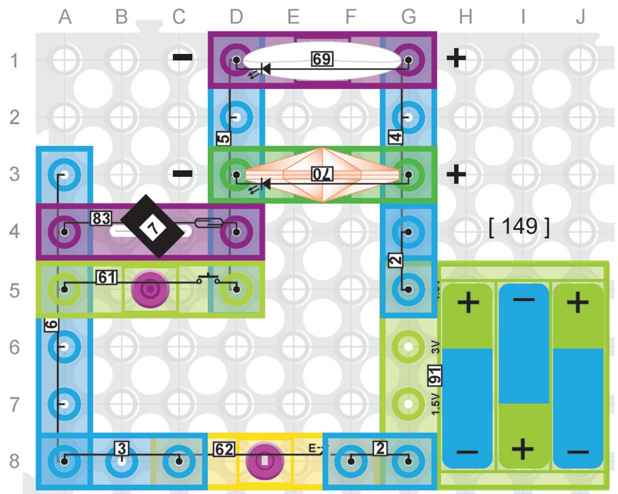
Build the circuit shown on the left. There are two ways to light the 2 LEDs in this circuit. You can either press the switch (62) and press and hold the press switch (61), or you can press the switch (62) and place the magnet (7) near the reed switch (83). The two LEDs are dim because they are in series as discussed in project #15. The logic diagram for this circuit is shown below.





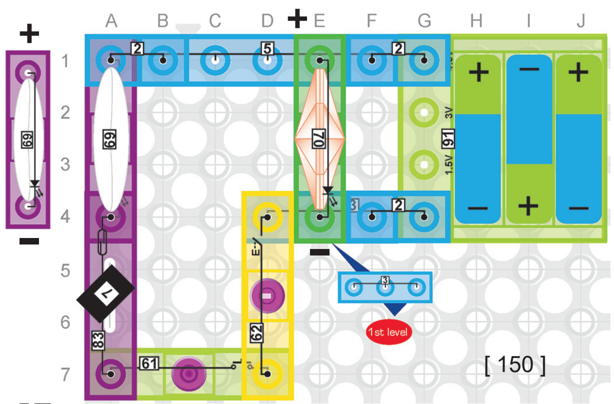
## 148. Series-Parallel Circuit Paths (II) – Boolean History

Build the circuit to the left. There are two ways to light the 2 LEDs in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). The two LEDs are bright because they are in parallel as discussed in project #19. Boolean Algebra was introduced by George Boole way back in 1847.



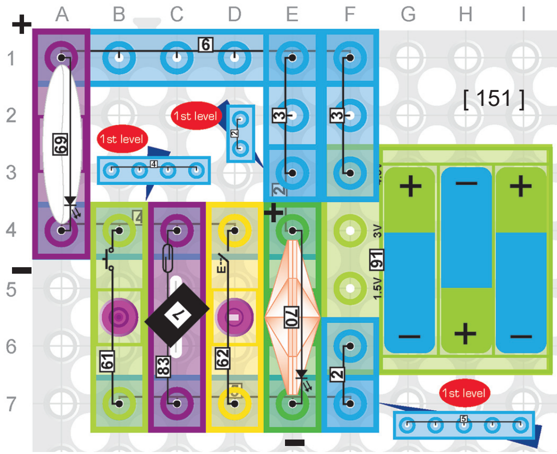
## 149. Series-Parallel Circuit Paths (III) – Boolean Equation

Build the circuit shown on the left. There are two ways to light the 2 LEDs in this circuit. You can either press the switch (62) and press and hold the press switch (61), or you can press the switch (62) and place the magnet (7) near the reed switch (83). The two LEDs are bright because they are in parallel as discussed in project #19. If you represent the switch (62) by the variable A, the press switch (61) by the variable B and the reed switch (83) by the variable C, then the output of this circuit (the two LEDs) can be represented in Boolean Algebra by the expression A*(B+C). This expression equals 1 (the LEDs ON) only if A is 1 (the switch (62) is ON) and either B is 1 (the press switch (61) is ON) or C is 1 (the reed switch (83) is ON) or B and C are both 1 (the press switch (61) and the reed switch (83) are ON).



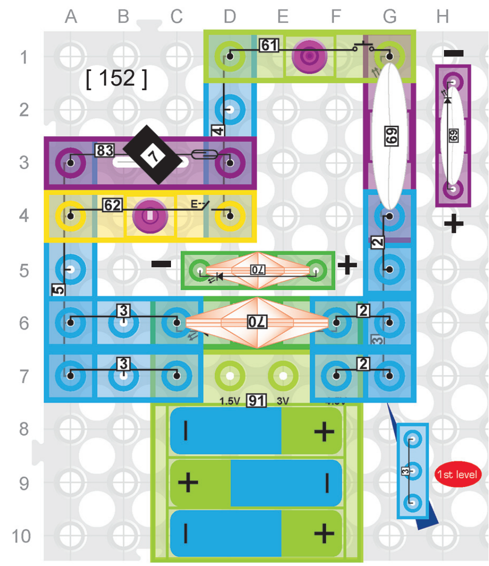
## 150. Boolean Equation for Triple Input AND Gate Circuit

Build the circuit shown on the left. The star LED (70) will be on, but the heart LED (69) will only be on if all three switches are on. If you represent the switch (62) by the variable A, the press switch (61) by the variable B and the reed switch (83) by the variable C, then the state of the heart LED (69) can be represented in Boolean Algebra by the expression A*B*C. This expression equals 1 (the heart LED (69) ON) only if A is 1 (the switch (62) is ON) and B is 1 (the press switch (61) is ON) and C is 1 (the reed switch (83) is ON).



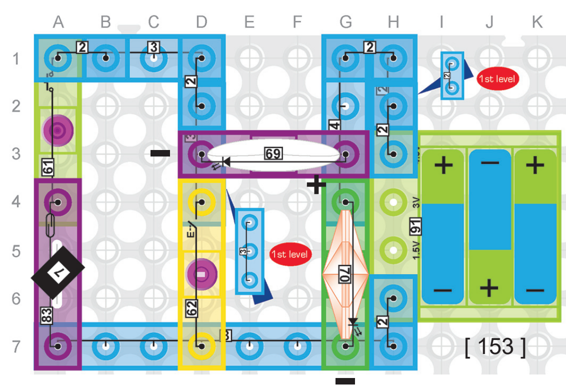

## 151. Boolean Equation for Triple Input OR Gate Circuit

Build the circuit shown on the left. The star LED (70) will be on, but the heart LED (69) will be on if any of the three switches are on. If you represent the switch (62) by the variable A, the press switch (61) by the variable B and the reed switch (83) by the variable C, then the state of the heart LED (69) can be represented in Boolean Algebra by the expression A+B+C. This expression equals 1 (the heart LED (69) ON) if A is 1 (the switch (62) is ON) or B is 1 (the press switch (61) is ON) or C is 1 (the reed switch (83) is ON).



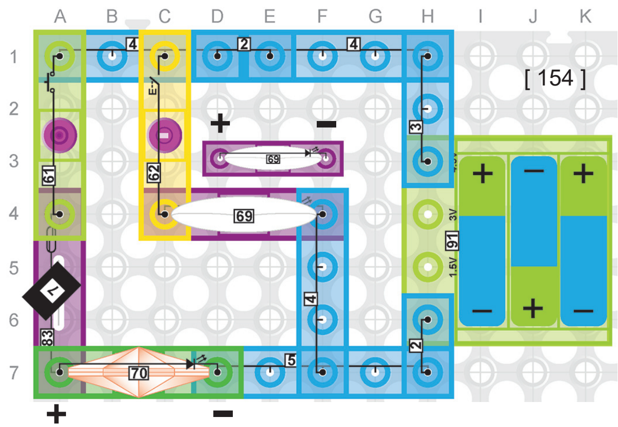

## 152. Boolean Algebra in Computers

Build the circuit shown on the left. The star LED (70) will be on and there are two ways to turn on the heart LED (69). You can either press the press switch (61) and place the magnet (7) next to the reed switch (83) or press the press switch (61) and press the switch (62). All computers today use Boolean Algebra in some way. The Boolean values (1 or 0) are generally called bits. Assembly language coding actually is based on Boolean Algebra, using registers where zero volts or ground represents 0, and a reference voltage (e.g. 5V) represents 1.




## 153. Boolean Algebra in Law

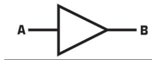
Build the circuit to the left. The star LED (70) will be on and there are two ways to turn on the heart LED (69). You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61). The concept of Boolean Algebra can also be applied to a court of law. In a court of law it is often advantageous to ask questions that only require a simple yes or no answer (i.e. a Boolean response) to avoid the person responding from bringing up information that could be harmful for the prosecutor or defense who is asking the question.



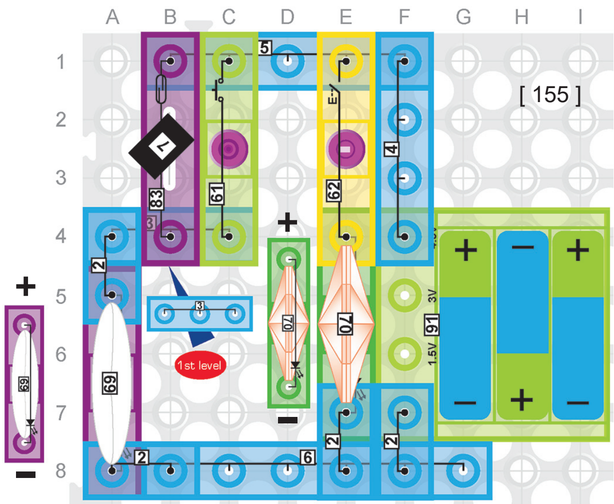

## 154. Buffer Gate

Build the circuit to the left. The heart LED (69) will light if you press the switch (62) and the star LED (70) will light if you press the press switch (61) and hold the magnet (7) near the reed switch (83). Sometimes it's convenient to have a symbol to represent the ON-OFF status of a switch, like the switch (62) in this circuit. This is often done through a buffer gate. A buffer gate is shown below with its logic table, which is basically the output equals the input.

**Buffer Gate**

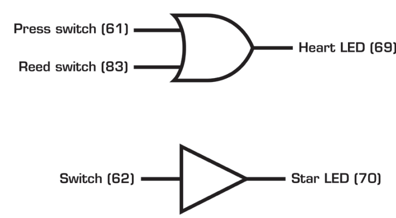


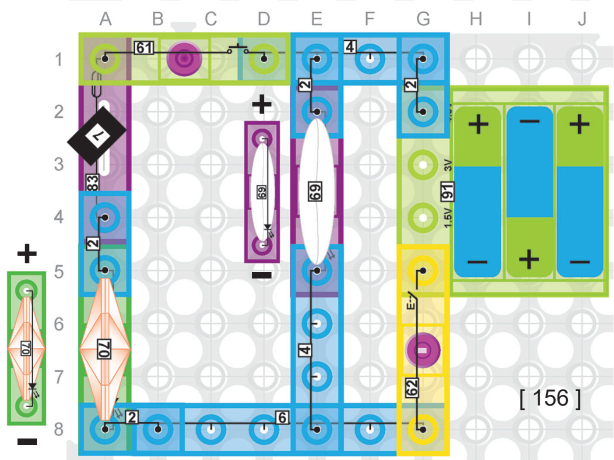

| Input | Output |
|---|---|
| A | B |
| ON | ON |
| OFF | OFF |




## 155. Series-Parallel Connection (IV) – Logical Diagram

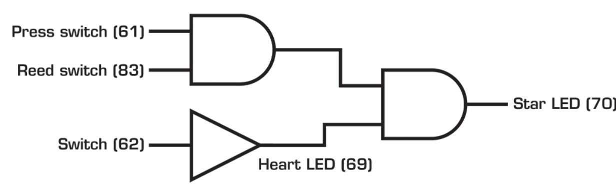
Build the circuit shown on the left. The star LED (70) will light if you press the switch (62) and the heart LED (69) will light if you press the press switch (61) or hold the magnet (7) near the reed switch (83). The logical diagram below represents this circuit.

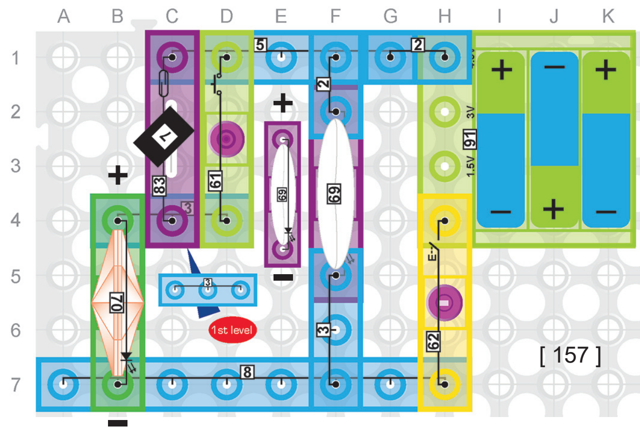



## 156. Series-Parallel Connection (V) – Logical Diagram

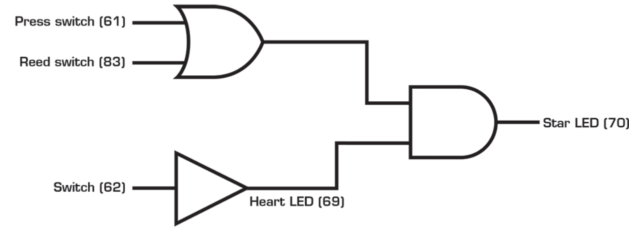
Build the circuit to the left. The star LED (70) will light only if you turn on all three switches, while the heart LED (69) will light if you press the switch (62). The logical diagram below represents this circuit.

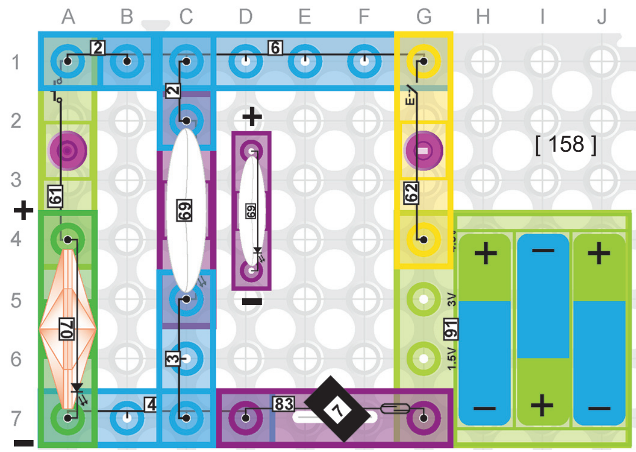





## 157. Series-Parallel Connection (VI) – Logical Diagram

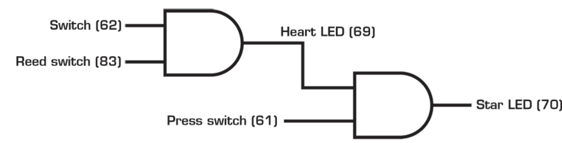
Build the circuit to the left. The star LED (70) will light if you turn on the switch (62) and either press and hold the press switch (61) or place the magnet (7) near the reed switch (83), while the heart LED (69) will light if you press the switch (62). The logical diagram below represents this circuit.

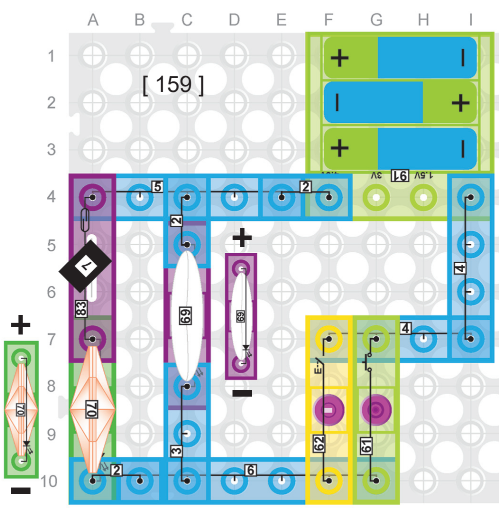



## 158. Series-Parallel Connection (VII) – Logical Diagram

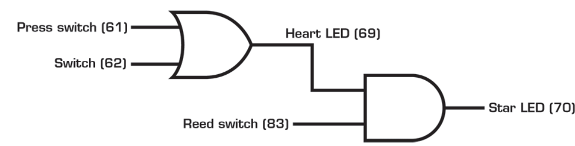
Build the circuit shown on the left. The star LED (70) will light only if you turn on all three switches, while the heart LED (69) will light if you place the magnet (7) near the reed switch (83) and press the switch (62). The logical diagram below represents this circuit

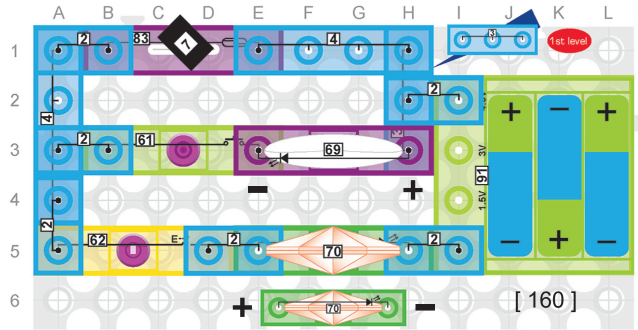



## 159. Series-Parallel Connection (VIII) – Logical Diagram

Build the circuit to the left. The star LED (70) will light if you place the magnet (7) near the reed switch (83) and press the switch (62) or press and hold the press switch (61), while the heart LED (69) will light if you press the switch (62) or press and hold the press switch (61). The logical diagram below represents this circuit.

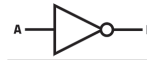





## 160. NOT Gate

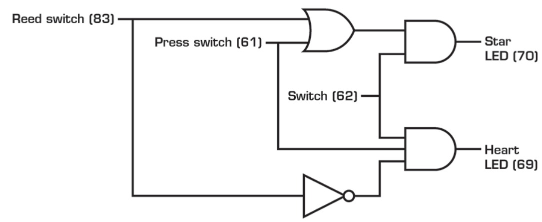
Build the circuit shown, turn on the switch (62) and press the press switch (61) and you will see both the LEDs are on dimly since they are in series. If you touch the reed switch (83) with the magnet (7), you will see that the heart LED (69) goes off, but the star LED (70) is brighter. This is because by activating the reed switch (83) you are by-passing the heart LED (69) so the star LED (70) sees the full 4.5V from the battery (91). In order to represent this circuit's logic, we need a NOT gate. The symbol for a NOT gate and logic table are shown below. The function of a NOT gate is to invert the input (if the input is ON then the output is OFF and if the input is OFF then the output is ON).

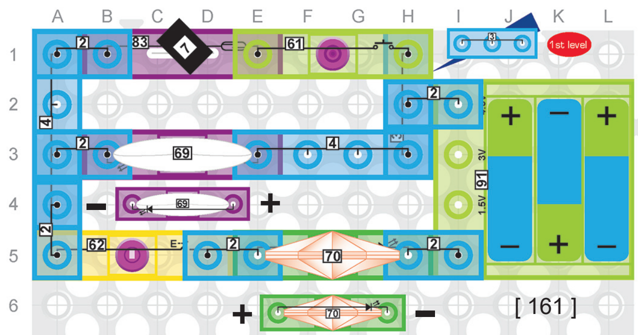
**NOT Gate**




| Input | Output |
|---|---|
| A | B |
| ON | OFF |
| OFF | ON |

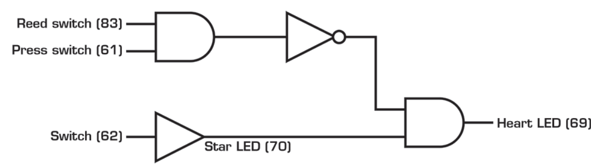
With the help of the NOT Gate, we can now represent the logic in this circuit as shown below.

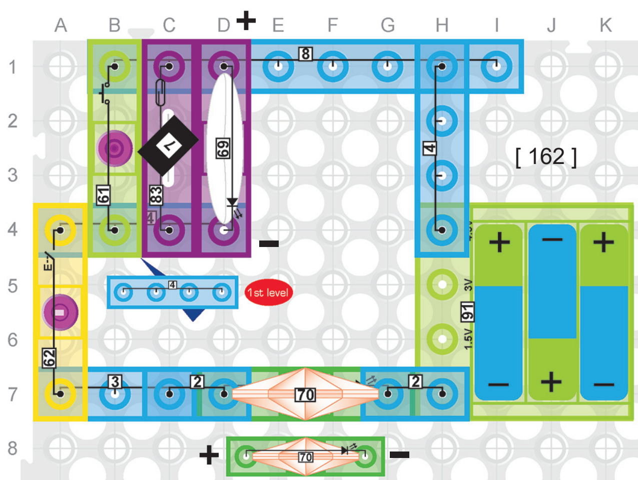



## 161. Series-Parallel Connection (IX) – Logical Diagram

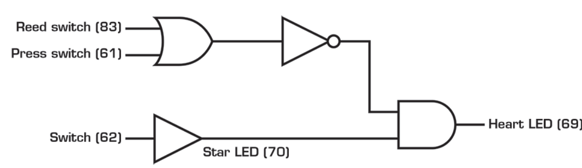
Build the circuit shown, turn on the switch (62) and you will see both the LEDs are on dimly since they are in series. If you touch the reed switch (83) with the magnet (7) and press the press switch (61), you will see that the heart LED (69) goes off, but the star LED (70) is brighter. The logical diagram for this circuit is shown below.

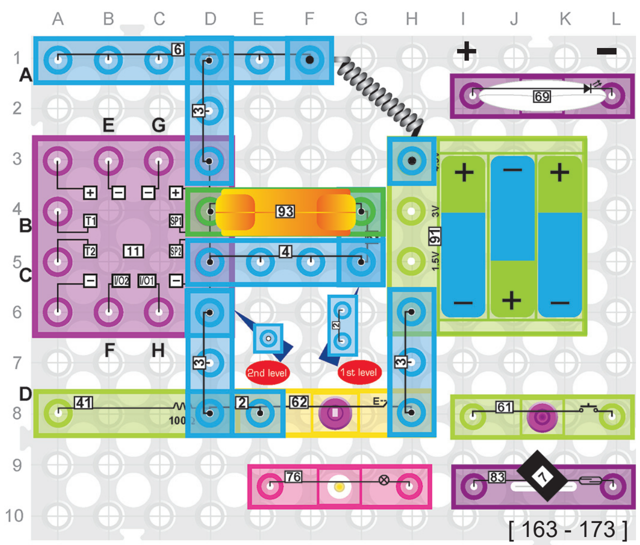



## 162. Series-Parallel Connection (X) – Logical Diagram

Build the circuit shown, turn on the switch (62) and you will see both the LEDs are on dimly since they are in series. If you touch the reed switch (83) with the magnet (7) or press the press switch (61), you will see that the heart LED (69) goes off, but the star LED (70) is brighter. The logical diagram for this circuit is shown below.






[ 163 - 173 ]

## 163. Siren
Build the circuit shown on the left. Press the switch (62) and you will hear the siren from the speaker (93). The 3-in-1 (11) contains an Integrated Circuit (IC) that produces the siren sound. An IC is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, normally silicon. ICs enable much more complicated circuits to be designed in orders of magnitude smaller, cheaper, and faster manners than those constructed using discrete electronic components.

## 164. Machine Gun Sounds
Place the touch plate (80) across points C and D, press the switch (62), press your finger across the touch plate (80) and you will hear a gun shot and machine gun sounds. You may need to rub your finger up and down on the touch plate (80) a few times to make it work. Sound technicians use electronics like this on the job to create all types of sounds.

## 165. Emergency Fire Siren
Place a 4-wire (4) across points A and B in project #163, press the switch (62) and you will hear the sound of an emergency fire siren. A Siren like this is designed by an engineer to cover a large spectrum of sound so all people can hear it, even if they have hearing problems.

## 166. Space Battle Sounds
Place a 4-wire (4) across points E and F in project #163, press the switch (62) and you will hear space battle sounds. Note the 4-wire (4) on the 3-in-1 (11) in this circuit is activating the space war sounds by grounding the I/O2 pin. In electronics, this type of input is called "active low".

## 167. Music
Place a 4-wire (4) across points G and H in project #163, press the switch (62) and you will hear music. This music is electronically generated and stored in this module during production and usually checked by a quality control technician to insure good audio quality.

## 168. Motion Detection Alarm
Replace the switch (62) with the reed switch (83) in project #163. Hold the magnet (7) near the reed switch (83) and you will hear the siren from the speaker (93). This circuit simulates motion detection alarms that are in your house.

## 169. No Touch Special Effects
Replace the switch (62) with the reed switch (83) in project #163. Place the touch plate (80) across points C and D, hold the magnet (7) near the reed switch (83), press your finger across the touch plate (80) and you will hear a gun shot and machine gun sounds. You may need to rub your finger up and down on the touch plate (80) a few times to make it work. This demonstrates how special sound effects can be activated and deactivated (through the reed switch (83)) without physically having to touch a switch on the circuit.

## 170. Proximity Warning
Replace the switch (62) with the reed switch (83) in project #163. Place a 4-wire (4) across points A and B and when you hold the magnet (7) near the reed switch (83) you will hear the sound of an emergency fire siren. The magnet (7) on the reed switch (83) could be like sensors on your car that activate a warning sound when it gets too close to an object.

## 171. Space Battle Sounds
Replace the switch (62) with the reed switch (83) in project #163. Place a 4-wire (4) across points E and F and when you hold the magnet (7) near the reed switch (83) you will hear space battle sounds. Many movie sound effects are made electronically like this.

## 172. Proximity Music Interrupt
Replace the switch (62) with the reed switch (83) in project #163. Place a 4-wire (4) across points G and H and when you hold the magnet (7) near the reed switch (83) you will hear music. Move the magnet (7) away from the reed switch (83) and the music will stop and reset. This circuit could simulate a disc jockey who holds a magnet and just wave their hand over the reed switch to restart a song.

## 173. Flickering Candle
Replace the speaker (93) with the lamp (76) in project #163, then connect points C and D with a 4-wire (4). If you turn on the switch (62) you will see the lamp (76) is flashing quickly. You could put this circuit in your window at night and it would look like a candle in a gentle breeze.

## 174. Flashing Quick Sale Sign

Replace the speaker (93) with the star LED (70) in project #163, then connect points C and D with a 4-wire (4). If you turn on the switch (62) you will see the star LED (70) is flashing quickly. An indicator like this could be used to show when a quick sale is available in a store.

## 175. Four Beats per Second

Replace the speaker (93) with the lamp (76) in project #163, then connect points G and H using 4-wires[4]. If you turn on the switch (62) you will see the lamp (76) flashing slowly, at approximately 4 beats per second. Trying counting them for yourself.

## 176. Two Channel Monitor

Replace the speaker (93) with star LED (70) in project #163, then connect points G and H using 4-wires[4]. If you turn on the switch (62) you will see the star LED (70) is flashing slowly. Remove the 4-wire (4) from points G and H and the star LED (70) flashes quickly.

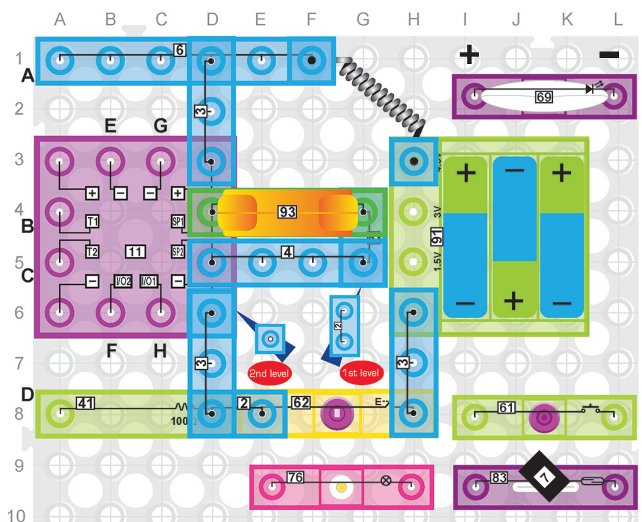
The light pulses from the star LED (70) could represent Morse code signals. This is similar to what a technician working for the FBI or CIA may see when they change the channel they are monitoring. Codes are only simulated, not real.

## 177. Attention Please

Replace the speaker (93) with the heart LED (69) in project #163, then connect points C and D with a 4-wire (4). If you turn on the switch (62) you will see the heart LED (69) is flashing quickly. A signal like this could be used to get someone's attention.

## 178. Heartbeat

Replace the speaker (93) with the heart LED (69) in project #163, then connect points G and H with a 4-wire (4). If you turn on the switch (62) now, you can see the heart LED (69) is flashing slowly, like a heartbeat.



[ 174 - 183 ]

## 179. Moore's Law

Replace the switch (62) with the press switch (61) in project #163. Press the press switch (61) and you will hear the siren from the speaker (93). The 3-in-1 (11) module has an IC in it which is more complicated to provide various sounds. The complexity of what needs to go on ICs continues to grow every year. Fortunately, semiconductor technology has been able to advance at a fast rate too. Moore's Law saws that microchips double in power every 18 to 24 months.

## 180. Sound Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #163. Place a 4-wire (4) across points C and D and when you press the press switch (61) you will hear a gun shot and machine gun sounds. Sound recording and reproduction is used to reproduce the sounds you hear from the speaker.

## 181. Types of Sound Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #163. Place a 4-wire (4) across points A and B and when you press the press switch (61) you will hear the sound of an emergency fire siren. There are two types of sound recording and reproduction: analog and digital.

## 182. Analog Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #163. Place a 4-wire (4) across points E and F and when you press the press switch (61) you will hear space battle sounds.

Analog recording uses a microphone that records the acoustic sound waves on either a phonograph record or magnetic tape. Analog reproduction then uses a speaker to reproduce the sound waves recorded.

## 183. Digital Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #163. Place a 4-wire (4) across points G and H and when you press the press switch (61) you will hear music.

Digital recording converts the analog sound waves picked up on a microphone to a digital signal represented by 1s and 0s. These 1s and 0s can be stored in memory on any type of storage device and then retrieved and used to recreate the analog signal.

## 184. Sampling

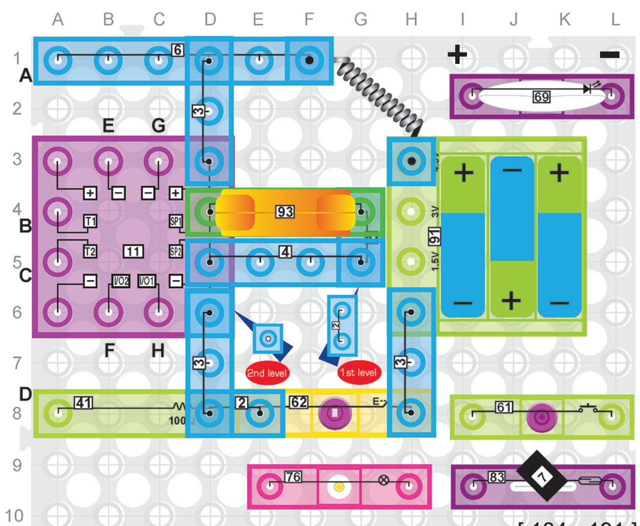
Replace the switch (62) with the press switch (61) and replace the speaker (93) with the lamp (76) in project #163. Connect points C and D with a 4-wire (4), press the press switch (61) and you will see the lamp (76) is flashing quickly.

Sampling is a method for digitally encoding sound signals including music. The idea is to sample the amplitude of the sound signal at regular points in time, and then encode these samples into a binary bit stream that can be stored and retrieved for future recreation of the sound signal.

## 185. Nyquist Theorem

Replace the switch (62) with the press switch (61) and replace the speaker (93) with the lamp (76) in project #163. Connect points G and H using a 4-wire (4), press the press switch (61) and you will see the lamp (76) flashing slowly.

The Nyquist Theorem relates to the minimum sampling rate needed to perfectly be able to reconstruct the original signal from the samples. The Nyquist Theorem states that if sampling is performed at least at twice the highest frequency component of the signal, then theoretically the signal can be perfectly recovered from the samples.



[ 184 - 191 ]

## 186. Digital to Analog Reconstruction

Replace the switch (62) with the press switch (61) and replace the speaker (93) with the heart LED (69) in project #163. Connect points C and D with a 4-wire (4), press the press switch (61) and you will see the heart LED (69) is flashing quickly.

While the Nyquist Theorem states that it's theoretically possible to recreate an analog signal from its samples (assuming the samples meet the Nyquist Criteria), it turns out that the filter needed to exactly reproduce the original analog signal is practically impossible to implement. However, practical smoothing filters can be used to reproduce a very close replica of the original analog signal. Think of this as like connecting the dots between the amplitude samples to get something that looks very much like the original analog signal.

## 187. The 3-in-1 Module

Replace the switch (62) with the press switch (61) and replace the speaker (93) with the heart LED (69) in project #163. Connect points G and H with a 4-wire (4), press the press switch (61) and you will see the heart LED (69) is flashing slowly.

The 3-in-1 (11) module has the music and sounds it produces stored in an IC in a digital format and uses techniques discussed in the previous projects to create the audio signals it sends to the speaker (93).

## 188. Geiger Counter

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the lamp (76) in project #163. Connect points C and D with a 4-wire (4), hold the magnet (7) near the reed switch (83) and you will see the lamp (76) is flashing quickly.

A Geiger Counter is a device for measuring radioactivity by detecting and counting ionizing particles. This circuit simulates a Geiger counter detecting radioactivity when the magnet (7) is near the reed switch (83).

## 189. Proximity-controlled Sign

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the lamp (76) in project #163. Connect points G and H using a 4-wire (4), hold the magnet (7) near the reed switch (83), and you will see the lamp (76) flashing slowly.

This circuit could simulate a person walking by a proximity activated sign. The sign turns on only when the person is close enough to read it. The speed and message on the sign could change depending on the time of day.

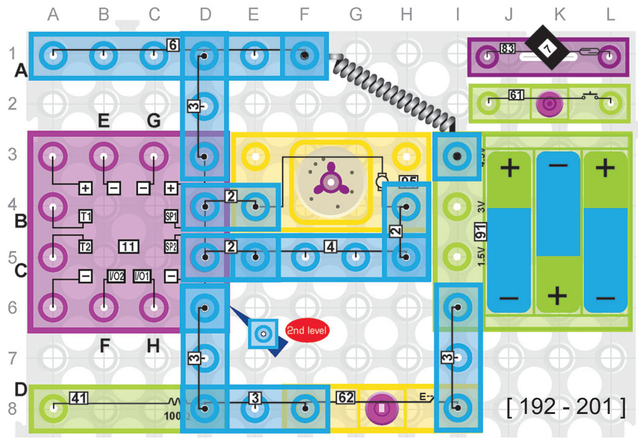
## 190. Flashing Alarm Light

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the heart LED (69) in project #163. Connect points C and D with a 4-wire (4), hold the magnet (7) near the reed switch (83) and you will see the heart LED (69) is flashing quickly.

This light could be in the alarm pane near your front door indicating that you need to close the door or window before you can set the alarm. Move the magnet (7) away from the reed switch (83) to simulate closing the door or window and now the light will go out indicating that you can set the alarm system.

## 191. A Pacemaker

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the heart LED (69) in project #163. Connect points G and H with a 4-wire (4), hold the magnet (7) near the reed switch (83) and you will see the heart LED (69) is flashing slowly. Notice how the light flashes steadily when the magnet (7) is near the reed switch (83). This could simulate a pacemaker that is keeping a person's heartbeat steady.



[ 192 - 201 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 192. Sound from Motor
Build the circuit shown on the left, press the switch (62) and you will hear a faint siren from the motor (95). The motor (95) is actually acting as a speaker.

As discussed in project #44, current through the motor creates a force on the shaft. It turns out this force is also being applied to the shell of the motor and the shell of the motor is acting like a cone in a speaker, which is creating the sound you hear.

## 193. Speed of an AC Motor
Place a 4-wire (4) across points C and D in project #192 and when you press the switch (62) you will hear a faint gun shot and machine gun sounds.

The number of poles in an AC motor, combined with the AC line frequency, can be used to determine the non-load speed of a motor. The derivation of the formula is beyond the scope of this manual but the result is that the speed of an AC motor is equal to $120 * f_l / p$ where $f_l$ is the line frequency of the AC power source and p is the number of poles in the motor. In the United States the AC line frequency is 60 Hz, and thus a simple 2-pole AC motor would spin at a rate of $120*60/2 = 3{,}600$ RPM.

## 194. First Electronic Motor Devices
Place a 4-wire (4) across points A and B in project #192 and when you press the switch (62) you will hear the faint sound of an emergency fire siren. Cars are a major consumer of motors. Did you know that the first electric motor devices were invented in the 1740s by Andrew Gordon?

## 195. Engine vs. Motor
Place a 4-wire (4) across points E and F in project #192 and when you press the switch (62) you will hear faint space battle sounds. Hopefully you did not count the engine in your car as a motor in project #102. They are two different things. Motors run on electricity (from the batteries in these projects), while engines run on combustion.

## 196. Combustion for Car Engines
Place a 4-wire (4) across points G and H in project #192 and when you press the switch (62) you will hear music. Combustion in car engines is the process where fuel (e.g. the gas you put in your car) is ignited in a small, enclosed space to create energy that is used to create a force that ultimately provides motion to your car.

## 197. Gears
Replace the switch (62) with the press switch (61) in project #192, press the press switch (61) and you will hear a faint siren from the motor (95). A gear is a part having teeth, or cogs, which can mesh with another toothed part to transmit torque. By having different size parts, gears can change the speed, torque, and direction of a power source.

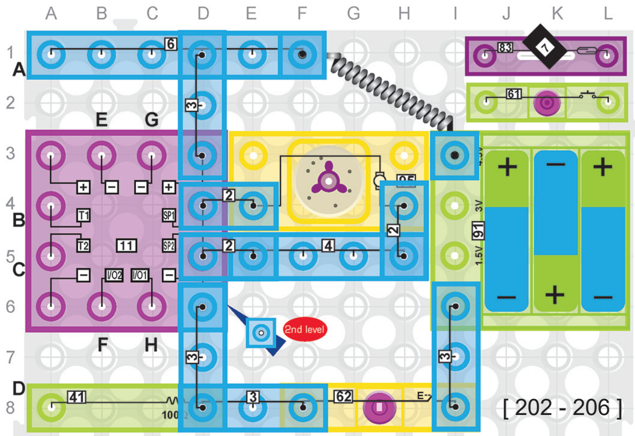
## 198. Gear Ratio
Replace the switch (62) with the press switch (61) in project #192, place a 4-wire (4) across points C and D and when you press the press switch (61) you will hear a faint gun shot and machine gun sounds. Assuming circular gears, it can be shown that the speed ratio (or gear ratio) is inversely related to the ratio of the radius (called the pitch radius) of the two gears engaged. So going from a large radius gear to a small radius gear increases speed, and vice versa.

## 199. Helical Gears
Replace the switch (62) with the press switch (61) in project #192, place a 4-wire (4) across points A and B and when you press the press switch (61) you will hear the faint sound of an emergency fire siren.

Your car uses helical gears. The leading edges of the teeth are set at an angle relative to the axis of rotation. This makes the gear curved to form the shape of a helix. The benefits of helix gears are improved strength and reduced noise in power transfer.

## 200. Gear Usages
Replace the switch (62) with the press switch (61) in project #192, place a 4-wire (4) across points E and F and when you press the press switch (61) you will hear faint space battle sounds. The three main usages of gears are to change/increase speed, increase force and change direction.

## 201. Gear Applications
Replace the switch (62) with the press switch (61) in project #192, place a 4-wire (4) across points G and H and when you press the press switch (61) you will hear music. Some common applications for gears are for factory automation, food processors, printing machines and factory automation.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 202. Magnets and Photons

Replace the switch (62) with the reed switch (83) in project #192, hold the magnet (7) near the reed switch (83) and you will hear a faint siren from the motor (95). Magnets attract to each other because they exchange photons, just like particles that make up light. But unlike the photons coming from a light source, these photons are virtual and you can't see them.

## 203. Magnet Material

Replace the switch (62) with the reed switch (83) in project #192, place a 4-wire (4) across points C and D. Hold the magnet (7) near the reed switch (83) and you will hear a faint gun shot and machine gun sounds. Most magnets are made of iron (like the magnet inside the casing for the magnet module[7] in this set). But magnets can also be made of any material with unpaired electrons including many metals and alloys.

## 204. Animals and Magnets

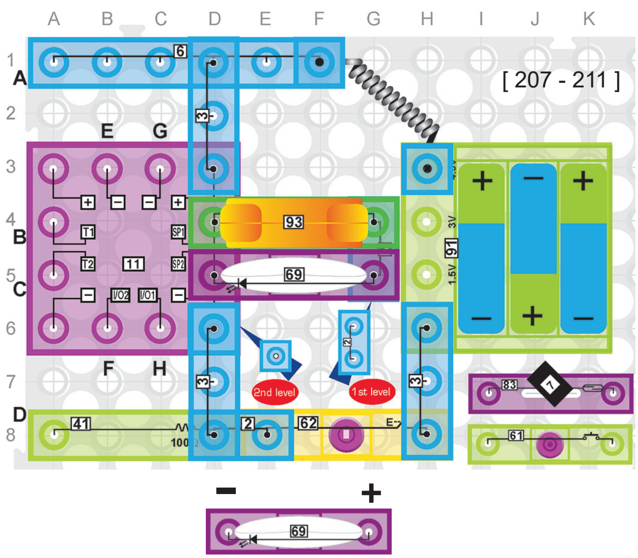
Replace the switch (62) with the reed switch (83) in project #192, place a 4-wire (4) across points A and B and when you hold the magnet (7) near the reed switch (83) you will hear the faint sound of an emergency fire siren. Some animals and bacteria have magnetite in their bodies. The chiton, a type of mollusk, actually has magnetite in its teeth that cover its tongue. This lets the animal scrape algae and can provide a homing sense enabling chitons to find their way back to their favorite places.

## 205. Neutron Star

Replace the switch (62) with the reed switch (83) in project #192, place a 4-wire (4) across points E and F and when you hold the magnet (7) near the reed switch (83) you will hear faint space battle sounds. Did you know that a collapsed star, called a neutron star, has stronger magnetic force than any other object in the universe?

## 206. Tesla

Replace the switch (62) with the reed switch (83) in project #192, place a 4-wire (4) across points G and H and when you hold the magnet (7) near the reed switch (83) you will hear music. Tesla is the unit used to specify magnetic flux density. One Tesla is equal to one weber per square meter. Weber is the unit of magnetic flux. One weber is the magnetic flux that, linking a circuit of one turn, would produce in it an electromotive force of 1 volt if it were reduced to zero at a uniform rate in 1 second.




## 207. Siren & Red Light Warning

Build the circuit to the left, then turn on the switch (62) and you will hear some low volume sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. The voltage changes at the speaker input SP2 are changing the voltage across the heart LED (69), causing it to flicker.

## 208. Gun with Flash on Shot

Connect points C and D with a 4-wire (4) in project #207, turn on the switch (62) and you will hear gun shots in low volume and the heart LED (69) with flash at the same time. This type of a circuit can be used to synchronize lights and sounds to create special effects.

## 209. Fire Siren & Red Light Warning

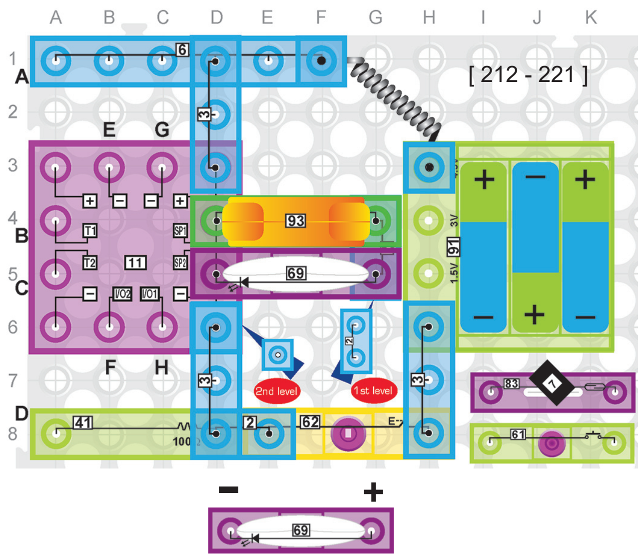
Connect points A and B with a 4-wire (4) in project #207, turn on the switch (62) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. The IC in the 3-in-1 (11) uses AND and NAND (Not AND) gate logic to make the fire engine siren sound when T1 is active AND I/01 and I/02 are NOT active.

## 210. Five Space Battle Sound Effects

Connect points E and F with a 4-wire (4) and connect points C and D with the press switch (61) in project #207. Turn on the switch (62) and the sounds of space battle will turn on in low volume with the heart LED (69) flashing with each sound. Press the press switch (61) to step through the five different battle sounds. The IC in the 3-in-1 (11) has these different sounds stored in memory and accesses them sequentially as you press the press switch (61).

## 211. Music with Red Beat

Connect points G and H with a 4-wire (4) in project #207, turn on the switch (62) and you will hear music in low volume and the heart LED (69) will dance to the music. Notice how the red heart beats with the music. This demonstrates how some devices can synchronize light patterns to music.




## 212. Magnet-controlled Fire Siren with Red Light Warning

Replace the switch (62) in project #207 with the reed switch (83), hold the magnet (7) near the reed switch (83) and you will hear some low volume sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. The reason the volume is low is because the heart LED (69) has resistance built into it which is limiting the current through the speaker (93).

## 213. Maglev trains

Connect points C and D with a 4-wire (4) in project #212, hold the magnet (7) near the reed switch (83) and you will hear gun shots in low volume and the heart LED (69) with flash at the same time. Magnets are now being used to make high speed trains. These trains use magnetic levitation and are called maglev trains. Magnetic levitation enables the train to float over the guideway and gain higher speeds with less energy due to there being essentially no friction to resist the motion of the train.

## 214. Visual & Audio Warning

Connect points A and B with a 4-wire (4) in project #212, hold the magnet (7) near the reed switch (83) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. Police cars, fire trucks and fire engines all provide both audio and visual warnings in case of emergency.

## 215. Proximity Warning of an Alien Spacecraft

Connect points E and F with a 4-wire (4) in project #212. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on in low volume with the heart LED (69) flashing with each sound. This simulates a proximity warning from an alien spacecraft.

## 216. Surprise Birthday

Connect points G and H with a 4-wire (4) in project #212. Hold the magnet (7) near the reed switch (83) and you will hear music in low volume and the heart LED (69) will dance to the music. On your friend's birthday, setup this circuit and tell them to hold the magnet (7) near the reed switch (83) for a surprise!

## 217. Distant Siren with Indicator

Replace the switch (62) in project #207 with the press switch (61). Press and hold the press switch (61) and you will hear some low volume sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. In this circuit the heart LED (69) is in series with the speaker (93), so the voltage drop across the heart LED (69) reduces the voltage across the speaker (93) reducing the volume of the sound.

## 218. Battle Far, Far Away

Connect points C and D with a 4-wire (4) in project #217. Press and hold the press switch (61) and you will hear gun shots in low volume and the heart LED (69) with flash at the same time. The red light indicator will help indicate sounds from the speaker (93) if the room is noisy and sounds are hard to hear. These are special effects for a space battle in a galaxy far away.

## 219. Non-Polarity Speaker

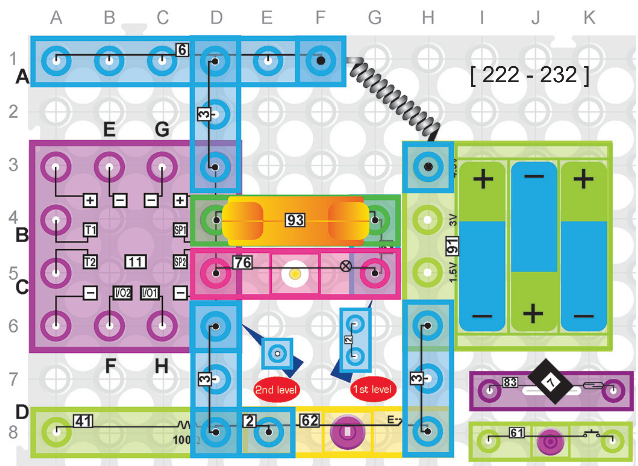
Connect points A and B with a 4-wire (4) in project #217. Press and hold the press switch (61) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. Try turning the speaker (93) around in this circuit. You will still hear the same sound. This shows that the speaker is a non-polarity component since it works both directions.

## 220. In a Galaxy Far, Far Away

Connect points E and F with a 4-wire (4) in project #217. Press and hold the press switch (61) and the sounds of space battle will turn on in low volume with the heart LED (69) flashing with each sound. The flashing red light from the heart LED (69) is indicator that there is sound in case the room is noisy.

## 221. Audio Spectrum Display

Connect points G and H with a 4-wire (4) in project #217. Press and hold the press switch (61) and you will hear music in low volume and the heart LED (69) will change to the music. This is a crude example of how an audio spectrum display works on an amplifier/music system.



## 222. Nearby Siren
Build the circuit to the left, then turn on the switch (62) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the lamp (76) is flashing at the same time. The resistance in the lamp (76) is lower than that in the heart LED (69), allowing more current to flow through the speaker (93) and thus the volume is higher.

## 223. Bank Robbery
Connect points C and D with a 4-wire (4) in project #222, turn on the switch (62) and you will hear gun shots in medium volume and the lamp (76) with flash at the same time. The lamp (76) simulates flashes from the gun shots.

## 224. Sound Engineering Tricks
Connect points A and B with the press switch (61) in project #222, turn on the switch (62) and you will hear a fire siren in medium volume and the lamp (76) will flash. Press and hold the press switch (61) and you will hear a fire siren in medium volume and the lamp (76) will flash at the same time. A change like this is used by movie set sound engineers to indicate the gun battle may be over.

## 225. Engineering a Space Battle
Connect points E and F with a 4-wire (4) in project #222. Turn on the switch (62) and the sounds of space battle will turn on in medium volume with the lamp (76) flashing with each sound. A sound technician on a movie set might start a scene with this effect.

## 226. Music Loudness Reduction
Connect points G and H with a 4-wire (4) in project #222, turn on the switch (62) and you will hear music in medium volume and the lamp (76) will flash to the music. The music plays at medium volume because the resistance in the lamp (76) is in series with the speaker (93) and reduces the voltage across the speaker.

## 227. Sound in Water
Replace the switch (62) with the press switch (61) in project #222. Press and hold the press switch (61) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the lamp (76) is flashing at the same time.

Did you know that sound actually travels more than 4 times faster in water than it does in air? Water molecules are more densely packed than air molecules so sounds can be passed more quickly between molecules.

## 228. Loudest Sound
Connect points C and D with a 4-wire (4) in project #227. Press and hold the press switch (61) and you will hear gun shots in medium volume and the lamp (76) with flash at the same time. Did you know that the loudest natural sound on Earth is that of an erupting volcano?

## 229. Animal Hearing
Connect points A and B with a 4-wire (4) in project #227. Press and hold the press switch (61) and you will hear a fire siren in medium volume and the lamp (76) will flash.

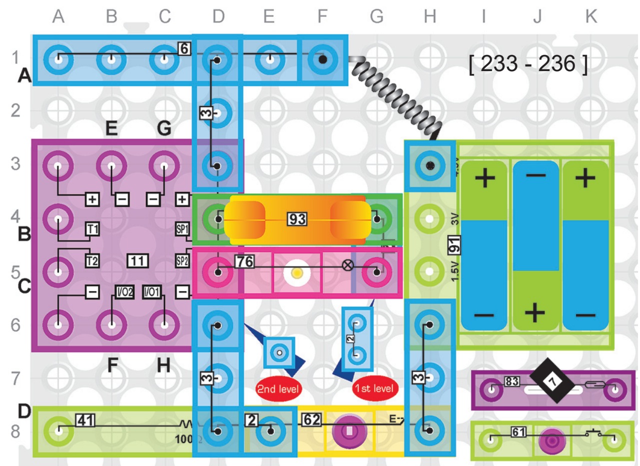
Have you ever wondered why animals like dogs can hear things you cannot? Dogs have more sensitive ears that can hear things more than 4 time farther away than humans, and dogs can hear up to higher frequencies than humans. It's all related to the shape of the dog's ears, and because dogs have more muscles in their ears than humans (dogs ears pop up why they think they hear something…try popping up your ears!).

## 230. Sound Technician
Connect points E and F with a 4-wire (4) and connect points A and B with the reed switch (83) in project #227. Press and hold the press switch (61) and the sounds of space battle will turn on in medium volume with the lamp (76) flashing with each sound. Move the magnet (7) close to and away from the reed switch (83) several times and you will cycle through space battle sounds while the lamp (76) flashes. You are now acting like a sound technician.

## 231. Birthday Party Disc Jockey
Connect points G and H with a 4-wire (4) and connect points A and B with the reed switch (83) in project #227. Press and hold the press switch (61) and you will hear music in medium volume and the lamp (76) will flash to the music. Move the magnet (7) close to and away from the reed switch (83) several times and the music will reset each time. You can make up a birthday rap song while starting over and over.

## 232. Flies and Sound
Replace the switch (62) with the reed switch (83) in project #222. Hold the magnet (7) near the reed switch (83) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the lamp (76) is flashing at the same time.

Did you know that flies cannot hear sound? So don't worry about being quiet when you are trying to catch that fly!




## 233. Dolphins Hearing Underwater

Connect points C and D with a 4-wire (4) in project #232. Hold the magnet (7) near the reed switch (83) and you will hear gun shots in medium volume and the lamp (76) will flash at the same time. Did you know that dolphins can hear sounds underwater that are up to 15 miles away? It must be pretty noisy for them under the sea!

## 234. Whale Voices

Connect points A and B with a 4-wire (4) in project #232. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren in medium volume and the lamp (76) will flash.

Did you know that whale voices can travel over 400 miles under water? They better be careful what they say!

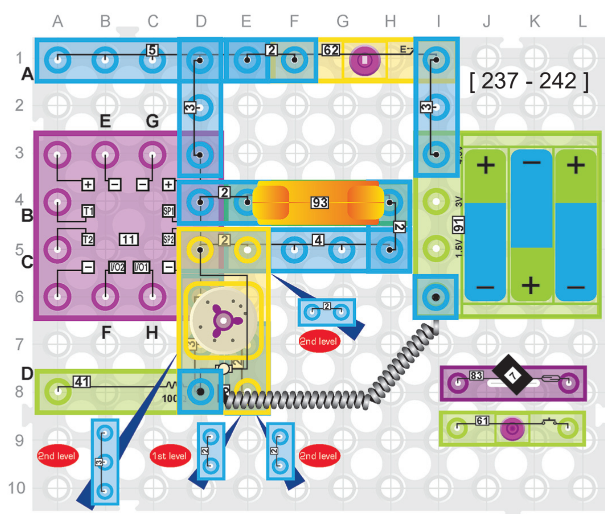
## 235. Sound in a Vacuum

Connect points E and F with a 4-wire (4) in project #232. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on in medium volume with the lamp (76) flashing with each sound. Sound cannot travel in a vacuum because there are no atoms of molecules to vibrate in a vacuum.

## 236. Is That My Voice?

Connect points G and H with a 4-wire (4) in project #232. Hold the magnet (7) near the reed switch (83) and you will hear music in medium volume and the lamp (76) will flash to the music.

Have you ever listened to a recording of your voice? It's not what you think you sound like. This is because our skull changes the resonance of our voice that makes it sound like we have more bass or low frequency in our voice. You may not like the way your voice sounds on a recording, but it's exactly the way it sounds to other people!




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 237. Motor and Speaker in Parallel

Build the circuit shown on the left, then turn on the switch (62) and you will hear sounds of a police siren from the speaker (93). Also, you will see the motor (95) is spinning at the same time. The motor (95) and speaker (93) are in parallel in this circuit so they both get enough current to operate.

## 238. Motor Syncing to Gun Shots

Connect points C and D with a 4-wire (4) in project #237, turn on the switch (62) and you will hear gun shots and the motor (95) will spin at the same time. Notice how the motor (95) spinning syncs to the gun shots. This could be used to create cool synchronized visual/audio effects.

## 239. Motor Syncing to Fire Siren

Connect points A and B with a 4-wire (4) in project #237, turn on the switch (62) and you will hear a fire siren and the motor (95) will spin at the same time.

Notice how the motor (95) spins fast when the fire siren is at its highest pitch and highest volume but spins slower when the fire siren is at its lowest pith and lowest volume. The speed that the motor (95) spins is related to the amplitude of the speaker signal, so it's the volume of the fire siren that the motor (95) is syncing to.

## 240. Electric Cars

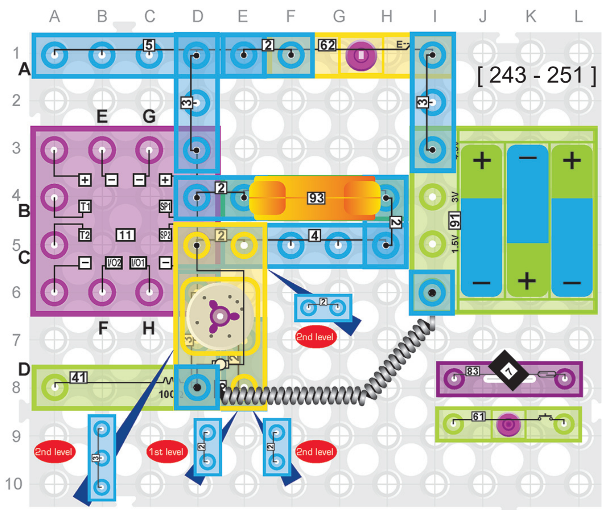
Connect points E and F with a 4-wire (4) in project #237, turn on the switch (62) and the sounds of space battle will turn on and the motor (95) will spin at the same time. Did you know that some electric cars are so quiet that they actually add noise for safety reasons? This is to protect people, particularly the blind, from not hearing a car coming.

## 241. Birthday Card

Connect points G and H with a 4-wire (4) in project #237, turn on the switch (62) and you will hear music and the motor (95) will spin at the same time. You could put this circuit into a birthday card that plays happy birthday while rotating a cool looking spin wheel.

## 242. Robotic Sensor

Replace the switch (62) with the reed switch (83) in project #237. Hold the magnet (7) near the reed switch (83) and you will hear sounds of a police siren from the speaker (93). Also, you will see the motor (95) is spinning at the same time. Reed switches can be used as proximity sensors for robotic motion and industrial automation.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 243. High Impedance Input

Connect points C and D with a 4-wire (4) in project #242. Hold the magnet (7) near the reed switch (83) and you will hear gun shots and the motor (95) will spin at the same time. Note that this circuit places a 100Ω resistor (41) between the T2 input and ground when you place the 4-wire (4) across points C and D. This is because T2 is a high impedance input. Impedance is a measure of the opposition of a circuit or input to current flow. Thus, a high input impedance means that in normal operation only a small amount of current will flow through the circuit or input, but which will be enough to activate the input.

## 244. Active High Input – T2

Connect points A and B with a 4-wire (4) in project #242. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren and the motor (95) will spin at the same time. Connecting points A and B connects the T1 input to 4.5V. This demonstrates that T1 is an active high input because the fire siren sound function is activated when the T1 input is pulled to a high voltage.

## 245. Active Low Input – I/O2

Connect points E and F with a 4-wire (4) in project #242. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on and the motor (95) will spin at the same time. Connecting points E and F connects the I/O2 input to ground (0V). This demonstrates that I/O2 is an active low input because the space war sound function is activated when the I/O2 input is pulled to a ground.

## 246. Active Low Input – I/O1

Connect points G and H with a 4-wire (4) in project #242. Hold the magnet (7) near the reed switch (83) and you will hear music and the motor (95) will spin at the same time. Connecting points G and H connects the I/O1 input to ground (0V). This demonstrates that I/O1 is an active low input because the music sound function is activated when the I/O1 input is pulled to a ground.

## 247. Floating Inputs

Replace the switch (62) with the press switch (61) in project #237. Press and hold the press switch (61) and you will hear sounds of a police siren from the speaker (93). Also, you will see the motor (95) is spinning at the same time. A floating input is one that is not connected to anything. While this circuit has not connected the T1, T2, I/O1 and I/O2 inputs to anything external to the 3-in-1 (11), internally it's possible the 3-in-1 (11) has tied these inputs to ground or 4.5V through a resistor, so they are not actually floating inputs.

## 248. Benefits of High Input Impedance

Connect points C and D with a 4-wire (4) in project #247. Press and hold the press switch (61) and you will hear gun shots and the motor (95) will spin at the same time. As discussed in project #243, T2 is a high impedance input. The benefit of high impedance inputs is that they consume less power due to the small current required to activate them.

## 249. Output Impedance

Connect points A and B with a 4-wire (4) in project #247. Press and hold the press switch (61) and you will hear a fire siren and the motor (95) will spin at the same time. The speaker outputs SP1 and SP2 have output impedance. Output impedance is a measure of the change in output voltage to the change in load current.

## 250. Thevinin's Theorem

Connect points E and F with a 4-wire (4) in project #247. Press and hold the press switch (61) and the sounds of space battle will turn on and the motor (95) will spin at the same time. Thevinin's Theorem states that any linear electrical network consisting entirely of voltage and current sources and resistances can be replaced by an equivalent voltage source and an equivalent resistance. Project #91 showed an example of how an equivalent resistance can be calculated.

## 251. Admittance

Connect points G and H with a 4-wire (4) in project #247. Press and hold the press switch (61) and you will hear music and the motor (95) will spin at the same time. Admittance is the reciprocal of impedance, that is admittance = 1/impedance. So admittance is a measure of how easily a circuit will let current flow.

## 252. Norton's Theorem

Build the circuit shown on the left, then turn on the switch (62) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the star LED (70) is flashing at the same time. Norton's Theorem states that any linear electrical network consisting entirely of voltage and current sources and resistances can be replaced by an equivalent current source in parallel with an equivalent resistance. Norton's Theorem is the inverse of Thevinin's Theorem.

## 253. Reactance

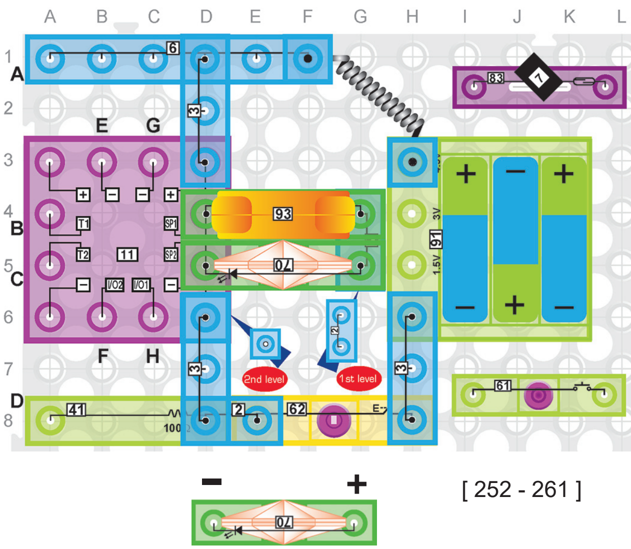
Connect points C and D with a 4-wire (4) in project #252, turn on the switch (62) and you will hear gun shots in medium volume and the star LED (70) with flash at the same time. Reactance is the opposition of a circuit or input to AC current due to inductance or capacitance. So the reactance in a circuit is only related to the capacitors and inductors in the circuit.

## 254. Relation between Reactance, Resistance, and Impedance

Connect points A and B with a 4-wire (4) in project #252, turn on the switch (62) and you will hear a fire siren in medium volume and the star LED (70) will flash. Impedance is the opposition to all types of current flow, due to resistance, capacitance and inductance. So you can think of impedance like the sum of resistance and reactance.

## 255. Conductance

Connect points E and F with a 4-wire (4) in project #252. Turn on the switch (62) and the sounds of space battle will turn on in medium volume with the star LED (70) will flash. Conductance is the measure of ease in which current can flow through a circuit or input. Conductance is the inverse of resistance, that is conductance = 1/resistance.




[ 252 - 261 ]

## 256. Unit of Measure for Conductance: Siemens & Mhos

Connect points G and H with a 4-wire (4) in project #252, turn on the switch (62) and you will hear music in medium volume and the star LED (70) will flash to the music. Conductance is measures in Siemens. One Siemen is equal to 1/(1 Ohm). Since Siemens are the inverse of Ohms, the term Mhos is sometimes used instead of Siemens as the unit for conductance.

## 257. Susceptance

Replace the switch (62) with the press switch (61) in project #252. Press and hold the press switch (61) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the star LED (70) is flashing at the same time. Susceptance is the measure of how easily (or susceptible) a circuit or input is to the flow of AC current due to inductance or capacitance.

## 258. Relation between Conductance, Susceptance, and Admittance

Connect points C and D with a 4-wire (4) in project #257. Press and hold the press switch (61) and you will hear gun shots in medium volume and the star LED (70) with flash at the same time. Admittance is the ease to which all types of current can flow, due to resistance, capacitance and inductance. So you can think of admittance like the sum of conductance and susceptance.

## 259. Linear Circuits

Connect points A and B with a 4-wire (4) in project #257. Press and hold the press switch (61) and you will hear a fire siren in medium volume and the star LED (70) will flash. A linear circuit is defined as one where for any sine wave input of any frequency, the output of the circuit is also a sinewave with the same frequency.

## 260. Superposition Principle

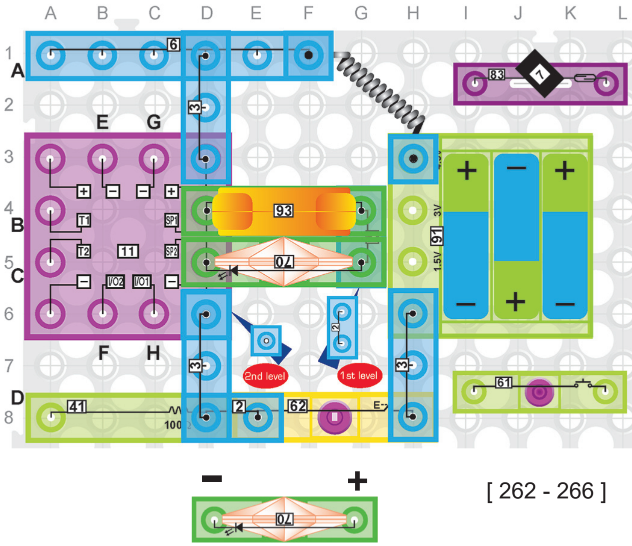
Connect points E and F with a 4-wire (4) in project #257. Press and hold the press switch (61) and the sounds of space battle will turn on in medium volume with the star LED (70) will flash. Another way to define a linear circuit is that it has to meet the superposition principle. The superposition principle states that any linear combination of input signals will lead to an output equal to the linear combination of the output signals from the individual input signals.

## 261. Superposition Principle Equation

Connect points G and H with a 4-wire (4) in project #257. Press and hold the press switch (61) and you will hear music in medium volume and the star LED (70) will flash to the music. The superposition principle discussed in the previous project can be stated in formula form, where the function F[ ] is linear if and only if

$$F[a*X_1(t) + b*X_2(t)] = a*F[X_1(t)] + b*F[X_2(t)]$$

Where a and b are constants, $X_1(\ )$ and $X_2(\ )$ are the input signals, and t is time.




[ 262 - 266 ]

## 262. Linear Circuit Components

Replace the switch (62) with the reed switch (83) in project #252. Hold the magnet (7) near the reed switch (83) and you will hear some medium volume sounds of a police siren from the speaker (93). Also, you will see the star LED (70) is flashing at the same time. A circuit will be linear if it consists entirely of ideal resistors, capacitors, inductors or other linear circuit elements.

## 263. Nonlinear Circuits

Connect points C and D with a 4-wire (4) in project #262. Hold the magnet (7) near the reed switch (83) and you will hear gun shots in medium volume and the star LED (70) with flash at the same time. A nonlinear circuit is an electric circuit whose parameters vary as a function of the current or voltage in the circuit. For example, in a non-linear electric circuit the resistance, capacitance, or inductance of the components in the circuit may change over time with the current and voltage in the circuit.

## 264. Nonlinear Circuit Components

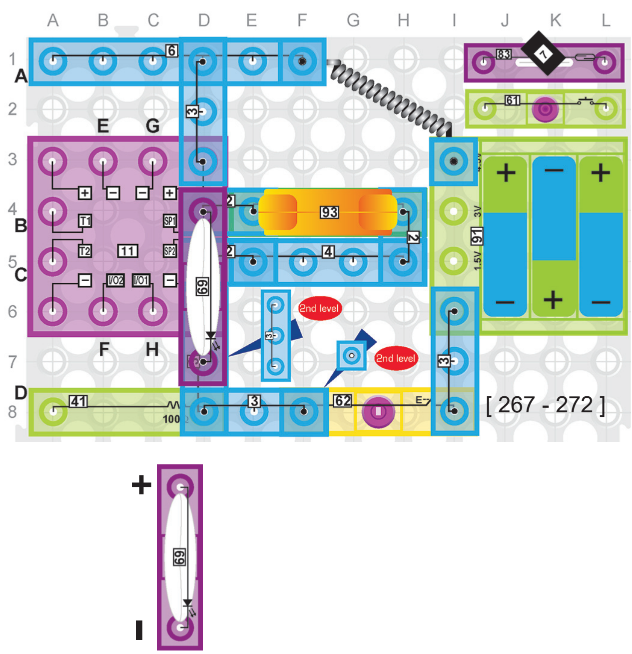
Connect points A and B with a 4-wire (4) in project #262. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren in medium volume and the star LED (70) will flash at the same time. Example of components in a circuit that will make it non-linear are diodes, transistors and transformers.

## 265. Shark Repellent

Connect points E and F with a 4-wire (4) in project #262. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on in medium volume with the star LED (70) will flash at the same time. Scientists have found that some of the strongest magnets in the world made of neodymium can be used as shark repellents. Sharks have electro-senses in their body that can be stimulated when near very strong magnets.

## 266. Discovery of Magnets

Connect points G and H with a 4-wire (4) in project #262. Hold the magnet (7) near the reed switch (83) and you will hear music in medium volume and the star LED (70) will flash to the music. The discovery of magnets is often credited to a Greek shepherd named Magnes who noticed that the nails from his shoe stuck to a rock made of magnetite, which is a rock mineral that is attracted to magnets.




[ 267 - 272 ]

## 267. Orientation of IC

Build the circuit shown, turn on the switch (62) and you will hear the sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. If you ever looked at an IC you would see that there is a dot or notch on them. Since many ICs are symmetrical in shape (e.g. rectangular or square), the notch or dot is use to represent the orientation of the IC relative to the pin locations of the IC.

## 268. Electric Fire

Connect points C and D with a 4-wire (4) in project #267. Turn on the switch (62) and you will hear gun shots and the heart LED (69) with flash at the same time. Did you know that the flames of a fire carry electrons, so that if a high enough voltage was applied then fire could actually carry current?

## 269. Electrocardiogram

Connect points A and B with the 4-wire (4) in project #267. Turn on the switch (62) and you will hear a fire siren and the heart LED (69) will flash at the same time. An Electrocardiogram (ECG) is a machine that measures the electricity flowing through your heart. If you have ever seen that monitor on a TV show that shows the heartbeat of a patient...that's an ECG.

## 270. Lightning

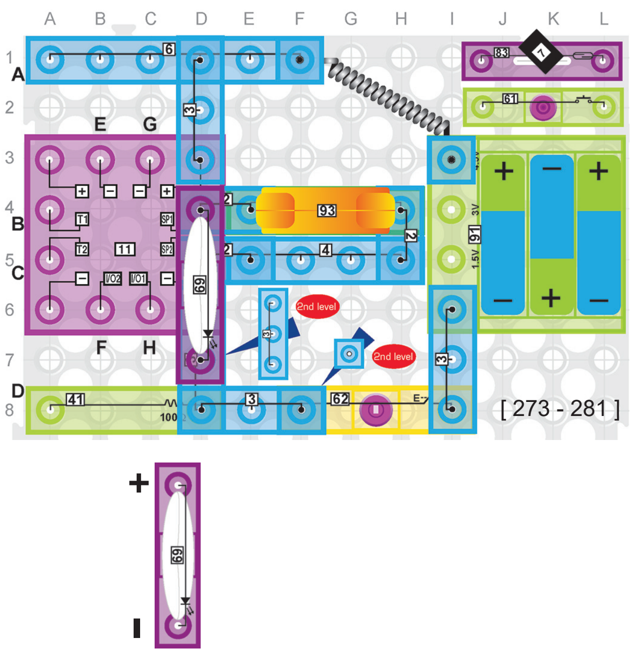
Connect points E and F with a 4-wire (4) in project #267. Turn on the switch (62) and the sounds of space battle will turn on with the heart LED (69) will flash at the same time. Did you know that a lightning bolt can carry 100 million Volts or more?

## 271. Electric EEL

Connect points G and H with a 4-wire (4) in project #267. Turn on the switch (62) and you will hear music and the heart LED (69) will flash to the music. Electric eels are dangerous because they can produce electric shocks of 500 V or more.

## 272. Work

Replace the switch (62) with the reed switch (83) in project #267. Hold the magnet (7) near the reed switch (83) and you will hear the sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. In physics, work is done when a force moves an object.




## 273. Formula for Work

Connect points C and D with a 4-wire (4) in project #272. Hold the magnet (7) near the reed switch (83) and you will hear gun shots and the heart LED (69) with flash at the same time.

The formula for work is W = F*d, where W = work, F = force, and d = distance.

## 274. Newtons

Connect points A and B with the 4-wire (4) in project #272. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren and the heart LED (69) will flash at the same time. The Newton is the unit of measurement of force. One Newton is the force needed to accelerate one kilogram of mass at a rate of one $m/s^2$ in the direction of the applied force.

## 275. Newton's Second Law of Motion - Force

Connect points E and F with a 4-wire (4) in project #272. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on and the heart LED (69) will flash at the same time. Based on Newton's second law of motion, the force on an object is related to its mass and acceleration. Specifically, Force = mass*acceleration (F = m*a).

## 276. Mass

Connect points G and H with a 4-wire (4) in project #272. Hold the magnet (7) near the reed switch (83) and you will hear music and the heart LED (69) will flash to the music. Mass is measure of the amount of matter that an object is made of. Mass can also be thought of as the resistance to acceleration (which is the rate of change in the objects velocity) when a net force is applied.

## 277. Weight

Replace the switch (62) with the press switch (61) in project #267. Press the press switch (61) and you will hear the sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. Weight is different than mass. Weight is based on the gravitational pull on an object. Mathematically, weight and mass are related through the formula Weight = mass*g, where g is the gravitational acceleration due to the Earth.

## 278. Velocity

Connect points C and D with a 4-wire (4) in project #277. Press the press switch (61) and you will hear gun shots and the heart LED (69) with flash at the same time. Velocity is the speed of an object in a certain direction. In the International System of Units, which is the modern-day form of the metric system, velocity is measured in meters/second (m/s).

## 279. Acceleration

Connect points A and B with the 4-wire (4) in project #277. Press the press switch (61) and you will hear a fire siren and the heart LED (69) will flash at the same time. Acceleration is the rate of change of velocity and is measure in $m/s^2$.

## 280. Gravitational Acceleration

Connect points E and F with a 4-wire (4) in project #277. Press the press switch (61) and the sounds of space battle will turn on and the heart LED (69) will flash at the same time. Gravitational acceleration is the acceleration on an object due to the Earth's gravitational field. It can vary based on your location, but roughly speaking the gravitational acceleration when you are near earth is 9.8 $m/s^2$.

## 281. Kinetic Energy

Connect points G and H with a 4-wire (4) in project #277. Press the press switch (61) and you will hear music and the heart LED (69) will flash to the music. An object in motion possesses energy. Kinetic Energy is the work that is required to bring this object to rest. Kinetic energy is defined as $E_k=mv^2/2$.

## 282. Buzzer

Build the circuit shown, turn on the switch (62) and you will hear faint sounds of a police siren from the buzzer (87). Also, you will see the lamp (76) is flashing at the same time. The difference between the buzzer (87) and the speaker (93) is that the speaker (93) has an internal resistance of around 16Ω, while the buzzer (87) is a high input impedance device (see project #243).

## 283. High Input Impedance Buzzer

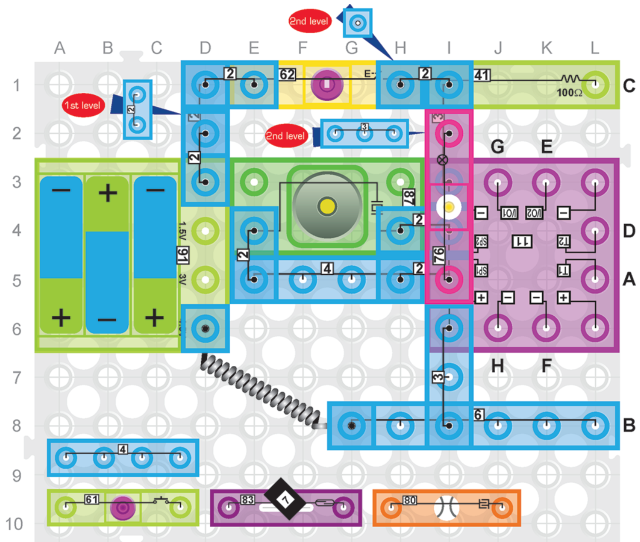
Connect points C and D with a 4-wire (4) in project #282. Turn on the switch (62) and you will hear faint gun shots and the lamp (76) with flash at the same time. Because the buzzer (87) is a high input impedance device, it limits the current through it which is why the sound level is lower than when using the speaker (93).

## 284. Benefits of High Input Impedance Speakers

Connect points A and B with the 4-wire (4) in project #282. Turn on the switch (62) and you will hear a faint fire siren and the lamp (76) will flash at the same time. One of the benefits of the high input impedance speakers is that because they only require low current levels, they can receive audio signals over larger distances more easily than low input impedance speakers (transporting high current over long distances is difficult and more costly).

## 285. Amplifier with High Input Impedance Speakers

Connect points E and F with a 4-wire (4) in project #282. Turn on the switch (62) and faint sounds of space battle will turn on and the lamp (76) will flash at the same time. High input impedance speakers generally require an amplifier to amplify the signal going into the speaker in order to get high volume out of the speaker.



[ 282 - 289 ]

## 286. Impedance Matching

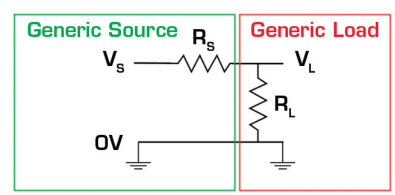
Connect points G and H with a 4-wire (4) in project #282. Turn on the switch (62) and you will hear faint music and the lamp (76) will flash to the music. When driving a high input impedance speaker with an amplifier, ideally the output impedance of the amplifier should match the input impedance of the speaker. This is done to maximize the power transfer between the amplifier and speaker.

## 287. Maximum Power Transfer Theorem

Replace the switch (62) with the reed switch (83) in project #282. Hold the magnet (7) near the reed switch (83) and you will hear faint sounds of a police siren from the buzzer (87). Also, you will see the lamp (76) is flashing at the same time. The maximum power transfer theorem proves that the maximum power is transferred from a source to a load when the impedance of the load is made equal to the impedance of the source.

## 288. Generic Load Connected to a Generic Source

Connect points C and D with a 4-wire (4) in project #287. Hold the magnet (7) near the reed switch (83) and you will hear faint gun shots and the lamp (76) with flash at the same time. Consider the diagram below that represents a generic source with voltage $V_S$ and internal resistance of $R_S$, connected to a generic load with internal resistance of $R_L$. The maximum power transfer theorem shows that the power transferred to the generic load is maximized if the internal resistance of the load $R_L$ (assuming a purely resistive load) is made equal to the internal resistance of the source $R_S$.




## 289. Voltage of Load

Connect points A and B with the 4-wire (4) in project #287. Hold the magnet (7) near the reed switch (83) and you will hear a faint fire siren and the lamp (76) will flash at the same time. Referring to the diagram in project #288, Ohm's law states that the current through the circuit is $V_S/(R_S + R_L)$. Since the two resistors are in series, this same current runs through each resistor. So we can again apply Ohm's Law to show that the Load voltage is $V_S*R_L/(R_S + R_L)$.

## 290. Power of Load

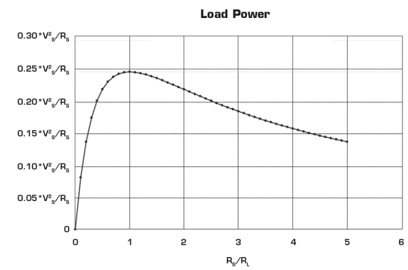
Connect points E and F with a 4-wire (4) in project #287. Hold the magnet (7) near the reed switch (83) and faint sounds of space battle will turn on and the lamp (76) will flash at the same time.

Recalling from project #28 that electrical power is P = V*I, then we can multiple the load voltage and current calculated in project #289 to get that the power transferred to the load is $V^2_S R_L/(R_S + R_L)^2$.

## 291. Proof of Maximum Power Transfer Theorem

Connect points G and H with a 4-wire (4) in project #287. Hold the magnet (7) near the reed switch (83) and you will hear faint music and the lamp (76) will flash to the music.

The calculation of load power from project #290 can be rewritten as $(V^2_S/R_S)*(R_L/R_S)/(1+ R_L/R_S)^2$. To find the maximum of this quantity, see the plot of this quantity shown below. This plot shows that the load power is maximum when $R_S/R_L$ = 1, or $R_S = R_L$. This proves that the load power is maximized when the internal resistance of the load is equal to that of the source.




## 292. Maximum Load Power

Replace the switch (62) with the press switch (61) in project #282. Press the press switch (61) and you will hear faint sounds of a police siren from the buzzer (87). Also, you will see the lamp (76) is flashing at the same time.

Assuming the internal resistance of the load is equal to the internal resistance of the source ($R_L = R_S$ = R), then from the plot in project #291 we see that the maximum load power is $0.25*V^2_S/R_S$.

## 293. Source Power

Connect points C and D with a 4-wire (4) in project #292. Press the press switch (61) and you will hear faint gun shots and the lamp (76) with flash at the same time. Based on the calculations in project #289, the power of the source is given as $V^2_S/(R_S + R_L)$.

## 294. Maximum Power Efficiency

Connect points A and B with a 4-wire (4) in project #292. Press the press switch (61) and you will hear a faint fire siren and the lamp (76) with flash at the same time.

Assuming the internal resistance of the load is equal to the internal resistance of the source ($R_L = R_S$ = R), then from the plot in project #291 we see that the maximum load power efficiency, defined as the output power from project #292 divided by the input power from project #293 when $R_L = R_S$ = R, is $(0.25*V^2_S/R)/(V^2_S/(2*R)) = 0.5$. This shows that the maximum power transfer you can get by impedance matching the load to the source is half the source power.

## 295. Applications of Impedance Matching

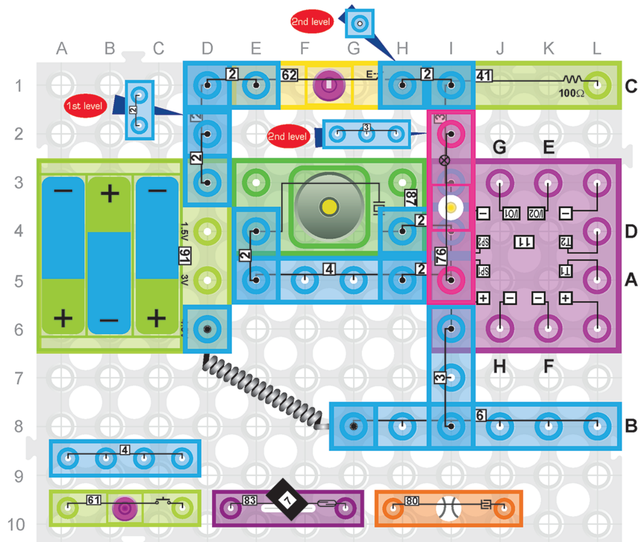
Connect points E and F with a 4-wire (4) in project #292. Press the press switch (61) and you will hear faint sounds of a space battle and the lamp (76) with flash at the same time.

Impedance matching is an important design criteria for many systems including ones that use antennas and transmission lines. Matching the impedance of antenna to the source impedance will maximize the radiated power, and matching the impedance of a load at the end of a transmission line (e.g. the impedance of your cable box that is connected to the RF cable that carries your cable TV signal) will minimize losses in the connection to the load.

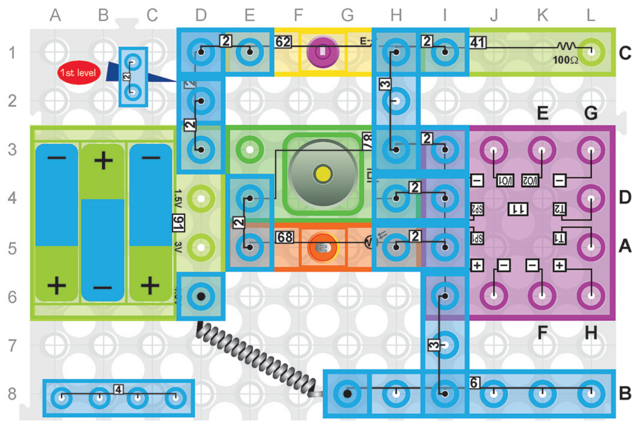
## 296. Source Impedance of the 3-in-1

Connect points G and H with a 4-wire (4) in project #292. Press the press switch (61) and you will hear faint music and the lamp (76) with flash at the same time.

You probably noticed that the volume of the speaker (93) when connected to the 3-in-1 (11) SP1 and SP2 outputs (like in project #163) is much higher than the volume of the buzzer (87). This is because the source impedance of the 3-in-1 (11) speaker outputs is small (around 10Ω), which is much more closely matched to the load impedance of the speaker (93) which is about 16Ω, than it is to the load impedance of the buzzer (87), which is very high impedance (likely Megohms).




[ 290 - 296 ]




[ 297 - 301 ]

## 297. The Photoresistor

Build the circuit shown on the left. Press the switch (62) and you will hear faint sounds of a police siren from the buzzer (87) as long as there is enough light shining on the photoresistor (68). You can adjust the volume of the buzzer (87) by holding your finger over the photoresistor (68). The photoresistor (68) is a device whose resistance is a function of the light it receives. When there is high light intensity put on the photoresistor (68), the there is low resistance through the photoresistor (68), but when there is no light shining on the photoresistor (68), the there is very high resistance through the photoresistor (68).

## 298. Photoresistor Details

Connect points A and B in project #297. Press the switch (62) and you will hear the sounds of a faint fire siren from the buzzer (87) as long as there is enough light shining on the photoresistor (68). You can adjust the volume of the buzzer (87) by holding your finger over the photoresistor (68). The photoresistor (68) is made of high resistance semiconductor material when in the dark. However, when light is shined on the photoresistor, this frees up electrons in the semiconductor material enabling conduction to occur, which reduces the resistance of the photoresistor (68).

## 299. Resistance of the Photoresistor

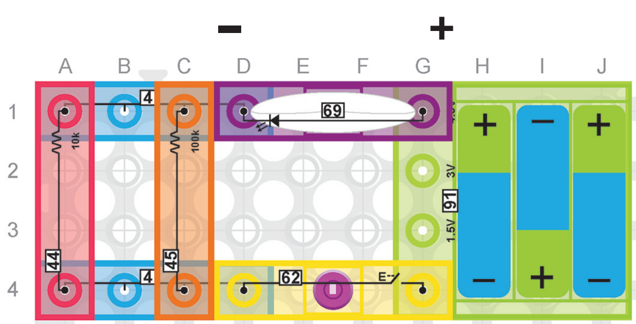
Connect points C and D in project #297. Press the switch (62) and you will hear the sounds of faint gun shots from the buzzer (87) as long as there is enough light shining on the photoresistor (68). You can adjust the volume of the buzzer (87) by holding your finger over the photoresistor (68). When in the dark, the photoresistor (68) can have a resistance of many Megohms, while when bright light is shining directly on the photoresistor (68) it can have a resistance as low as 100Ω to 200Ω.

## 300. TV Brightness

Connect points E and F in project #297. Press the switch (62) and you will hear faint sounds of space battle from the buzzer (87) as long as there is enough light shining on the photoresistor (68). You can adjust the volume of the buzzer (87) by holding your finger over the photoresistor (68). One application of photoresistors is to be used as light sensors to control TV brightness. When it's very bright in the room, the photoresistor (68) allows more current to flow to make your TV signal brighter, but when it's dark at night then less current flows through the photoresistor dimming your TV brightness.

## 301. Alarm Clock

Connect points G and H in project #297. Press the switch (62) and you will hear faint music from the buzzer (87) as long as there is enough light shining on the photoresistor (68). You can adjust the volume of the buzzer (87) by holding your finger over the photoresistor (68). Another application for photoresistors is alarm clocks. You could place this circuit near the window in your room and when the sun starts shining, the music will start playing to wake you up.



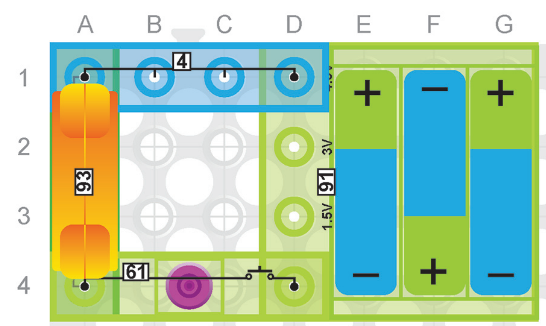

[ 302 ]

## 302. Resistors in Parallel

Build the circuit, turn on the switch (62) and you will see the heart LED (69) is on. Take out either resistor and you will see the heart LED (69) get dimmer. You may need to be in a dark room to see this. As shown in project #91, two resistors in parallel have an equivalent resistance of:

$$R_{equivalent} = (R_1 * R_2)/(R_1 + R_2)$$

In this case $R_{equivalent}$ = (5.1k * 10k)/(5.1k + 10k) = 3.4kΩ. So as you can see, the equivalent resistance of the parallel combination of the two resistors is less than the value of either resistor, so when you pull one of the resistors out of the circuit it actually increases the resistance in the circuit, which makes the heart LED (69) dimmer.

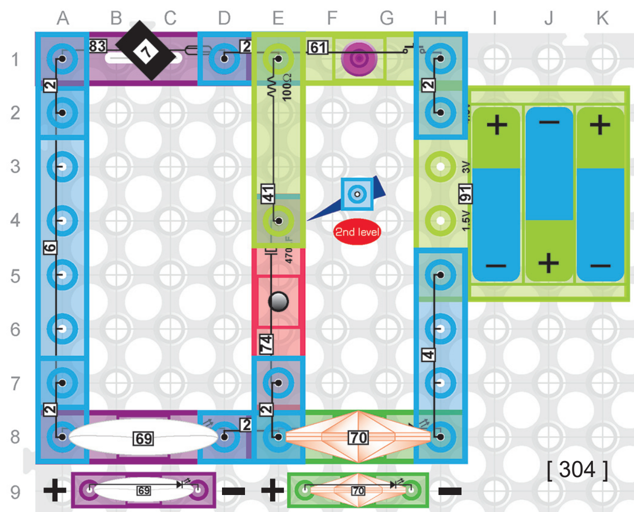


[ 303 ]

## 303. Speakers

Build the circuit shown, press and release the press switch (61) several times and you will hear some clicks and pops from the speaker (93).

In order to translate an electrical signal into an audible sound, speakers contain electromagnets made from a metal coil that creates a magnetic field when an electric current flows through it. The coil is designed such that reversing the direction of the current in the coil flips the polarity of the magnet. Inside a speaker, an electromagnet is placed in front of a permanent magnet. The permanent magnet is mounted firmly while the electromagnet can move. As pulses of electricity pass through the coil of the electromagnet, the direction of the magnetic field generated is rapidly changed. This makes it repel from the permanent magnet, vibrating back and forth. The electromagnet is attached to a cone made of a flexible material such as paper or plastic which amplifies these vibrations, pumping sound waves into the surrounding air and towards your ears.

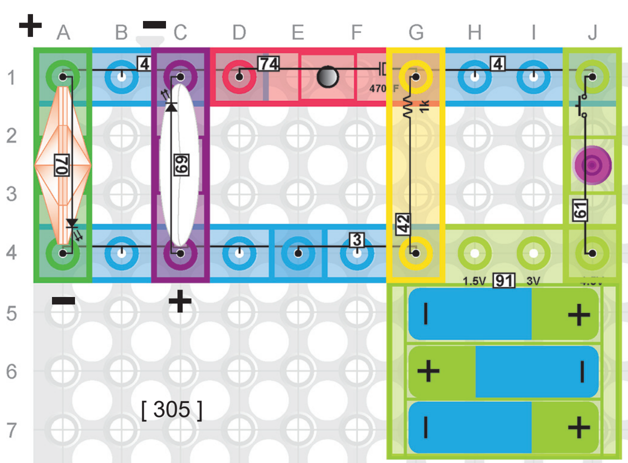


[ 304 ]

## 304. The Capacitor

In this circuit, we are going to learn how to charge and discharge a capacitor. Build the circuit shown on the left. To charge the 470μF capacitor (74), press & hold the press switch (61) and you will see the star LED (70) turn on briefly and fade out (you should be in a very dark room to see these effects).

Capacitors come in all shapes and sizes, but usually have the same basic components: two conductors (known as plates) and an insulator in between them (called the dielectric). The two plates inside a capacitor are wired to two electrical connections to the outside. When you connect these wires to the battery, the plates in the 470μF capacitor (74) build up charge. This charge is typically held by the capacitor until it is inserted in a circuit where it can be discharged. When you see the star LED (70) fade out then the 470μF capacitor (74) is near full charge. Release the press switch (61) to disconnect the circuit. To discharge the 470μF capacitor (74), touch the reed switch (83) with the magnet (7), and you will see the heart LED (69) turn on briefly and fade out, at which point the 470μF capacitor (74) is near fully discharged.

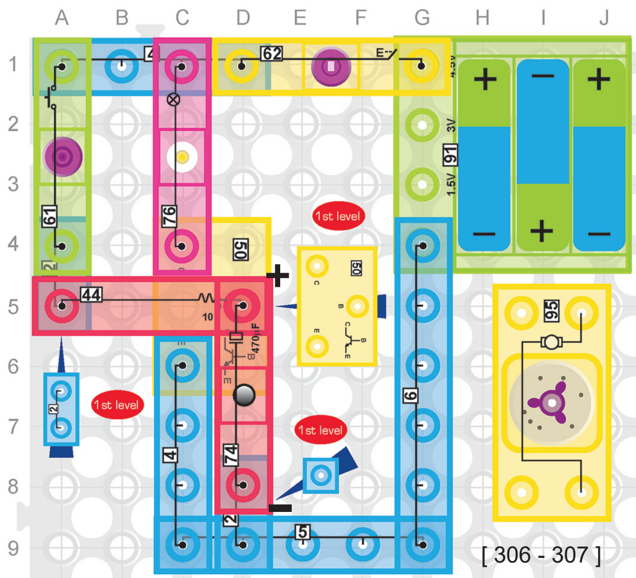


[ 305 ]

## 305. Charging the Capacitor

Build the circuit shown on the left, press and hold the press switch (61). As the star LED (70) turns on and fades out, the 470μF capacitor (74) is being charged. Release the press switch (61) and the heart LED (69) will turn on and fade out.

The reason the star LED (70) turns on for just a short time and fades out when you hold the press switch (61) can be explained by Kirchhoff's Voltage Law. Initially, the 470μF capacitor (74) has zero charge across it and thus the full 4.5V is across the star LED (70). But as the 470μF capacitor (74) charges, the voltage drop across it increases, which means the voltage seen by the star LED (70) decreases, which is why the star LED (70) fades out. Release the press switch (61) and the heart LED (69) will turn on for a short time and fade out. This happens because the charge on the 470μF capacitor (74) is being discharged across the 1kΩ resistor (42) and heart LED (69).



[ 306 - 307 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 306. NPN Transistor – a Current Switch

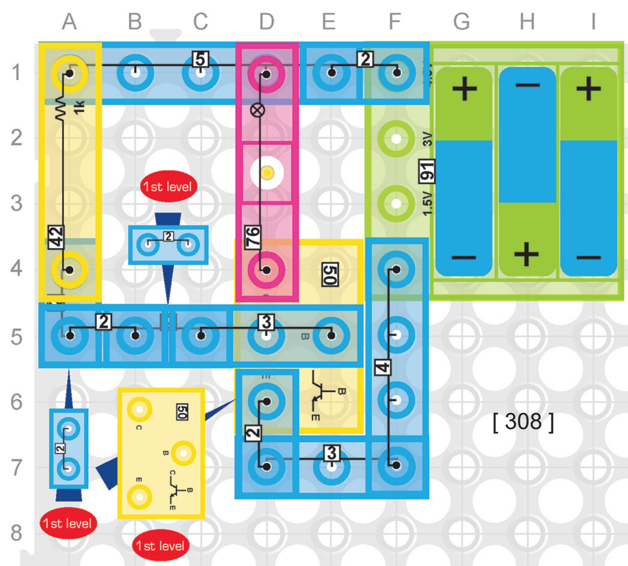
Build the circuit shown on the left and turn on the switch (62); the lamp (76) is still off. Press and hold the press switch (61) and you will see the lamp (76) turns on after a short delay. Make sure your 470μF capacitor (74) is fully discharged before you start this project (you can discharge the 470μF capacitor (74) by placing a 4-wire (4) across the bottom of the 470μF capacitor (74) module for a few seconds).

This circuit includes an NPN transistor (50). Transistors can sometimes be thought of as switches where, in the case of the NPN transistor (50), a current flowing into the base (labeled with a "B" on the NPN transistor (50)) enables current to flow from the collector (labeled "C" on the NPN transistor (50)) to the Emitter (labeled "E" on the NPN transistor (50)).

## 307. Delay Circuit

Replace the lamp (76) with the motor (95) in the previous project; the motor (95) is still off. Press and hold the press switch (61) and you will see the motor (95) turns on after a short delay. Make sure your 470μF capacitor (74) is fully discharged before you start this project (you can discharge the 470μF capacitor (74) by placing a 4-wire (4) across the bottom of the 470μF capacitor (74) module for a few seconds).

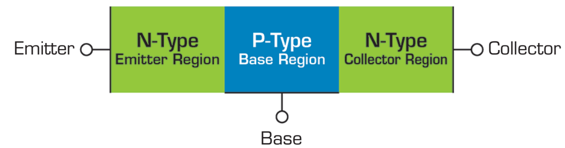
The reason there is a delay before the motor (95) starts spinning in this project (and before the lamp (76) turns on in the previous project) is because the 470μF capacitor (74) initially has no charge across it and takes time to charge up. So initially the 470μF capacitor (74) is holding the Base of the NPN transistor to ground (0V), and eventually when the 470μF capacitor (74) charges up enough, there is enough voltage at the Base of the NPN transistor (50) to enable current to flow in the Base and turn on the current flow from the Collector to the Emitter of the NPN transistor (50), which enables current to flow through the motor (95) making it spin.



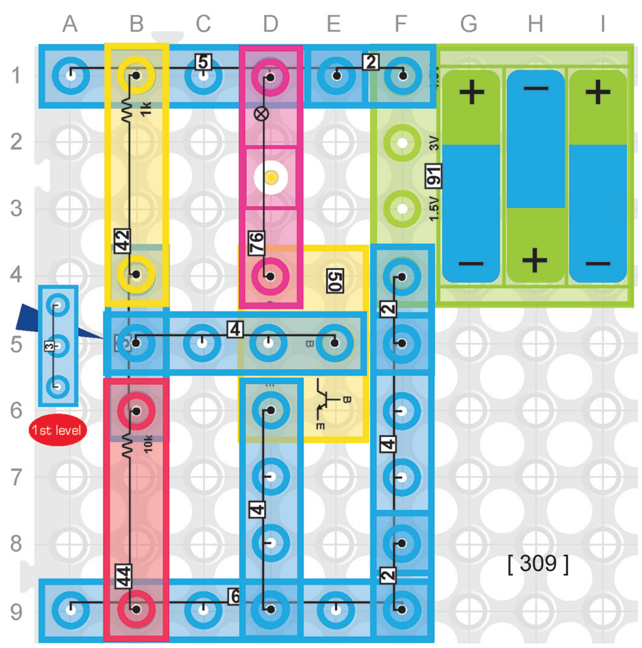
[ 308 ]

## 308. NPN Transistor Basics

Build the circuit to the left and you will see the lamp (76) light. The base of the NPN transistor (50) is connected to the 4.5V terminal from the battery through the 1kΩ resistor (42), enabling current to flow into the base of the NPN transistor (50), which turns on the NPN transistor (50) enabling current to flow through the lamp (76) into the collector and out of the emitter, which turns on the lamp (76). The NPN Transistor (50) is built by stacking three different layers of semiconductor material together. Two layers have extra electrons added to them (a process called "doping") and are called N-type layers, while one layer has electrons removed (doped with "holes" – the absence of electrons) and is called a P-type layer. This is shown in the diagram below.

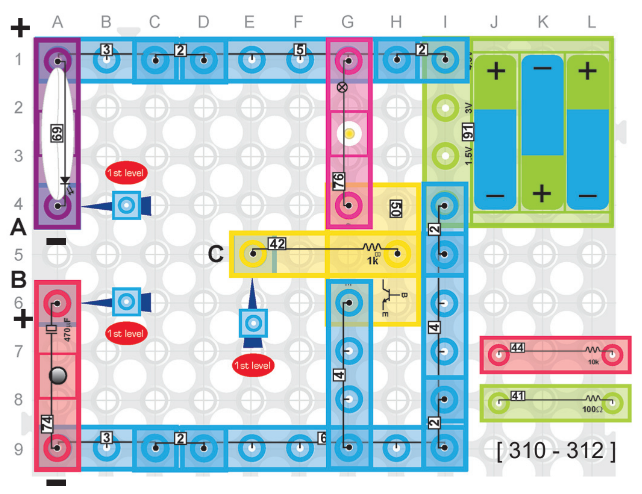



Roughly speaking, the NPN transistor (50) is designed so that conventional current can easily flow from the Base region (P-type) to the Emitter region (N-type) when the Base is at a high enough voltage above the Emitter. Once current begins flowing from Base to Emitter, then it becomes much easier for current to flow from the Collector to the Emitter.




## 309. Voltage Divider

Build the circuit shown on the left and the lamp (76) will be on. This type of circuit is often used to hold the voltage level at the Base of the NPN transistor (50) at a constant level to set a particular operating point for the NPN transistor (50).




## 310. Electricity Storage

Build the circuit shown on the left, then connect points A and B with the spring wire (9). The heart LED (69) will turn on and then fade out as the 470μF capacitor (74) is charging.

Now remove the spring wire (9) from points A and B and connect the spring wire (9) between points B and C. The lamp (76) will turn on for a while and then fade out. This is because when the 470μF capacitor (74) is charged, it stores electrical energy. While this electrical energy is being discharged through the Base of the NPN transistor (50), current is enabled to flow from Collector to Emitter lighting up the lamp (76). Once all the electrical energy is discharged from the 470μF capacitor (74), current no longer flows through the Base, and thus current will no longer flow from the Collector to the Emitter and the lamp (76) turns off.

## 311. Capacitor Discharge

Using the circuit from project #310, replace the 1kΩ resistor (42) with the 10kΩ resistor (44), connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) with light and then fade out as the 470μF capacitor (74) is charging.

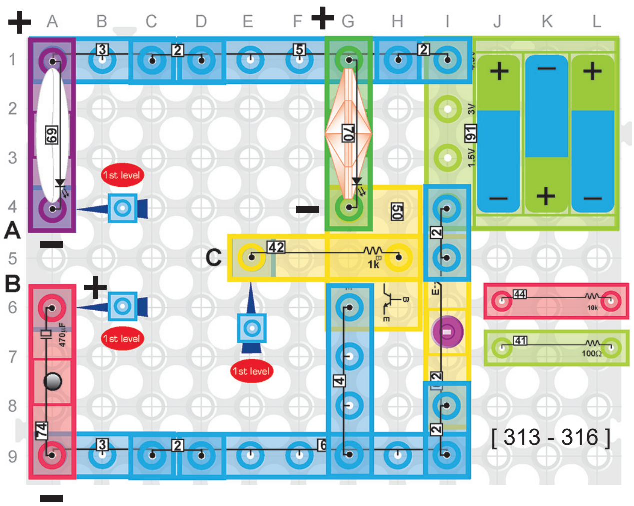
Remove the spring wire (9) from points A and B and place the spring wire (9) across points B and C. You will see the lamp (76) light for a while and then fade out very slowly as the 470μF capacitor (74) discharges. Notice in this case, though, that the lamp (76) will stay dim for a long time. This is because it takes a long time for the 470μF capacitor (74) to fully discharge with the 10kΩ resistor (44) in the circuit.

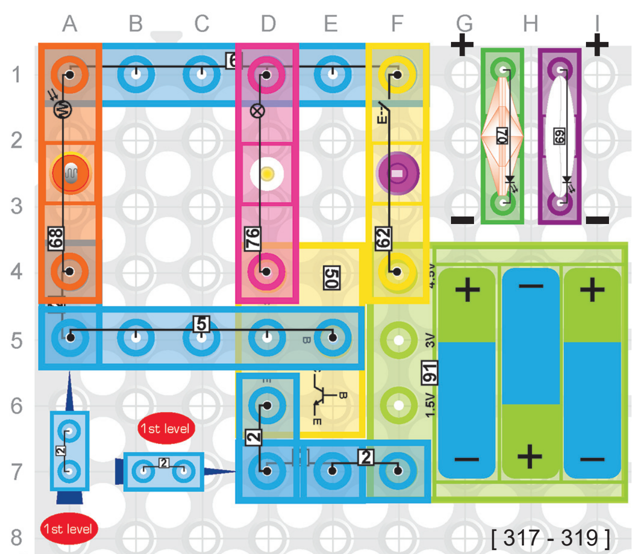
## 312. Capacitor Basics

Using the circuit from project #310, replace the 1kΩ resistor (42) with the 100Ω resistor (41), connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) with light and then fade out as the 470μF capacitor (74) is charging.

Remove the spring wire (9) from points A and B and place the spring wire (9) across points B and C. You will see the lamp (76) light for a while and fade out quickly as the 470μF capacitor (74) discharges.

Capacitors are made of two plates separated by an insulating material between them. When a battery or voltage source is placed across the leads of a capacitor, one plate builds up a positive charge (like a build-up of a holes) while the other plate builds up a negative charge (build-up of electrons). Once charged, even when the voltage source is removed the capacitor will maintain its build-up of charge until connected to a circuit where the charge build-up can be discharged through a resistance.




### 313. Capacitance

Build the circuit shown. Connect points A and B with the spring wire (9) and turn on the switch (62). The heart LED (69) with light and then fade out as the 470μF capacitor (74) is charging. Remove the spring wire (9) from points A and B and place the spring wire (9) across points B and C. You will see the star LED (70) light for a while and fade out slowly as the 470μF capacitor (74) discharges.

Capacitance is a measure the capacitors ability to store energy. There are three primary factors that determine the capacitance of a capacitor: the size of the plates, the distance between the plates and the type of insulating material (called a dielectric) placed between the plates.

### 314. Measure of Electric Charge - The Coulomb

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in project #313. Connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) with light and then fade out as the 470μF capacitor (74) is charging.

As discussed in the previous project, capacitors build up charge on their plates when a voltage source is placed across their leads. The amount of electric charge built up on the plates of a capacitor is measured in Coulombs. 1 Coulomb is equal to the electricity conveyed in 1 second by 1 Amp of current.

### 315. Measure of Capacitance - The Farad

Remove the spring wire (9) from points A and B in project #314 and place the spring wire (9) across points B and C. You will see the star LED (70) light for a while and fade out very slowly as the 470μF capacitor (74) discharges.

The capacitance of a capacitor is measured in Farads. A capacitor is said to have 1 Farad of capacitance when a potential difference of 1 Volt across it's plates will charge it with 1 Coulomb of electricity.

### 316. Approximation for Capacitance of a Capacitor

Replace the 1kΩ resistor (42) with the 100Ω resistor (41) in project #313. Connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) with light and then fade out as the 470μF capacitor (74) is charging. Remove the spring wire (9) from points A and B and place the spring wire (9) across points B and C. You will see the star LED (70) light for a while and then fade out quickly as the 470μF capacitor (74) discharges.

It was discussed in project #313 that the capacitance of a capacitor is related to the size of the plates, the distance between the plates, and the dielectric material between the plates. You can actually approximate the capacitance of a capacitor through a formula based on Gauss's law to be $C = \varepsilon A/d$ where A is the area of the plates, d is the distance between the plates and $\varepsilon$ is the permittivity of the dielectric between the plates (permittivity is the ability of a substance to store electrical energy in an electric field).

### 317. Latency of a Photoresistor

Build the circuit shown and turn on the switch (62). Whenever light shines on the photoresistor (68), the lamp (76) will light. Cover the photoresistor (68) with your finger and the lamp (76) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the lamp (76).

Photoresistors exhibit latency between exposure to light and the subsequent decrease in resistance. This latency is usually on the order of 10 milliseconds. The latency in going from a lit to dark environment is even greater, often as long as one second.

### 318. Advantages of Photoresistors

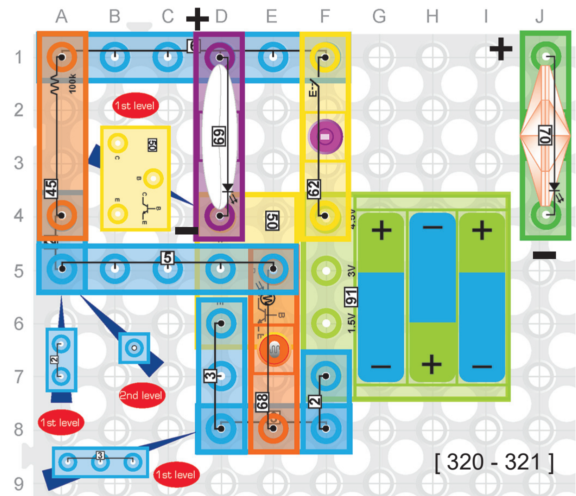
Replace the lamp (76) with the star LED (70) in project #317 and turn on the switch (62). Whenever light shines on the photoresistor (68), the star LED (70) will be bright. Cover the photoresistor (68) with your finger and the star LED (70) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the star LED (70).

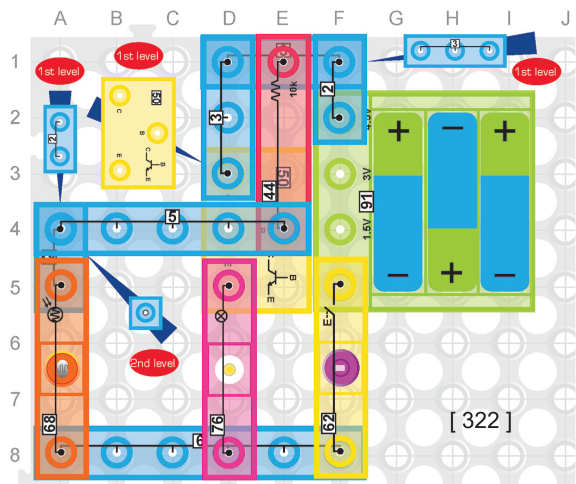
The advantages of photoresistors are that they are small in size and thus can be carried or placed in just about anywhere easily, and they are low cost.

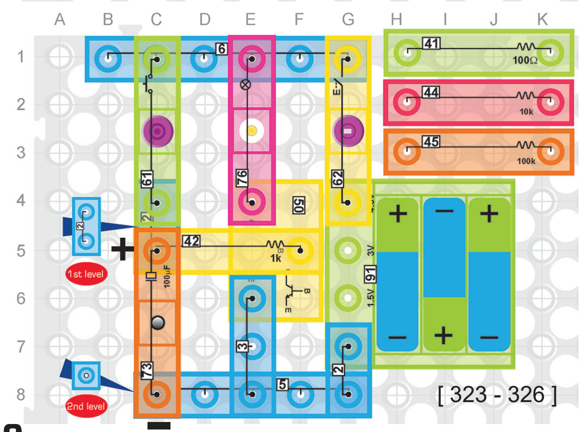
### 319. Disadvantages of Photoresistors

Replace the lamp (76) with the heart LED (69) in project #317. Whenever light shines on the photoresistor (68), the heart LED (69) will be bright. Cover the photoresistor (68) with your finger and the heart LED (69) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the heart LED (69).

The main disadvantage of photoresistors are their accuracy. The instantaneous resistance of a photoresistor is dependent on wavelength of the light and can vary based on temperature. So photoresistors are typically not used to make accurate light measurements.




## 320. Reverse Control using Photoresistors

Build the circuit shown and turn on the switch (62). Now, whenever light shines on the photoresistor (68), the heart LED (69) will be off. Cover the photoresistor (68) with your finger and the heart LED (69) will turn on.

This circuit does the reverse of the circuit in project #319 by turning on the heart LED (69) in darkness and turning off the heart LED (69) in light. This is done by using the NPN transistor (50) as a switch. When light shines on the photoresistor (68), this creates a very low resistance path from the Base of the transistor to ground (0V), and thus very little current will flow through the Base. This means very little current will flow from Collector to Emitter of the NPN transistor (50) and thus the heart LED (69) does not light. But if you cover the photoresistor (68) with your finger making it dark, this creates a very high resistance path from Base to ground and thus the current through the 100kΩ resistor (45) now flows through the Base of the NPN transistor (50), turning it "ON" (allowing a large current to flow from Collector to Emitter) which turns on the heart LED (69).

## 321. Street Lights

Replace the heart LED (69) with the star LED (70) and turn on the switch (62). Whenever light shines on the photoresistor (68), the star LED (70) will be off. Cover the photoresistor (68) with your finger and the star LED (70) will turn on.

This circuit could be used to control street lights, where during the day when light shines it turns off the street lights, but once the sun goes down and it gets dark, the street lights turn on.

## 322. Load on Emitter

Build the circuit shown on the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the lamp (76) will be off. Cover the photoresistor (68) with your finger and the lamp (76) will turn on.

This circuit demonstrates that the photoresistor (68) and NPN transistor (50) can be used like a switch to turn on and off a load (in this case the lamp (76)), and the load can be placed on either the Emitter of the NPN transistor (50) (like in this project) or the Collector of the NPN transistor (50). The main difference is that when you place the load on the Emitter, then the internal resistance of the load will increase the voltage level that is required at the Base to turn on the flow of current from the Collector to the Emitter.

## 323. RC Circuit

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the lamp (76) light. Release the press switch (61) and the lamp (76) will stay bright briefly and then turn dim.

This is an example of an Resistor-Capacitor (RC) circuit. This is a first order RC circuit because there is a single resistor and single capacitor in the circuit.

## 324. Resistor in RC Circuit

Replace the 1kΩ resistor (42) in project #323 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the lamp (76) light. Release the press switch (61) and the lamp (76) will quickly turn off.

This RC circuit has the smaller 100Ω resistor (41) (compared to the 1kΩ resistor (42) in project #323), making this circuit act more like a switch than a delay circuit.

## 325. Delayed Lights

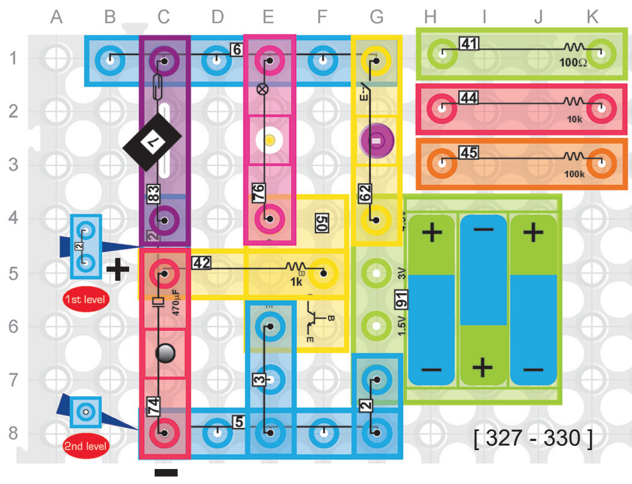
Replace the 1kΩ resistor (42) in project #323 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the lamp (76) light. Release the press switch (61) and the lamp (76) will stay bright for a while and then turn dim.

This circuit could be used in your house to keep the lights on for a short while after you turn them off so that you can exit the room before it gets dark.

## 326. RC Time Constant

Replace the 1kΩ resistor (42) in project #323 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the lamp (76) will not light. This is because with a 100kΩ resistor (45) at the base of the NPN transistor (50), there is very little current going into the base, and even though the current from collector to emitter is much greater, it's not enough to light the lamp (76).

Through use of Kirchhoff's laws, the voltage level of the 100µF capacitor (73) as a function of time can be determined. Solving this requires differential equations, which is beyond scope for this manual, but the result is that the voltage of the 100µF capacitor (73) decays as an exponential function with a time constant of R*C.




## 327. Calculating RC Time Constant

Build the circuit shown on the left and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the lamp (76) light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay bright for a little while and then turn dim. As discussed in the previous project, the time constant of an RC circuit is R*C, which in this case is $1000*(470x10^{-6}) = 0.47$ seconds. If the 1kΩ resistor and 470μF capacitor (74) represented the only resistance and capacitance in the circuit, then 0.47 seconds would represent the time for the voltage on the capacitor to reduce from its maximum value to ~63% of its maximum value.

## 328. Relative RC Time Constant

Replace the 1kΩ resistor (42) in project #327 with the 100Ω resistor (41) and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the lamp (76) light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay bright briefly and then go dim. The time constant of this circuit is $100*(470x10^{-6}) = 0.047$ seconds. The lamp (76) will likely take longer than 0.047 seconds to dim in this circuit due to other resistance and capacitance not accounted for in the circuit, but relatively speaking the lamp (76) should dim about 10 times sooner in this circuit compared to the previous circuit.

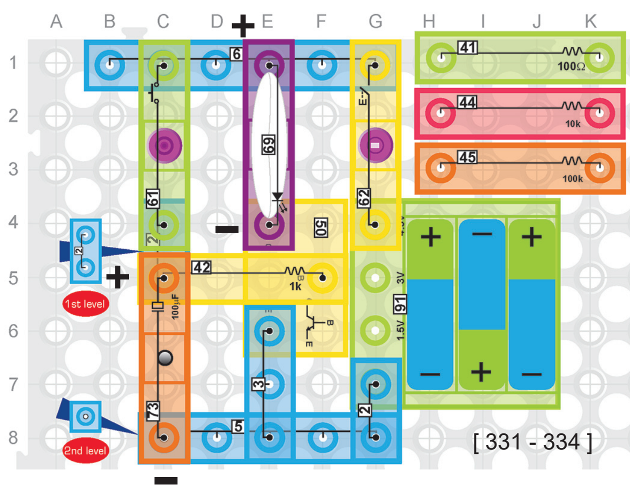
## 329. Intermittent Windshield Wipers

Replace the 1kΩ resistor (42) in project #327 with the 10kΩ resistor (44) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the lamp (76) light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay bright for a several seconds and then turn dim. This circuit could be used to create the delay for your windshield wipers.

## 330. Resistor Color Code Table

Replace the 1kΩ resistor (42) in project #327 with the 100kΩ resistor (45) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the lamp (76) will not light. This is because with a 100kΩ resistor (45) at the base of the NPN transistor (50), there is very little current going into the base, and even though the current from collector to emitter is much greater, it's not enough to light the lamp (76). Project #85 introduced the 4-band resistor. The first three bands define the resistance of the resistor using the table to the right. So for instance, a 100Ω resistor would have the colors brown, black and brown as the first three bands ($10x10^1 = 100$).

| Color | 1st Band (1st digit) | 2nd Band (2nd digit) | 3rd Band (Multiplier) |
|---|---|---|---|
| Black | 0 | 0 | $10^0$ |
| Brown | 1 | 1 | $10^1$ |
| Red | 2 | 2 | $10^2$ |
| Orange | 3 | 3 | $10^3$ |
| Yellow | 4 | 4 | $10^4$ |
| Green | 5 | 5 | $10^5$ |
| Blue | 6 | 6 | $10^6$ |
| Violet | 7 | 7 | $10^7$ |
| Gray | 8 | 8 | $10^8$ |
| White | 9 | 9 | $10^9$ |

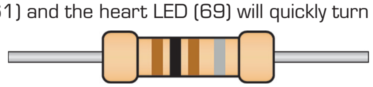



## 331. 1kΩ Resistor

Build the circuit above and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) light. Release the press switch (61) and the heart LED (69) will stay bright briefly and then turn dim. The 1kΩ resistor (42) in this circuit would have the colors brown, black and red as the first three bands ($10x10^2 = 1,000$) as shown on the right.

## 332. 100Ω Resistor

Replace the 1kΩ resistor (42) in project #331 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) light. Release the press switch (61) and the heart LED (69) will quickly turn dim. The 100Ω resistor (41) in this circuit would have the colors brown, black, and brown as the first three bands ($10x10^1 = 100$) as shown on the right.

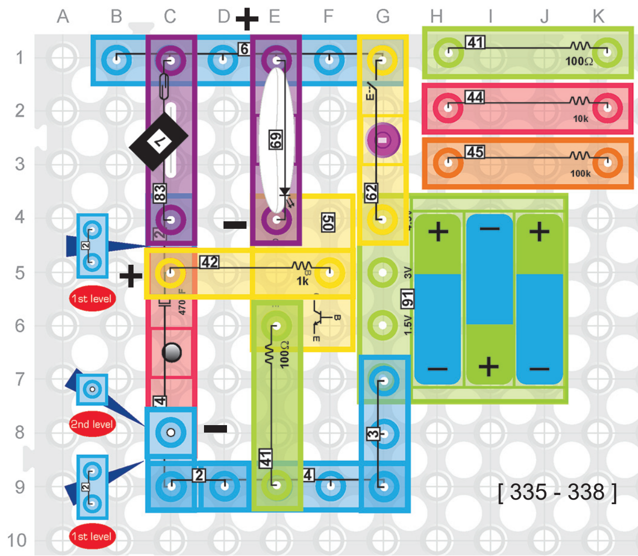


## 333. 10kΩ Resistor

Replace the 1kΩ resistor (42) in project #331 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) light. Release the press switch (61) and the heart LED (69) will stay bright for a while and then turn dim. The 10kΩ resistor (44) in this circuit would have the colors brown, black and orange as the first three bands ($10x10^3 = 10,000$) as shown on the right.

## 334. 100kΩ Resistor

Replace the 1kΩ resistor (42) in project #331 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) light. Release the press switch (61) and the heart LED (69) will stay bright for many seconds before turning dim. The 100kΩ resistor (45) in this circuit would have the colors brown, black and yellow as the first three bands ($10x10^4 = 100,000$) as shown on the right.




## 335. The Number *e*
Build the circuit above and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will stay bright for a little while and then turn dim.

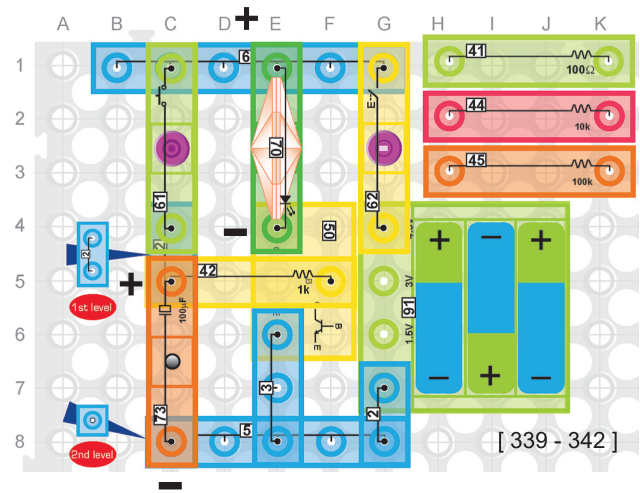
As discussed in the project #326, the voltage of the capacitor decays with a time constant of R*C. The decay rate is given by $e^{-t/(R*C)}$ where *e* is a constant known as Euler's number, named after Swiss mathematician Leonhard Euler and t represents time in seconds. The value of *e* is approximately 2.71828.

## 336. Time Constant τ
In project #335, replace the 100Ω resistor (41) with a 4-wire (4) and replace the 1kΩ resistor (42) with the 100Ω resistor (41) and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will stay bright briefly then turn dim.

As discussed in project #327, the time constant for an RC circuit is R*C and is often times given the symbol τ. Note from the previous project that when time t = τ = R*C, then the signal has decayed by $e^{-1}$ = 0.367, or to approximately 37% of its initial value at time t = 0.

## 337. τ for 10kΩ Resistor and 470μF Capacitor
Replace the 1kΩ resistor (42) in project #335 with the 10kΩ resistor (44) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will stay bright for a several seconds and then turn dim. The τ for this circuit is 10,000*470$e^{-6}$ = 4.7 seconds.

## 338. τ for 100kΩ Resistor and 470μF Capacitor
Replace the 1kΩ resistor (42) in project #335 with the 100kΩ resistor (45) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will stay bright for a long time and then turn dim. The τ for this circuit is 100,000*470$e^{-6}$ = 47 seconds.




## 339. τ for 1kΩ Resistor and 100μF Capacitor
Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) light. Release the press switch (61) and the star LED (70) will stay bright briefly and then turn dim.

The τ for this circuit is 1,000*100$e^{-6}$ = 0.1 second.

## 340. τ for 100Ω Resistor and 100μF Capacitor
Replace the 1kΩ resistor (42) in project #339 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) light. Release the press switch (61) and the star LED (70) will quickly dim.

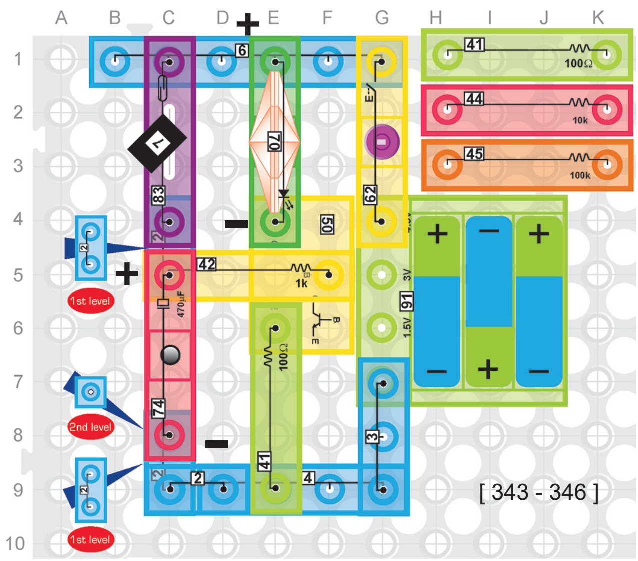
The τ for this circuit is 100*100$e^{-6}$ = 0.01 second.

## 341. τ for 10kΩ Resistor and 100μF Capacitor
Replace the 1kΩ resistor (42) in project #339 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) light. Release the press switch (61) and the star LED (70) will stay bright for a while and then turn dim.

The τ for this circuit is 10,000*100$e^{-6}$ = 1 second.

## 342. τ for 100kΩ Resistor and 100μF Capacitor
Replace the 1kΩ resistor (42) in project #339 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) light. Release the press switch (61) and the star LED (70) will stay bright for many seconds before turning dim.

The τ for this circuit is 100,000*100$e^{-6}$ = 10 seconds.




## 343. Transistor Gain β

Build the circuit shown on the left and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the star LED (70) light. Move the magnet (7) away from the reed switch (83) and the star LED (70) will stay bright for a little while and then turn dim. Transistors like the NPN transistor (50) can be used as amplifiers where a small current into the Base can be "amplified" to produce a large current out of the Emitter. The gain of the NPN transistor (50) is defined as the ratio of the Collector current to the Base current and called β (pronounced Beta). If you had an ammeter and measured the current going into the Base it would be around 3.7 mA, while the current coming out of the Emitter would be about 42 mA. This yields a β = 42/3.7 = 11.4.

## 344. Transistor Gain with 100Ω Resistor

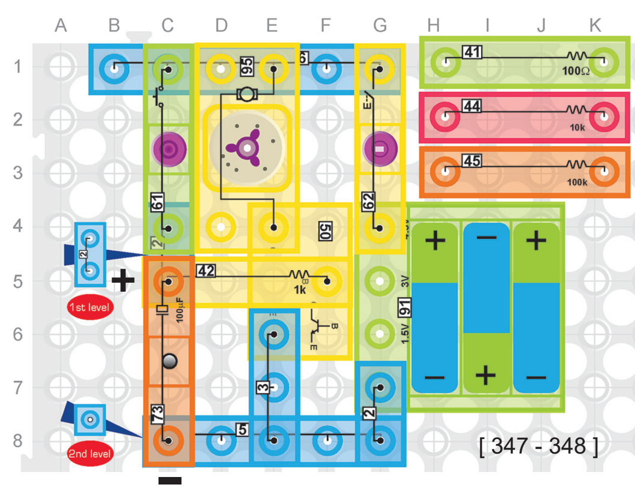
In project #343, replace the 100Ω resistor (41) with a 4-wire (4) and replace the 1kΩ resistor (42) with the 100Ω resistor (41) and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the star LED (70) light. Move the magnet (7) away from the reed switch (83) and the star LED (70) will stay bright briefly then turn dim. If you had an ammeter and measured the current going into the Base it would be around 0.37 mA, while the current coming out of the Emitter would be about 90 mA. This yields a β = 90/37 = 2.4.

## 345. Transistor Gain with 10kΩ Resistor

Replace the 1kΩ resistor (42) in project #343 with the 10kΩ resistor (44) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the star LED (70) light. Move the magnet (7) away from the reed switch (83) and the star LED (70) will stay bright for a several seconds and then turn dim. If you had an ammeter and measured the current going into the Base it would be around 0.37 mA, while the current coming out of the Emitter would be about 41 mA. This yields a β = 41/0.37 = 111.

## 346. Transistor Gain with 100kΩ Resistor

Replace the 1kΩ resistor (42) in project #343 with the 100kΩ resistor (45) and then turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the star LED (70) light. Move the magnet (7) away from the reed switch (83) and the star LED (70) will stay bright for a long time and then turn dim. If you had an ammeter and measured the current going into the Base it would be around 0.038 mA, while the current coming out of the Emitter would be about 10.6 mA. This yields a β = 10.6/0.038 = 279. As seen in the last three projects, the β of the transistor is different for each project. This is because the β of a transistor is not a constant but a function of the current through the transistor.

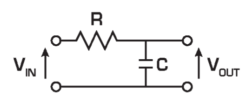



**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 347. RC Low Pass Filter Circuit

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and the motor (95) will spin. Release the press switch (61) and the motor (95) will keep spinning briefly and then stop.

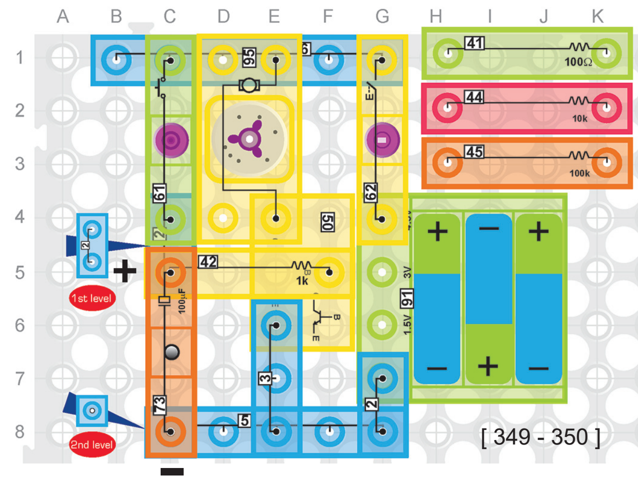
One important application of RC circuits is that they can be used as filters to pass certain frequencies and reject certain frequencies. Consider the Input/Output of the RC circuit shown below. It has been discussed that capacitors can store charge from a voltage source. However, up to now we have only been considering a constant voltage source (called a Direct Current or DC voltage source). Imagine turning the input signal to the circuit below on and off quickly. If you turn the input signal on and off fast enough, then there will not be enough time for the 100μF capacitor (73) to charge and the output will just be 0V. However, if the input signal is turned on and off slow enough, then the 100μF capacitor (73) will have time to charge and the output will look like the input. We have just described a low pass filter (high frequencies do not get through while low frequencies do).



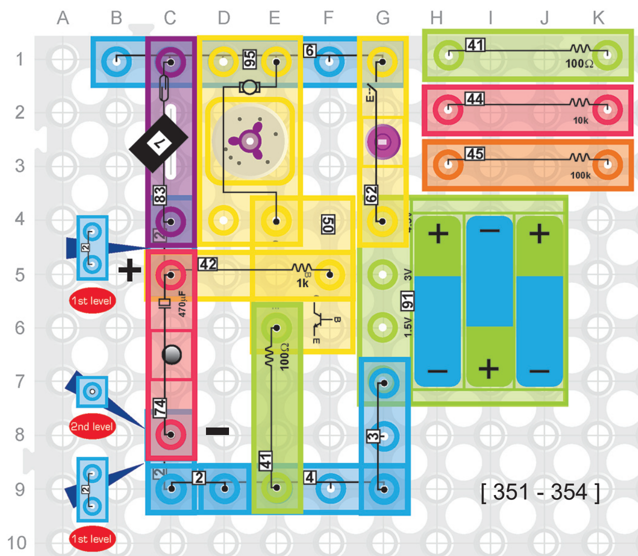

## 348. RC Low Pass Filter Cutoff Frequency

Replace the 1kΩ resistor (42) in project #347 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and the motor (95) will spin. Release the press switch (61) and the motor (95) will stop quickly.

As discussed in the last project, an RC circuit can act like a low pass filter. The easiest method for determining the cutoff frequency of an RC filter circuit uses frequency domain analysis techniques like Fourier Transform theory which is beyond the scope of this manual. But it turns out that the cutoff frequency of a single pole (single resistor and single capacitor) circuit is $f_{cutoff} = 1/(2*\pi*R*C)$ where π (pronounced as "pie") is a constant defined as approximately 3.1416. If the 100Ω resistor (41) and 100μF capacitor (73) in this project were used in an RC low pass filter, then the cutoff frequency would be $1/(2*3.14*100*100e^{-6}) = 16$ Hz. Only very low frequencies (near DC) would pass through such a circuit.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 349. Cutoff Frequency of 10kΩ Resistor and 100μF Capacitor RC Circuit

Replace the 1kΩ resistor (42) in project #347 with the 10kΩ resistor (44) and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin. Release the press switch (61) and the motor (95) will continue to spin for a while and then stop. If the 10kΩ resistor (44) and 100μF capacitor (73) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*10,000*100$e^{-6}$) = 0.16 Hz. Only very low frequencies (near DC) would pass through such a circuit.

## 350. Cutoff Frequency of 100kΩ Resistor and 100μF Capacitor RC Circuit

Replace the 1kΩ resistor (42) in project #347 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and the motor (95) will not spin. This is because with a 100kΩ resistor (45) at the base of the NPN transistor (50), there is very little current going into the base, and even though the current from collector to emitter is much greater, it's not enough to make the motor (95) spin. If the 100kΩ resistor (45) and 100μF capacitor (73) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*100,000*100$e^{-6}$) = 0.016 Hz. Only very low frequencies (near DC) would pass through such a circuit.

## 351. Cutoff Frequency of 1kΩ Resistor and 470μF Capacitor RC Circuit

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin. Release the press switch (61) and the motor (95) will continue spinning for a little while and then stop. If the 1kΩ resistor (42) and 470μF capacitor (74) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*1,000*470$e^{-6}$) = 0.34 Hz. Only very low frequencies (near DC) would pass through such a circuit.

## 352. Cutoff Frequency of 100Ω Resistor and 470μF Capacitor RC Circuit

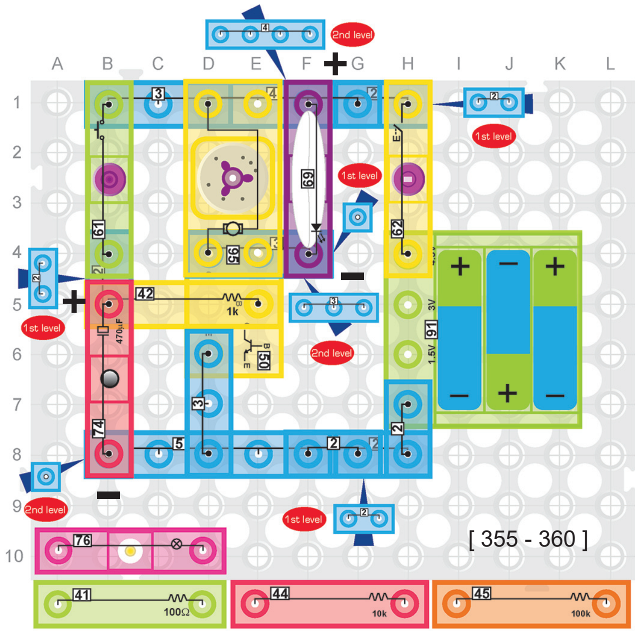
In project #351, replace the 100Ω resistor with a 4-wire (4) and replace the 1kΩ resistor (42) with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin. Release the press switch (61) and the motor (95) will continue to spin for a while and then stop. If the 100Ω resistor (41) and 470μF capacitor (74) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*5,100*470$e^{-6}$) = 0.066 Hz. Only very low frequencies (near DC) would pass through such a circuit.

## 353. Cutoff Frequency of 10kΩ Resistor and 470μF Capacitor RC Circuit

Replace the 1kΩ resistor (42) in project #351 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin. Release the press switch (61) and the motor (95) will continue to spin for several seconds and then stop. If the 10kΩ resistor (44) and 470μF capacitor (74) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*10,000*470$e^{-6}$) = 0.034 Hz. Only very low frequencies (near DC) would pass through such a circuit.

## 354. Cutoff Frequency of 100kΩ Resistor and 470μF Capacitor RC Circuit

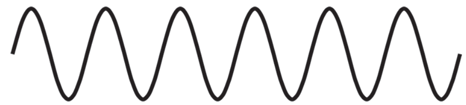
Replace the 1kΩ resistor (42) in project #351 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and the motor (95) will not spin. This is because with a 100kΩ resistor (45) at the base of the NPN transistor (50), there is very little current going into the base, an even though the current from collector to emitter is much greater, it's not enough to make the motor (95) spin. If the 100kΩ resistor (45) and 470μF capacitor (74) in this project were used in an RC low pass filter, then the cutoff frequency would be 1/(2*3.14*100,000*470$e^{-6}$) = 0.0034 Hz. Only very low frequencies (near DC) would pass through such a circuit.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 355. Sine Wave

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and the heart LED (69) light. Release the press switch (61) and the motor (95) will continue to spin for a while and then stop and the heart LED (69) will stay on for a while and then turn off. When the motor (95) is spinning, you can hear a sound that this is like a high pitch tone. A pure tone is produced by a sinusoidal wave (called a sine wave), which is shown in the figure below.

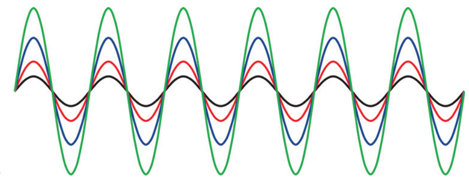


## 356. Formula for a Sine Wave

Replace the 1kΩ resistor (42) in project #355 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and the heart LED (69) light. Release the press switch (61) and the motor (95) will spin briefly and then stop and the heart LED (69) will stay on briefly and then go dim. The sine wave discussed in the previous project can be defined as $A*\sin(2\pi f_c t+\theta)$, where $f_c$ is the frequency of the sine wave, A is the amplitude of the sine wave, θ (the Greek letter theta) is the phase of the sine wave, and t is time.

## 357. Amplitude of a Sine Wave

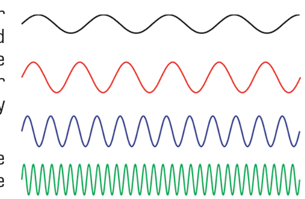
Replace the 1kΩ resistor (42) in project #355 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and the heart LED (69) light. Release the press switch (61) and the motor (95) will continue spinning for several seconds and then stop and the heart LED (69) will stay on for several seconds and then go dim. A was defined as the amplitude of a sine wave in project #356. The figure on the right shows various sine waves with different amplitudes. The green sine wave has the largest amplitude and the black sine wave has the smallest amplitude.



## 358. Frequency of Sine Wave

Replace the press switch (61) with the reed switch (83) and replace the 470μF capacitor (74) with the 100μF capacitor (73) in project #355. Turn on the switch (62) and hold the magnet (7) near the reed switch (83) and you will see the motor (95) spin and the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue to spin briefly and then stop and the heart LED (69) will stay on briefly and then go off.

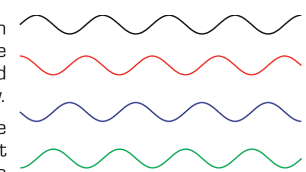
$f_c$ was defined as the frequency of a sine wave in project #356. The frequency of a sine wave represents the number of cycles per second of the sine wave. Higher frequency sine waves have more cycles per second and lower frequency sine waves have fewer cycles per second. The figure on the right shows various sine waves of different frequencies.



## 359. Phase of a Sine Wave

Replace the 1kΩ resistor (42) in project #358 with the 100Ω resistor (41) and turn on the switch (62). Hold the magnet (7) near the reed switch (83) and you will see the motor (95) spin and the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the motor (95) will stop quickly and the heart LED (69) will go off quickly.

θ was defined as the phase of a sine wave in project #356. The phase of a sine wave represents the starting point of the sine wave cycle. When θ = 0, the sine wave starts at 0 amplitude at time t = 0. When $\theta = \pi/2$, the sine wave starts at its maximum amplitude of A at t = 0. The figure on the right shows various sine waves of different phases.



## 360. Speed of Sound

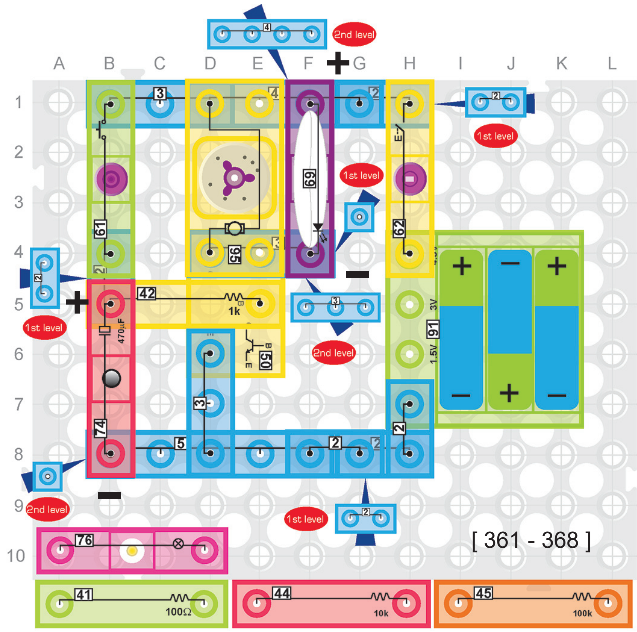
Replace the 1kΩ resistor (42) in project #358 with the 10kΩ resistor (44) and then turn on the switch (62). Hold the magnet (7) near the reed switch (83) and you will see the motor (95) spin and the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue to spin for a while and then stop and the heart LED (69) will stay on for a while and then go off.

The motor (95) also makes a high pitch sound while spinning. The speed of sound varies depending on the substance it travels through. In dry air at 0 degrees Celsius, the speed of sound is approximately 331.2 meters/s.

### 361. Resistor Tolerance

Replace the motor (95) with the lamp (76) in project #355. Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will stay bright for a while and then turn dim. In project #85 the 4-band resistor was discussed. The 4th band on the right represents the tolerance of the resistor.

Tolerance is specified in percentage and means that the actual resistor value will be within the defined tolerance percentage of the value defined by the first three bands on the left of the resistor. The most common color codes for tolerance are Red = 2%, Silver = 5% and Gold = 10%. For example, if the 1kΩ resistor (42) in this circuit had a 4th band that was red, then the actual resistance of the resistor could be anywhere from 0.98*1,000 = 980Ω to 1.02*1,000 = 1020Ω.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

### 362. 100Ω Resistor Tolerance – Red Band

Replace the 1kΩ resistor (42) in project #361 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will stay bright briefly and then turn dim. If we had a 100Ω resistor with a 4th band that is red, then this would mean that the actual resistance of the resistor could be anywhere from 0.98*100 = 98Ω to 1.02*100 = 102Ω.

### 363. 10kΩ Resistor Tolerance – Red Band

Replace the 1kΩ resistor (42) in project #361 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will stay bright for several seconds and then turn dim. If we had a 10kΩ resistor with a 4th band that is red, then this would mean that the actual resistance of the resistor could be anywhere from 0.98*10,000 = 9,800Ω to 1.02*10,000 = 10,200Ω.

### 364. 100kΩ Resistor Tolerance – Red Band

Replace the 1kΩ resistor (42) in project #361 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) do not light. Because there is not enough current flowing through the base of the NPN transistor (50) to light the lamp (76), the voltage across the lamp (76) (which is in parallel with the heart LED (69)) is too small to turn on the LED in the heart LED (69). If we had a 100kΩ resistor (45) with a 4th band that is red, then this would mean that the actual resistance of the resistor could be anywhere from 0.98*100,000 = 98,000Ω to 1.02*100,000 = 102,000Ω.

### 365. 1kΩ Resistor Tolerance – Silver Band

Replace the 470µF capacitor (74) in project #361 with the 100µF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will stay bright briefly and then turn dim. If the 1kΩ resistor (42) in this circuit had a 4th band that was silver, then the actual resistance of the resistor could be anywhere from 0.95*1,000 = 950Ω to 1.05*1,000 = 1050Ω.

### 366. 100Ω Resistor Tolerance – Silver Band

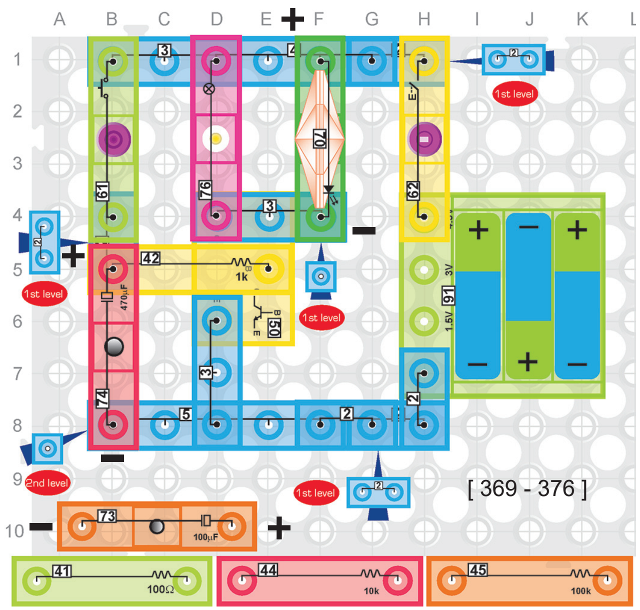
Replace the 1kΩ resistor (42) in project #365 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will turn dim quickly. If we had a 100Ω resistor with a 4th band that is silver, then this would mean that the actual resistance of the resistor could be anywhere from 0.95*100 = 95Ω to 1.05*100 = 105Ω.

### 367. 10kΩ Resistor Tolerance – Silver Band

Replace the 1kΩ resistor (42) in project #365 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) light. Release the press switch (61) and the heart LED (69) and lamp (76) will stay bright for a while and then turn dim. If we had a 10kΩ resistor (44) with a 4th band that is silver, then this would mean that the actual resistance of the resistor could be anywhere from 0.95*10,000 = 9,500Ω to 1.05*10,000 = 10,500Ω.

### 368. 100kΩ Resistor Tolerance – Silver Band

Replace the 1kΩ resistor (42) in project #365 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and lamp (76) do not light. Because there is not enough current flowing through the base of the NPN transistor (50) to light the lamp (76), the voltage across the lamp (76) (which is in parallel with the heart LED (69)) is too small to turn on the LED in the heart LED (69). If we had a 100kΩ resistor (45) with a 4th band that is red, then this would mean that the actual resistance of the resistor could be anywhere from 0.95*100,000 = 95,000Ω to 1.05*100,000 = 105,000Ω.




| Color | Tolerance |
|---|---|
| Black | N/A |
| Brown | 1% |
| Red | 2% |
| Orange | N/A |
| Yellow | N/A |
| Green | 0.50% |
| Blue | 0.25% |
| Violet | 0.10% |
| Gray | 0.05% |
| White | N/A |
| Silver | 5% |
| Gold | 10% |

## 369. 1kΩ Resistor Tolerance – Gold Band

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will stay bright for a while and then turn dim. If the 1kΩ resistor (42) in this circuit had a 4th band that was gold, then the actual resistance of the resistor could be anywhere from 0.9*1,000 = 900Ω to 1.1*1,000 = 1100Ω.

## 370. 100Ω Resistor Tolerance – Gold Band

Replace the 1kΩ resistor (42) in project #369 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will stay on briefly and then go dim. If we had a 100Ω resistor with a 4th band that is gold, then this would mean that the actual resistance of the resistor could be anywhere from 0.9*100 = 90Ω to 1.1*100 = 110Ω.

## 371. 10kΩ Resistor Tolerance – Gold Band

Replace the 1kΩ resistor (42) in project #369 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will stay bright for several seconds and then turn dim. If we had a 10kΩ resistor (44) with a 4th band that is gold, then this would mean that the actual resistance of the resistor could be anywhere from 0.9*10,000 = 9,000Ω to 1.1*10,000 = 11,000Ω.

## 372. 100kΩ Resistor Tolerance – Gold Band

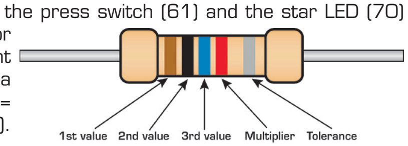
Replace the 1kΩ resistor (42) in project #369 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) will not light. Because there is not enough current flowing through the base of the NPN transistor (50) to light the lamp (76), the voltage across the lamp (76) (which is in parallel with the star LED (70)) is too small to turn on the LED in the star LED (70). If we had a 100kΩ resistor (45) with a 4th band that is gold, then this would mean that the actual resistance of the resistor could be anywhere from 0.9*100,000 = 90,000Ω to 1.1*100,000 = 110,000Ω.

## 373. High Accuracy Resistors

Replace the 470μF capacitor (74) in project #369 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will stay bright briefly and then turn dim. Although most resistors use red, silver or gold as the 4th band, there are other colors that may appear as the 4th band for higher accuracy resistors. See the table on the lower left for all the possible 4th band color markings.

## 374. 5-Band Resistors

Replace the 1kΩ resistor (42) in project #373 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will turn dim quickly. When high accuracy is needed for resistor values, it can become important to specify more than the first two significant digits. Because of this, 5-band resistors have been introduced that provide a 3rd significant digit. See the figure to the right. This would be a $316*10^2$ = 31,600Ω resistor that would be accurate to within 1% (31,284Ω to 31,916Ω).

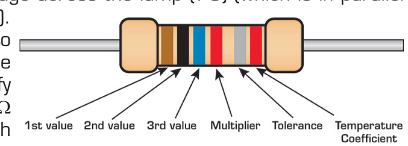


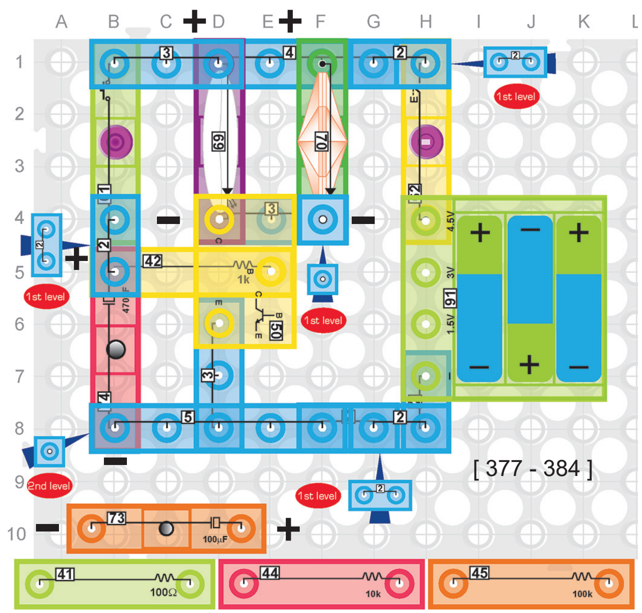

## 375. Resistor Temperature Effects

Replace the 1kΩ resistor (42) in project #373 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) light. Release the press switch (61) and the star LED (70) and lamp (76) will stay bright for a while and then turn dim. Actual resistance of a resistors can vary based on temperature. At higher temperatures, electrons become more free to move around and this reduces resistance. At lower temperatures electrons are less free to move around which increases resistance. Again, for the need for very high accuracy resistors, it becomes necessary to specify the Temperature Coefficient of Resistance (TCR) of the resistor. TCR is usually expressed in Parts Per Million per degree Centigrade (often just referred to as PPM). This tells you how much the resistance of the resistor can change for every degree change in temperature.

## 376. 6-Band Resistors

Replace the 1kΩ resistor (42) in project #373 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and lamp (76) will not light. Because there is not enough current flowing through the base of the NPN transistor (50) to light the lamp (76), the voltage across the lamp (76) (which is in parallel with the star LED (70)) is too small to turn on the LED in the star LED (70). When high accuracy is needed for resistor values, it can become important to specify how the resistance of the resistor changes with temperature. Because of this, 6-band resistors have been introduced that provide a band to specify the TCR. See the figure to the right. This would be a $316*10^2$ = 31,600Ω resistor that would be accurate to within 1% (31,284Ω to 31,916Ω) with 50ppm change per degree Centigrade.






## 377. Understanding PPM

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright for a little while and then turn dim. Understanding how to calculate the effects of temperature on a resistor value can be confusing as it is specified in Parts Per Million (PPM). You can think of the PPM value of a resistor as providing the resistance tolerance per degree Centigrade for a 1MΩ resistor. If a 1MΩ resistor was specified as 50 PPM, this would mean the actual value of the resistor could be between 9,999,950Ω to 1,000,050Ω for a 1 degree temperature change from the reference temperature (usually 20 or 25 degrees Celsius). Basically, for every million Ohms, a 50 PPM resistor could vary by 50 Ohms for every degree Centigrade change.

## 378. PPM Color Code

Replace the 1kΩ resistor (42) in project #377 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright briefly and then turn dim. The table below shows the color coding for the Temperature Coefficient of Resistance (TCR) for 6 band resistors.

| Color | TCR (ppm/°C) |
|---|---|
| Brown | 100 |
| Red | 50 |
| Orange | 15 |
| Yellow | 25 |
| Green | 20 |
| Blue | 10 |
| Violet | 5 |
| Gray | 1 |

## 379. 10kΩ Resistor Temperature Tolerance Example

Replace the 1kΩ resistor (42) in project #377 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright for several seconds and then turn dim. If we had a 10kΩ resistor (44) with a 6th band that is yellow, then this would mean that for every temperature degree change from the reference, the actual resistance of the resistor could vary by 25*10,000/1,000,000 = 0.25Ω. So if the resistor was used in an unusually hot environment, say 20 degrees above the reference, then this could lead to a 20*0.25 = 5Ω difference in the actual resistance of the resistor.

## 380. 100kΩ Resistor Temperature Tolerance Example

Replace the 1kΩ resistor (42) in project #377 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright for a long time before turning dim. If we had a 100kΩ resistor (45) with a 6th band that is green, then this would mean that for every temperature degree change from the reference, the actual resistance of the resistor could vary by 20*100,000/1,000,000 = 2Ω. So if the resistor was used in an unusually cold environment, say 20 degrees below the reference, then this could lead to a 20*2 = 40Ω difference in the actual resistance of the resistor.

## 381. Fiber Optic Communication

Replace the 470μF capacitor (74) in project #377 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright briefly and then turn dim. LEDs can be used to drive fiber optic cables to send high bandwidth data over long distances.

## 382. Fiber Optic Communication Distances

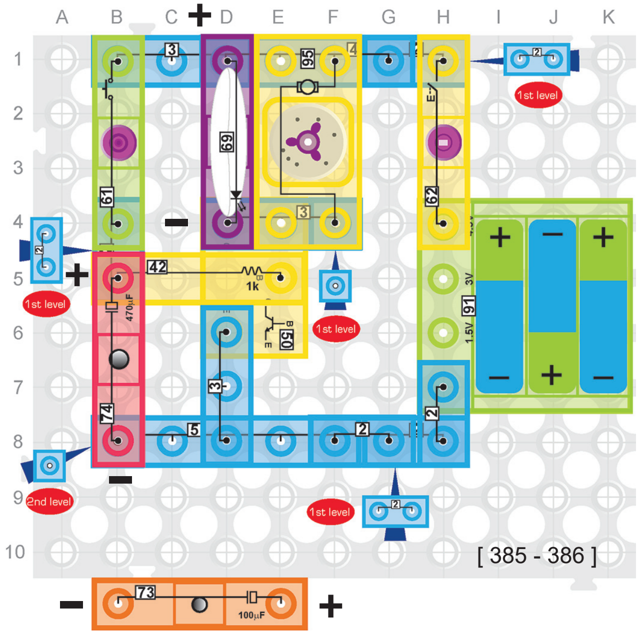
Replace the 1kΩ resistor (42) in project #381 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs turn dim quickly. The simplest form of fibers (called single mode fibers) can actually carry light over 60 miles or more.

## 383. Advantages of Fiber Optics

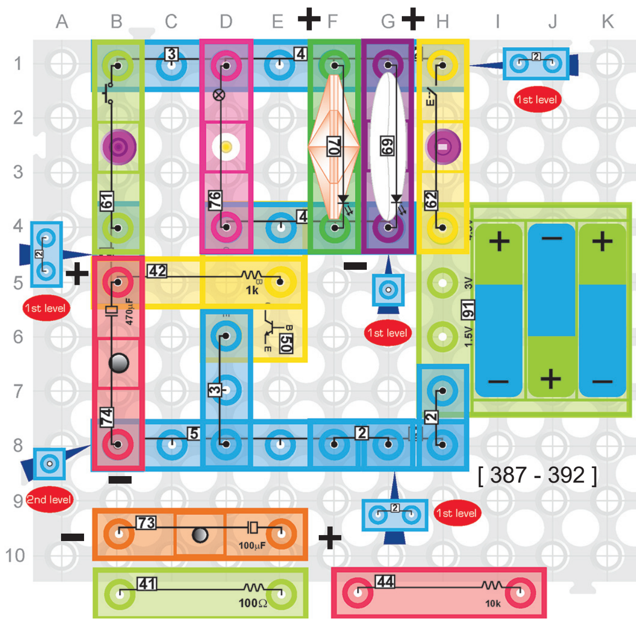
Replace the 1kΩ resistor (42) in project #381 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright for a while and then turn dim. Some of the advantages of fiber optic transmission are that they do not overheat and are not affected by rain, wind and other weather factors. They are also stronger than copper and can endure much larger tension than copper.

## 384. Disadvantages of Fiber Optics

Replace the 1kΩ resistor (42) in project #381 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see both LEDs light. Release the press switch (61) and both LEDs will stay bright for several seconds before turning dim. The major disadvantage of fiber optic is that it is difficult to make connections. The core of optical cable is as fine as a human hair, so when making splices the fiber cores must be perfectly aligned. Also, the ends of the optical fiber must be highly polished to allow light to pass with little loss.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




## 385. Capacitor Polarity

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and the heart LED (69) light. Release the press switch (61) and the motor will continue to spin for a while and then stop and the heart LED (69) will stay bright for a while then turn dim.

The capacitors in your set have polarity, just like the LEDs. If you look closely at your 470μF capacitor (74). You will see a white band marked with a "–" sign along the side of them. This indicates that the 470μF capacitor (74) should always be placed in the circuit so that lower voltage in on the "–" side of the 470μF capacitor (74), like in this circuit.

## 386. Capacitor Voltage Rating

Replace the 470μF capacitor (74) in project #385 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and the heart LED (69) light. Release the press switch (61) and the motor (95) will continue to spin briefly and then stop and the heart LED (69) will stay bright briefly and then turn dim.

Light travels at a speed of approximately 300 million meters/second. If you look closely at the 100μF capacitor (73) you will see that it has a voltage rating of 10V on the side. This 100μF capacitor (73) should not be used in any circuit that could product more than 10V across it. The battery module (91) only provides 4.5V (and at most 5V with brand new batteries) so there is no need to worry about ever going above 10V with the components in this set.

## 387. Capacitor Tolerance

Build the circuit above and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will stay bright for a while and then turn dim. Capacitor tolerances usually are not marked because most capacitors have a tolerance of ±20%. So the actual resistance of the 470μF capacitor (74) should be between 0.8*470 = 376μF and 1.2*470 = 564μF.

## 388. Capacitor Operating Temperature

Replace the 1kΩ resistor (42) in project #387 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will stay bright briefly and then turn dim. If you look closely at the 470μF capacitor (74) you will see that it is marked as –40 to +105°C. This is the temperature operating range for this part. Outside this temperature range the actual capacitance may be outside the ±20% that is typical.

## 389. Ceramic Capacitors

Replace the 1kΩ resistor (42) in project #387 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will stay bright for several seconds and then turn dim. Not all capacitors are polarized. Small capacitance capacitors (typically 1μF or less) are often ceramic capacitors that do not have polarity. Ceramic capacitors use a ceramic material as the dielectric between the two plates.

## 390. Electrolytic Capacitor

Replace the 470μF capacitor (74) in project #387 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will stay bright briefly and then turn dim. The 100μF capacitor (73) is called an electrolytic capacitor because it is designed where one plate is made of a metal that forms an insulating layer that acts as the dielectric. This makes the design of the 100μF capacitor (73) asymmetric where the higher voltage must always be on one lead, and the lower voltage on the other lead (which is marked on the capacitor with a "–" sign).

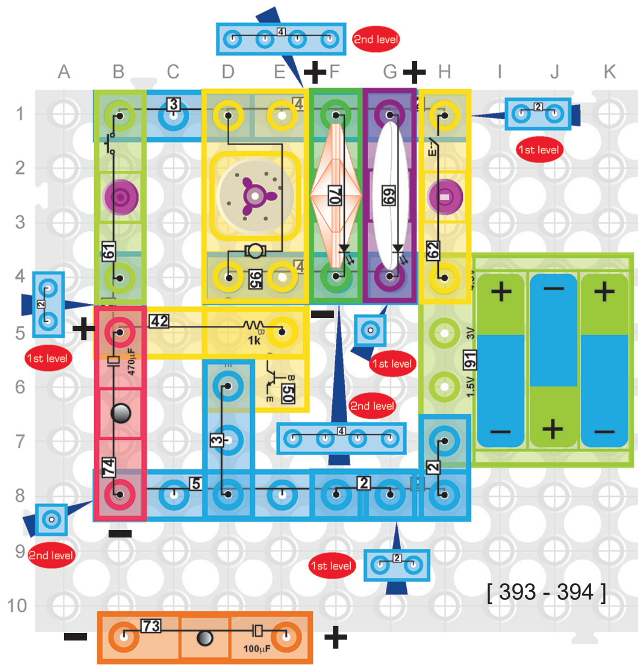
## 391. Tolerance of 100μF Capacitor

Replace the 1kΩ resistor (42) in project #390 with the 100Ω resistor (41) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will turn dim quickly. As discussed in project #387, the typical tolerance of capacitors is ±20%. That means that the actual capacitance of the 100μF capacitor (73) should be between 0.8*100 = 80μF and 1.2*100 = 120μF.

## 392. Capacitors in Cameras

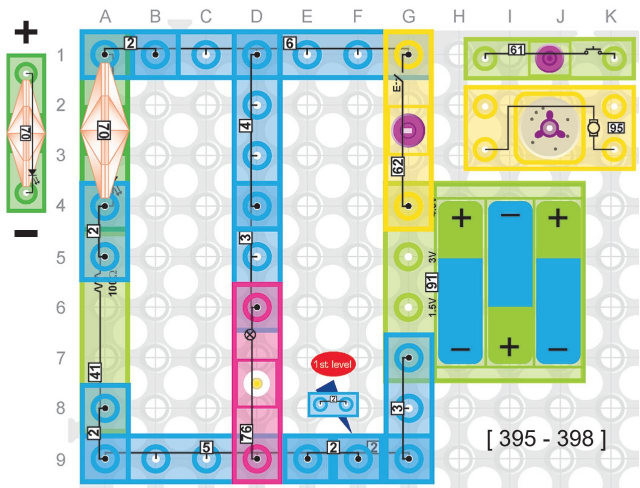
Replace the 1kΩ resistor (42) in project #390 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70) and lamp (76) light. Release the press switch (61) and the heart LED (69), star LED (70) and lamp (76) will stay bright for a while and then turn dim.

Did you know that Electrolytic capacitors are often used in cameras to create the flash? The battery in the camera is used to charge a capacitor and when you press the button to take the picture the sudden discharge of the capacitor is used to produce the flash.



[ 393 - 394 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



[ 395 - 398 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 393. Equalizer

Build the circuit to the left and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and both LEDs light. Release the press switch (61) and the motor (95) will continue to spin for a while and then stop and both LEDs will stay bright for a while and then turn dim. The sound from the motor (95) is like a tone, but if it played music with a range of frequencies, then you wouldn't want to amplify all the frequencies the same like in this circuit.

Equalizers are filters that modify the audio amplitude of specific frequencies to prevent distortion and optimize the sound of music to our ears.

## 394. Decibels

Replace the 470μF capacitor (74) in project #393 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the motor (95) spin and both LEDs light. Release the press switch (61) and the motor (95) will continue to spin for briefly and then stop and both LEDs will stay bright briefly and then turn dim.

Decibels (abbreviated as dB) are used, among other things, to measure audio volume level. It is often used to define large differences between audio levels. For instance, if the audio power of a signal initially is P1 and then the audio power level of the signal is increases to P2, then the audio level would be said to have increased by 10*log(P2/P1) dB, where log represents the log base 10 function.

## 395. Relative Light Intensity

Build the circuit shown, turn on the switch (62) and the lamp (76) and the star LED (70) will be turned on at the same time. Decibels can also be used to compare light intensity levels. For instance, if the star LED (70) was twice as bright as the lamp (76), the this would lead to a 10*log(2) = 3dB difference between the light intensity of the star LED (70) and the lamp (76). You can find the log function on your typical scientific calculator.

## 396. Fiber Optic Communication Underwater

Replace the switch (62) with the press switch (61) in project #395, then press the press switch (61) and the lamp (76) and the star LED (70) will be turned on at the same time.

LEDs like the star LED (70) can be used to drive fiber optic cables. One of the benefits of fiber optic transmission is that fibers can be placed underwater. In fact, submarine communication cables (underwater cables) primarily use fiber and carry about 99% of data exchanged internationally.

## 397. Fiber Optic Communication – Near the Speed of Light

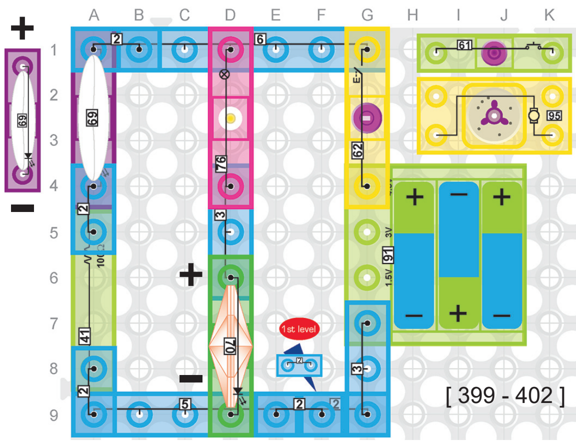
Replace the lamp (76) in project #395 with the motor (95). Now If you turn on the switch (62) you will see the star LED (70) is on and the motor (95) is spinning too.

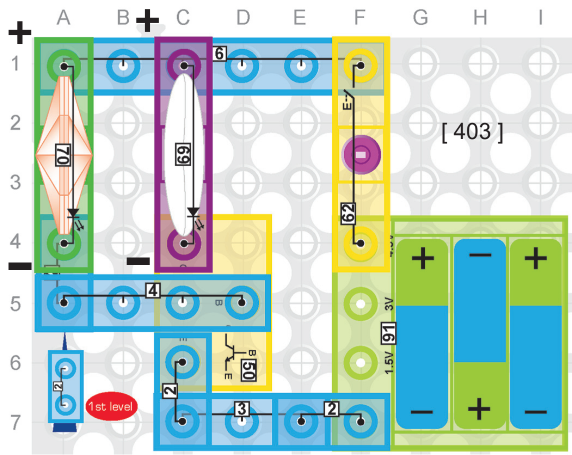
Light travels at a speed of approximately 300 million meters/second. Since fibers use light to communicate, fiber transmissions are nearly as fast as the speed of light (about 99.7% of the speed of light). Actual data speeds are related to various modulation, coding and decoding techniques, but one thing is for sure...the time it takes for the data transmission to travel over the fiber is not a limiting factor in the data speeds.

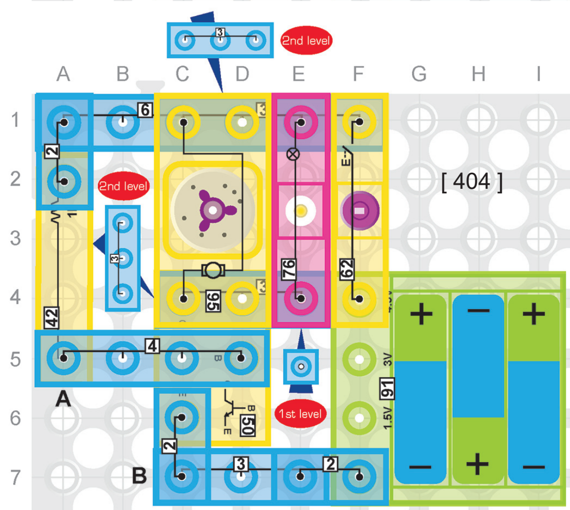
## 398. Poles in an AC Motor

In project #395, replace the switch (62) with the press switch (61) and replace the lamp (76) with the motor (95). Now if you press the press switch (61) you will see the star LED (70) is on and the motor (95) is spinning too.

Motors that run off of AC current (i.e. ones that you plug into the outlets in your house) have poles, similar to the poles in a magnet. Unlike a magnet, though, these poles are created by windings of magnet wire.




## 399. IC Packaging

Build the circuit shown on the left, connect the switch (62) and the two LEDs will light but the lamp (76) will be off or very dim. The turn on voltage and internal resistance of the star LED (70) prevent the lamp (76) from lighting brightly. The turn on voltage and internal resistance of the star LED (70) prevent the lamp (76) from lighting.

Circuits like this and much more complicated than this often get put into ICs, which are then packaged in many different ways but typically have pins of pads coming out of the packaging to connect the circuit to power and to provide inputs and outputs.

## 400. Making ICs – Step 1

Replace the switch (62) with the press switch (61) in project #399, then press the press switch (61) and you will see the two LEDs will be turned on but the lamp (76) does not light or is very dim.

To make ICs to support circuits like the one here and more complicated circuits, recall the discussions on how LEDs and transistors are made. The key is the semiconductor material that is doped to have either an excess of electrons or a depletion of electrons (excess of holes). By placing two different types of doped material next to each other we created the LED (which is a diode). By placing three different types of doped materials in layers we created the transistor. And by placing lots of different doped materials at various layers you can create all different types of circuits in an IC. The first step in making an IC is to make the wafers, or thin pieces of silicon.

## 401. Making ICs – Step 2

Replace the lamp (76) with the motor (95) in project #399. Press the switch (62) and you will see the two LEDs will be turned on and the motor (95) will spin slowly.

The second step in making an IC for a circuit like this or more complicated circuits is to perform masking. This is the process of heating the wafers to coat them in silicon dioxide and then add a hard, protective layer called photoresist.

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 402. Making ICs – Step 3

Replace the switch (62) with the press switch (61) in project #401, then press the press switch (61) and you will see the two LEDs will be turned on and the motor (95) will spin slowly.

The third step in making an IC for a circuit like this or more complicated circuits is to perform etching. Etching is the process of removing the photoresist from step 2 in a specific way to create a blueprint of where p-type areas (areas with an excess of holes) and n-type areas (areas with an excess of electrons) will be placed. The blueprint created is specific to the circuit function desired.

## 403. Making ICs – Step 4

Build the circuit, then turn on the switch (62), you will see the heart LED (69) is on and the star LED (70) is shining too.

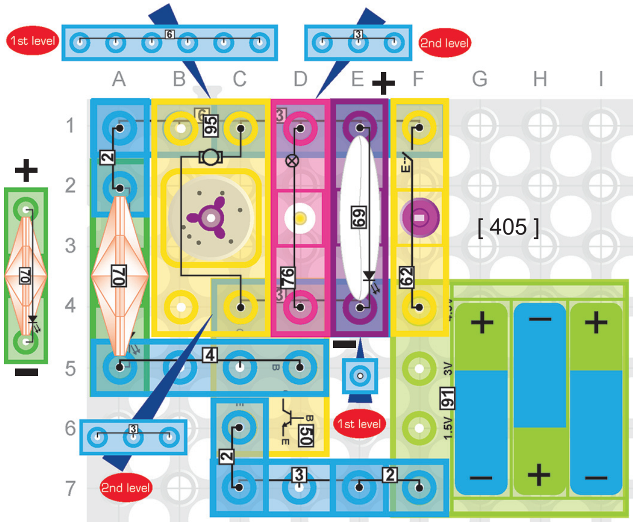
The fourth step in making an IC for a circuit like this or more complicated circuits is to perform doping. Doping is the process of heating the etched wafers with gases containing impurities to physically create the areas of n-type and p-type silicon. Steps 2 through 3 may be repeated a number of times to create layers of silicon for more complex circuits.

## 404. Making ICs – Step 5

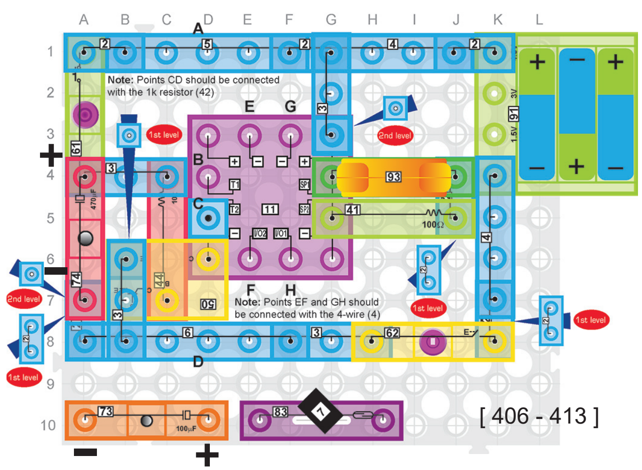
Build the circuit shown on the left. Use a piece of long wire to connect between points A and B (you might need to do this through the bottom where you can insert the wire ends into the pins). Then connect the middle of the wire to something valuable in your room. If anyone takes your valuable, it will pull the wire out of the circuit, the lamp (76) will turn on and a warning will be given by the motor (95) spinning. You caught the burglar!

The fifth step in making an IC for a circuit like this or more complicated circuits is to perform testing. Testing is performed by a computer-controlled machine connected to the chips after step 4 is complete.

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.




## 405. Making ICs – Step 6

Build the circuit to the left, turn on the switch (62) and you will see both LEDs will be on, the motor (95) will spin and also the lamp (76) will be on. The sixth step in making an IC for a circuit like this or more complicated circuits is to perform packaging. All the chips that pass the testing step are cut out of the wafer and packaged as discussed in project #399.

## 406. Siren is Breaking up and Fading Out

Build the circuit shown and turn on the switch (62). Press the press switch (61) for a while and you will hear the siren. Release the press switch (61) and wait for a while. You will eventually hear the siren start breaking up and fading out. This is because the 470μF capacitor (74) in the circuit is initially being charge when you press the press switch (61), and when you release the press switch (61), the charge on the 470μF capacitor (74) continues to power the 3-in-1 (11). But eventually the charge on the 470μF capacitor (74) runs out and the 3-in-1 (11) is not getting enough voltage to operate correctly. This is why you hear the siren breaking up and fading out.

## 407. Potential Energy

Connect points C and D with the 1kΩ resistor (42) in project #406. Press the press switch (61) for a while and you will hear gun shots. Release the press switch (61) and wait for a while. You will eventually hear the gun shots start breaking up and fading out. While Kinetic energy discussed in project #281 is related to an object in motion, potential energy relates to an object at rest in the Earth's gravitational field. If the object were to fall freely it would gain kinetic energy, and this is the potential energy of the object. Mathematically, potential energy is defined as $E_p = m*h*g$ where m is the mass of the object, h is the height of the object, and g is the gravitational acceleration discussed in project #280.

## 408. Joules

Connect points A and B with the 4-wire (4) in project #406. Press the press switch (61) for a while and you will hear the fire siren. Release the press switch (61) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. The Joule is the unit of energy. It is equal to work done on an object when a force of one Newton acts on that object in the direction of its motion through a distance of one meter.

## 409. Power

Connect points E and F with a 4-wire (4) in project #406. Press the press switch (61) for a while and you will hear space battle sounds. Release the press switch (61) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out. Power is the rate of doing work, or the energy transferred per unit of time. Mathematically, Power = Work/Time.

## 410. Watts

Connect points G and H with a 4-wire (4) in project #406. Press the press switch (61) for a while and you will hear music. Release the press switch (61) and wait for a while. You will eventually hear the music start breaking up and fading out. Watts is the unit of measure for power defined as 1 Joule per second.

## 411. Einstein's E = mc²

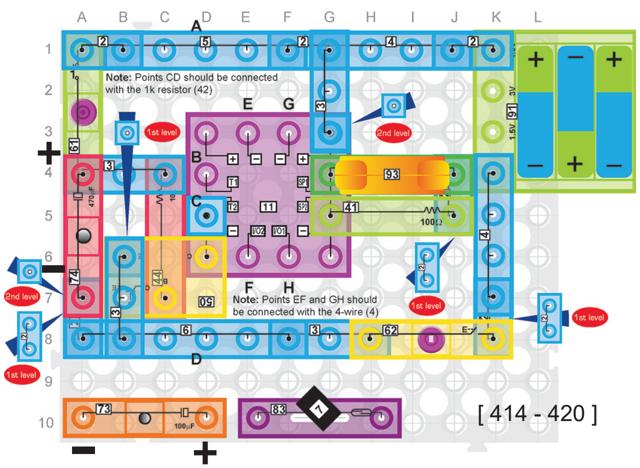
Replace the press switch (61) with the reed switch (83) in project #406. Hold the magnet (7) near the reed switch (83) for a while and you will hear the siren. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the siren start breaking up and fading out. You may have heard of Einstein's formula of $E = mc^2$ where E is Energy, m is mass, and c is the speed of light. This formula states that the Energy and Mass are related, and if the mass of an object were to be completely converted to energy, then the energy it would create would be equal to its mass times the speed of light squared.

## 412. Alessandro Volta

Connect points C and D with the 1kΩ resistor (42) in project #411. Hold the magnet (7) near the reed switch (83) for a while and you will hear gun shots. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the gun shots start breaking up and fading out. Did you know that Alessandro Volta invented the first battery, the voltaic pile, in 1800? The very first circuits used a battery and electrodes immersed in a container of water.

## 413. Transformers

Connect points A and B with the 4-wire (4) in project #411. Hold the magnet (7) near the reed switch (83) for a while and you will hear the fire siren. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. A transformer transfers electrical energy between two or more circuits through electromagnetic induction. Transformers are used to increase or decrease the alternating voltage levels in electric power applications.




[ 414 - 420 ]

## 414. Inductors

Connect points E and F with a 4-wire (4) in project #411. Hold the magnet (7) near the reed switch (83) for a while and you will hear space battle sounds. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out.

An inductor is a passive two-terminal electrical component that stores electrical energy in a magnetic field when electric current flows through it. You can think of an inductor kind of like a capacitor, the main difference being that a capacitor preserves voltage by storing energy in an electric field, while inductors preserve current by storing energy in a magnetic field. An inductor typically consists of an insulated wire wound into a coil around a core.

## 415. The Henry

Connect points G and H with a 4-wire (4) in project #411. Hold the magnet (7) near the reed switch (83) for a while and you will hear music. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the music start breaking up and fading out.

The Henry is the unit of measurement for inductance. One Henry is equal to one kilogram-meter squared per second squared per ampere squared, or $kg*m^2/(s^2*A^2)$.

## 416. Faster Fade Out

Replace the 470µF capacitor (74) with the 100µF capacitor (73) in project #406. Press the press switch (61) for a while and you will hear the siren. Release the press switch (61) and wait for a while. You will eventually hear the siren start breaking up and fading out.

The siren fades out sooner than in project #406 because the capacitance is smaller in the 100µF capacitor (73) in this circuit so it discharges more quickly.

## 417. Monolithic IC

Connect points C and D with the 1kΩ resistor (42) in project #416. Press the press switch (61) for a while and you will hear gun shots. Release the press switch (61) and wait for a while. You will eventually hear the gun shots start breaking up and fading out.

The IC in the 3-in-1 (11) is a monolithic IC, which means all the circuitry for producing the sounds is contained in a single silicon chip.

## 418. Hybrid ICs

Connect points A and B with the 4-wire (4) in project #416. Press the press switch (61) for a while and you will hear the fire siren. Release the press switch (61) and wait for a while. You will eventually hear the fire siren start breaking up and fading out.

More advanced circuits than in your 3-in-1 (11) may require several silicon chips, where the use of a Hybrid IC would incorporate multiple silicon chips into a single package.

## 419. Rectifier

Connect points E and F with a 4-wire (4) in project #416. Press the press switch (61) for a while and you will hear space battle sounds. Release the press switch (61) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out.

If you installed alkaline batteries in your set, you will probably see that they last pretty long. That's because the power draw for most of the circuits you build is not too large, and as long as you don't leave your circuit on for a very long time then the batteries should last a while. But some real-world applications of DC circuits like the ones you built here require the circuit to be on all the time. In this case you would want to be able to plug the circuit into an AC outlet in your house and not worry about batteries. A rectifier converts AC power from your house outlets to DC power just for this purpose.

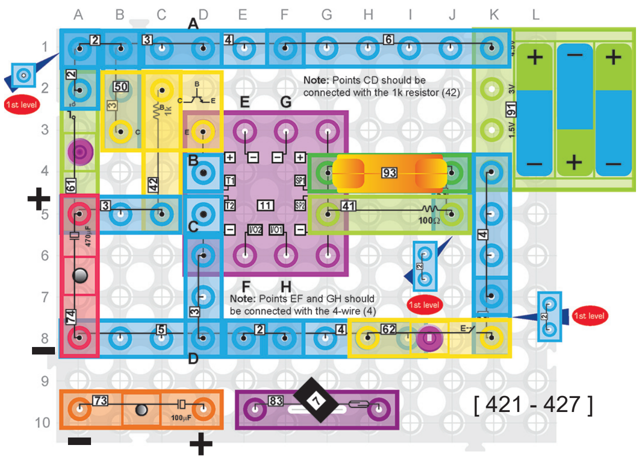
## 420. Sound Waves

Connect points G and H with a 4-wire (4) in project #416. Press the press switch (61) for a while and you will hear music. Release the press switch (61) and wait for a while. You will eventually hear the music start breaking up and fading out.

The speaker (93) makes sound by creating sound waves, much like light waves, but at much longer wavelengths and much lower frequencies. Frequency is the inverse of wavelength (Frequency = 1/Wavelength) and is measured in Hertz (Hz). The human ear can hear sound waves between about 20 Hz and 20 kHz (20,000 Hz).

## 421. Shorter Siren Fade Out

Build the circuit shown and turn on the switch (62). Press the press switch (61) for a while and you will hear the siren in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). Release the press switch (61) and wait for a while. You will eventually hear the siren start breaking up and fading out. Since there is a 1kΩ resistor (42) in this RC circuit, the siren should fade out slightly sooner than in project #406 where a 10kΩ resistor (44) is used because the RC time constant in this circuit is 1/10 the RC time constant of that in project #406.




[ 421 - 427 ]

## 422. Fire Drill Alarm

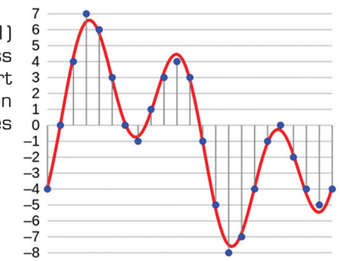
Connect points C and D with the 10kΩ resistor (44) in project #421. Press the press switch (61) for a while and you will hear gun shots in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the gun shots start breaking up and fading out. This type of circuit could be used for fire drill tests where a switch is turned ON to set off the fire alarm for the fire drill and when if fades out and turns OFF then the fire drill is over.

## 423. Pulse Code Modulation

Connect points A and B with the 4-wire (4) in project #421. Press the press switch (61) for a while and you will hear the fire siren in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. As discussed in projects #184 and #187, your 3-in-1 (11) stores samples of the analog sounds that it produces. These samples are converted to a digital bit stream typically through pulse code modulation (PCM). PCM takes samples of the original analog signal amplitude, quantizes them and then converts the quantized amplitudes to a digital bit stream.

## 424. Quantization and Encoding

Connect points E and F with a 4-wire (4) in project #421. Press the press switch (61) for a while and you will hear space battle sounds in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out. The picture to the right shows the process of quantization and encoding of the quantized values to a digital bit steam. Notice how the samples are "quantized" to one of 16 levels.




## 425. Decimal to Binary Conversion

Connect points G and H with a 4-wire (4) in project #421. Press the press switch (61) for a while and you will hear music in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the music start breaking up and fading out. The sample levels in project #424 can be converted to bit sequences of 0s and 1s through decimal to binary conversion. Binary numbers only use 1s and 0s, and thus the numbers 0 through 7 can be represented in binary as shown in the table on the right. Further, the leftmost digit in a binary sequence is also commonly used to show the sign (positive of negative) of the number with a 0 meaning positive and a 1 meaning negative.

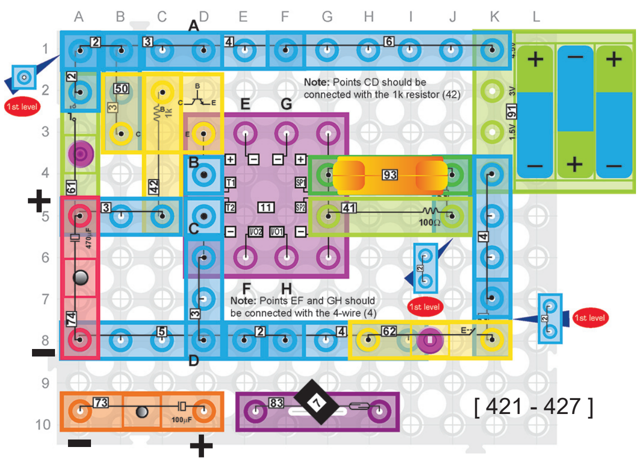
| Decimal | Binary | Decimal | Binary |
|---|---|---|---|
| 7 | 111 | -1 | 1001 |
| 6 | 110 | -2 | 1010 |
| 5 | 101 | -3 | 1011 |
| 4 | 100 | -4 | 1100 |
| 3 | 011 | -5 | 1101 |
| 2 | 010 | -6 | 1110 |
| 1 | 001 | -7 | 1111 |
| 0 | 000 | -8 | 1000 |

## 426. ADC Converter

Replace the press switch (61) with the reed switch (83) in project #421. Hold the magnet (7) near the reed switch (83) for a while and you will hear the siren in soft volume. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the siren start breaking up and fading out. An Analog to Digital Converter (ADC) is a system that performs the processes of sampling, quantization and encoding to convert and analog signal to a digital bit stream.

## 427. DAC Converter

Connect points C and D with the 10kΩ resistor (44) in project #426. Hold the magnet (7) near the reed switch (83) for a while and you will hear gun shots in soft volume. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the gun shots start breaking up and fading out. A Digital to Analog Converter (DAC) is a system that performs the process of interpolating and filtering of the digital samples to recreate the analog signal.



[ 421 - 427 ]

## 428. Quantization Error
Connect points A and B with the 4-wire (4) in project #426. Hold the magnet (7) near the reed switch (83) for a while and you will hear the fire siren in soft volume. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. Looking back at the figure in project #424, it can be seen that the samples don't always line up exactly with a level and thus the closest level for each sample is chosen to represent the quantized version of that sample. The difference between the actual sample value and its quantized approximation is the quantization error.

## 429. Digital Signal Processing
Connect points E and F with a 4-wire (4) in project #426. Hold the magnet (7) near the reed switch (83) for a while and you will hear space battle sounds in soft volume. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out. Digital Signal Processing consists of the process of performing ADC, processing the digital bit stream in some way and then returning the signal to analog through DAC. This could be done, for instance, on music signals (like the ones stored in the 3-in-1 (11)) to improve the sound of the music. This can help account for quantization errors.

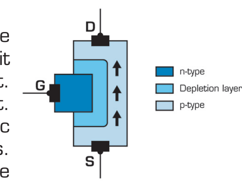
## 430. Adaptive Pulse Code Modulation
Connect points G and H with a 4-wire (4) in project #426. Hold the magnet (7) near the reed switch (83) for a while and you will hear music in soft volume. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the music start breaking up and fading out. In order to reduce the quantization error in the ADC process, Adaptive Pulse Code Modulations (ADPC) can be used where the quantization level is not fixed but varies. This way, for the same number of levels, more levels can be placed where the analog signal resides the majority of the time and fewer levels can be place where the analog signal only briefly resides. This reduces the quantization error because more quantization levels spaced closer together are used where the analog signal resides the majority of the time.

## 431. Even Shorter Siren Fade Out
Replace the 470μF capacitor (74) with the 100μF capacitor (73) in project #421. Press the press switch (61) for a while and you will hear the siren in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the siren start breaking up and fading out. Since there is a 100μF capacitor (73) in this RC circuit, the siren should fade out sooner than in project #421 where a 470μF capacitor (74) is used because the RC time constant in this circuit is about 1/5 the RC time constant of that in project #421.

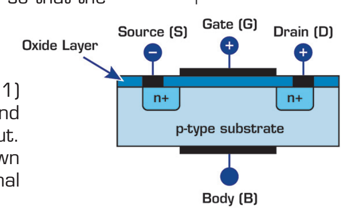
## 432. BJT and FET
Connect points C and D with the 10kΩ resistor (44) in project #431. Press the press switch (61) for a while and you will hear gun shots in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the gun shots start breaking up and fading out. There are two types of transistors: Bi-polar Junction Transistors (BJT) like the ones discussed in project #308, and Field Effect Transistors (FET).

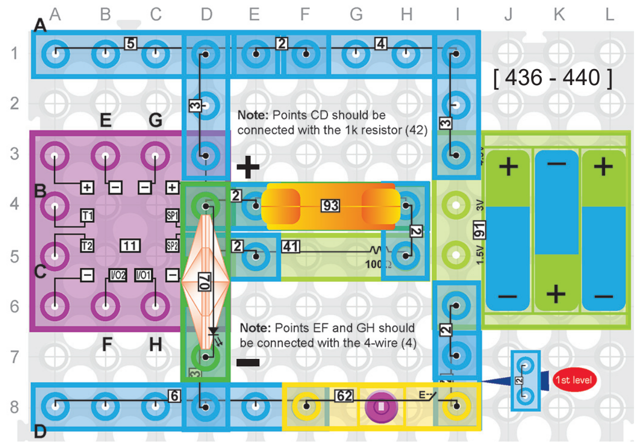
## 433. FETs
Connect points A and B with the 4-wire (4) in project #431. Press the press switch (61) for a while and you will hear the fire siren in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. FET is a type of transistor where the current is controlled by electric fields. FET transistors consist of three terminals: source, drain and gate. Holes or electrons flow from the source terminal to drain terminal via an active channel, and the flow of holes or electrons can be controlled by the voltage applied across the source and gate terminals. There are two main types of FET transistors: JFET and MOSFET.

## 434. JFET
Connect points E and F with a 4-wire (4) in project #431. Press the press switch (61) for a while and you will hear space battle sounds in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading out. The makeup of a p-type Junction Field Effect Transistor (JFET) is shown in the figure to the right. Unlike BJTs, JFETs are exclusively voltage-controlled. They do not need a biasing current. Electric charge nominally flows through a semiconducting channel between source and drain terminals. Then, applying a reverse bias voltage to the gate terminal, the channel is squeezed so that the electric current is reduced or blocked completely.




## 435. MOSFET
Connect points G and H with a 4-wire (4) in project #431. Press the press switch (61) for a while and you will hear music in soft volume. Release the press switch (61) and wait for a while. You will eventually hear the music start breaking up and fading out. The makeup of a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is shown in the figure to the right. MOSFET's operate the same as JFET's but the gate terminal is electrically isolated from the conductive channel by the oxide layer.






## 436. Low Volume Siren

Build the circuit to the left, turn on the switch (62) and you will hear a low volume siren and the star LED (70) will be flashing quickly. Turn off the switch (62) and the siren will go off. In this circuit, the speaker (93) is in series with the 100Ω resistor (41). The 100Ω resistor (41) limits the current through the speaker which is why the volume is lower.

## 437. Lower Volume Machine Gun

Replace the 100Ω resistor (41) with the 1kΩ resistor (42) and connect points C and D with the 100Ω resistor (41) in project #436. Turn on the switch (62) and you will hear lower volume gun shots and machine gun sounds and the star LED (70) will be flashing quickly. Turn off the switch (62) and the sounds will go off. The 1kΩ resistor (42) limits the current more than the 100Ω resistor (41) which is why the volume is lower in this project than in project #436.

## 438. Visual and Audio Alarm

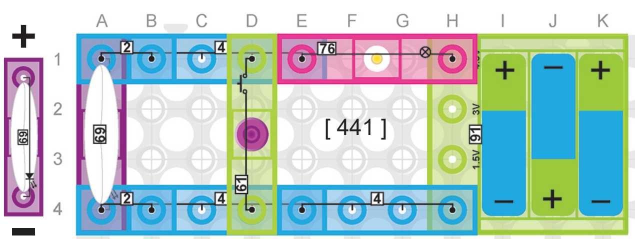
Replace the star LED (70) with the heart LED (69) and connect points A and B with a 4-wire (4) in project #436. Turn on the switch (62) and you will hear a low volume fire siren and the heart LED (69) will be flashing quickly. Turn off the switch (62) and the sounds will go off. This type of circuit could be used to provide both an audio alarm and a visual alarm in case the room was too loud to hear the audio alarm.

## 439. Barely Audible Space Battle Sounds

Replace the 100Ω resistor (41) with the 10kΩ resistor (44) and connect points E and F with a 4-wire (4) in project #436. Turn on the switch (62) and you will barely be able to hear space battle sounds and the star LED (70) will be flashing quickly. Turn off the switch (62) and the sounds will go off. The 10kΩ resistor (44) limits the current more than the 1kΩ resistor (42) which is why you can barely hear the space battle sounds in this project.

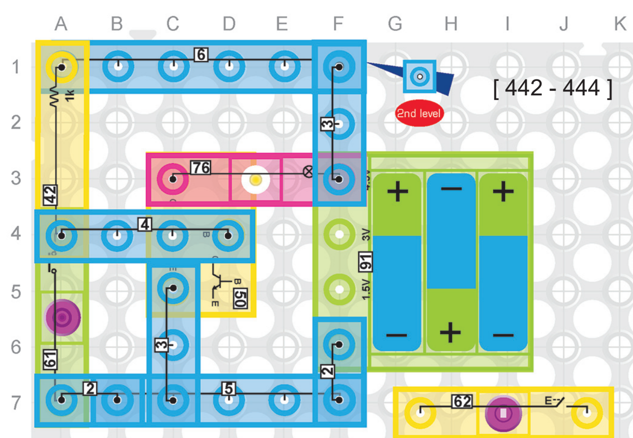
## 440. Can You Hear Music?

Replace the 100Ω resistor (41) with the 100kΩ resistor (45) and Connect points G and H with a 4-wire (4) in project #436. Turn on the switch (62). The star LED (70) will be flashing with the music, but can you hear music? Hold your ear very close to the speaker and see if you can hear the music. Turn off the switch (62) and the music will go off. 100kΩ is a lot of resistance which is why you really have to have a good ear close to the speaker to hear the music in this circuit.




## 441. NOT Gate

Build the circuit shown on the left. The lamp (76) is off, but if you press the press switch (61), the lamp (76) will turn on. Note that the heart LED (69) is on when the press switch (61) is off and the heart LED (69) is off when the press switch (61) is on. This was discussed as a NOT Gate in project #160, and this circuit now demonstrates how NOT Gate logic works.



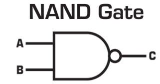

## 442. NOT-Gate Application

Build the circuit shown on the left. Note that the lamp (76) is on when the press switch (61) is off and the lamp (76) is off when the press switch (61) is on. You might have a circuit like this in your car, where the light in your car stays on while the door is open, but when you close the door it's like pressing the press switch (61) and the light goes out.

## 443. NAND Gate

Build the circuit from project #442 but add the switch (62) in series with the press switch (61). Note that the lamp (76) is always on unless both the switch (62) and the press switch (61) are on. This describes a Not-AND-Gate or NAND Gate. The symbol and logic diagram for the NAND gate are shown to the right. A circle at the right end of the AND gate symbol represents a "NOT" function, so you can think of the NAND gate as an AND gate followed by a NOT gate.

NAND Gate

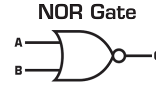



| Inputs | | Output |
|---|---|---|
| A | B | C |
| OFF | OFF | ON |
| OFF | ON | ON |
| ON | OFF | ON |
| ON | ON | OFF |

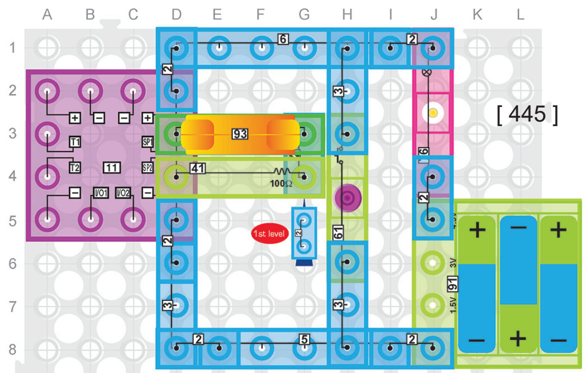
## 444. NOR Gate

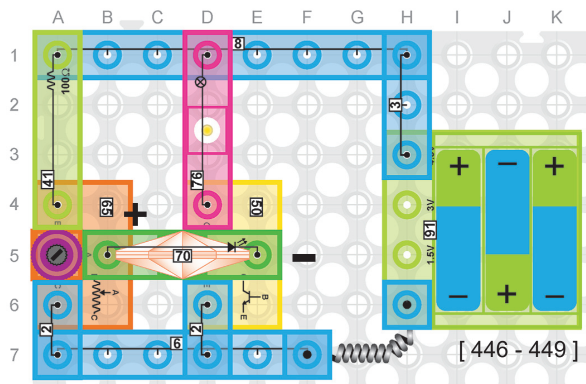
Build the circuit from project #442 but add the switch (62) in parallel with the press switch (61). Note that the lamp (76) is ON unless either the switch (62) or the press switch (61) are on. This describes a Not-OR-Gate or NOR Gate. The symbol and logic diagram for the NOR gate are shown to the right. A circle at the right end of the OR gate symbol represents a "NOT" function, so you can think of the NOR gate as an OR gate followed by a NOT gate.

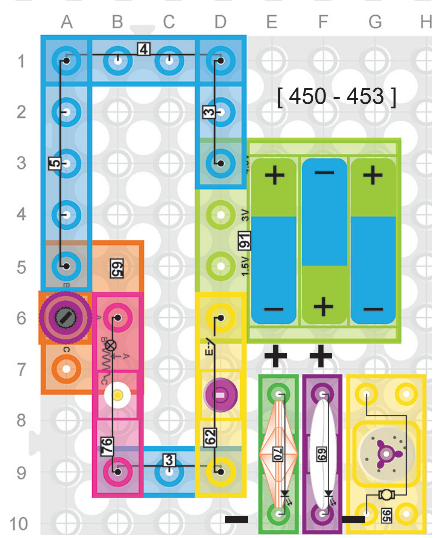
NOR Gate




| Inputs | | Output |
|---|---|---|
| A | B | C |
| OFF | OFF | ON |
| OFF | ON | OFF |
| ON | OFF | OFF |
| ON | ON | OFF |




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 445. More NOT-Gate Applications
Build the circuit to the left. The lamp (76) is off and you will hear the sounds of a siren. Press the press switch (61) and the lamp (76) will turn ON and the siren will go OFF. This type of circuit could act like a mute button for the sound on your TV where the lamp (76) indicates that the TV is muted.

## 446. Potentiometer
Build the circuit shown on the left. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) and lamp (76) will light. The variable resistor (65) varies the amount of resistance between the points marked A, B and C on the variable resistor (65). As you turn the knob clockwise, the resistance between points A and B is increased while the resistance between points A and C is decreased. Similarly, when the knob is turned counter-clockwise the resistance between points A and B is decreased and the resistance between points A and C is increased. This type of device is called a potentiometer because it essentially acts as a voltage divider. As you turn the knob counter-clockwise, eventually there is enough voltage at point A to turn on the NPN transistor (50) and enable enough current to flow to light the star LED (70) and lamp (76).

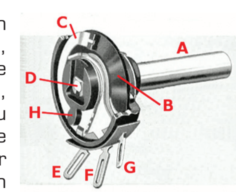
## 447. Variable Current
Replace the star LED (70) with the heart LED (69) in project #446. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) and heart LED (69) will light. The variable resistor (65) in this circuit varies the amount of resistance between the points marked A and B on the variable resistor (65). As you turn the knob counter-clockwise the resistance between points A and B is decreased, which increases the amount of current that flows through the base of the NPN transistor (50). As the current through the base of NPN the transistor (50) increases, the current from collector to emitter of the NPN transistor (50) increases which is why the heart LED (69) and lamp (76) get brighter the more you turn the knob counter-clockwise.

## 448. Variable Motor Speed
Replace the lamp (76) with the motor (95) in project #446. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will start to spin and the star LED (70) will light. This circuit could be used to adjust the speed of the ceiling fan in your house.

## 449. Light Dimmer
Replace the star LED (70) with the heart LED (69) in project #448. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light and the motor (95) will spin. This circuit could be used to dim the lights in your house.

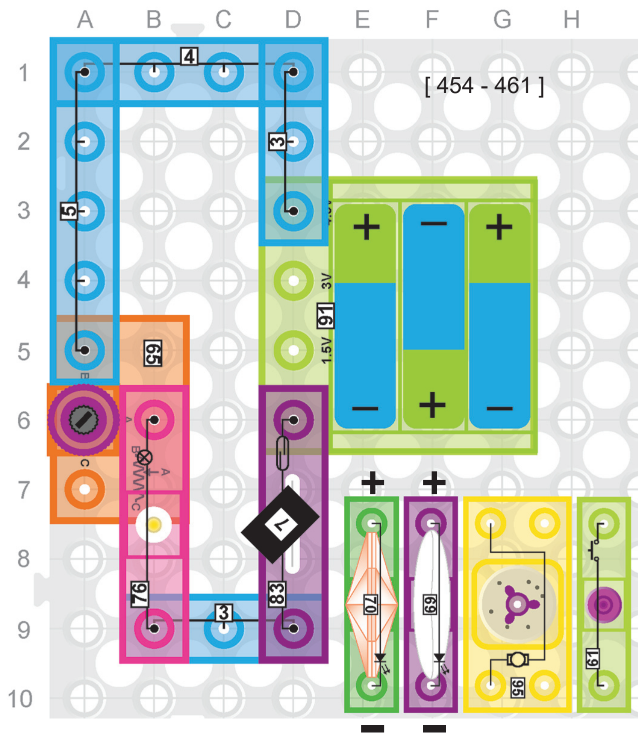
## 450. Variable Resistor
Build the circuit shown on the left and turn on the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light. When the variable resistor (65) uses only two terminals (terminals A and B or terminals A and C), then it's truly being used as a variable resistor rather than a potentiometer like in the previous four projects.

## 451. Variable Resistor Design
Replace the lamp (76) with the star LED (70) in project #450 and turn on the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) will light. The figure on the right shows a picture of how the variable resistor (65), or potentiometer, is designed. Points F, E and G are the terminals as marked A, B and C respectively on the variable resistor (65). A in the figure is the shaft that turns as you turn the knob. B in the figure is a resistive element. C in the figure is a wiper that rides along the resistive element. D is where the shaft attaches to the wiper. So as you turn the knob, the wiper moves to different points along the resistive element which changes the resistance between points E & F and points F & G.




## 452. Materials Used for Resistive Element
Replace the lamp (76) with the heart LED (69) and turn on the switch (62) in project #450. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light. Various materials can be used as the resistive element in a variable resistor or potentiometer including cermet, conductive plastic and carbon composition. Alternatively, variable resistors or potentiometers can be wirewound.

## 453. Mechanical Types of Potentiometers
Replace the lamp (76) with the motor (95) and turn on the switch (62) in project #450. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin. There are two main mechanical types of potentiometers, one is the rotary type like the variable resistor (65). The other type is a slide potentiometer where you where you slide a lever in a straight line to adjust the resistance.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 454. TV Applications of Potentiometers

Build the circuit shown on the left. Place the magnet (7) near the reed switch (83). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light. In the early days of TV, potentiometers were often used to adjust volume, brightness, contrast and other TV settings.

## 455. Transducers

Replace the lamp (76) with the star LED (70) in project #454 and place the magnet (7) near the reed switch (83). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) will light. Another very important application of potentiometers is for measurement purposes. A potentiometer could be used to convert displacement (i.e. movement of the rotary knob or slide bar) to an electrical signal that is proportional to the amount of displacement (both linear displacement or rotational displacement). Devices that convert this type of mechanical energy to electrical energy are generally called transducers.

## 456. Potentiometer Symbol

Replace the lamp (76) with the heart LED (69) and place the magnet (7) near the reed switch (83) in project #454. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light. On the right is the symbol generally used for potentiometers.

## 457. Adjustable vs. Preset Potentiometers

Replace the lamp (76) with the motor (95) and place the magnet (7) near the reed switch (83) in project #454. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin. Another factor that distinguishes different types of potentiometers is whether they are adjustable or preset. Adjustable potentiometers are like the ones discussed in project #451, while preset potentiometers are used for design purposes in equipment. Normally preset potentiometers are not accessible by the end user of the equipment but used to “tune” the equipment for optimal performance by the manufacturer of the equipment.

## 458. Linear vs. Logarithmic Potentiometers

Replace the reed switch (83) with the press switch (61) in project #454. Press and hold the press switch (61). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light. Although most potentiometers are linear, some follow a logarithmic law. This can provide a much larger dynamic range for the variable resistance. Also, the ear is non-linear, and thus a logarithmic scale on the potentiometer can provide a more graceful change in volume as perceived by the ear as you adjust the knob on the potentiometer.

## 459. Digital Potentiometer

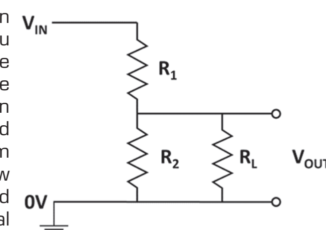
Replace the lamp (76) with the star LED (70) in project #458 and press and hold the press switch (61). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) will light. A digital potentiometer is an electronic component that simulates an analog potentiometer. Instead of the design discussed in project #451, a digital potentiometer varies the resistance between two terminals digitally. Digital Potentiometers have the advantage of being able to be electronically secure so that only authorized personnel can make adjustments.

## 460. Voltage Divider Circuit

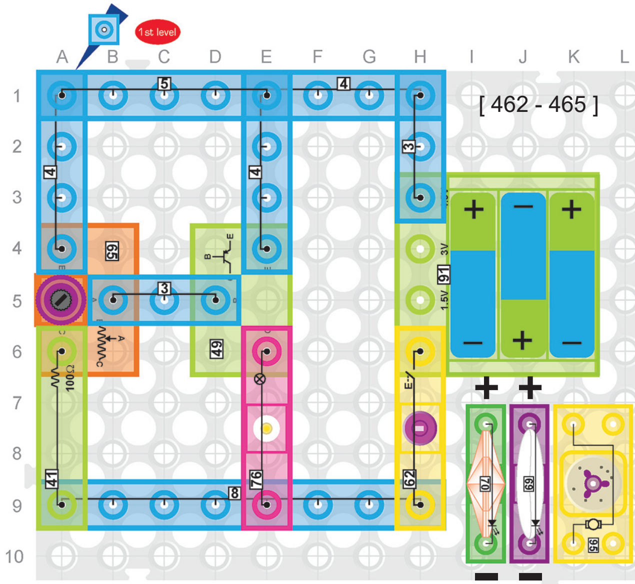
Replace the lamp (76) with the heart LED (69) and press and hold the press switch (61) in project #458. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light. Recall the voltage divider circuit from project #58. The output voltage of this circuit would be the same as what you would see on the center tap (point A on the variable resistor (65)) of a potentiometer assuming a very high impedance load was connected to the center tap. Through Ohm’s law, we know that the current through this circuit is $V_{IN}/(R_1 + R_2)$. Since $R_1$ and $R_2$ are in series, Ohm’s law can again be applied to see that the output voltage is $V_{OUT} = R_2 * V_{IN}/(R_1 + R_2)$.

## 461. Output Voltage of Potentiometer

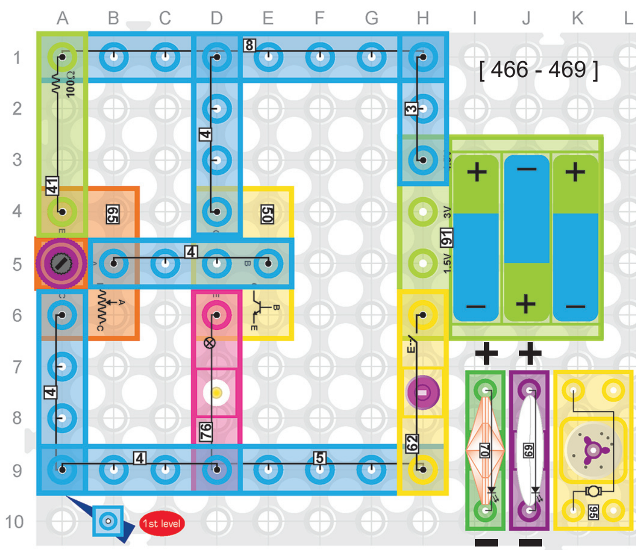
Replace the lamp (76) with the motor (95) and press and hold the press switch (61) in project #458. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin. To calculate the voltage output from a potentiometer, consider the diagram below where $R_1$ is the resistance between points A and B on your variable resistor (65), R2 is the resistance between points A and C on your variable resistor (65) and $R_L$ is the resistance of the load connected to the center tap (point A) on you variable resistor (65). We know from project #91 that equivalent resistance of $R_2$ and $R_L$ in parallel is $R_2 * R_L/(R_2 + R_L)$. Now from the previous project, we can substitute this equivalent resistance for $R_2$ and get that the output voltage from the potentiometer connected to a load with general resistance of $R_L$ is:




$$V_{OUT} = [R_2 * R_L/(R_2+R_L)] * V_{IN}/[R1+R_2 * R_L/(R_2+R_L)]$$
$$\text{or } V_{OUT} = [R_2 * R_L] * V_{IN}/[R_1 * (R_2+R_L) + R_2 * R_L]$$
$$\text{or } V_{OUT} = V_{IN} * R_2 * R_L/[R_1 * R_2 + R1 * R_L + R_2 * R_L]$$




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



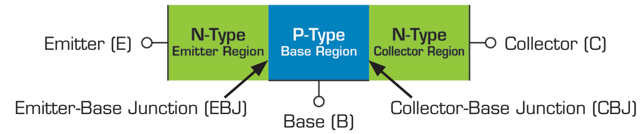

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 462. PNP Transistor – a Current Switch

Build the circuit to the left. Press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the lamp (76) will light. Transistors can be thought of as switches where, in the case of the PNP transistor (49), a current flowing out of the base (labeled with a "B" on the PNP transistor (49)) enables current to flow from the emitter (labeled "E" on the PNP transistor (49)) to the collector (labeled "C" on the PNP transistor (49)).

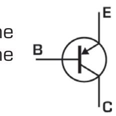
## 463. PNP Transistor Basics

Replace the lamp (76) with the star LED (70) in project #462 and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the star LED (70) will light. The PNP transistor (49) is built by stacking three different layers of semiconductor material together. Two layers have electrons removed from them (doped with "holes' – the absence of electrons) and are called P-type layers, while one layer is doped with an excess of electrons and is called the N-type layer. This is shown in the diagram below. Roughly speaking, the PNP transistor (49) is designed so that conventional current can easily flow from the Emitter region (P-type) to the Base region (N-type) when the Base is at a low enough voltage below the Emitter. Once current begins flowing from Emitter to Base, then it becomes much easier for current to flow from the Emitter to the Collector.




## 464. Symbol for PNP Transistor

Replace the lamp (76) with the heart LED (69) and press the switch (62) in project #462. Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the heart LED (69) will light. The symbol for a PNP transistor (49) is shown on the right.




## 465. Turning on the PNP Transistor

Replace the lamp (76) with the motor (95) and press the switch (62) in project #462. Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the motor (95) will spin. Recall from project #446 that turning the knob of the variable resistor (65) clockwise increases the resistance between points A and B on the variable resistor (65). This lowers the voltage at the base of the PNP transistor (49). Once the voltage of the base is low enough (approximately 0.6V below the emitter voltage), the PNP transistor (49) will "turn on" and allow current to flow from emitter to collector.

## 466. Turning on the NPN Transistor

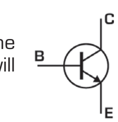
Build the circuit shown. Press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light. The NPN transistor (50) was discussed in projects #306 and #308. Recall from project #446 that turning the knob of the variable resistor (65) counter-clockwise increases the resistance between points A and C on the variable resistor (65). This raises the voltage at the base of the NPN transistor (50). Once the voltage of the base is high enough (approximately 0.6V above the emitter voltage), the NPN transistor (50) will "turn on" and allow current to flow from collector to emitter.

## 467. NPN vs. PNP Transistor

Replace the lamp (76) with the star LED (70) in project #466 and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) will light. The main difference between NPN and PNP transistors are the direction of current flow and the voltage biasing at the base that turns on the transistor. For an NPN transistor (50), a high enough voltage at the base which enables a small current to flow into the base leads to a large current flow from collector to emitter. For a PNP transistor (49), a low enough voltage at the base which enables a small current to flow out of the base leads to a large current flow from emitter to collector.

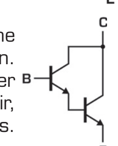
## 468. Symbol for NPN Transistor

Replace the lamp (76) with the heart LED (69) and press the switch (62) in project #466. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light. The symbol for a NPN transistor (50) is shown on the right.




## 469. Darlington NPN Transistor

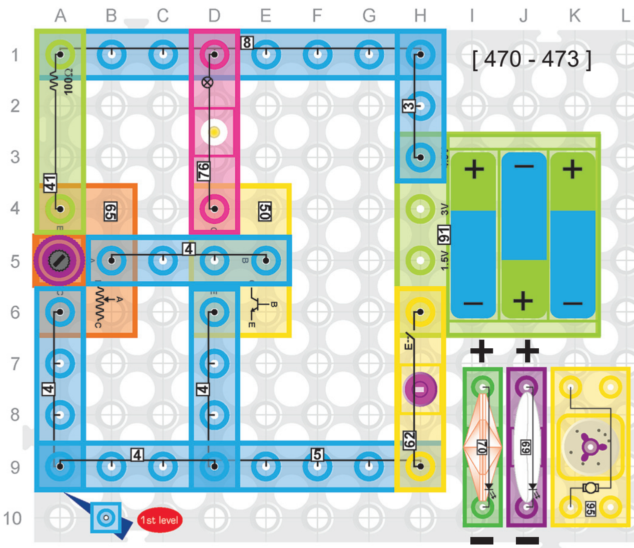
Replace the lamp (76) with the motor (95) and press the switch (62) in project #466. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin. The gain of the NPN transistor (50) was discussed in project #343. Sometimes it's desirable to have even higher gain than a single transistor can provide. The Darlington transistor, or sometimes called the Darlington pair, uses two transistors to increase the gain. The figure on the right shows a Darlington pair using NPN transistors.



## 470. Load on Collector of NPN Transistor

Build the circuit shown on the left and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light.

The main difference in this project compared to the previous four projects is that here the load (the lamp (76)) is on the collector rather than the emitter. With the load on the collector and no load on the emitter, the base voltage consistently just needs to be approximately 0.6V to turn on the transistor. When the load was on the emitter, the voltage you need at the base to turn on the transistor depends on the voltage across the load (plus 0.6V). This is less predictable so often times you will see the load on the collector.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 471. Gain of Darlington NPN Transistor

Replace the lamp (76) with the star LED (70) in project #470 and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the star LED (70) will light.

Project #469 introduced the Darlington transistor as a way to increase gain. The gain of a transistor was defined in project #343 to be the collector current divided by the base current. Based on the figure below, we can consider the base of NPN transistor 1 on the left to be the base of the Darlington transistor, the emitter of transistor 2 on the right to be the emitter of the Darlington transistor, and the input to the junction between the two transistor collectors to be the collector of the Darlington transistor.

To calculate the gain of the Darlington transistor we need to calculate $\beta = I_C/I_B$. From the diagram, $I_C = I_{C1} + I_{C2}$. So,

$$\beta = I_C/I_B = (I_{C1} + I_{C2})/I_B = I_{C1}/I_B + I_{C2}/I_B = \beta_1 + I_{C2}/I_B$$

since the gain of the first transistor is $\beta_1 = I_{C1}/I_B$.

Now we also know that the gain of the second transistor is $\beta_2 = I_{C2}/I_{B2}$, which means $I_{C2} = \beta_2 * I_{B2}$. Substituting for $I_{C2}$ we get that

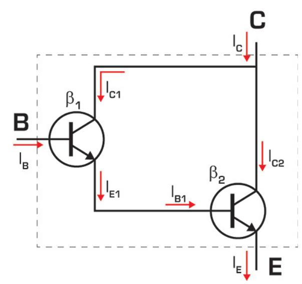
$$\beta = \beta_1 + I_{C2}/I_B = \beta_1 + \beta_2 * I_{B2}/I_B = \beta_1 + \beta_2 * I_{E1}/I_B = \beta_1 + \beta_2 * (I_{C1} + I_B)/I_B$$

since $I_{C1} + I_B = I_{E1}$.

This simplifies to

$$\beta = \beta_1 + \beta_2 * (I_{C1} + I_B)/I_B = \beta_1 + \beta_2 * I_{C1}/I_B + \beta_2 * I_B/I_B = \beta_1 + \beta_2 * \beta_1 + \beta_2$$

So the gain of the Darlington transistor is the product of the gains plus the sum of the gains of the two transistors that make up the Darlington transistor.




## 472. Approximation for Gain of Darlington Transistor

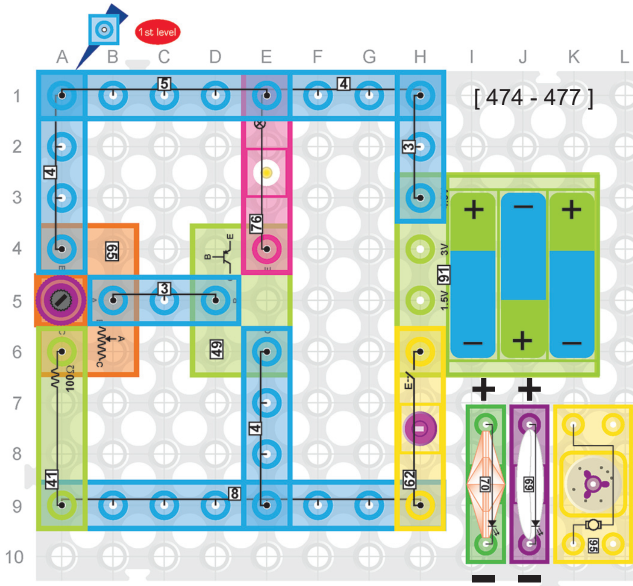
Replace the lamp (76) with the heart LED (69) and press the switch (62) in project #470. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the heart LED (69) will light.

If the gains of the individual transistors in the Darlington transistor are both very high, then $\beta_2 * \beta_1 >> \beta_1$ and $\beta_2 * \beta_1 >> \beta_2$. Thus, the gain of the Darlington transistor is often approximated as simply the product of the gains of the two transistors that make up the Darlington transistor (i.e. $\beta_1 + \beta_2 * \beta_1 + \beta_2 \cong \beta_2 * \beta_1$).

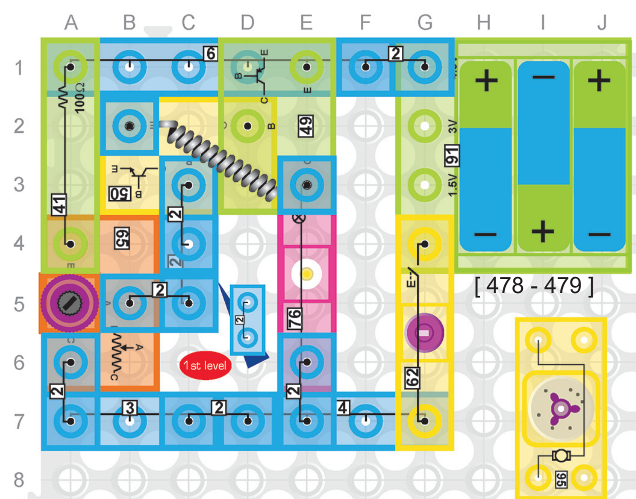
## 473. Disadvantage of Darlington Transistor

Replace the lamp (76) with the motor (95) and press the switch (62) in project #470. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin.

While the clear benefit of the Darlington transistor is much higher gain, one of the disadvantages of the Darlington transistor is it's turn on voltage. Per the diagram in project #471, both transistors must be on to get the full gain of $\beta_1 + \beta_2 + \beta_2 * \beta_1$. Since each transistor requires about 0.6V to turn on, this means that the voltage between base and emitter of the Darlington transistor must be about 1.2V to turn on.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



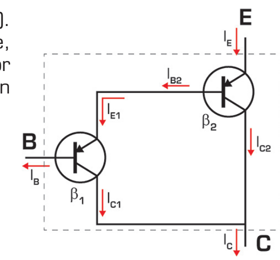

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 474. Load on Emitter of PNP Transistor

Build the circuit shown on the left and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the lamp (76) will light. The main difference in this project compared to the project #462 is that here the load (the lamp (76)) is on the emitter rather than the collector. With the load on the emitter and no load on the collector, the voltage that you need at the base to turn on the transistor depends on the voltage across the load. This is less predictable than when the load is on the collector and you consistently just need to be approximately 0.6V below the emitter voltage to turn on the transistor. So often times you will see the load on the collector.

## 475. Darlington PNP Transistor

Replace the lamp (76) with the star LED (70) in project #474 and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the star LED (70) will light. Project #469 introduced the Darlington transistor as a way to increase gain. On the right is the figure for a PNP version of the Darlington transistor.




## 476. Gain of Darlington PNP Transistor

Replace the lamp (76) with the heart LED (69) and press the switch (62) in project #474. Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the heart LED (69) will light. The gain of a transistor was defined in project #343 to be the collector current divided by the base current. Based on the figure from project #475, we can consider the base of PNP transistor 1 on the left to be the base of the Darlington transistor, the emitter of transistor 2 on the right to be the emitter of the Darlington transistor, and the output from the junction between the two transistor collectors to be the collector of the Darlington transistor. You can calculate the gain of the PNP version of the Darlington transistor the exact same way it was done for the NPN version in project #471 and get the exact same result:

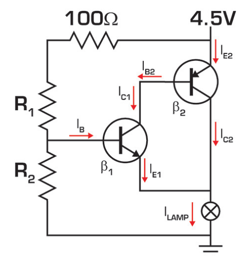
$$\beta = \beta_1 + \beta_2 + \beta_1 * \beta_2.$$

## 477. Applications of Darlington Transistor

Replace the lamp (76) with the motor (95) and press the switch (62) in project #474. Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the motor (95) will spin. Darlington transistors can be very sensitive, enough so that even low currents that can be passed by your skin on contact can turn them on. For this reason, Darlington transistors are sometimes used in touch-sensitive switches.

## 478. 2-stage NPN and PNP Transistor Circuit

Build the circuit shown and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the lamp (76) will light.The diagram for this circuit is shown to the right. As you turn the variable resistor (65) knob counter-clockwise, the resistance $R_2$ is increasing and $R_1$ decreasing which increases the voltage to the base of the NPN transistor (50). Once the voltage at the base of the NPN transistor (50) is enough to turn on the NPN transistor (50) (0.6V plus the voltage across the lamp (76)), then current will start to flow from the collector to the emitter of the NPN transistor (50), which in turn leads to current flowing out of the base of the PNP transistor (49), which then turns on the PNP transistor (49) enabling current to flow from the emitter to collector of the PNP transistor (49), which then lights the lamp (76).




## 479. Gain of 2-stage NPN and PNP Transistor Circuit (I)

Replace the lamp (76) with the motor (95) and press the switch (62) in project #478. Turn the knob on the variable resistor (65) and you will see that as you turn it counter-clockwise, eventually the motor (95) will spin. To calculate the gain of the circuit in this project we need to calculate $\beta = I_{Lamp}/I_B$ from the figure in project #478.

From the diagram, $I_{Lamp} = I_{E1} + I_{C2}$. So,

$$\beta = I_{Lamp}/I_B = (I_{E1} + I_{C2})/I_B = I_{E1}/I_B + I_{C2}/I_B = (I_{C1} + I_B)/I_B + I_{C2}/I_B = 1 + (I_{C1} + I_{C2})/I_B$$

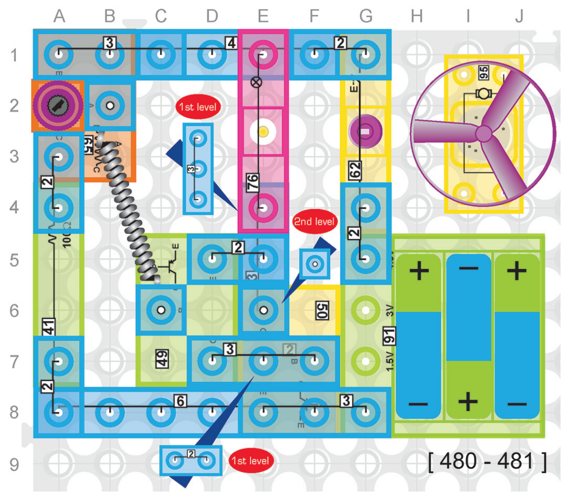
Now we also know that the gain of the second transistor is $\beta_2 = I_{C2}/I_{B2}$, which means $I_{C2} = \beta_2 * I_{B2}$.

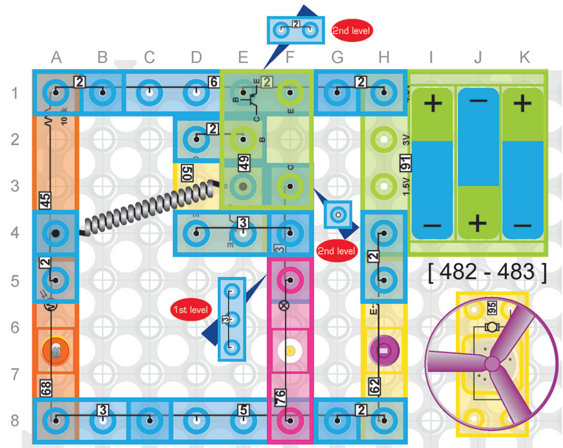
Substituting for $I_{C2}$ we get that $\beta = 1 + (I_{C1} + \beta_2 * I_{B2})/I_B$.

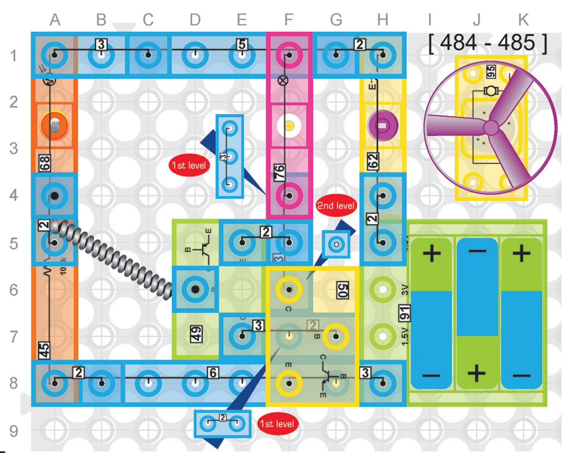
But $I_{C1} = I_{B2}$ so, $\beta = 1 + (1 + \beta_2) * I_{C1}/I_B$. Now, $I_{C1} = \beta_1 * I_B$ so,

$$\beta = 1 + (1 + \beta_2) * \beta_1 * I_B/I_B = 1 + \beta_1 + \beta_1 * \beta_2$$

So again, assuming the transistor gains are high, the gain of this circuit is approximately equal to the product of the gains of the NPN and PNP transistors.



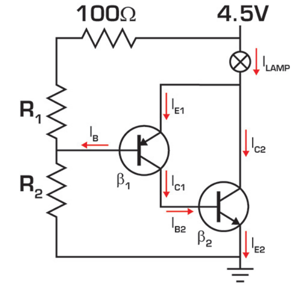




## 480. 2-stage NPN and PNP Transistor Circuit (II)

Build the circuit shown and press the switch (62). Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the lamp (76) will light. The diagram for this circuit is shown below. As you turn the variable resistor (65) knob clockwise, the resistance R1 is increasing and R2 decreasing which decreases the voltage to the base of the PNP transistor (49). Once the voltage at the base of the PNP transistor (49) is low enough to turn on the PNP transistor (49) (0.6V plus the voltage across the lamp (76) below 4.5V), then current will start to flow from the emitter to the collector of the PNP transistor (49), which in turn leads to current flowing into the base of the NPN transistor (50), which then turns on the NPN transistor (50) enabling current to flow from the collector to emitter of the NPN transistor (50), which then lights the lamp (76).

**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.




## 481. Gain of 2-stage NPN and PNP Transistor Circuit (II)

Replace the lamp (76) with the motor (95) and press the switch (62) in project #480. Turn the knob on the variable resistor (65) and you will see that as you turn it clockwise, eventually the motor (95) will spin. You can calculate the gain of this circuit the exact same way it was done for project #479 and get the exact same result:

$$\beta = 1 + \beta_1 + \beta_1 * \beta_2.$$

## 482. Optimized Street Lights

Build the circuit shown on the left and turn on the switch (62). While light shines on the photoresistor (68), the lamp (76) will be off but as the light that shines on the photoresistor (68) dims, the lamp (76) will start to get bright.

This circuit could be an optimized way of turning street lights on when it gets dark because it's like project #321, but here the street lights would fade in and out more gracefully as the sun goes down at night and comes back up during the day.

## 483. Motor controlled by Light Sensor

Replace the lamp (76) with the motor (95) in the previous project and turn on the switch (62). While light shines on the photoresistor (68), the motor (95) will be off because there is very low resistance through the photoresistor (68) which leads to a voltage at the base of the NPN transistor (50) that is too low to turn on the NPN transistor (50). When the photoresistor (68) is made dark, then the resistance of the photoresistor (68) increases, increasing the voltage level seen by the base of the NPN transistor (50). This turns on the NPN transistor (50), which then turns on the PNP transistor (49) allowing current to flow through the motor (95) from the collector of the PNP transistor (49) which is why the motor (95) spins.

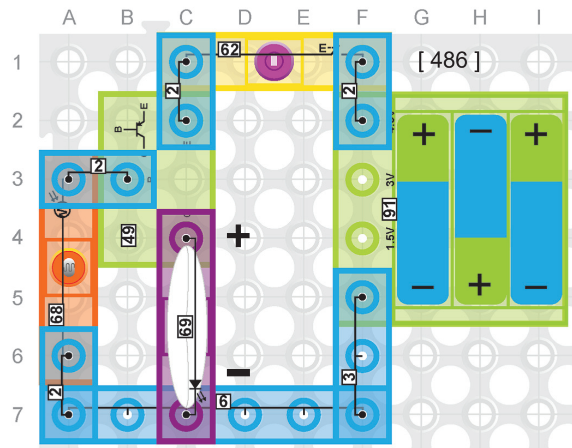
## 484. Phototransistor

Build the circuit shown and turn on the switch (62). While light shines on the photoresistor (68), the lamp (76) will be off but as the light that shines on the photoresistor (68) dims, the lamp (76) will start to get bright. This circuit represents the function of a phototransistor.

## 485. Motor controlled by Light Sensor

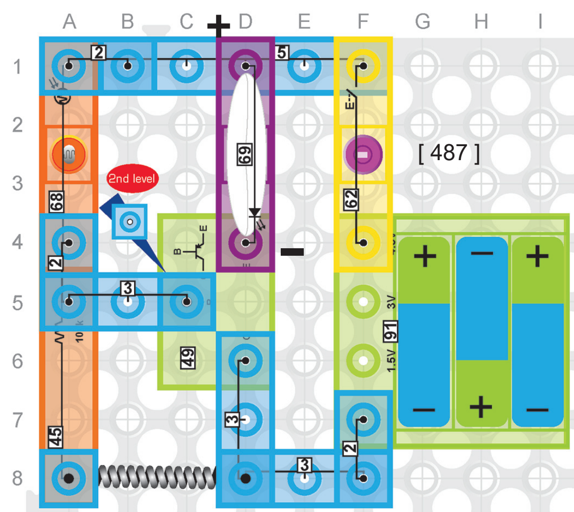
Replace the lamp (76) with the motor (95) in the previous project and turn on the switch (62). While light shines on the photoresistor (68), the motor (95) will be off because there is very low resistance through the photoresistor (68) which leads to a voltage at the base of the PNP transistor (49) that is too high to turn on the PNP transistor (49). When the photoresistor (68) is made dark, then the resistance of the photoresistor (68) increases, decreasing the voltage level seen by the base of the PNP transistor (49). This turns on the PNP transistor (49), which then turns on the NPN transistor (50) allowing current to flow through the motor (95) to the collector of the NPN transistor (50) which is why the motor (95) spins.

**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.



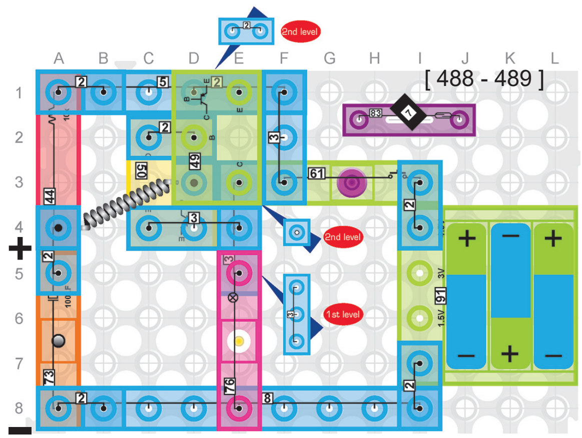

## 486. Feedback Loop

Build the circuit shown and turn on the switch (62). While light shines on the photoresistor (68), the heart LED (69) will be on but block all light on the photoresistor (68) then the heart LED (69) will go off. Try going into a completely dark room while the heart LED (69) is on. You may find that the heart LED (69) stays on, unless you block the light from the heart LED (69) from illuminating the photoresistor (68). This demonstrate a feedback loop where the light from the heart LED (69) shines on the photoresistor (68), leading to low resistance and thus current to flow to the base of the PNP transistor (49), which enables current to flow from emitter to collector of the PNP transistor (49) and then through the heart LED (69), which lights the heart LED (69), which shines on the photoresistor (68), and so on and so on...




## 487. Backup Lights

Build the circuit shown and turn on the switch (62). While light shines on the photoresistor (68), the heart LED (69) will be off but block all light on the photoresistor (68) then the heart LED (69) will turn on. This circuit could be used with a backup battery or backup generator to keep some dim lights on in a building whenever there is a power outage and the main lights go off at night.

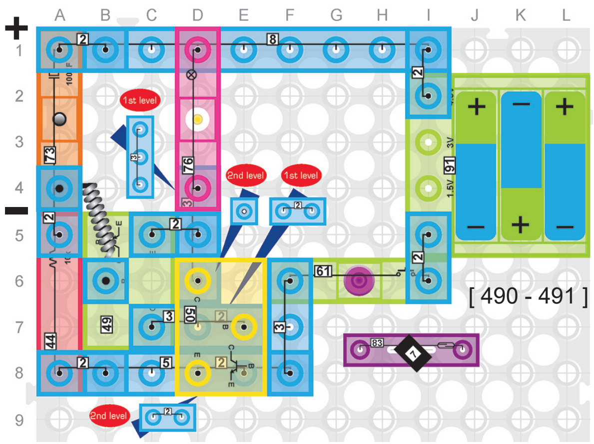


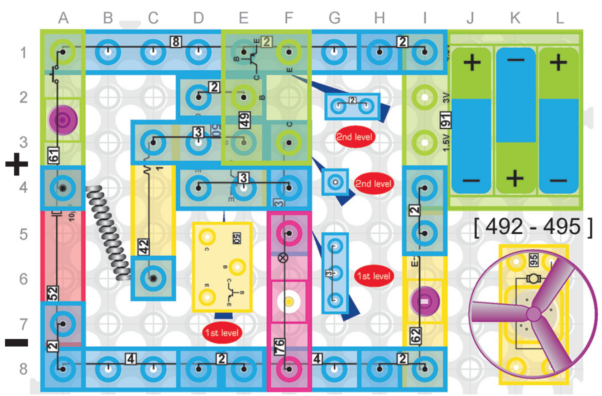

## 488. Delay Circuit

Build the circuit shown. Press and hold the press switch (61) and there will be a short delay and then the lamp (76) will turn on slowly. Release the press switch (61) and the lamp (76) will turn off immediately. Pressing the press switch (61) begins to charge up the 100µF capacitor (73), but it takes time for the 100µF capacitor (73) to charge. As it's charging, the voltage level at the base of the 2-stage NPN-PNP transistor pair starts to increase and eventually it will turn on the transistors. This is why there is a delay and slow ramp up in the lamp (76) lighting.

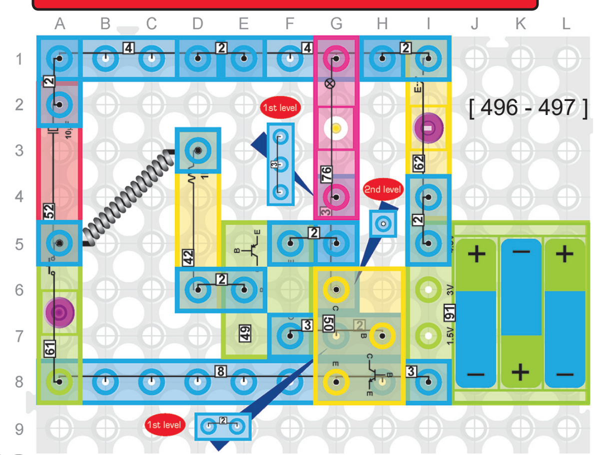
## 489. Fast Turn Off

Replace the press switch (61) in project #488 with the reed switch (83). Hold the magnet (7) near the reed switch (83) and there will be a short delay and then the lamp (76) will turn on slowly. Move the magnet (7) away from the reed switch (83) and the lamp (76) will turn off immediately. The reason the lamp (76) turns off immediately is because when you move the magnet (7) away from the reed switch (83), this also disables the path for current to flow from the collectors and emitters of the transistors. So the instant you move the magnet (7) away from the reed switch (83), no current is able to flow through the lamp (76) and thus it shuts off immediately, even though there still may be charge on the 100µF capacitor (73) and thus the base of the NPN transistor (50).




**WARNING:** Moving parts. Do not touch the fan or motor during operation. Do not lean over the motor.




## 490. Battery Charge Indicator

Build the circuit shown. Press and hold the press switch (61) and there will be a short delay and then the lamp (76) will turn on slowly. Release the press switch (61) and the lamp (76) will turn off immediately. Pressing the press switch (61) begins to charge up the 100μF capacitor (73), but it takes time for the 100μF capacitor (73) to charge. As it's charging, the voltage level at the base of the 2-stage PNP-NPN transistor pair starts to decrease and eventually it will turn on the transistors. This is why there is a delay and slow ramp up in the lamp (76) lighting. This type of circuit could be used to show when the charge on a battery is full.

## 491. First Bipolar Junction Transistor

Replace the press switch (61) in project #490 with the reed switch (83). Hold the magnet (7) near the reed switch (83) and there will be a short delay and then the lamp (76) will turn on slowly. Move the magnet (7) away from the reed switch (83) and the lamp (76) will turn off immediately. Did you know that the first bipolar junction transistor was invented by William Shockley at Bell Labs in 1948.

## 492. Long Hold Time

Build the circuit shown and press the switch (62); the lamp (76) will be off. Press the press switch (61) and the lamp (76) will light. Release the press switch (61) and the lamp (76) will stay on for a long time. When you first press the switch (62) in this project, the 10μF capacitor (73) is not charged and thus the base of the NPN-PNP transistor pair sees 0V and thus no current flows through the collectors & emitters and the lamp (76) is off. When you press the press switch (61), the 10μF capacitor (73) charges quickly since it sees the full 4.5V from the battery (91), and the transistors turn on since there is 4.5V at the base of the NPN transistor (50). But when you release the press switch (61), the 10μF capacitor (73) takes a long time to discharge through the NPN-PNP transistor pair and lamp (76) due to the high gain of the NPN-PNP transistor pair which makes the effective RC time constant in the circuit very high.

## 493. Toy Circuit

Replace the lamp (76) with the motor (95) in project #492 and press the switch (62); the motor (95) will be off. Press the press switch (61) and the motor (95) will spin. Release the press switch (61) and the motor (95) will continue spinning for a long time. This type of a circuit might be used in infant toys where just a touch of the button turns on a fan that will spin for a long while, and will eventually stop if the button is not pressed for a while.

## 494. Nobel Prize

Replace the press switch (61) with the reed switch (83) in project #492; the lamp (76) will be off. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay on for a long time. The transistor was such an important discovery that it won the Nobel Prize in 1956. The Noble Prize is awarded annually for outstanding work in physics, chemistry, physiology or medicine, literature, economics (since 1969), and the promotion of peace.

## 495. Vacuum Tubes

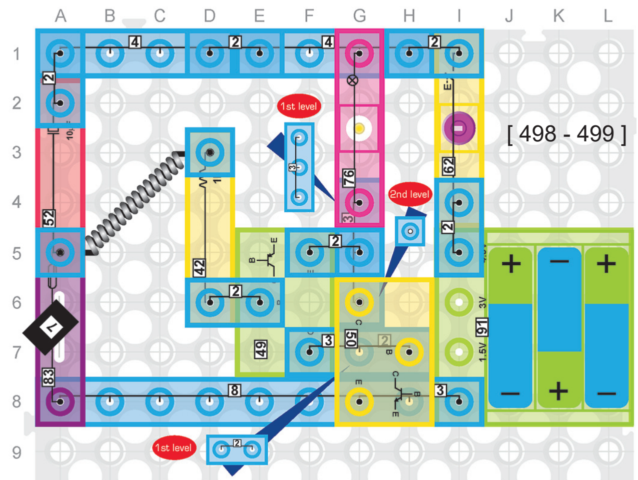
Replace the lamp (76) with the motor (95) in project #494 and press the switch (62); the motor (95) will be off. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue spinning for a long time. Before the invention of the transistor, vacuum tubes were used to control current. A vacuum tube uses a heated "cathode" that boils off electrons into a vacuum. The electrons pass through grids that control the current. Then the electrons strike a plate (the anode) and are absorbed. With proper design, the tube will turn a small AC signal voltage into a larger AC voltage, thus amplifying it just like a transistor does.

## 496. Another Long Hold Time Circuit

Build the circuit shown and press the switch (62); the lamp (76) will be off. Press the press switch (61) and the lamp (76) will light. Release the press switch (61) and the lamp (76) will stay on for a long time. When you first press the switch (62) in this project, the 100μF capacitor (73) is not charged and thus the base of the PNP-NPN transistor pair sees 4.5V and thus no current flows through the collectors & emitters and the lamp (76) is off. When you press the press switch (61), the 100μF capacitor (73) charges quickly since it sees the full 4.5V from the battery (91), and the transistors turn on since the 100μF capacitor (73) lowers the voltage at the base of the PNP transistor (49). But when you release the press switch (61), the 100μF capacitor (73) a long time to discharge through the PNP-NPN transistor pair and lamp (76) due to the high gain of the PNP-NPN transistor pair which makes the effective RC time constant in the circuit very high.

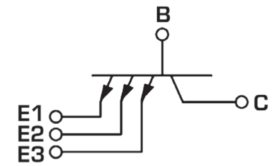
## 497. Benefits of Transistors vs. Vacuum Tubes

Replace the lamp (76) with the motor (95) in project #496 and press the switch (62); the motor (95) will be off. Press the press switch (61) and the motor (95) will spin. Release the press switch (61) and the motor (95) will continue spinning for a long time. While vacuum tubes were commonly used for things like TVs and radios prior to invention of the transistor, they are very bulky, often fragile (made of glass), were costly, inefficient, required higher operating voltages and produced a lot of heat. All of these issues were addressed by the transistor which is why it's one of the most important inventions of the 20th century.




## 498. Multiple Emitter Transistor

Build the circuit shown on the left. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay on for a long time. Special types of transistors can be used to create logic gates like the ones discussed in project #114. A multiple-emitter transistor is shown below that provides NAND gate logic. Input signals are applied to the emitters. Collector current will only stop flowing (output OFF) if all emitters are driven by a logical high voltage (all inputs are ON), which is the exact logic of a NAND gate.




## 499. Operation Modes of Transistors

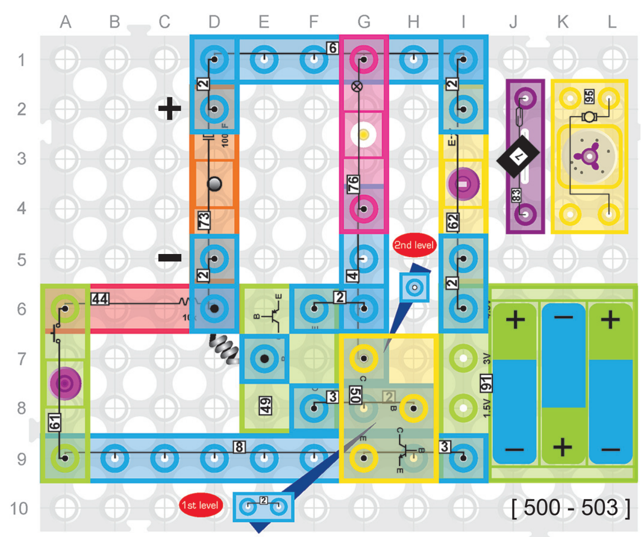
Replace the lamp (76) with the motor (95) in project #498 and press the switch (62). The motor (95) will be off. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue spinning for a long time. Transistors are non-linear devices that have four distinct modes of operation where the current flowing through the collector and emitter is defined by the mode of operation. The four modes of operation are described below.

**Forward Active Mode** – The current through the collector & emitter is proportional to the current flowing into the base.

**Saturation Mode** – The transistor acts like a short circuit. Current freely flows through collector & emitter.

**Cut-off Mode** – The transistor acts like an open circuit. No current flows through collector & emitter.

**Reverse-Active Mode** – Like active mode, the current through the collector & emitter is proportional to the base current but with much lower gain since the current flows in the opposite direction that the transistor was designed for.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 500. Longer Hold Time Circuit

Build the circuit shown and press the switch (62); the lamp (76) will be off. Press the press switch (61) and the lamp (76) will light slowly. Release the press switch (61) and the lamp (76) will stay on for a long time. Because this circuit uses a 10kΩ resistor (44) and a 100μF capacitor (73), this increases the time constant of the RC circuit and thus it takes longer for the 100μF capacitor (73) to charge (hence the delay in the lamp (76) lighting) and discharge (you should see the lamp (76) stay on longer than in the previous 4 projects).

## 501. Forward Active Mode of Transistors

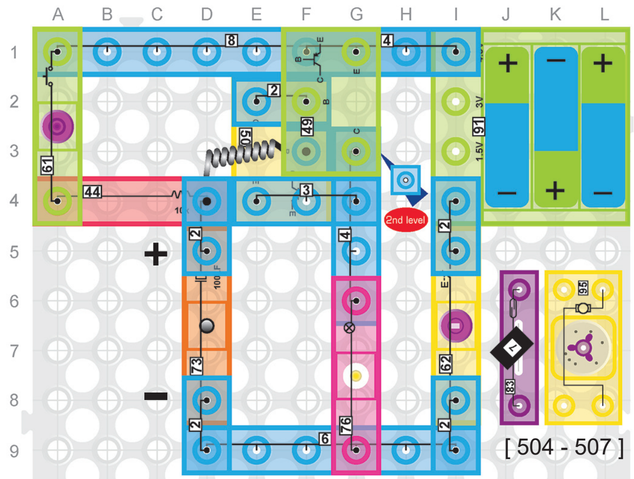
Replace the lamp (76) with the motor (95) in project #500 and press the switch (62). The motor (95) will be off. Press the press switch (61) and the motor (95) will gradually start to spin. Release the press switch (61) and the motor (95) will continue spinning for a long time. When a transistor is in Forward Active mode, the current from collector to emitter (for an NPN transistor) or emitter to collector (for a PNP transistor) is proportional to the current flowing into (NPN) or out of (PNP) the base. In general, an NPN transistor should be in Forward Active mode when the collector voltage is greater than the base voltage which is greater than the emitter voltage. Likewise, a PNP transistor should be in Forward Active mode when the emitter voltage is greater than the base voltage which is greater than the collector voltage. Forward Active mode is used when you want the transistor to act like an amplifier of current.

## 502. Saturation Mode of a Transistor

Replace the press switch (61) with the reed switch (83) in project #500 and press the switch (62). The lamp (76) will be off. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light slowly. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay on for a long time. When a transistor is in Saturation mode, current flows freely between collector and emitter and thus the transistor is acting like a short circuit. In general, a transistor should be in Saturation mode when the base voltage is greater than the collector and emitter voltages.

## 503. Cut-off Mode of Transistors

Replace the lamp (76) with the motor (95) in project #502 and press the switch (62). The motor (95) will be off. Hold the magnet (7) near the reed switch (83) and the motor (95) will gradually start to spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue spinning for a long time. When a transistor is in Cut-off mode, no current flows between collector and emitter and thus the transistor is acting like an open circuit. In general, a transistor should be in Cut-off mode when the base voltage is less than the collector and emitter voltages.



[ 504 - 507 ]

## 504. Transistor as a Switch

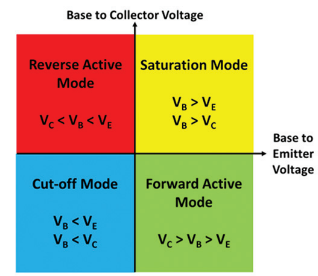
Build the circuit shown and press the switch (62); the lamp (76) will be off. Press the press switch (61) and the lamp (76) will light. Release the press switch (61) and the lamp (76) will stay on for a long time. Saturation and Cut-off modes of transistors are often used when you want the transistor to act like a switch. Placing a higher voltage at the base than the collector and emitter (Saturation mode) turns on the switch (short circuit), while placing a lower voltage at the base than the collector and emitter (Cut-off mode) turns off the switch (open circuit).

## 505. Reverse Active Mode of Transistors

Replace the lamp (76) with the motor (95) in project #504 and press the switch (62); the motor (95) will be off. Press the press switch (61) and the motor (95) will spin. Release the press switch (61) and the motor (95) will continue spinning for a long time. When a transistor is in Reverse Active mode, the current from collector to emitter (for a PNP transistor) or emitter to collector (for an NPN transistor) is proportional to the current flowing into (NPN) or out of (PNP) the base. In general, an NPN transistor should be in Reverse Active mode when the collector voltage is less than the base voltage which is less than the emitter voltage. Likewise, a PNP transistor should be in Reverse Active mode when the emitter voltage is less than the base voltage which is less than the collector voltage. Reverse Active is not the intended mode for transistors because the gain of the transistor is much smaller than when in Forward Active mode. So if you are looking for the transistor to provide current gain, just use it in Forward Active mode.

## 506. Summary of NPN Transistor Modes

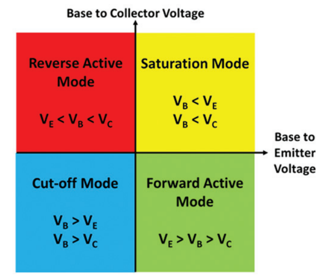
Replace the press switch (61) with the reed switch (83) in project #504; the lamp (76) will be off. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay on for a long time. The table on the right summarizes the conditions for being in each mode of an NPN transistor.

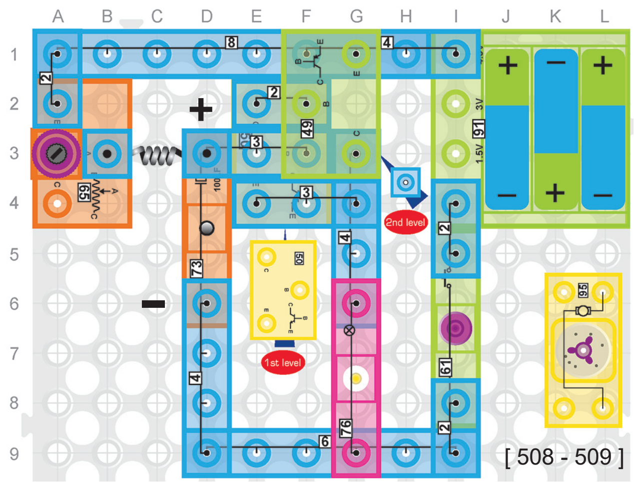



**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 507. Summary of PNP Transistor Modes

Replace the lamp (76) with the motor (95) in project #506 and press the switch (62). The motor (95) will be off. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will continue spinning for a long time. The table on the right summarizes the conditions for being in each mode of an PNP transistor.



[ 508 - 509 ]

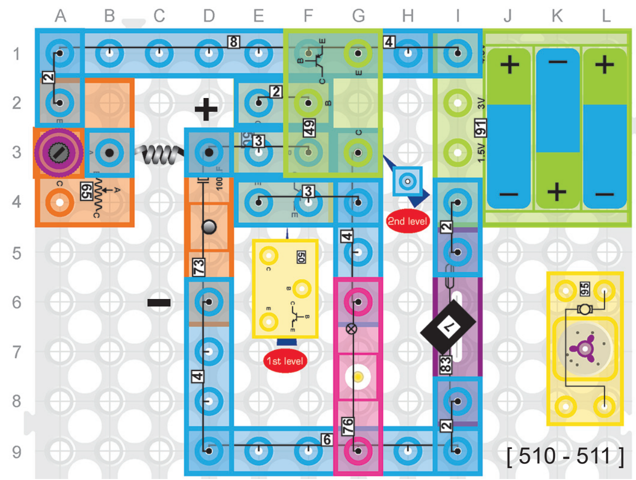
## 508. Variable Charge Time Circuit (I)

Build the circuit shown and press and hold the press switch (61). The lamp (76) will light and the speed at which it lights depends on where you set the variable resistor (65). If you turn the knob on the variable resistor (65) clockwise, this introduces resistance between the 100μF capacitor (73) and 4.5V which makes the 100μF capacitor (73) charge more slowly, the voltage at the base of the NPN transistor (50) increases more slowly and thus the lamp (76) lights more slowly. If you turn the knob on the variable resistor (65) counter-clockwise, this reduces resistance between the 100μF capacitor (73) and 4.5V which makes the 100μF capacitor (73) charge more quickly, the voltage at the base of the NPN transistor (50) increases more quickly, and thus the lamp (76) lights more quickly.

## 509. Sziklai Transistor Pair

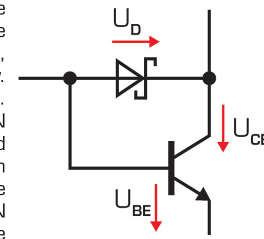
Replace the lamp (76) with the motor (95) in project #508 and press and hold the press switch (61). The motor (95) will spin and the speed at which it starts to spin depends on where you set the variable resistor (65) as discussed in project #508. Many of the 2-stage NPN with PNP transistor circuits used in the previous projects can be considered Sziklai transistor pairs. These are very similar to Darlington transistor pairs, except that it only takes around 0.6V to turn on a Sziklai transistor pair, compared to close to 1.2V to turn on a Darlington transistor pair.

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



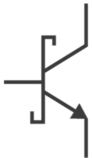

WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 510. Schottky Transistor




Build the circuit shown on the left. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light and the speed at which it lights depends on where you set the variable resistor (65) as discussed in project #508. When a transistor is being used as a switch, sometimes it's desirable to be able to switch from ON to OFF and OFF to On very quickly. The switching time of bi-polar junction transistors can be too slow for some applications. One solution is to introduce a Schottky diode between the base and collector (for an NPN transistor) as shown on the right. A Schottky Diode has much faster switching time, and turns on at around 0.2V rather than 0.6V. So by introducing the Schottky diode as shown to the right, the collector voltage never drops more than 0.2V below the base, and thus the transistor never goes into saturation (base has to be about 0.6V below collector in an NPN transistor to go into saturation). This makes the switching time between ON and OFF mode much faster than if just a bi-polar junction transistor was used.

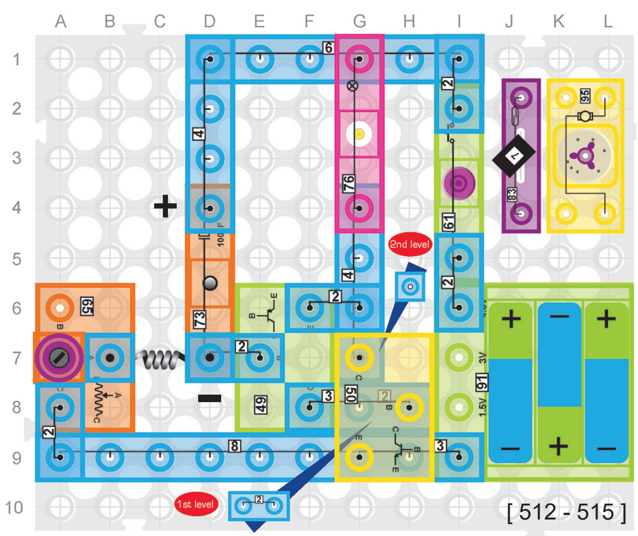
## 511. Symbol for Schottky Transistor



Replace the lamp (76) with the motor (95) in project #510. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin and the speed at which it spins depends on where you set the variable resistor (65) as discussed in project #508. The symbol for the Schottky transistor is shown on the right.

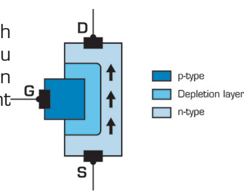
## 512. Variable Charge Time Circuit (II)

Build the circuit shown and press and hold the press switch (61). The lamp (76) will light and the speed at which it lights depends on where you set the variable resistor (65). If you turn the knob on the variable resistor (65) counter-clockwise, this introduces resistance between the 100μF capacitor (73) and ground which makes the 100μF capacitor (73) charge more slowly, the voltage at the base of the PNP transistor (49) decreases more slowly and thus the lamp (76) lights more slowly. If you turn the knob on the variable resistor (65) clockwise, this reduces resistance between the 100μF capacitor (73) and ground which makes the 100μF capacitor (73) charge more quickly, the voltage at the base of the PNP transistor (49) decreases more quickly, and thus the lamp (76) lights more quickly.



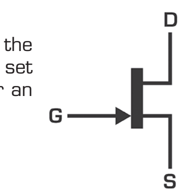

WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 513. N-type JFET Transistor Diagram



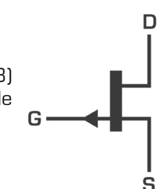

Replace the lamp (76) with the motor (95) in project #512 and press and hold the press switch (61). The motor (95) will spin and the speed at which it starts to spin depends on where you set the variable resistor (65) as discussed in project #512. JFET transistors were discussed in project #434. The figure in project #434 shows a p-type JFET, whereas the figure on the right shows an n-type JFET.

## 514. Symbol for N-type JFET

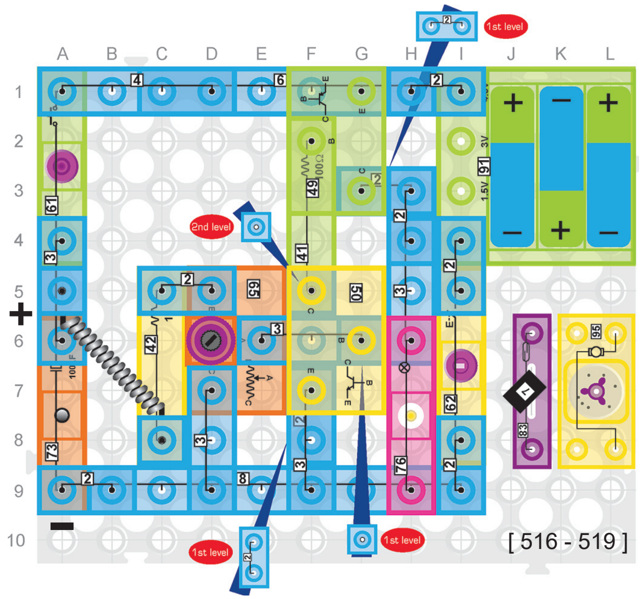



Replace the press switch (61) with the reed switch (83) in project #512. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light and the speed at which it lights depends on where you set the variable resistor (65) as discussed in project #512. The figure to the right shows the symbol for an n-type JFET.

## 515. Symbol for P-type JFET




Replace the lamp (76) with the motor (95) in project #514. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin and the speed at which it starts to spin depends on where you set the variable resistor (65) as discussed in project #512. The figure to the right shows the symbol for an p-type JFET.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 516. Variable Delay Circuit (I)

Build the circuit shown, press the switch (62) and the lamp (76) will be off. Press the press switch (61) and the lamp (76) will turn on. Release the press switch (61) and the lamp (76) will stay on for a while and then fade out. The time that the lamp (76) stays on depends on how you set the variable resistor (65). If you turn the knob clockwise, this adds resistance between the base of the NPN transistor (50) and the 100μF capacitor (73), increasing the RC time constant in the circuit, and thus it takes longer before the lamp (76) fades out. If you turn the knob counter-clockwise, this reduces resistance between the base of the NPN transistor (50) and the 100μF capacitor (73), decreasing the RC time constant in the circuit, and thus it takes less time before the lamp (76) fades out.

## 517. Transistor Specifications

Replace the lamp (76) with the motor (95) in project #516, press the switch (62) and the motor (95) will be off. Press the press switch (61) and the motor (95) will start to spin. Release the press switch (61) and the motor (95) will continue to spin for a while and then slow down and stop. The time that the motor (95) continues to spin depends on how you set the variable resistor (65) as discussed in project #516. There are a wide range of transistors you can choose from when looking to obtain a transistor for a circuit you are building. Because of this, transistors have specifications that are made available so you can understand the performance to be expected from the transistor. Below lists the common transistor specifications that are made available.

| Parameter | Description |
|---|---|
| Type Number | Type number of device |
| Case | Case style |
| Material | Material used for device |
| Polarity | NPN vs. PNP |
| $V_{CEO}$ | Collector-emitter voltage with open circuit base |
| $V_{CBO}$ | Collector-base voltage with open circuit collector |
| $V_{EBO}$ | Emitter-base voltage with open circuit collector |
| $I_C$ | Collector current |
| $I_{CM}$ | Peak collector current |
| $I_{BM}$ | Peak base current |
| $P_{TOT}$ | Total power dissipation |

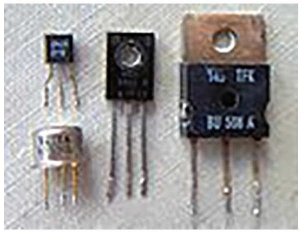
| Parameter | Description |
|---|---|
| $T_J$ | Junction temperature |
| $T_{amb}$ | Ambient temperature |
| $T_{stg}$ | Storage temperature |
| $I_{CBO}$ | Collector-base cut-off current |
| $I_{EBO}$ | Emitter-base cut-off current |
| $h_{FE}$ | Forward current gain |
| $V_{CEsat}$ | Collector-emitter saturation voltage |
| $V_{BEsat}$ | Base emitter saturation voltage |
| $C_c$ | Collector capacitance |
| $C_e$ | Emitter capacitance |
| $F_t$ | Frequency transition |

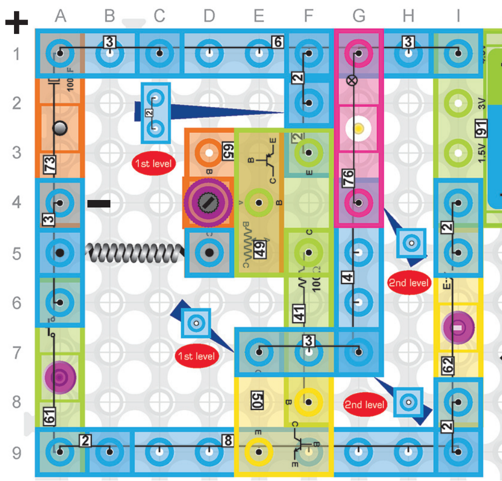
## 518. Transistor Specifications – Type Number

Replace the press switch (61) with the reed switch (83) in project #516. Press the switch (62) and the lamp (76) will be off. Hold the magnet (7) near the reed switch (83) and the lamp (76) will turn on. Move the magnet (7) away from the reed switch (83) and the lamp (76) will stay on for a while and then fade out. The time that the lamp (76) stays on depends on how you set the variable resistor (65) as discussed in project #516. The type number for a transistor is like a part number for the device. The Joint Electron Device Engineering Counsel is one association that standardizes and publishes type numbers for transistors and other devices.

## 519. Transistor Specifications – Case

Replace the lamp (76) with the motor (95) in project #518. Press the switch (62) and the motor (95) will be off. Hold the magnet (7) near the reed switch (83) and the motor (95) will spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will spin for a while and then stop. The time that the motor (95) continues to spin depends on how you set the variable resistor (65) as discussed in project #516. Transistors come in various different types of packaging to make them easy to handle, protect them from getting damaged and to manage power dissipation. The below figure provides just a few examples.





[ 520 - 523 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 520. Variable Delay Circuit (II)

Build the circuit shown, press the switch (62) and the lamp (76) will be off. Press the press switch (61) and the lamp (76) will turn on. Release the press switch (61) and the lamp (76) will stay on for a while and then fade out. The time that the lamp (76) stays on depends on how you set the variable resistor (65). If you turn the knob counter-clockwise, this adds resistance between the base of the PNP transistor (49) and the 100μF capacitor (73), increasing the RC time constant in the circuit, and thus it takes longer before the lamp (76) fades out. If you turn the knob clockwise, this reduces resistance between the base of the PNP transistor (49) and the 100μF capacitor (73), decreasing the RC time constant in the circuit, and thus it takes less time before the lamp (76) fades out.

## 521. Transistor Specifications - Material

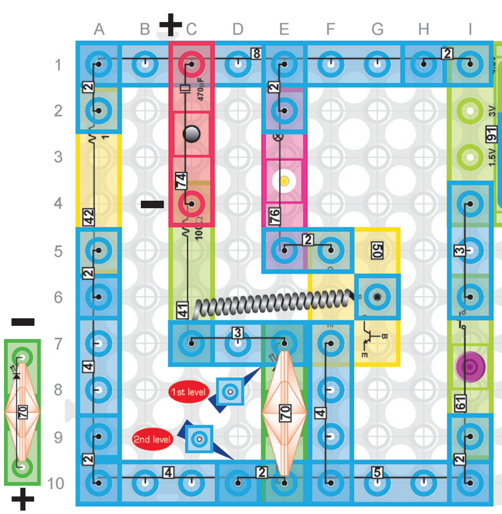
Replace the lamp (76) with the motor (95) in project #520, press the switch (62) and the motor (95) will be off. Press the press switch (61) and the motor (95) will start to spin. Release the press switch (61) and the motor (95) will continue to spin for a while and then slow down and stop. The time that the motor (95) continues to spin depends on how you set the variable resistor (65) as discussed in project #520. The material used to manufacture the device affects various performance characteristics. The two most common types of materials used for bi-polar junction transistors are silicon and germanium.

## 522. Transistor Specifications – Polarity

Replace the switch (62) with the reed switch (83) in project #520. Hold the magnet (7) near the reed switch (83) and the lamp (76) will be off. Press the press switch (61) and the lamp (76) will turn on. Release the press switch (61) and the lamp (76) will stay on for a while and then fade out. The time that the lamp (76) stays on depends on how you set the variable resistor (65) as discussed in project #520. The polarity of a transistor specifies whether it is a NPN vs. PNP, or n-type vs. p-type transistor.

## 523. Transistor Specifications – $V_{CEO}$

Replace the lamp (76) with the motor (95) in project #522. Hold the magnet (7) near the reed switch (83) and the motor (95) will be off. Press the press switch (61) and the motor (95) will start to spin. Release the press switch (61) and the motor (95) will continue to spin for a while and then slow down and stop. The time that the motor (95) continues to spin depends on how you set the variable resistor (65) as discussed in project #520. The $V_{CEO}$ of a transistor specifies the maximum voltage that can be applied from the collector to the emitter without damaging the device. This is often called the breakdown voltage rating and is specified assuming an open circuit at the base (the "O" in $V_{CEO}$ stands for "open circuit"). Applying a voltage from collector to emitter that is greater than $V_{CEO}$ could destroy the device. Typical values for $V_{CEO}$ are around 30V or greater.



[ 524 - 527 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 524. Alternating Fade Out Circuit (I)

Build the circuit shown. Press the press switch (61) and the lamp (76) will turn on and then fade out. Release the press switch (61) and the star LED (70) will turn on and then fade out. Initially the 470μF capacitor (74) has no charge on it, so when you press the press switch (61) the voltage to the base of the NPN transistor (50) is near 4.5V, which turns the NPN transistor (50) on enabling current to flow through the lamp (76) to the collector and to the emitter, which lights the lamp (76). But as the 470μF capacitor (74) charges up, the voltage level at the base of the NPN transistor (50) decreases, decreasing the current into the base of the NPN transistor (50), decreasing the current through the collector and emitter (and hence the lamp (76)) which is why the lamp (76) fades out. When you release the press switch (61), the capacitor starts discharging through the star LED (70), which lights up the star LED (70) until the 470μF capacitor (74) is fully discharged.

## 525. Transistor Specifications – $V_{CBO}$

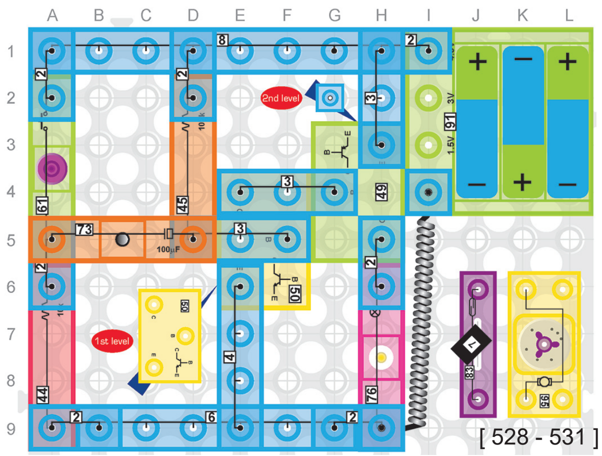
Replace the lamp (76) with the motor (95) in project #524. Press the press switch (61) and the motor (95) will start to spin and then stop. Release the press switch (61) and the star LED (70) will turn on and then fade out as discussed in project #524. The $V_{CBO}$ of a transistor specifies the maximum voltage that can be applied across the collector to the base junction without damaging the device. $V_{CBO}$ is specified assuming an open circuit at the emitter. Applying a voltage from collector to base that is greater than $V_{CBO}$ could destroy the device. Typical values for $V_{CBO}$ are around 50V or greater.

## 526. Transistor Specifications – $V_{EBO}$

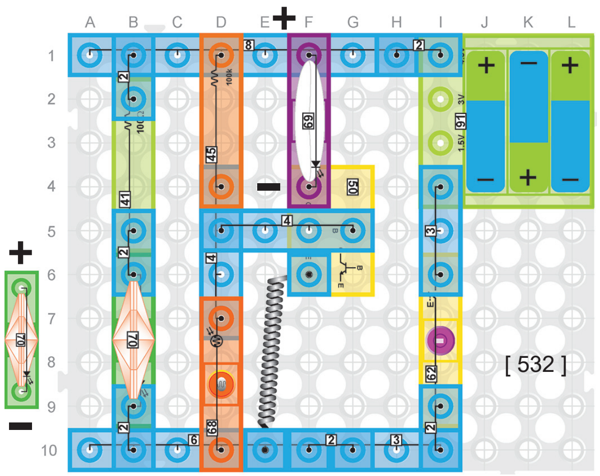
Replace the press switch (61) with the reed switch (83) in project #524. Hold the magnet (7) near the reed switch (83) and the lamp (76) will light and then fade out. Move the magnet (7) away from the reed switch (83) and the star LED (70) will turn on and then fade out as discussed in project #524. The $V_{EBO}$ of a transistor specifies the maximum voltage that can be applied across emitter to base junction without damaging the device. $V_{EBO}$ is specified assuming an open circuit at the collector. Applying a voltage from emitter to base that is greater than $V_{EBO}$ could destroy the device. Typical values for $V_{EBO}$ are around 5V or greater.

## 527. Transistor Specifications – $I_C$

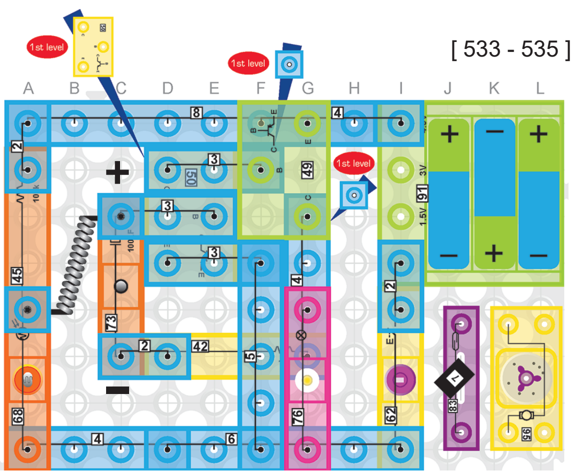
Replace the lamp (76) with the motor (95) in project #526. Hold the magnet (7) near the reed switch (83) and the motor (95) will start to spin and then stop. Move the magnet (7) away from the reed switch (83) and the star LED (70) will turn on and then fade out as discussed in project #524. The IC of a transistor specifies the typical operating DC collector current for the device. Operating the transistor at this current will provide the gain specified for the transistor. Typical values for IC range from 100 mA to 1 Amp or more.



[ 528 - 531 ]



[ 532 ]



[ 533 - 535 ]

## 528. Return of the Light

Build the circuit shown; the lamp (76) will be on. Press the press switch (61) and the lamp (76) stays on. Release the press switch (61) and the lamp (76) will turn off for a while and then turn back on again.

Since the turn on voltage of the NPN transistor (50) is about 0.6V, initially there is 0.6V at the base of the NPN transistor (50). This doesn't change when you press the press switch (61). But when the press switch (61) is pressed, there is 4.5V at both points D2 and A6 in the circuit. This means that the voltage drop across the 100kΩ resistor (45) of about 4.5 - 0.6 = 3.9V leads to the 100μF capacitor (73) being charged up to 3.9V in the opposite polarity (let's call it –3.9V).

Now when the press switch (61) is released, the –3.9V on the 100μF capacitor (73) pulls the NPN transistor (50) base voltage down to 0V initially, turning off the 2-stage transistor circuit and thus turning off the lamp (76). But as the 100μF capacitor (73) discharges, the voltage at the base of the NPN transistor (50) eventually goes up to around 0.6V and turns on the 2-stage transistor circuit again, and then the lamp (76) turns back on.

## 529. Transistor Specifications - $I_{CM}$

Replace the lamp (76) with the motor (95) in project #528. The motor (95) will be spinning. Press the press switch (61) and the motor (95) continues to spin. Release the press switch (61) and the motor (95) will stop spinning for a while and then start spinning again as explained in project #528. The $I_{CM}$ of a transistor specifies the maximum DC collector current that the device supports. Running any larger currents through the collector could damage the device.

## 530. Transistor Specifications – $I_{BM}$

Replace the press switch (61) with the reed switch (83) in project #528. The lamp (76) will be on. Hold the magnet (7) near the reed switch (83) and the lamp (76) stays on. Move the magnet (7) away from the reed switch (83) and the lamp (76) will turn off for a while and then turn back on again as explained in project #528. The $I_{BM}$ of a transistor specifies the maximum DC base current that the device supports. Running any larger currents through the base could damage the device.

## 531. Transistor Specifications – $P_{TOT}$

Replace the lamp (76) with the motor (95) in project #530. The motor (95) will be spinning. Hold the magnet (7) near the reed switch (83) and the motor (95) continues to spin. Move the magnet (7) away from the reed switch (83) and the motor (95) will stop spinning for a while and then start spinning again as explained in project #528. $P_{TOT}$ represents the total power that can be dissipated by the device. Typical values for $P_{TOT}$ range from 350mW to 1W or more.

## 532. Mail Indicator

Build the circuit shown and press the switch (62). The star LED (70) will be on but the heart LED (69) will be off. Cover the photoresistor (68) so it sees no light and the heart LED (69) will turn on. You could use this circuit as a way to indicate when you have mail. Just put it in your mail bin and whenever there is mail covering the photoresistor (68), the heart LED (69) will turn on.

## 533. Holding on to Darkness

Build the circuit shown and press the switch (62); the lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will turn on. Let light shine on the photoresistor (68) again and the lamp (76) will go off. When you turn on the switch (62) and are in a bright room, the low resistance of the photoresistor (68) pulls down the voltage at the NPN transistor (50) base so that the 2-stage transistor circuit is off and thus the lamp (76) is off. At the same time, the 100μF capacitor (73) is being charged. So now when no light is shining on the photoresistor (68), the charge on the 100μF capacitor (73) keeps the voltage level at the base of the NPN transistor (50) low for a short while before it eventually goes above about 0.6V, turns on the 2-stage transistor circuit and lights the lamp (76).

## 534. Transistor Specifications – $T_j$

Replace the lamp (76) with the motor (95) in project #533. Turn on the switch (62); the motor (95) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the motor (95) will start to spin. Let light shine on the photoresistor (68) again and the motor (95) will go off as discussed in project #533. The $T_j$ of a transistor specifies the maximum temperature that actual semiconductor in the device can tolerate. If the junction temperature of the device exceeds $T_j$, then the device can be damaged. Note that this is different than the ambient temperature (i.e. room temperature), but see next project.

## 535. Transistor Specifications – $T_{amb}$

Replace the switch (62) with the reed switch (83) in project #533. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will turn on. Let light shine on the photoresistor (68) again and the lamp (76) will go off as discussed in project #533. The $T_{amb}$ of a transistor specifies the maximum ambient temperature (or room temperature) that the device can tolerate. If the ambient temperature exceeds $T_{amb}$, then the device can be damaged. When the device is active, it begins to dissipate power and the junction temperature rises above the ambient temperature. Some of this dissipated power is transferred to the casing and thus the $T_j$ is generally larger than $T_{amb}$.

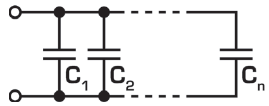
## 536. Transistor Specifications – $h_{FE}$

Replace the lamp (76) with the motor (95) in project #535. Place the magnet (7) near the reed switch (83); the motor (95) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the motor (95) will start to spin. Let light shine on the photoresistor (68) again and the motor (95) will go off as discussed in project #533. The $h_{FE}$ of a transistor specifies the forward current gain of the transistor when in forward active mode. This is the same as the gain β discussed in project #343. Typical values for $h_{FE}$ are between 50 to 400 or more, and are typically specified at a particular collector current (recall the variance in gains in projects #343 to #346).

## 537. Capacitors in Parallel

Place the 470μF capacitor (74) directly on top of the 100μF capacitor (73) in project #533. Make sure that both capacitors in the circuit are in the same direction. Turn on the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a longer delay than in project #533 and then the lamp (76) will turn on. Let light shine on the photoresistor (68) again and the lamp (76) will go off. When you place the 470μF capacitor (74) directly on top of the 100μF capacitor (73), you are putting the capacitors in parallel like in the figure below.

From the figure, you can see that when capacitors are placed in parallel, the top plates of the capacitors are all connected together and the bottom plates of the capacitors are all connected together. Recall from project #316 that the capacitance of a capacitor is directly related to the area of the plates. So by connecting the plates together, you are essentially creating a single plate with a larger area which is the sum of the areas of each capacitor. Thus, the total capacitance of capacitors in parallel equals the sum of the capacitances of each capacitor (i.e. $C_{TOT} = C_1 + C_2 + \ldots + C_n$). So by putting the two capacitors in this project in parallel, the total capacitance increases to 570μF, which is why the delay in the lamp (76) lighting is longer than in project #533.




## 538. Transistor Specifications – $T_{stg}$

Replace the lamp (76) with the motor (95) in project #537. Turn on the switch (62). The motor (95) will be off. Go into a dark room or cover the photoresistor (68) and there will be longer delay and then the motor (95) will start to spin. Let light shine on the photoresistor (68) again and the motor (95) will go off as discussed in project #533. The $T_{stg}$ of a transistor specifies the temperature range over which the device can be stored. Outside this range the device may be damaged. The operating temperature range is normally well within the bounds of the storage temperature range.

## 539. Transistor Specifications – $I_{CBO}$

Replace the switch (62) with the reed switch (83) in project #537. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a longer delay and then the lamp (76) will turn on. Let light shine on the photoresistor (68) again and the lamp (76) will go off as discussed in project #533. $I_{CBO}$ is the collector-base cutoff current assuming an open circuit at the emitter. This represents the leakage current from the collector to base when operating in cut-off mode.

## 540. Transistor Specifications – $I_{EBO}$

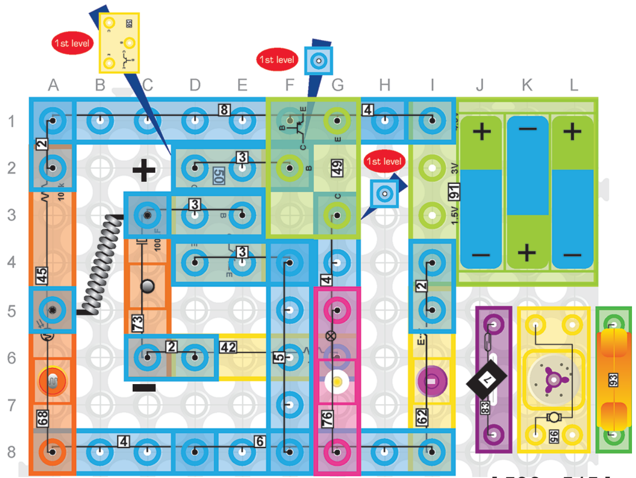
Replace the lamp (76) with the motor (95) in project #539. Place the magnet (7) near the reed switch (83). The motor (95) will be off. Go into a dark room or cover the photoresistor (68) and there will be a longer delay and then the motor (95) will start to spin. Let light shine on the photoresistor (68) again and the motor (95) will go off as discussed in project #533. $I_{EBO}$ is the emitter-base cutoff current assuming an open circuit at the collector. This represents the leakage current from the emitter to base when operating in cut-off mode.

## 541. Hearing the Transistor Turn On and OFF

Replace the lamp (76) with the speaker (93) in project #533. Turn on the switch (62). Go into a dark room or cover the photoresistor (68) and you will hear a couple "clicks" or "pops". Wait a little while and you will hear more "clicks" and "pops".

The "clicks" and "pops" you are hearing are when the 2-stage transistor circuit turns on and off and there is a sudden change or burst in current through the speaker (93). When you block the photoresistor (68) from light, this greatly increases the resistance from the base of the NPN transistor (50) to ground and thus current through the 100kΩ resistor (45) starts to flow to the base of the 2-stage transistor. A little current to the base of the NPN transistor (50) starts a little current to flow through the 2-stage transistor circuit, out the collector of the PNP transistor (49), into the 1kΩ resistor (42), through the 100μF capacitor (73) and back into the base of the NPN transistor (50). This in turn increases the current flow through the 2-stage transistor circuit providing a feedback loop that quickly provides a burst of current through the speaker (93) and you hear a "click".

Now once the 2-stage transistor circuit is on for a short while, the 100μF capacitor (73) charges up quickly through the 1kΩ resistor (42), which then stops the feedback current from flowing into the base of the NPN transistor (50) and this causes the 2-stage transistor circuit to turn off and you hear a second "click". It then takes a longer time for the 100μF capacitor (73) to charge up with the opposite polarity through the 100kΩ resistor (45), but eventually it does reach a voltage level that again allows a small amount of current to flow into the base of the NPN transistor (50) which starts the whole process over again.




[ 536 - 545 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 542. Transistor Specifications – $V_{CEsat}$

Replace the switch (62) with the reed switch (83) in project #541. Place the magnet (7) near the reed switch (83). Go into a dark room or cover the photoresistor (68) and you will hear a "click" or a "pop". Wait a little while and you will hear more "clicks" and "pops". $V_{CEsat}$ is the collector-emitter saturation voltage.

It turns out then even when the voltage at the base of an NPN transistor (50) (for instance) is greater than that of the emitter and the collector, there still may not be perfect conduction between collector and emitter depending on the voltage level across the collector-emitter. So $V_{CEsat}$ specifies the minimum voltage needed to insure the transistor is in saturation (i.e. current flows freely from collector to emitter) when the base voltage is greater than both the emitter and collector voltages, and is usually a small value like 0.05V to 0.2V.

## 543. Faster "Clicks" and "Pops"

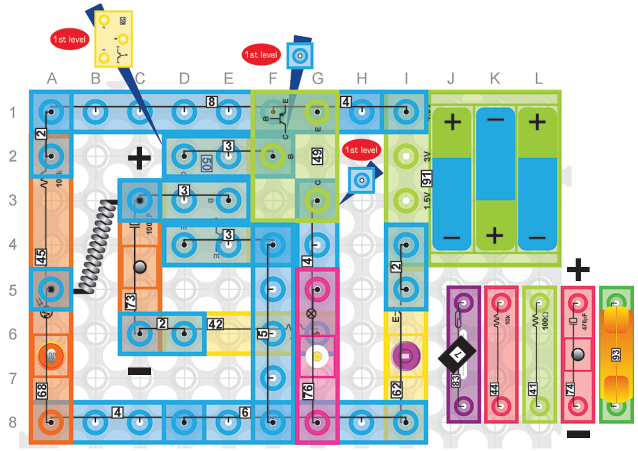
Replace the 1kΩ resistor (42) with the 100Ω resistor (41) in project #541. Turn on the switch (62). Go into a dark room or cover the photoresistor (68) and you will hear a couple "clicks" or "pops". The "clicks" and "pops" you hear this time are closer together because with a smaller resistor in the circuit, the RC time constant is smaller so the 100μF capacitor (73) is discharging faster.

## 544. Transistor Specifications – $V_{BEsat}$

Replace the switch (62) with the reed switch (83) in project #543. Place the magnet (7) near the reed switch (83). Go into a dark room or cover the photoresistor (68) and you will hear faster "clicks" and "pops". $V_{BEsat}$ is the base-emitter saturation voltage. It's essentially the voltage required across the base-emitter to put the transistor into saturation mode.

## 545. Slower "Clicks" and "Pops"

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in project #541. Turn on the switch (62). Go into a dark room or cover the photoresistor (68) and you will hear a couple "clicks" or "pops". The "clicks" and "pops" you hear this time are further apart because with a larger resistor in the circuit, the RC time constant is larger so the 100μF capacitor (73) is discharging slower.



[ 542 - 549 ]

## 546. Transistor Specifications – $C_e$

Replace the switch (62) with the reed switch (83) in project #545. Place the magnet (7) near the reed switch (83). Go into a dark room or cover the photoresistor (68) and you will hear slower "clicks" and "pops". $C_e$ is the emitter-base capacitance of the transistor. As demonstrated in many projects, capacitance introduces delays in circuits. For fast switching and high frequency applications, even a small capacitance can be an issue. Therefore, transistors specifications include the emitter-base capacitances of the device.

## 547. Even Slower "Clicks" and "Pops"

Place the 470μF capacitor (74) on top of the 100μF capacitor (73) in project #545. Turn on the switch (62). Go into a dark room or cover the photoresistor (68) and you will hear a couple "clicks" or "pops". The "clicks" and "pops" you hear this time are even further apart because with a larger capacitor in the circuit, the RC time constant is larger so the 100μF and 470μF capacitors are discharging slower.

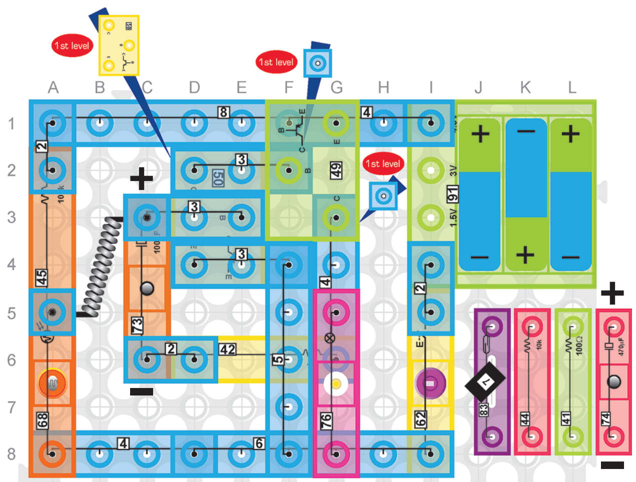
## 548. Transistor Specifications – $F_t$

Replace the switch (62) with the reed switch (83) in project #547. Place the magnet (7) near the reed switch (83). Go into a dark room or cover the photoresistor (68) and you will hear even slower "clicks" and "pops". $F_t$ is the frequency transition of the transistor. The gain of a transistor is dependent on the frequency of the input signal. The operating frequency of the transistor should normally be well below the transition frequency.

## 549. Flashing Light

Build the circuit in project #533 but place the speaker (93) on top of the lamp (76) (use two 1-wire (1) blocks to connect the speaker (93) in parallel with the lamp (76)). Press the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear "clicks" and "pops" from the speaker (93).

The reason why the lamp (76) flashes in this circuit, but not in project #533 is because the resistance in the speaker (93) is much smaller than the resistance of the lamp (76) when the lamp (76) is on. With the speaker (93) in parallel with the lamp (76), the combined resistance is even lower than either individual resistances and so this circuit acts like the one discussed in project #541. But without the speaker (93) in parallel with the lamp (76), the higher resistance of the lamp (76) (around 75Ω) when on keeps enough current flowing through the 1kΩ resistor (42) to 100μF capacitor (73) to NPN transistor (50) base feedback loop discussed in project #541 to keep the 2-stage transistor circuit on all the time, which is why the lamp (76) does not flash in project #533.




[ 550 - 557 ]

## 550. Transistor Specifications – $C_C$

Replace the switch (62) with the reed switch (83) in project #549. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93) as discussed in project #549.

$C_C$ is the collector-base capacitance of the transistor. As demonstrated in many projects, capacitance introduces delays in circuits. For fast switching and high frequency applications, even a small capacitance can be an issue. Therefore, transistors specifications include the collector-base capacitances of the device.

## 551. Faster Flashing Light

Replace the 1kΩ resistor (42) with the 100Ω resistor (41) in project #549. Press the switch (62). The lamp (76) will be off.Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93). The lamp (76) flashes on and off more quickly in this project since the 100μF capacitor (73) charges up more quickly with only a 100Ω resistor (41) in series.

## 552. Positive Feedback Loop

Replace the switch (62) with the reed switch (83) in project #551. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off quickly and you will hear quick “clicks” and “pops” from the speaker (93) as discussed in projects #549 and #551.

The feedback loop from the PNP transistor (49) collector output to the NPN transistor (50) base input provides feedback current that helps turn on the 2-stage transistor circuit. This is call a positive feedback loop.

## 553. Slower Flashing Light

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in project #549. Press the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93). The lamp (76) flashes on and off more slowly in this project since the 100μF capacitor (73) charges up more slowly with a 10kΩ resistor (44) in series.

## 554. Oscillators

Replace the switch (62) with the reed switch (83) in project #553. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off slowly and you will hear slow “clicks” and “pops” from the speaker (93) as discussed in projects #549 and #551. Positive feedback is used in oscillators. Oscillators are devices that produce voltages and/or currents that oscillate (e.g. sine wave type signals).

## 555. Longer Period Flashing Lights

Build the circuit in project #549 but replace the 100μF capacitor (73) with the 470μF capacitor (74). Press the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93).

You will notice that there is a longer period of time between flashes of light and “clicks” and “pops” in this circuit than in project #549. This is because with the larger 470μF capacitor (74), it takes longer for it to charge and discharge which increases the time between turning on and off the 2-stage transistor circuit as discussed in project #541.

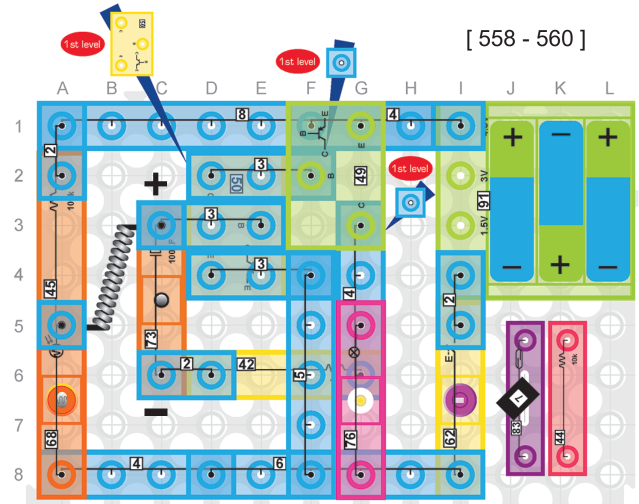
## 556. The Negative of Positive Feedback

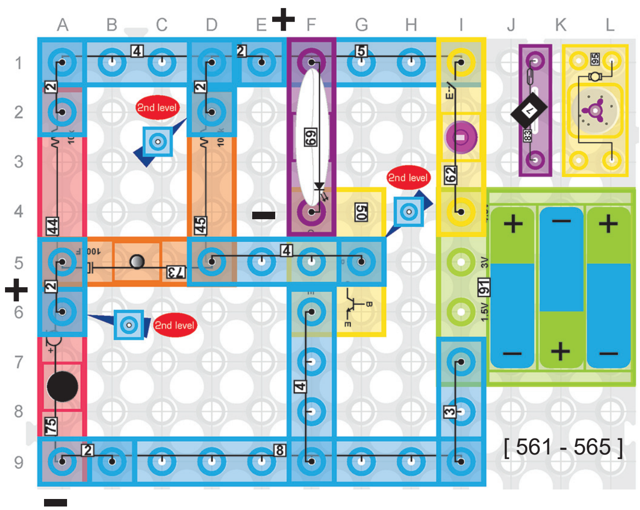
Replace the switch (62) with the reed switch (83) in project #555. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93) with longer delays between light flashes and “clicks” and “pops”.

While positive feedback can be useful in creating oscillators as discussed in project #554, it can also be a very bad thing. Positive feedback can provide instability in circuits that lead to catastrophic behavior. Have you ever held a microphone too close to the speaker that is producing the sound and you hear a piercing sound? This is caused by positive feedback from the speaker into the microphone through the amplifier and back to the speaker.

## 557. Faster Flashing Light with Longer Flashing Period

Replace the 1kΩ resistor (42) with the 100Ω resistor (41) in project #555. Press the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear “clicks” and “pops” from the speaker (93). The lamp (76) flashes on and off more quickly in this project since the 470μF capacitor (74) charges up more quickly with only a 100Ω resistor (41) in series.




⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 558. Clock Generators

Replace the switch (62) with the reed switch (83) in project #557. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off quickly and you will hear quick "clicks" and "pops" from the speaker (93) with longer delays between light flashes and "clicks" and "pops".

This circuit produces flashes of light and "clicks" and "pops" at a consistent rate like a clock. In fact oscillator circuits are used as clock generators for microprocessors.

## 559. Slower Flashing Light with Longer Flashing Period

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in project #555. Press the switch (62). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off and you will hear "clicks" and "pops" from the speaker (93). The lamp (76) flashes on and off more slowly in this project since the 470μF capacitor (74) charges up more slowly with a 10kΩ resistor (44) in series.

## 560. Electronic Communications & Navigation Systems

Replace the switch (62) with the reed switch (83) in project #559. Place the magnet (7) near the reed switch (83). The lamp (76) will be off. Go into a dark room or cover the photoresistor (68) and there will be a short delay and then the lamp (76) will flash on and off slowly and you will hear slow "clicks" and "pops" from the speaker (93).

Oscillators are used to stabilize time-frequency generators, which provide carrier and pilot signals for electronic communication and navigation systems.

## 561. Sound Activated LED

Build the circuit shown and turn on the switch (62). The heart LED (69) will be on, and if you blow on or make sounds into the microphone (75) you will see the heart LED (69) flicker. By making sounds into the microphone (75) you are creating voltage signals into the base of the NPN transistor (50). This changes the base current which is amplified by the NPN transistor (50) to produce a varying collector-emitter current, and the heart LED (69) is showing fluctuations in the collector current.

## 562. Dancing Light

Replace the switch (62) with the reed switch (83) in project #561 and place the magnet (7) near the reed switch (83). The heart LED (69) will be on. Play music into the microphone (75) you will see the heart LED (69) dance to the music. You may need to use an earphone to focus the sound into the microphone, and you may need to be in a dark room to best see the effects.

## 563. Sound Amplifier

Replace the heart LED (69) with the speaker (93) in project #561 and turn on the switch (62). If you blow on or make sounds into the microphone (75) you will hear it on the speaker (93).

The sounds you make into the speaker (93) are changing the voltage levels at the base of the NPN transistor (50). This changes the base current which is amplified by the NPN transistor (50) to produce a varying collector-emitter current, and the speaker (93) converts these current variations to sound. You can even place an earphone playing music into the microphone and you will hear the music on the speaker (93).

## 564. The Microphone

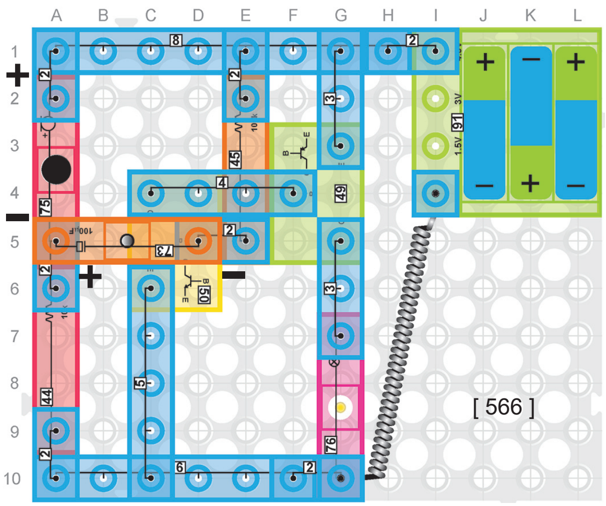
Replace the switch (62) with the reed switch (83) in project #563 and place the magnet (7) near the reed switch (83). If you blow on or make sounds into the microphone (75) you will hear it on the speaker (93).

The microphone (75) takes in sound waves and converts them to an electrical signal representing the audio waves. It does this using a diaphragm (a thin piece of material like plastic or aluminum) which vibrates when it encounters sound waves. The vibrations in the diaphragm are then converted to the electrical audio signal.

## 565. Motor Activated LED

Replace the microphone (75) with the motor (95) in project #561 and turn on the switch (62). The heart LED (69) will be on and when you spin the motor (95) shaft you will see the heart LED (69) flash off.

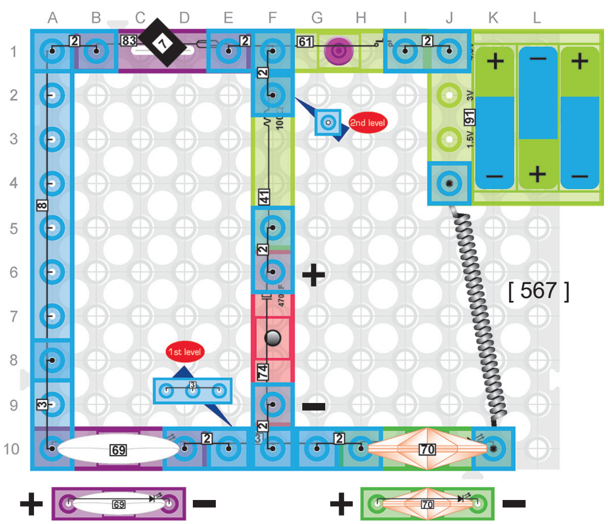
When you spin the motor (95) shaft, you create voltage fluctuations at the base of the NPN transistor (50). This changes the base current which is amplified by the NPN transistor (50) to provide the collector-emitter current, and the heart LED (69) is showing fluctuations in the collector current.




## 566. Dimming Lamp

Build the circuit shown; the lamp (76) will be on. Blow on the microphone (75) and you will see the lamp dim slightly.

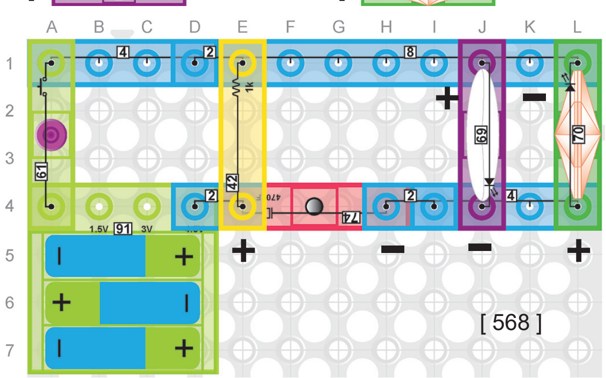
In this circuit, the voltage at the base of the NPN transistor (50) is high enough to turn on the 2-stage resistor circuit and put it in Forward Active mode. So when you blow on the microphone (75), this varies the current into the base of the NPN transistor (50), which varies the current out of the collector of the PNP transistor (49), varying the current seen by the lamp (76) which is why you see it dim.




## 567. Charging and Discharging (I)

Build the circuit shown. Press the press switch (61) and you will see the star LED (70) flash on and then off. Release the press switch (61) and put the magnet (7) near the reed switch (83) and you will see the heart LED (69) flash on and off.

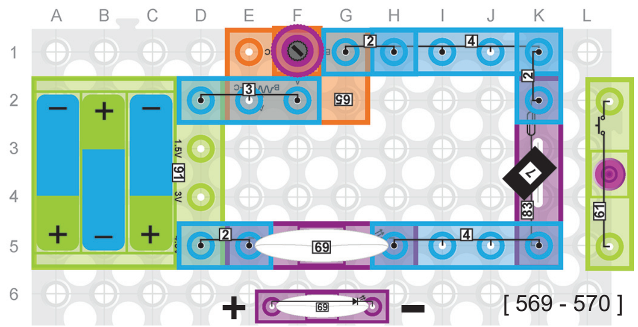
When you press the press switch (61) this creates a circuit path to charge the 470μF capacitor (74). Initially the 470μF capacitor (74) has zero charge across it so it acts like a short circuit and the star LED (70) lights. But as the 470μF capacitor (74) charges up, it acts like an open circuit so no current flows to the star LED (70) which is why the star LED (70) fades out. By releasing the press switch (61) and putting the magnet (7) near the reed switch (83), this creates a circuit path for the 470μF capacitor (74) to discharge through the heart LED (69). This lights the heart LED (69), but as the 470μF capacitor (74) discharges (loses its charge), the heart LED (69) fades out.




## 568. Charging and Discharging (II)

Build the circuit shown. Press the press switch (61) and you will see the star LED (70) flash on and then off. Release the press switch (61) and you will see the heart LED (69) flash on and off.

When you press the press switch (61) this creates a circuit path to charge the 470μF capacitor (74). Initially the 470μF capacitor (74) has zero charge across it so it acts like a short circuit and the star LED (70) lights. But as the 470μF capacitor (74) charges up, it acts like an open circuit so no current flows to the star LED (70) which is why the star LED (70) fades out. By releasing the press switch (61), this creates a circuit path for the 470μF capacitor (74) to discharge through the heart LED (69) and 1kΩ resistor (42). This lights the heart LED (69), but as the 470μF capacitor (74) discharges (loses its charge), the heart LED (69) fades out.



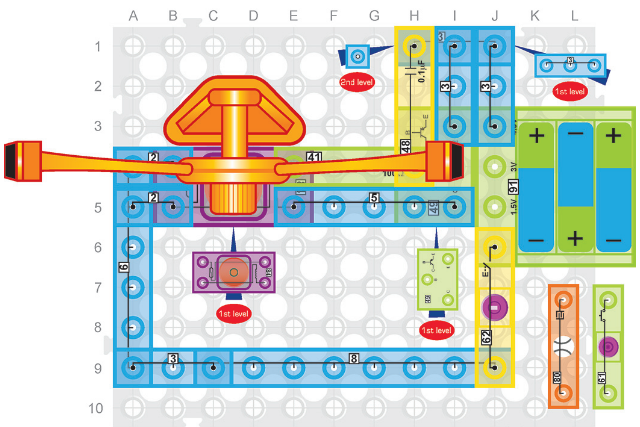
[ 569 - 570 ]

## 569. Varying Current with the Variable Resistor

Build the circuit shown and place the magnet (7) on the reed switch (83). Turn the knob on the variable resistor (65) and the brightness of the heart LED (69) will change. As you turn the knob on the variable resistor (65) clockwise, this increases the resistance between points A and B in the variable resistor (65), which reduces the current through the circuit and makes the heart LED (69) dim or off. As you turn the knob on the variable resistor (65) counter-clockwise, this decreases the resistance between points A and B in the variable resistor (65), which increases the current through the circuit and makes the heart LED (69) brighter.

## 570. House Light Dimmer

Replace the reed switch (83) with the press switch (61) in project #569. Press and hold the press switch (61). Turn the knob on the variable resistor (65) and the brightness of the heart LED (69) will change. This type of circuit can be used to a light dimming adjustable switch for the lights in your house.



[ 571 - 573 ]

## 571. Spinning Windmill

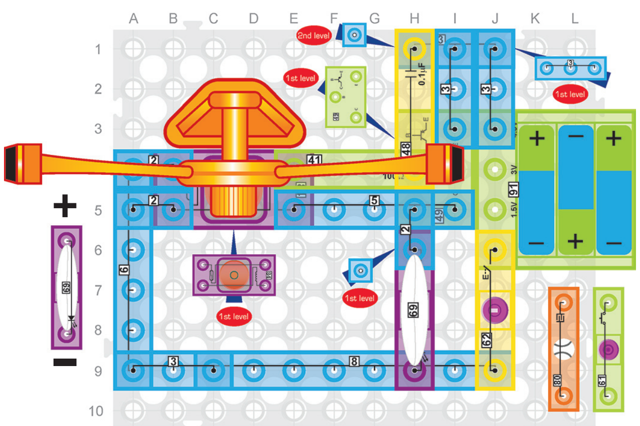
Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning (the magnets on the windmill (90) need to be directly over the center of the inductor (84) and at just the right height above the inductor (84)). The inductor (84) module creates a magnetic field when current runs through it, and this magnetic field creates a force on the magnets on the windmill (90) as they cross over the inductor (84) that keeps the windmill (90) spinning.

## 572. The Inductor

Replace the switch (62) with the press switch (61) in project #571. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. The inductor (84) is a very simple device. It's basically a wire that is wound around in circles into a coil around a core (often made of a material like iron). When a current flows through a wire it always creates a magnetic field around the wire. But the magnetic field created by a single wire is very, very small. However, by winding the wire into a coil, the magnetic field through the center of the coil is much greater.

## 573. Inductance

Replace the switch (62) with the reed switch (83) in project #571. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Inductance is a measure of ability for an electrical conductor to oppose a change in current. When current starts to flow through an inductor, a magnetic field begins to build up around the coil. But building up this magnetic field actually resists the flow of current through the coil. Then once the magnetic fields builds up and current is flowing freely through the coil, the inductor will resist a decrease in current due to the built up magnetic field. This resistance to a change in current in an inductor is called inductance.



[ 574 - 575 ]

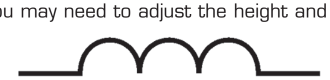
## 574. LED Flashing to Windmill

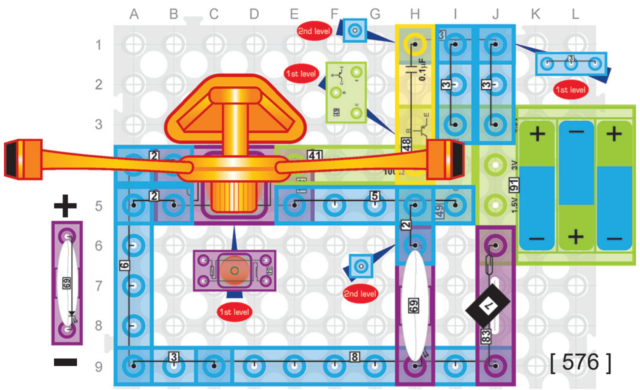
Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the heart LED (69) will flash every time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

Notice that the inductor (84) module has multiple markings on it. On one side it shows a figure of a coil connected to two pins (which are the inductor connections), but on the other side it shows a reed switch figure connected to the other two pins. Thus, the inductor (84) module actually contains both an inductor and a reed switch. So in this circuit (and the previous three circuits), when the magnets on the windmill (90) cross down over the inductor (84), this closes the reed switch (83), which brings the base of the PNP transistor (49) to ground turning on the PNP transistor (49), which creates a current out the collector of the PNP transistor (49) that makes the heart LED (69) turn on and sends current through the inductor pins on the inductor (84) which creates the magnetic field that pushes the magnet on the windmill (90) and keeps it spinning. Then as the magnet moves off the inductor (84), the reed switch opens, turning off the PNP transistor (49), stopping current from flowing out the collector of the PNP transistor (49) and the heart LED (69) turns off until the next magnet on the windmill (90) crosses the inductor and this process repeats.

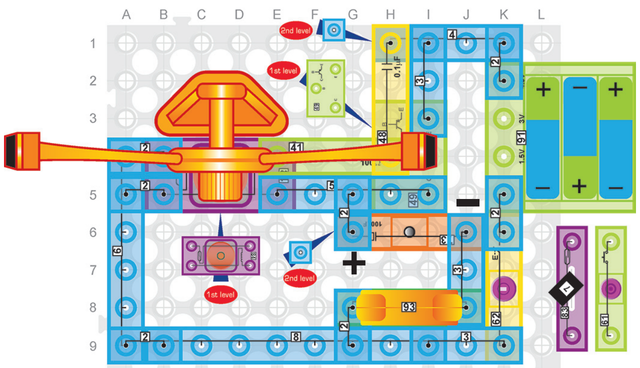
## 575. Symbol for an Inductor

Replace the switch (62) with the press switch (61) in project #574. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the heart LED (69) will flash every time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. The symbol for an inductor is shown on the right.

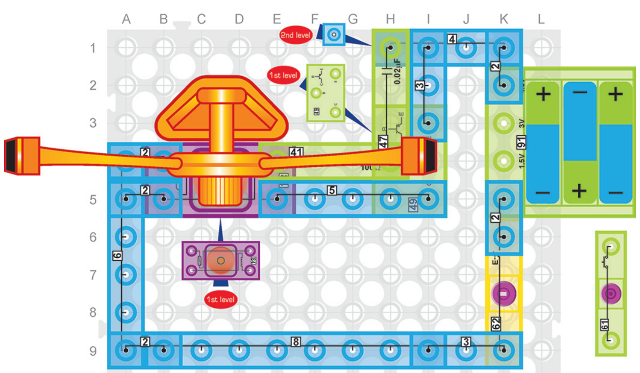




[ 576 ]



[ 577 - 579 ]



[ 580 - 581 ]

## 576. Inductance of a Coil

Build the circuit shown on the left. Place the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the heart LED (69) will flash every time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

The derivation for the inductance of a coil is beyond the scope of this manual, but below is the approximate formula:

$$\text{Coil Inductance} \approx N_2 * \mu * A/l$$

Where N is the number of turns in the coil, $\mu$ is the permeability of the core (see project #578), A is the area of the circle created by the coil, and l is the length of the coil. As discussed in project #415, the Henry is the unit of inductance.

## 577. Clicking Windmill

Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and hear clicking from the speaker (93). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

This circuit is similar to the one in project #574, except that now the bursts of current coming from the collector of the PNP transistor (49) feed into the speaker (93) rather than the heart LED (69). Every time there is a burst of current through the speaker (93), you hear a “click”.

## 578. Permeability

Replace the switch (62) with the press switch (61) in project #577. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and hear clicking from the speaker (93). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

Permeability is a measure of a material’s ability to form a magnetic field within itself. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field.

## 579. Transformers

Replace the switch (62) with the reed switch (83) in project #577. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and hear clicking from the speaker (93). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

One of the main applications of inductors is in creating transformers. In a transformer, a primary coil is connected to an AC input source. The AC input source leads to a constantly varying magnetic field around the primary coil. This primary coil is placed near a secondary coil so the constantly varying magnetic field from the primary coil produces a constantly varying magnetic field in the second coil. This in turn produces a constantly varying voltage/current in the second coil which provides the AC output from the transformer. By choosing the characteristics of the two coils appropriately, you can change the amplitude of the AC signal through the transformer.

## 580. Faster Windmill

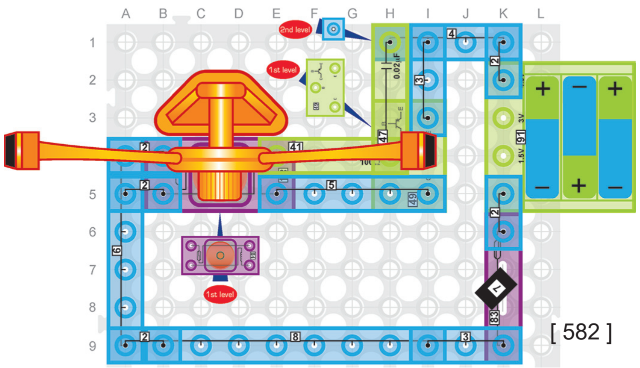
Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a fast rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

The windmill (90) spins a little faster in this circuit because the 0.02μF capacitor (47) provides less capacitance than the 0.1μF capacitor (48). This means that the 0.02μF capacitor (47) will charge up more quickly when the reed switch in the inductor (84) is closed, and by charging up more quickly the current from emitter to collector of the PNP transistor (49) ramps up more quickly, and thus the current through the inductor (84) ramps up more quickly, and thus the magnetic field created by the inductor (84) ramps up more quickly. This means that the magnets on the windmill (90) will begin to be “pushed” through the inductor (84) sooner, which creates more momentum to spin the windmill (90).

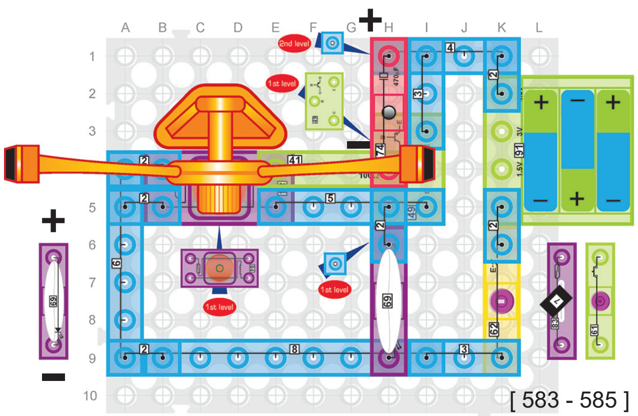
## 581. Core of an Inductor

Replace the switch (62) with the press switch (61) in project #580. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a fast rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

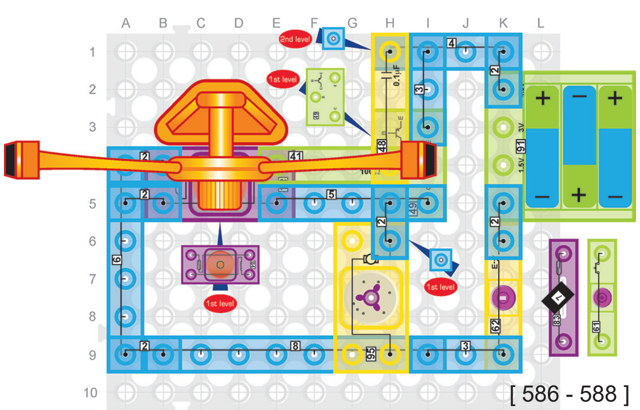
Project #576 provided the approximation for the inductance of a coil. This assumed no core material in the center of the coil. If you wind the coil around a core material, then you can increase the inductance of the inductor by using core materials that have unique magnetic properties like iron.



[ 582 ]



[ 583 - 585 ]



[ 586 - 588 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 582. Solenoid

Build the circuit shown on the left. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a fast rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. A solenoid is very similar to an inductor. A solenoid is also a coil but with a length that is substantially greater than its diameter. The coil is also often wound around a metallic core just like an inductor, but often times the core is mobile (maybe attached to a spring at one end but able to quickly "shoot" out the other end when a current runs through the solenoid, and then the spring pulls it back). The purpose of a solenoid is to create a large, uniform, controlled magnetic field when a current is passed through it for either testing purposes or to launch a core as discussed above. Inductors, on the other hand, are typically used to impede changes in current.

## 583. Slower Flashing Heart

Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a fast rate and the heart LED (69) flash at a fast rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. The windmill (90) spins slower and the heart LED (69) flashes slowly in this circuit because the 470μF capacitor (74) provides more capacitance than the 0.1μF capacitor (48). This means that the 470μF capacitor (74) will charge up more slowly when the reed switch in the inductor (84) is closed, and by charging up more slowly the current from emitter to collector of the PNP transistor (49) ramps up more slowly, and thus the current through the inductor (84) ramps up more slowly, and thus the magnetic field created by the inductor (84) ramps up more slowly. This means that the magnets on the windmill (90) will begin to be "pushed" through the inductor (84) later, which creates less momentum to spin the windmill (90). And since the rate at which the windmill (90) spins determines the rate at which the heart LED (69) flashes, the heart LED (69) flashes slowly.

## 584. Solenoids for Medical Applications

Replace the switch (62) with the press switch (61) in project #583. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a slow rate and the heart LED (69) flash at a slow rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Solenoids are used in medical applications where very precise and accurate magnetic fields are required. For example, solenoids are used in dialysis machines to control a person's blood flow. Dosing machines also use solenoids to control the flow of medicine going into a person's blood stream.

## 585. Solenoids in Pinball Machines

Replace the switch (62) with the reed switch (83) in project #583. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin at a slow rate and the heart LED (69) flash at a slow rate. You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Pinball machines use solenoids for the flippers and bumpers by launching the core as discussed in project #582 whenever the flipper buttons are pressed or the ball hits a bumper.

## 586. Spin the Motor

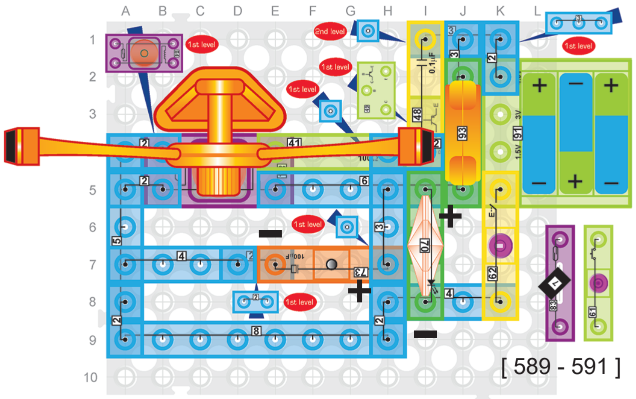
Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the motor (95) will spin each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. In this circuit, each time a magnet closes the reed switch in the inductor (84) causing the PNP transistor (49) to turn on, a burst of current comes out the collector and into the motor (95) which makes the motor (95) spin.

## 587. Induction Motors

Replace the switch (62) with the press switch (61) in project #586. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the motor (95) will spin each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Induction motors use inductors to create magnetic fields produce the current to drive and spin the rotor. This way, an induction motor does not require electrical connections to the rotor. This eliminates the need for brushes, commutators and slip rings in motors that make induction motors more reliable and less expensive.

## 588. Filters

Replace the switch (62) with the reed switch (83) in project #586. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin and the motor (95) will spin each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Inductors are used in electrical circuits to create low pass filters. Low pass filters reject high frequency signals and pass low frequency signals. As discussed in project #573, inductors oppose quick changes in current, which explains why high frequency AC currents are blocked by inductors, while low frequency AC or DC current is passed by inductors (i.e. a low pass filter).



[ 589 - 591 ]

## 589. Flashing Light with Clicking Sound

Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin, the star LED (70) will flash and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

In this circuit, each time a magnet closes the reed switch in the inductor (84) causing the PNP transistor (49) to turn on, a burst of current comes runs through the speaker (93) (making a "click") and into the emitter of the PNP transistor (49), out the collector and into the star LED (70) making it light.

## 590. Details of Faraday's Law of Induction

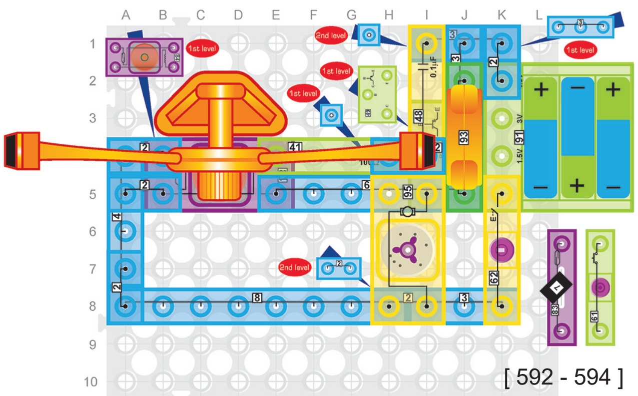
Replace the switch (62) with the press switch (61) in project #589. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin, the star LED (70) will flash and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

The derivation of Faraday's Law of Induction is beyond the scope of this manual, but Faraday's law proved that the induced electromotive force in a closed circuit is equal to the negative of the time rate of change of the magnetic flux enclosed by the circuit. This means that when current flows through an inductor, the magnetic field created by the inductor also creates an electromotive force (or voltage in the case of an inductor coil) in the opposite direction (i.e. a voltage opposing the direction of flow of current that created the magnetic field in the first place). This also explains why inductors oppose fast changes in current.

## 591. Lenz's Law

Replace the switch (62) with the reed switch (83) in project #589. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin, the star LED (70) will flash and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

Lenz's Law is very similar to Faraday's law but stated differently. Lenz's law states that an induced electromotive force generates a current that sets up a magnetic field which acts to oppose the change in magnetic flux. This means that if you held a magnet near a coil or inductor, the change in magnetic field as you move the magnet near the coil of inductor will create a current in the coil or inductor that creates its own magnetic field in the opposite direction of the magnetic field introduced by the magnet.



[ 592 - 594 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 592. Spinning Motor with Clicking Sound

Build the circuit shown and turn on the switch (62). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin, the motor (95) will spin and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. In this circuit, each time a magnet closes the reed switch in the inductor (84) causing the PNP transistor (49) to turn on, a burst of current comes runs through the speaker (93) (making a "click") and into the emitter of the PNP transistor (49), out the collector and into the motor (95) making it spin.

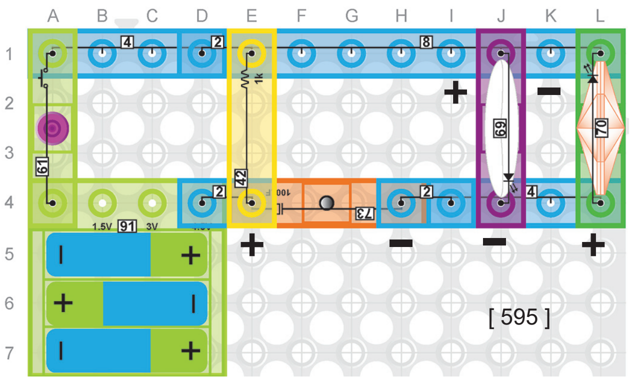
## 593. Solenoids for Locking Doors

Replace the switch (62) with the press switch (61) in project #592. Press and hold the press switch (61). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin, the motor (95) will spin and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning. Another application of a solenoid is for locking and unlocking doors. The key cards you get for hotels have magnetic strips in them, so that when you hold them up to the door where the solenoid is, the solenoid launches the core to lock or unlock the door.

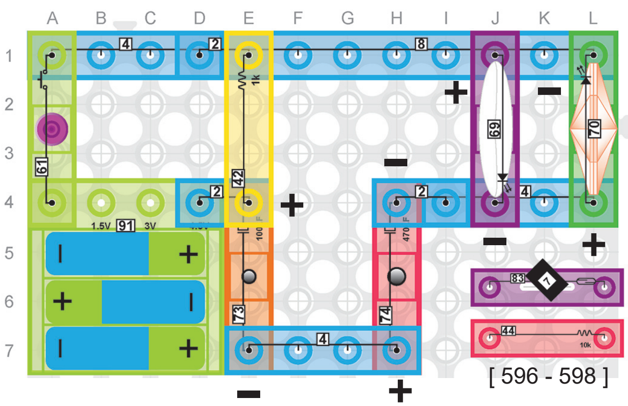
## 594. Variable Inductors

Replace the switch (62) with the reed switch (83) in project #592. Hold the magnet (7) near the reed switch (83). Give the windmill (90) a spin in the counter-clockwise direction and you should see the windmill (90) continue to spin the motor (95) will spin and you will hear a click from the speaker (93) each time a magnet on the windmill (90) passes the inductor (84). You may need to adjust the height and position of the windmill (90) with respect to the inductor (84) to keep the windmill (90) spinning.

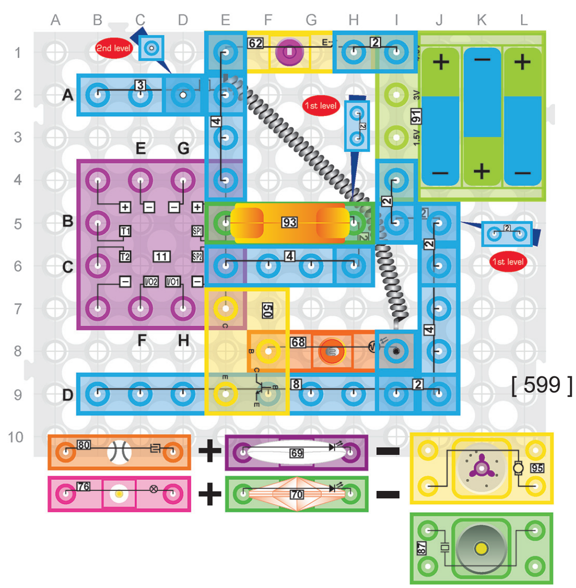
Variable inductors are ones where you can adjust the inductance of the inductor. This is done by have a moveable magnetic core that can be slid in and out of the coil. Sliding the magnetic core further into the coil increases the permeability, which per the equation for inductance from project #576, increases the inductance.



[ 595 ]



[ 596 - 598 ]



[ 599 ]

## 595. Faster Charging and Discharging

Build the circuit shown. Press the press switch (61) and you will see the star LED (70) flash on and then off. Release the press switch (61) and you will see the heart LED (69) flash on and off. Notice that the star LED (70) and heart LED (69) flash on and off more quickly in this project than in project #568. This is because the 100μF capacitor (73) used in this project reduces the RC time constant compared to the 470μF capacitor (74) in project #568. A smaller RC time constant means that the 100μF capacitor (73) will charge and discharge more quickly than the 470μF capacitor (74), which is seen by the LEDs.

## 596. Capacitors in Series

Build the circuit shown. Press the press switch (61) and you will see the star LED (70) flash on and then off. Release the press switch (61) and you will see the heart LED (69) flash on and off. Notice that the star LED (70) and heart LED (69) flash on and off more quickly in this project than in project #568, similar to what was seen in the previous project. This is because the equivalent capacitance of two capacitors in series is given by the formula:

$$C_{Equivalent} = C_1 * C_2/(C_1 + C_2)$$

So the equivalent capacitance of the 100μF capacitor (73) and 470μF capacitor (74) in series is 100*470/(100 + 470) = 82μF. This is close to but less than the capacitance of the 100μF capacitor (73) which is why the LEDs show faster charging and discharging for the series combination of the 100μF capacitor (73) and 470μF capacitor (74).

## 597. Deriving Formula for Capacitors in Series

Replace the press switch (61) with the reed switch (83) in project #596. Hold the magnet (7) near the reed switch (83) and you will see the star LED (70) flash on and then off. Move the magnet (7) away from the reed switch (83) and you will see the heart LED (69) flash on and off. Recall from project #315 that the measure of capacitance, the Farad, was defined as being able to produce 1 Coulomb of charge per volt. In other words, capacitance is charge per volt, or **C = Q/V** where C is in Farads, Q is in Coulombs, and V is in volts. When you have a number of capacitors in series as shown below, then to find the equivalent capacitance we start with $C_{Equivalent} = Q/V$ for the circuit.

Now we know that the current through each capacitor must be the same because they are in series. This means that the charge on each capacitor must be the same, regardless of the individual capacitance of each capacitor, and that this is the same charge Q as for the series circuit of capacitors. So this means that:

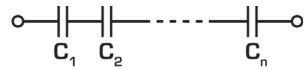
$$C_1 = Q/V_1,\ C_2 = Q/V_2, \ldots, C_n = Q/Vn.$$

This implies that: $V_1 = Q/C_1,\ V_2 = Q/C_2, \ldots,\ V_n = Q/C_n$.

Now through Kirchhoff's voltage law we know that $V = V_1 + V_2 + \ldots + V_n$.

This means that $V = Q/C_1 + Q/C_2 + \ldots + Q/C_n$.

Therefore, $C_{Equivalent} = Q/V = Q\ /(Q/C_1 + Q/C_2 + \ldots + Q/C_n) = 1/(1/C_1 + 1/C_2 + \ldots + 1/C_n)$.




## 598. Slower Charging and Discharging

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in project #596. Press the press switch (61) and you will see the star LED (70) flash on and then off. Release the press switch (61) and you will see the heart LED (69) flash on and off. Notice that the star LED (70) and heart LED (69) flash on and off more slowly in this project than in project #596. This is because the 10kΩ resistor (44) in this circuit increases the RC time constant, which results in the capacitors charging and discharging more slowly.

## 599. Light-controlled High Volume Siren

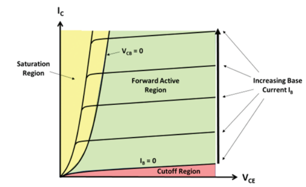
Build the circuit shown. Press the switch (62) and you will hear the siren at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off.

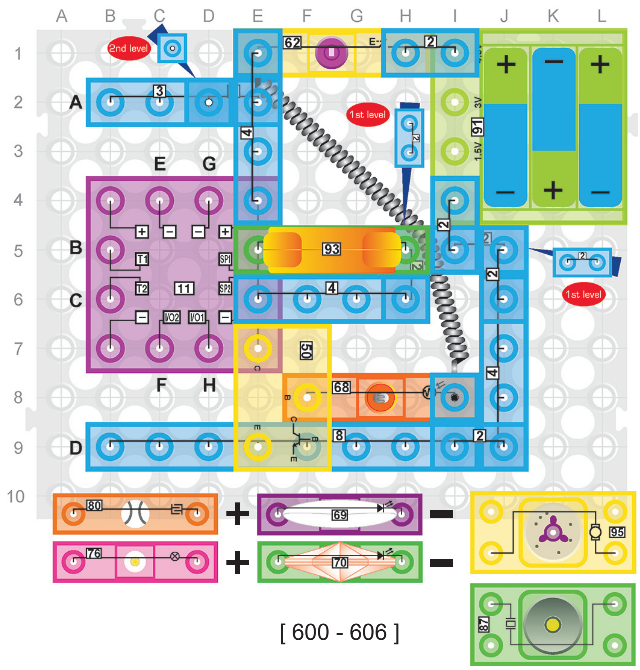
While light is shining on the photoresistor (68), the resistance of the photoresistor (68) is low, which enables current to flow to the base of the NPN transistor (50), that turns on the NPN transistor (50) enabling current to flow from the "–" terminal of the 3-in-1 (11) module to ground, which makes the siren sound. When you block light from getting to the photoresistor (68), this increases the resistance of the photoresistor (68), which stops current from flowing to the base of the NPN transistor (50), that turns off the NPN transistor (50) disabling the current flow from the "–" terminal of the 3-in-1 (11) module to ground, and then the siren turns off.

## 600. Transistor Characteristic Chart

Place the touch plate (80) across points C and D in project #599 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots will go off.

Typical transistor specifications where shown in project #517 and were discussed in the subsequent projects. Often times these specifications are easier to understand when shown in a graph form as in the figure below, which shows the collector current ($I_C$) as a function of the collector-emitter voltage ($V_{CE}$) for an NPN transistor. Note that the base currents for the curves shown in the chart are positive in value and increasing as you go up the chart.



[ 600 - 606 ]

## 601. Forward Active Region for NPN Transistor

Place a 4-wire (4) across points A and B in project #599 and press the switch (62). You will hear a fire siren at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off. Based on the figure in project #600, it can be seen that an NPN transistor will be operating in forward active mode as long as the collector to base voltage is positive (to the right of the $V_{CB}$ = 0 line), and there is a positive base current (above the $I_B$ = 0 line).

## 602. Saturation Region for NPN Transistor

Place a 4-wire (4) across points E and F in project #599 and press the switch (62). You will hear space battle sounds at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. Based on the figure in project #600, it can be seen that an NPN transistor will be operating in saturation mode if the collector-base voltage is negative (i.e. the base voltage is higher than the collector voltage, or to the left of the $V_{CB}$ = 0 line).

## 603. Cutoff Region for NPN Transistor

Place a 4-wire (4) across points G and H in project #599 and press the switch (62). You will hear music at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off. Based on the figure in project #600, it can be seen that an NPN transistor will be operating in cutoff mode if there is no current flowing into the base (below the $I_B$ = 0 line).

## 604. Light-controlled Flickering Light

Replace the speaker (93) with the heart LED (69) in project #599. Press the switch (62) and you will see the heart LED (69) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) will go off. This project lets you turn on and off the flickering heart LED (69), just like you turned on and off the siren as discussed in project #599. But now the siren audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the siren audio levels and frequencies of the siren audio signal change quickly, the heart LED (69) flashes quickly.

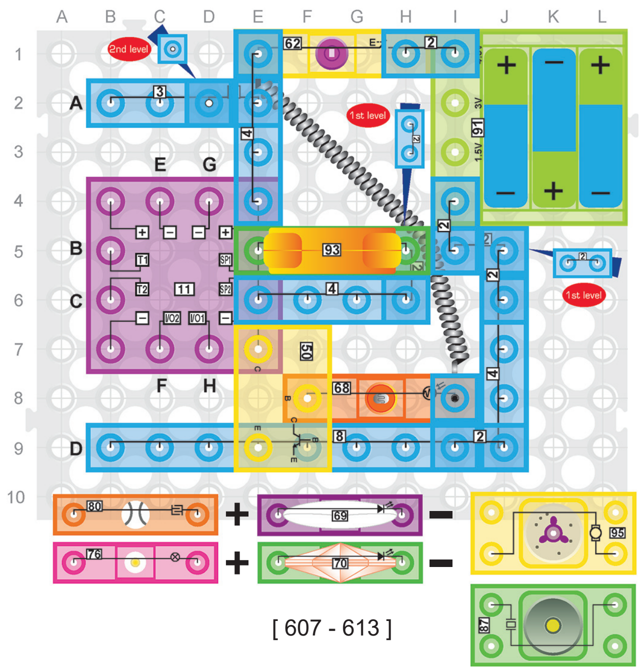
## 605. Light-controlled Heartbeat

Place a 4-wire (4) across points G and H in project #604. Press the switch (62) and you will see the heart LED (69) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) will go off.

This project lets you turn on and off the flickering heart LED (69), just like you turned on and off the siren as discussed in project #599. But now the music audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the music audio levels and frequencies of the music audio signal change more slowly, the heart LED (69) flashes more slowly like a heartbeat.

## 606. Light-controlled Medium Volume

Replace the speaker (93) with the buzzer (87) in project #599. Press the switch (62) and you will hear the siren at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off. As discussed in project #283, the reason the volume from the buzzer (87) is lower than that from the speaker is because the buzzer (87) is a high input impedance device which limits the current through it. If you had an Ammeter and measure the current through the buzzer in this circuit, you would see that it's much, much less than even 1 mA!



[ 607 - 613 ]

## 607. What Happened to the Reverse Active Region?

Place the touch plate (80) across points C and D in project #606 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots will go off.

Notice that the figure in project #600 does not show a reverse active region. Recall from project #506 that an NPN transistor is in reverse active mode when the emitter voltage is greater than the base voltage which is greater than the collector voltage. So the reverse active region in the figure in project #600 would be to the left of the $I_C$ axis (i.e. where $V_{CE}$ would be negative). Since transistors are not designed to operate in the reverse active region, this region is typically not shown in transistor characteristic graphs like the one shown in project #600.

## 608. Reading the Gain β from the NPN Transistor Characterization Graph

Place a 4-wire (4) across points A and B in project #606 and press the switch (62). You will hear a fire siren at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off.

Recall from project #343 and subsequent projects that the gain of a transistor is the ratio of the collector to base current, and that the gain depends on the mode of operation of the transistor. You can determine the gain β of a transistor from its characteristic graph like the one in project #600 by reading it from the various base current ($I_B$) curves. For each $I_B$ curve, you can look along the curve and for a given $V_{CE}$ see what the collector current $I_C$ is, and then calculate the β by dividing the collector current $I_C$ by the base $I_B$.

## 609. Good NPN Transistor Design

Place the a 4-wire (4) across points E and F in project #606 and press the switch (62). You will hear space battle sounds at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. Ideally, transistors are designed so that when operating in the forward active region, the gain β is nearly constant. This would be the case, for instance, if the $I_B$ curves in the figure in project #600 were completely flat and if the label on each $I_B$ curve increased proportionally to $I_C$. In other words, if the curve labeled $I_B$ = x was flat at the level $I_C$ = y, then for any positive value c, the curve labeled $I_B$ = c*x would be flat at a value of $I_C$ = c*y.

## 610. Variations from Ideal β with $V_{CE}$

Place a 4-wire (4) across points G and H in project #606 and press the switch (62). You will hear music at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off. While project #609 discussed the ideal characteristics of an NPN transistor, the figure shown in project #600 shows that the $I_B$ = 0 curves are not flat, but actually increase slightly in the forward active region as $V_{CE}$ increases. So even in forward active mode, the β of an NPN transistor is not completely constant. This is not usually a big issue because the $I_B$ curves are almost flat, and the slight increases in $I_C$ as $V_{CE}$ increases will only lead to a slightly higher β anyways. And transistor manufacturers try to design the $I_B$ = x lines to increase as linearly as possible with $I_C$.

## 611. β in Saturation

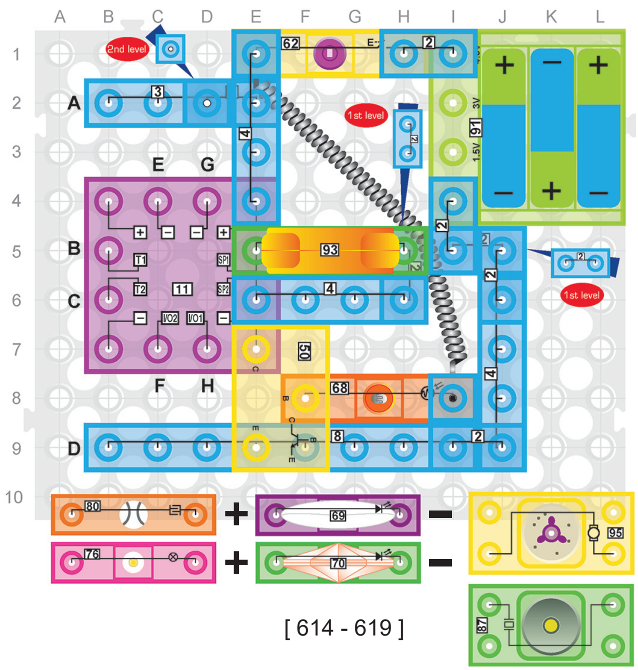
Replace the speaker (93) with the star LED (70) in project #606. Press the switch (62) and you will see the star LED (70) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) will go off. From the figure in project #600, it can be seen that when in the saturation region, the current $I_C$ becomes the same regardless of the value of $I_B$. This means that for a given operating $I_C$, the gain β reduces as $I_B$ increases in the saturation region. Transistors intended to provide gain are not generally operated in the saturation region because it can lead to very poor gain.

## 612. Using the NPN Transistor in Saturation Mode as a Switch

Place a 4-wire (4) across points G and H in project #611. Press the switch (62) and you will see the star LED (70) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) will go off. While operating NPN transistors in saturation mode are not ideal for proving gain, saturation mode is useful when using the NPN transistor as a switch. As can be seen from the figure in project #600, for a given low $V_{CE}$, the collector current $I_C$ switches "ON" to a fixed value once $I_B$ > 0 (and stays there no matter how large $I_B$ becomes) and switches "OFF" ($I_C$ = 0) when $I_B$ = 0.

## 613. Light-controlled Low Volume Siren

Replace the speaker (93) with the motor (95) in project #599. Press the switch (62) and you will hear the siren at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off. As discussed in project #192, the shell of the motor (95) can act like the cone in a speaker, which is why you hear the siren from the motor (95). The volume from the motor (95) is much lower than that from the speaker (93) because the cone in the speaker (93) is designed acoustically to more efficiently transfer the energy from the vibrations in the cone to airwaves.




[ 614 - 619 ]

## 614. Insulated Gate FET Transistors

Place the touch plate (80) across points C and D in project #613 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots will go off. MOSFET transistors were discussed on project #435. Another term for MOSFET is Insulated Gate FET (IGFET) transistors.

## 615. Types of MOSFETs

Place a 4-wire (4) across points A and B in project #613 and press the switch (62). You will hear a fire siren at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off. There are actually 4 different types of MOSFET transistors. MOSFETS can be either depletion mode or enhanced mode, and can be either n-channel or p-channel.

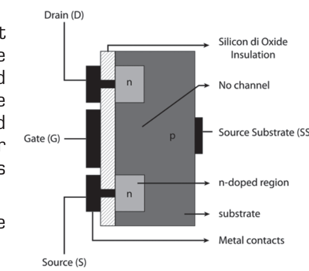
## 616. Depletion vs. Enhanced Mode MOSFETs

Place a 4-wire (4) across points E and F in project #613 and press the switch (62). You will hear space battle sounds at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. The difference between depletion mode MOSFETs and enhanced mode MOSFETs are the state that the transistor is in when the gate of the transistor is an open circuit. Depletion mode MOSFETs are normally "ON" when the gate is open, while enhanced mode MOSFETs are normally "OFF" when the gate is open.

## 617. N-channel Enhancement Mode MOSFET

Place a 4-wire (4) across points G and H in project #613 and press the switch (62). You will hear music at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off.

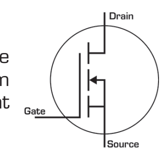
The figure to the right shows an n-type enhancement mode MOSFET. An open circuit at the gate leads to the transistor being in the "OFF" state normally. Then when a positive voltage is applied to the gate, this attracts electrons in the oxide layer to the gate and pushing holes away from the gate. With an excess of holes in the oxide layer near the p-type substrate, electrons in the p-type substrate are attracted to the oxide layer and form an n-channel between the two n-type doped regions, turning "ON" the transistor enabling current to flow from the Drain to the Source (assuming a positive voltage is applied from drain to source).




The term "enhancement" comes from the applied voltage at the gate "enhancing" the flow of current between the two n-type doped regions through the induced n-channel.

## 618. N-channel Enhancement Mode MOSFET Symbol

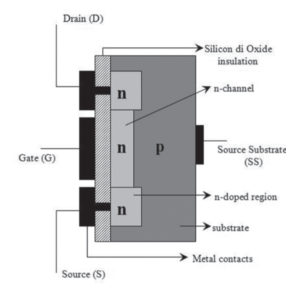
Replace the speaker (93) with the lamp (76) in project #613. Press the switch (62) and you will see the lamp (76) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the lamp (76) will go off. The symbol for an N-channel enhancement mode MOSFET is shown on the right.




## 619. N-channel Depletion Mode MOSFET

Place a 4-wire (4) across points G and H in project #618. Press the switch (62) and you will see the lamp (76) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the lamp (76) will go off.

The figure to the right shows an n-type depletion mode MOSFET. Note that the main difference with the depletion mode MOSFET is the existence of an n-channel in the p-type substrate. An open circuit at the gate leads to the transistor being in the "ON" state normally due to the existing n-channel. Then when a positive voltage is applied to the gate, this attracts holes in the oxide layer to the gate and pushing electrons away from the gate. With an excess of electrons in the oxide layer near the p-type substrate, holes in the p-type substrate are attracted to the oxide layer and deplete the n-channel between n-type doped regions. This stops the flow of current and turns "OFF" the transistor.

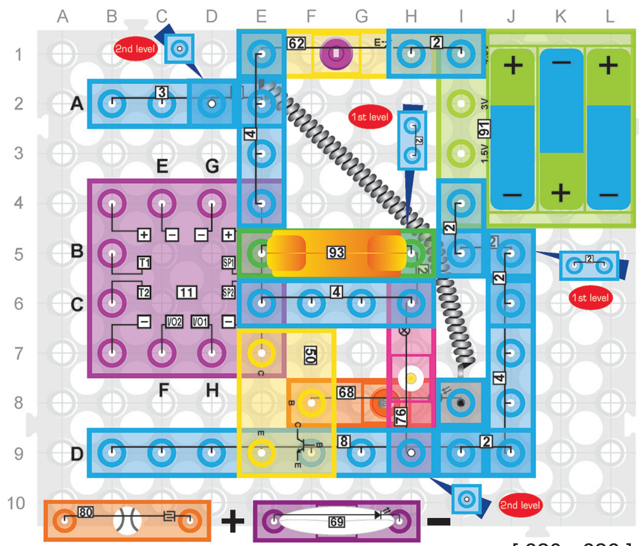



The term "depletion" comes from the applied voltage at the gate "depleting" the n-channel which cuts off the flow of current between the two n-type doped regions.

## 620. Light-controlled High Volume Siren and Lamp

Build the circuit shown. Press the switch (62) and you will hear the siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off.

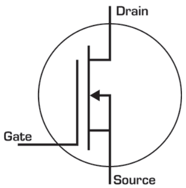
The siren audio signal from the 3-in-1 (11) produces voltage variations through the speaker (93) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the speaker (93).



[ 620 - 626 ]

## 621. N-channel Depletion Mode MOSFET Symbol

Place the touch plate (80) across points C and D in project #620 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off. The symbol for an N-channel depletion mode MOSFET is shown on the right.




## 622. Enhanced vs. Depletion Mode Tradeoffs

Place a 4-wire (4) across points A and B in project #620 and press the switch (62). You will hear a fire siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off.

The main tradeoff between enhancement mode MOSFETs and depletion mode MOSFETs is the generally "OFF" vs. generally "ON" state of the transistor when the gate is open. For some applications it may be beneficial to have the transistor "OFF" unless a voltage is applied to the gate, while for other applications it may be beneficial to have the transistor "ON" unless a voltage difference is applied across the source-gate.

In addition, enhancement mode MOSFETs can have issues with leakage current from source to drain because the drain and source terminals are typically closer physically. This is not the problem with depletion mode MOSFETs because a pinched channel stops the current from source to drain completely.

## 623. Benefits of MOSFETs vs. JFETs: Enhancement Mode

Place a 4-wire (4) across points E and F in project #620 and press the switch (62). You will hear space battle sounds at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off.

JFET transistors were discussed in projects #434 and #513. One benefit of MOSFET transistors is that they can be operated in both enhancement and depletion mode, whereas JFET transistors only operate in depletion mode.

## 624. Benefits of MOSFETs vs. JFETs: Input Impedance

Place a 4-wire (4) across points G and H in project #620 and press the switch (62). You will hear music at high volume from the speaker (93) and see the lamp (76) beating dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off.

Another benefit of MOSFET transistors is that they generally have higher input impedance than JFET transistors because they typically have very small leakage current.

## 625. Benefits of JFETs vs. MOSFETs: Characteristic Curves

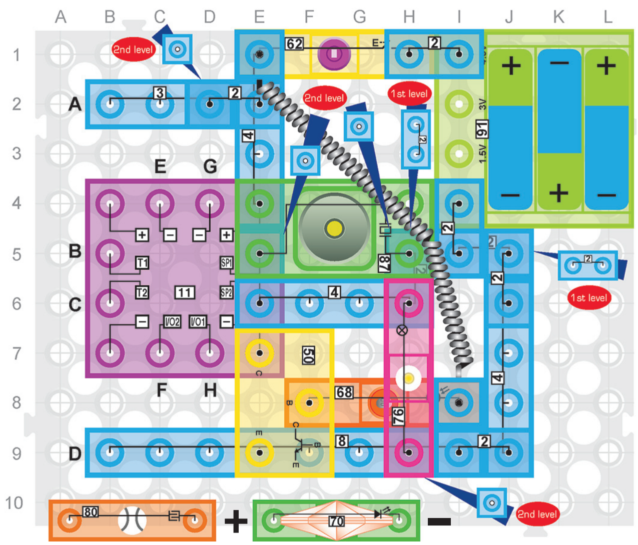
Replace the speaker (93) with the heart LED (69) in project #620. Press the switch (62) and you will see the heart LED (69) and lamp (76) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and lamp (76) will go off.

One of the benefits of JFET transistors is that they typically have characteristic curves flatter than those of MOSFETs due to larger drain resistance. Also, the oxide layer between the gate and the channel in MOSFETs is very fragile, and thus much care must be taken to avoid damage by electro-statics during installation. Finally, MOSFETs are susceptible to overload voltages, so again care must be taken during installation.

## 626. Benefits of MOSFETs vs. JFETs: Manufacturing

Place a 4-wire (4) across points G and H in project #625. Press the switch (62) and you will see the heart LED (69) and lamp (76) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and lamp (76) will go off.

One of the benefits of MOSFET transistors is that they are generally easier to manufacture than JFET transistors.



[ 627 - 633 ]

## 627. Light-controlled Medium Siren and Lamp

Build the circuit shown. Press the switch (62) and you will hear the siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off.

The siren audio signal from the 3-in-1 (11) produces voltage variations through the buzzer (87) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the buzzer (87).

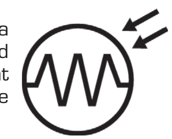
## 628. Source Substrate Terminal of MOSFET

Place the touch plate (80) across points C and D in project #627 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off.

You may have noticed there was a Source Substrate terminal on the MOSFET figures in projects #617 and #619. This is sometimes called the Body terminal. Usually this terminal is grounded, but a bias voltage could also be applied to it to adjust the turn on voltage of the transistor.

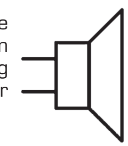
## 629. Symbol for the Photoresistor

Place a 4-wire (4) across points A and B in project #627 and press the switch (62). You will hear a fire siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off. The symbol for the photoresistor (68) is shown on the right.



## 630. Symbol for the Speaker

Place a 4-wire (4) across points E and F in project #627 and press the switch (62). You will hear space battle sounds at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off. The symbol for the speaker (93) is shown on the right, which we can also use to represent the buzzer (87).



## 631. Symbol for the Lamp

Place a 4-wire (4) across points G and H in project #627 and press the switch (62). You will hear music at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off. Below is the symbol for the lamp (76).

## 632. Light-controlled Synchronized Lights

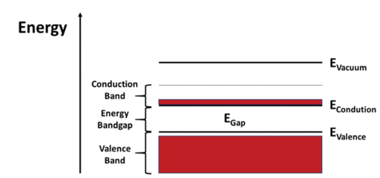
Replace the buzzer (87) with the star LED (70) in project #627. Press the switch (62) and you will see the star LED (70) flickering and see the lamp (76) flickering dimly while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) and lamp (76) will go off.

The siren audio signal from the 3-in-1 (11) produces voltage variations through the star LED (70) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the star LED (70). This circuit could be used to synchronize flashing lights on a stage and turn them on and off with the wave of a hand over the photoresistor (68).

## 633. Energy Bands

Place a 4-wire (4) across points G and H in project #632. Press the switch (62) and you will see the star LED (70) beating and see the lamp (76) flickering dimly while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) and lamp (76) will go off.

Project #298 discussed the photoresistor (68). In order to better understand how the photoresistor (68) provides low resistance when in light and high resistance when in darkness, it is important to understand energy bands for semiconductors. Below is a figure that shows the valence band, conduction band and bandgap for semiconductors.



## 634. Light-controlled Low Siren and Lamp

Build the circuit shown. Press the switch (62) and you will hear the siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off.

The siren audio signal from the 3-in-1 (11) produces voltage variations through the motor (95) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the motor (95).

## 635. Valence Band

Place the touch plate (80) across points C and D in project #634 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off.

Any semiconductor material is made up of atoms with groups of electrons that orbit around the atoms. The valence band consists of electrons that have the lowest energy level as shown in the figure in project #633. However, the electrons in the valence band, called valence electrons, are the ones furthest from the nucleus (i.e. the center) of the atom which are thus the most likely to move out of the valence band (when excited) and into the conduction band.

## 636. Conduction Band

Place a 4-wire (4) across points A and B in project #634 and press the switch (62). You will hear a fire siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off. The conduction band is the group of electron orbitals that electrons can jump into from the valence band when excited. Once electrons are in the conduction band, they then have enough energy to move freely in the semiconductor material, which then enables the flow of current.

## 637. Energy Gap

Place a 4-wire (4) across points E and F in project #634 and press the switch (62). You will hear space battle sounds at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off.

The energy difference between the highest occupied energy state of the valence band and the lowest unoccupied energy state of the conduction band is called the energy band gap. The energy band gap is indicative of the conductivity of a material. Larger energy band gaps mean that a lot of energy is needed to excite valence electrons to the conduction band, making the material not very conductive. Smaller energy band gaps and cases where the valence and conduction bands overlap (like in metals) require little energy to excite valence electrons to the conduction band and electrons can more freely move between the two bands making the material more conductive.

## 638. Conductors, Non-Conductors and Semiconductors

Place a 4-wire (4) across points G and H in project #634 and press the switch (62). You will hear music at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off.

The energy band graph for a given material, like the one shown in project #633, is helpful in understanding the properties of the material. Insulators are characterized by a large band gap, so an excessively large amount of energy is required to move electrons out of the valence band and into the conduction band to enable current to flow through the material. Conversely, conductors have overlapping conduction and valence bands, so that valence electrons can freely move to the conductance band, and hence current can easily flow through the material. Semiconductors, on the other hand, have a small band gap that enables some percentage of the valence electrons of the material to move from the valence band into the conduction band given a reasonable amount of energy. Thus, semiconductors have conductivity properties that fall between that of an insulator and a conductor, and make them ideal for being able to switch from one to the other with an applied energy (or voltage/current).

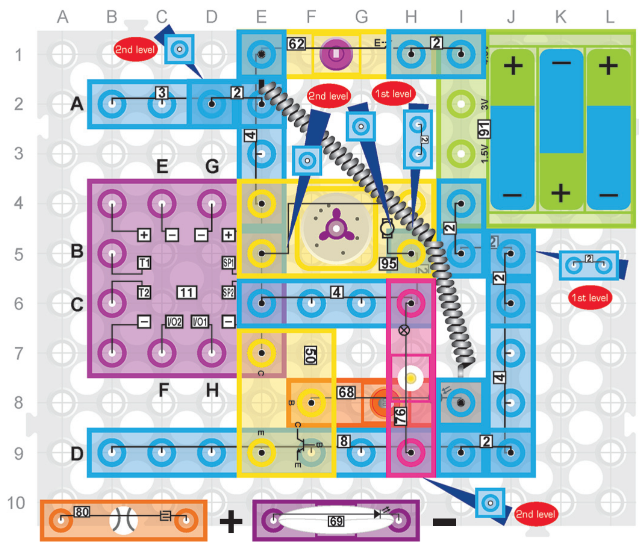
## 639. Photons

Replace the motor (95) with the heart LED (69) and replace the lamp (76) with the star LED (70) in project #634. Press the switch (62) and you will see the heart LED (69) and star LED (70) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and star LED (70) will go off. Photons are particles in light as well as in electromagnetic radiation that carry energy. So when light is shined on the photoresistor (68), energy in the form of photons is exposed to the semiconductor material in the photoresistor (68).

## 640. Understanding the Photoresistor

Place a 4-wire (4) across points G and H in project #639. Press the switch (62) and you will see the heart LED (69) and star LED (70) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and star LED (70) will go off.

When light is exposed to the photoresistor (68), the energy in the photons from the light excite the electrons in the valence band, increasing their energy levels and allowing them to cross the energy gap into the conduction band. More/brighter light shining on the photoresistor (68) will lead to more valence electrons moving to the conduction band. This in turn means there are more electrons available to conduct electricity, and thus the resistance of the photoresistor reduces as the light energy increases.



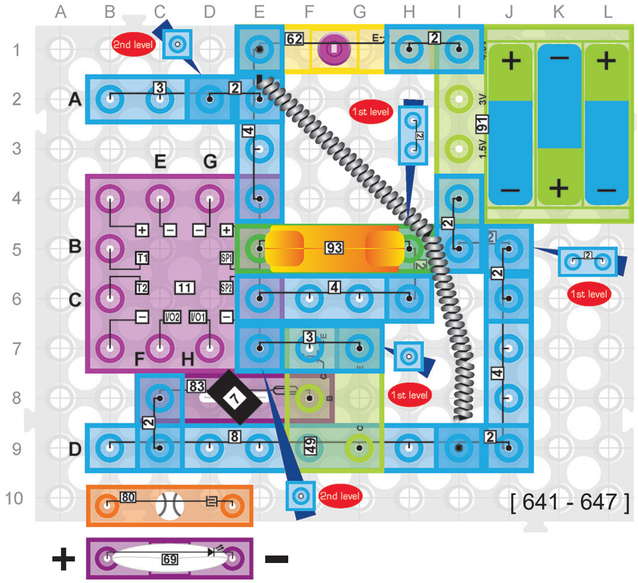

[ 634 - 640 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 641. Magnet-controlled High Volume Siren

Build the circuit shown. Press the switch (62), place the magnet (7) near the reed switch (83) and you will hear the siren at high volume from the speaker (93). Move the magnet (7) away from the reed switch (83) and the siren will go off.

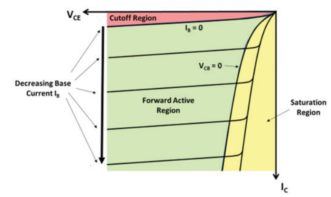
While the magnet (7) is near the reed switch (83), this enables current to flow out of the base of the PNP transistor (49), that turns on the PNP transistor (49) enabling current to flow from the "–" terminal of the 3-in-1 (11) module to ground, which makes the siren sound. When you move the magnet (7) away from the reed switch (83), this stops current from flowing from the base of the PNP transistor (49), that turns off the PNP transistor (49) disabling the current flow from the "–" terminal of the 3-in-1 (11) module to ground, and then the siren turns off.




## 642. Transistor Characteristic Chart

Place the touch plate (80) across points C and D in project #641, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93). Move the magnet (7) away from the reed switch (83) and the gun shots will go off.

Typical transistor specifications where shown in project #517 and were discussed in the subsequent projects. Often times these specifications are easier to understand when shown in a graph form as in the figure below, which shows the collector current ($I_C$) as a function of the collector-emitter voltage ($V_{CE}$) for a PNP transistor. Note here that negative current means current flowing out of the base and current flowing from emitter to collector. The base currents corresponding to the curves shown in the chart are negative and decreasing as you go down the chart.




## 643. Forward Active Region for PNP Transistor

Place a 4-wire (4) across points A and B in project #641, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at high volume from the speaker (93). Move the magnet (7) away from the reed switch (83) and the fire siren will go off. Based on the figure in project #642, it can be seen that a PNP transistor will be operating in forward active mode as long as the collector to base voltage is negative (to the left of the $V_{CB}$ = 0 line), and there is a negative base current (below the $I_B$ = 0 line).

## 644. Saturation Region for PNP Transistor

Place a 4-wire (4) across points E and F in project #641, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at high volume from the speaker (93). Move the magnet (7) away from the reed switch (83) and the space battle sounds will go off. Based on the figure in project #642, it can be seen that a PNP transistor will be operating in saturation mode if the collector-base voltage is positive (i.e. to the right of the $V_{CB}$ = 0 line).

## 645. Cutoff Region for PNP Transistor

Place a 4-wire (4) across points G and H in project #641, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at high volume from the speaker (93). Move the magnet (7) away from the reed switch (83) and the music will go off. Based on the figure in project #642, it can be seen that a PNP transistor will be operating in cutoff mode if there is no current flowing out of the base (above the $I_B$ = 0 line).

## 646. Magnet-controlled Flickering Light

Replace the speaker (93) with the heart LED (69) in project #641, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) flickering. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will go off. This project lets you turn on and off the flickering heart LED (69), just like you turned on and off the siren as discussed in project #641. But now the siren audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the siren audio levels and frequencies of the siren audio signal change quickly, the heart LED (69) flashes quickly.

## 647. Magnet-controlled Heartbeat

Place a 4-wire (4) across points G and H in project #646, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) beating. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will go off. This project lets you turn on and off the flickering heart LED (69), just like you turned on and off the siren as discussed in project #641. But now the music audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the music audio levels and frequencies of the music audio signal change more slowly, the heart LED (69) flashes more slowly like a heartbeat.

## 648. Magnet-controlled Medium Volume Siren

Build the circuit shown. Press the switch (62) and place the magnet (7) near the reed switch (83). You will hear the siren at medium volume from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the siren will go off.

As discussed in project #283, the reason the volume from the buzzer (87) is lower than that from the speaker is because the buzzer (87) is a high input impedance device which limits the current through it.

## 649. What Happened to the Reverse Active Region?

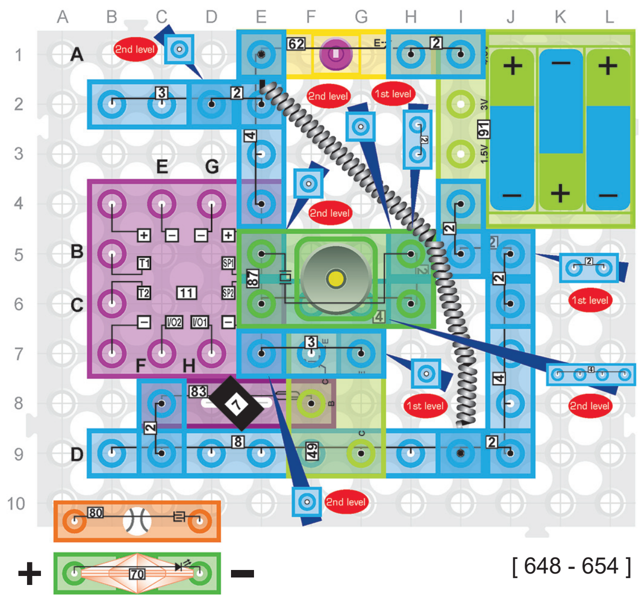
Place the touch plate (80) across points C and D in project #648, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the gun shots will go off.

Notice that the figure in project #642 does not show a reverse active region. Recall from project #507 that a PNP transistor is in reverse active mode when the emitter voltage is less than the base voltage which is less than the collector voltage. So the reverse active region in the figure in project #642 would be to the right of the $I_C$ axis (i.e. where $V_{CE}$ would be positive). Since transistors are not designed to operate in the reverse active region, this region is typically not shown in transistor characteristic graphs like the one shown in project #642.

## 650. Reading the Gain β from the PNP Transistor Characterization Graph

Place a 4-wire (4) across points A and B in project #648, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at medium volume from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the fire siren will go off.

Recall from project #343 and subsequent projects that the gain of a transistor is the ratio of the collector to base current, and that the gain depends on the mode of operation of the transistor. You can determine the gain β of a transistor from its characteristic graph like the one in project #642 by reading it from the various base current ($I_B$) curves. For each $I_B$ curve, you can look along the curve and for a given $V_{CE}$ see what the collector current $I_C$ is, and then calculate the β by dividing the collector current $I_C$ by the base $I_B$.



[ 648 - 654 ]

## 651. Good PNP Transistor Design

Place a 4-wire (4) across points E and F in project #648, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at medium volume from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the sounds of space battle will go off.

Ideally, transistors are designed so that when operating in the forward active region, the gain β is nearly constant. This would be the case, for instance, if the $I_B$ curves in the figure in project #642 were completely flat and if the label on each $I_B$ curve decreased proportionally to $I_C$. In other words, if the curve labeled $I_B$ = x was flat at the level $I_C$ = y, then for any positive value c, the curve labeled $I_B$ = c*x would be flat at a value of $I_C$ = c*y.

## 652. Variations from Ideal β with $V_{CE}$

Place a 4-wire (4) across points G and H in project #648, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at medium volume from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the music will go off.

While project #651 discussed the ideal characteristics of a PNP transistor, the figure shown in project #642 shows that the $I_B$ = 0 curves are not flat, but actually decrease slightly in the forward active region as $V_{CE}$ decreases. So even in forward active mode, the β of a PNP transistor is not completely constant. This is not usually a big issue because the $I_B$ curves are almost flat, and the slight decreases in $I_C$ as $V_{CE}$ decreases will only lead to a slightly higher β anyways. And transistor manufacturers try to design the $I_B$ = x lines to increase as linearly as possible with $I_C$.

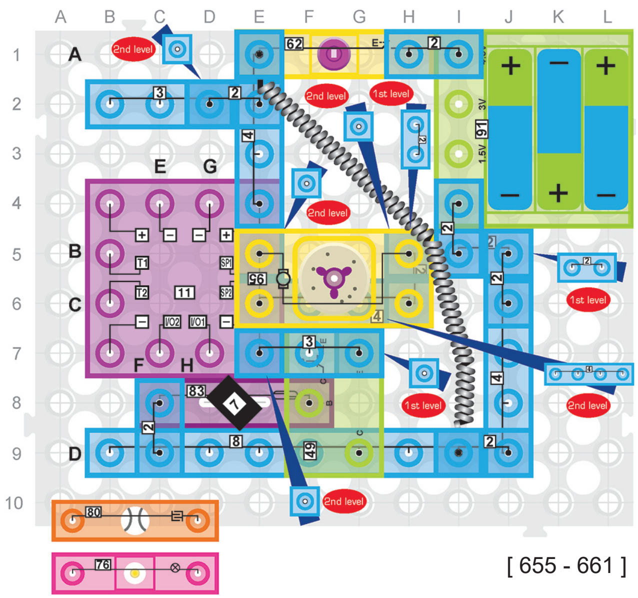
## 653. β in Saturation

Replace the buzzer (87) with the star LED (70) in project #648. Press the switch (62) and place the magnet (7) near the reed switch (83). You will see the star LED (70) flickering. Move the magnet (7) away from the reed switch (83) and the star LED (70) will go off.

From the figure in project #642, it can be seen that when in the saturation region, the current $I_C$ becomes the same regardless of the value of $I_B$. This means that for a given operating $I_C$, the gain β reduces as $I_B$ decreases in the saturation region. Transistors intended to provide gain are not generally operated in the saturation region because it can lead to very poor gain.

## 654. Using the PNP Transistor in Saturation Mode as a Switch

Place a 4-wire (4) across points G and H in project #653. Press the switch (62) and place the magnet (7) near the reed switch (83). You will see the star LED (70) beating. Move the magnet (7) away from the reed switch (83) and the star LED (70) will go off. While operating PNP transistors in saturation mode are not ideal for proving gain, saturation mode is useful when using the PNP transistor as a switch. As can be seen from the figure in project #642, for a given high $V_{CE}$, the collector current $I_C$ switches "ON" to a fixed value once $I_B$ < 0 (and stays there no matter how small $I_B$ becomes) and switches "OFF" ($I_C$ = 0) when $I_B$ = 0.



[ 655 - 661 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 655. Magnet-controlled Low Volume Siren

Build the circuit shown. Press the switch (62) and place the magnet (7) near the reed switch (83). You will hear the siren at low volume from the motor (95). Move the magnet (7) away from the reed switch (83) and the siren will go off. As discussed in project #192, the shell of the motor (95) can act like the cone in a speaker, which is why you hear the siren from the motor (95). The volume from the motor (95) is much lower than that from the speaker (93) because the cone in the speaker (93) is designed acoustically to more efficiently transfer the energy from the vibrations in the cone to airwaves.

## 656. NPN vs. PNP

Place the touch plate (80) across points C and D in project #655, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95). Move the magnet (7) away from the reed switch (83) and the gun shots will go off. There are not many theoretical advantages or disadvantages of using an NPN vs. PNP transistor. However, there may be technical advantages based on actual NPN and PNP transistor designs available in the market.

## 657. NPN vs. PNP Reference Point

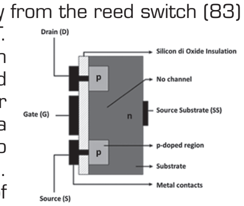
Place a 4-wire (4) across points A and B in project #655, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at low volume from the motor (95). Move the magnet (7) away from the reed switch (83) and the fire siren will go off. One of the differences between NPN and PNP transistors is that the turn on voltage for an NPN is referenced to ground, while the turn on voltage for a PNP is referenced to the supply voltage (often called B+).

## 658. Convenience of NPN vs. PNP

Place a 4-wire (4) across points E and F in project #655, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at low volume from the motor (95). Move the magnet (7) away from the reed switch (83) and the sounds of space battle will go off. Since many ICs use ground as the reference, for convenience NPN transistors may be preferred over PNP transistors. This is not a technical or theoretical reason and for pretty much any application either NPN or PNP transistors can be used. But if you are working with a circuit based on common ground then for convenience you may choose to use an NPN, and if you are working with a circuit that uses common B+, then for convenience you may choose to use a PNP. For instance, many ICs use common ground and for this reason NPN transistors may be more commonly used.

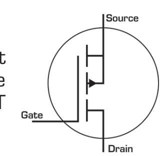
## 659. P-channel Enhancement Mode MOSFET

Place a 4-wire (4) across points G and H in project #655, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at low volume from the motor (95). Move the magnet (7) away from the reed switch (83) and the music will go off. The figure on the right shows an p-type enhancement mode MOSFET. An open circuit at the gate leads to the transistor being in the “OFF” state normally. Then when a negative voltage is applied to the gate, this attracts holes in the oxide layer to the gate and pushing electrons away from the gate. With an excess of electrons in the oxide layer near the n-type substrate, holes in the n-type substrate are attracted to the oxide layer and form a p-channel between the two p-type doped regions, turning “ON” the transistor enabling current to flow from the Source to the Drain (assuming a positive voltage is applied from source to drain). The term “enhancement” comes from the applied voltage at the gate “enhancing” the flow of current between the two p-type doped regions through the induced p-channel.



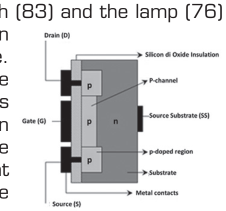

## 660. P-channel Enhancement Mode MOSFET Symbol

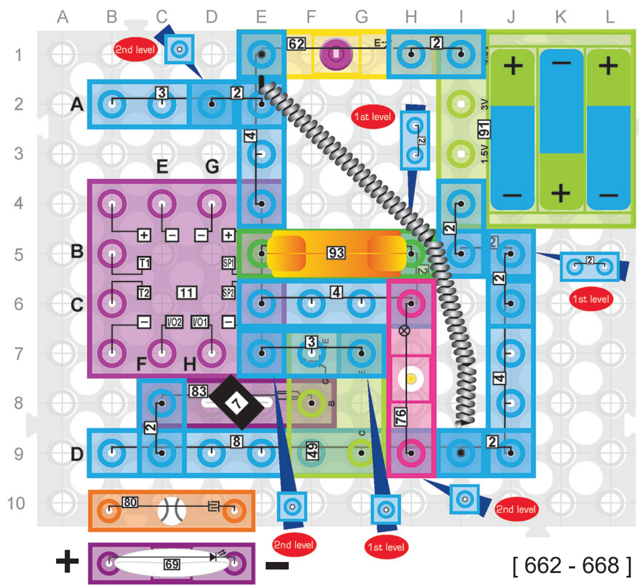
Replace the speaker (93) with the lamp (76) in project #655, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the lamp (76) flickering. Move the magnet (7) away from the reed switch (83) and the lamp (76) will go off. The symbol for an P-channel enhancement mode MOSFET is shown on the right.




## 661. P-channel Depletion Mode MOSFET

Place a 4-wire (4) across points G and H in project #660, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the lamp (76) beating. Move the magnet (7) away from the reed switch (83) and the lamp (76) will go off. The figure on the right shows an p-type depletion mode MOSFET. Note that the main difference with the depletion mode MOSFET is the existence of an p-channel in the n-type substrate. An open circuit at the gate leads to the transistor being in the “ON” state normally due to the existing p-channel. Then when a negative voltage is applied to the Gate, this attracts electrons in the oxide layer to the gate and pushing holes away from the gate. With an excess of holes in the oxide layer near the n-type substrate, electrons in the n-type substrate are attracted to the oxide layer and deplete the p-channel between p-type doped regions. This stops the flow of current and turns “OFF” the transistor. The term “depletion” comes from the applied voltage at the gate “depleting” the p-channel which cuts off the flow of current between the two p-type doped regions.





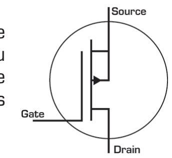

[ 662 - 668 ]

## 662. Magnet-controlled High Volume Siren and Lamp

Build the circuit shown. Press the switch (62) and place the magnet (7) near the reed switch (83). You will hear the siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93). Move the magnet (7) away from the reed switch (83) and the siren and lamp (76) will go off.

The siren audio signal from the 3-in-1 (11) produces voltage variations through the speaker (93) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the speaker (93).

## 663. P-channel Depletion Mode MOSFET Symbol




Place the touch plate (80) across points C and D in project #662, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93). Move the magnet (7) away from the reed switch (83) and the gun shots and lamp (76) will go off. The symbol for an N-Channel depletion mode MOSFET is shown on the right.

## 664. MOSFET Voltage Threshold $V_{th}$

Place a 4-wire (4) across points A and B in project #662, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93). Move the magnet (7) away from the reed switch (83) and the fire siren and lamp (76) will go off.

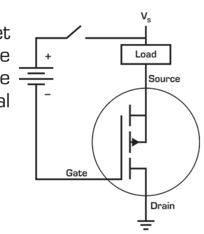
MOSFET design specifications and characteristic charts commonly refer to the Voltage Threshold, or $V_{th}$. The Voltage Threshold for a MOSFET transistor is the minimum gate to source voltage required to either create a conducting path (enhancement mode) or eliminate the conducting path (depletion mode).

## 665. Operating Regions of a MOSFET

Place a 4-wire (4) across points E and F in project #662, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93). Move the magnet (7) away from the reed switch (83) and the sounds of space battle and lamp (76) will go off.

Similar to bi-polar junction transistors that have active, saturation and cut-off regions of operation, MOSFETs typically identify linear, saturation and cutoff regions. In linear mode, the MOSFET channel is open and the drain current is linearly related to the voltage level across the source to drain. In saturation mode, the channel is open but the drain current is at its maximum (for a given gate voltage) and thus is no longer changing as source to drain voltage changes. In cut-off mode, the channel is closed and there is no drain current.

## 666. Typical Operation for Enhancement P-channel MOSFET




Place a 4-wire (4) across points G and H in project #662, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at high volume from the speaker (93) and see the lamp (76) beating dimly with the sound from the speaker (93). Move the magnet (7) away from the reed switch (83) and the music and lamp (76) will go off. The figure on the right shows the typical operating circuit for an enhancement p-channel MOSFET.

## 667. Enhancement P-channel MOSFET in Cut-off Mode

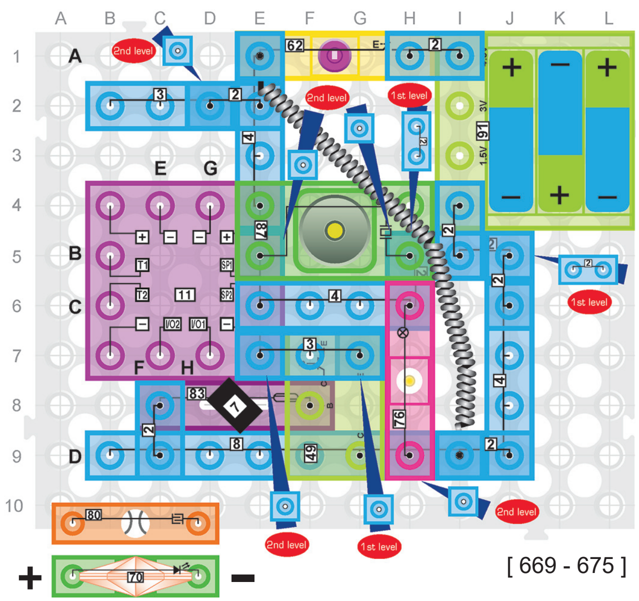
Replace the speaker (93) with the heart LED (69) in project #662, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) and lamp (76) flickering. Move the magnet (7) away from the reed switch (83) and the heart LED (69) and lamp (76) will go off.

An enhancement p-channel MOSFET is operating in cutoff mode when $V_{GS} > V_{th}$, where for a p-channel MOSFET the threshold voltage $V_{th}$ is a negative number. As discussed in project #659, an enhancement p-channel MOSFET is nominally OFF (with an open circuit at the gate), and as long as the voltage between the gate-source is greater than the negative valued $V_{th}$, it will be in this OFF or cut-off region.

## 668. Enhancement P-channel MOSFET in Linear Mode

Place a 4-wire (4) across points G and H in project #667, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) and lamp (76) beating. Move the magnet (7) away from the reed switch (83) and the heart LED (69) and lamp (76) will go off.

To operate an enhancement p-channel MOSFET in the linear region, it is required that $V_{GS} < V_{th}$ (not in cut-off mode) and $V_{DS} > V_{GS} - V_{th}$. So applying a gate-source voltage that is $|V_{th}|$ below the drain-source voltage $V_{DS}$ as shown in the figure from project #666 will enable the transistor to operate in linear mode.




## 669. Magnet-controlled Medium Siren and Lamp

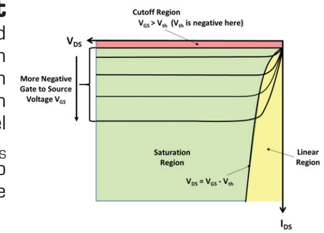
Build the circuit shown. Press the switch (62) and place the magnet (7) near the reed switch (83). You will hear the siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the siren and lamp (76) will go off. The siren audio signal from the 3-in-1 (11) produces voltage variations through the buzzer (87) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the buzzer (87).

## 670. Enhancement P-channel MOSFET in Saturation Mode

Place the touch plate (80) across points C and D in project #669, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the gun shots and lamp (76) will go off. An enhancement p-channel MOSFET will be in saturation mode if $V_{GS} < V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. This means that the gate-source voltage has to be more negative than the drain-source voltage by at least $|V_{th}|$ to keep the transistor in the linear region, otherwise the transistor will go into saturation.

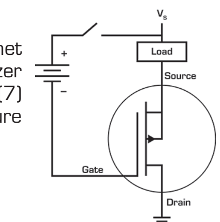
## 671. Enhancement P-Channel MOSFET Characteristic Chart

Place a 4-wire (4) across points A and B in project #669, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the fire siren and lamp (76) will go off. The figure to the right shows a typical enhancement p-channel MOSFET characteristic chart. Per the discussions in the several previous projects, $V_{GS}$ has to be less than the negatively valued $V_{th}$ to turn on the transistor, and the gate to source voltage has to be at least $|V_{th}|$ more negative than the drain to source voltage to stay in the linear region.




## 672. Typical Operation for Depletion P-channel MOSFET

Place a 4-wire (4) across points E and F in project #669, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the sounds of space battle and lamp (76) will go off. The figure to the right shows the typical operating circuit for a depletion p-channel MOSFET.




## 673. Depletion P-channel MOSFET in Cut-off Mode

Place a 4-wire (4) across points G and H in project #669, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87). Move the magnet (7) away from the reed switch (83) and the music and lamp (76) will go off. A depletion p-channel MOSFET is operating in cutoff mode when $V_{GS} < V_{th}$, where for a p-channel MOSFET the threshold voltage $V_{th}$ is a negative number. As discussed in project #661, a depletion p-channel MOSFET is nominally ON (with an open circuit at the gate), and as long as the voltage between the gate and source does not become too negative (i.e. fall below the negative valued $V_{th}$), it will stay ON. To turn OFF a depletion mode p-channel MOSFET and put it in cut-off mode, a voltage can be applied across the gate-source as shown in the figure in project #672. When this voltage is large enough to make the gate to source voltage drop below the negatively valued Vth, then the transistor will go into cut-off mode.

## 674. Magnet-controlled Synchronized Lights

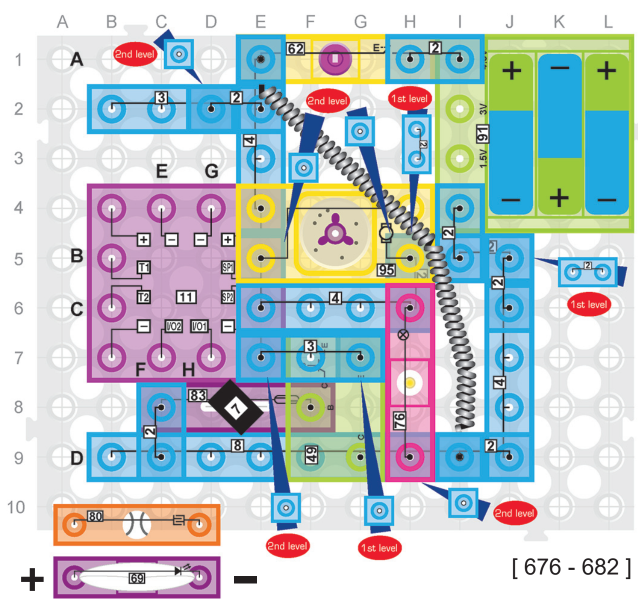
Replace the buzzer (87) with the star LED (70) in project #669, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the star LED (70) flickering and see the lamp (76) flickering dimly. Move the magnet (7) away from the reed switch (83) and the star LED (70) and lamp (76) will go off. The siren audio signal from the 3-in-1 (11) produces voltage variations through the star LED (70) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the star LED (70). This circuit could be used to synchronize flashing lights on a stage and turn them on and off with the wave of the magnet (7) over the reed switch (83).

## 675. Depletion P-channel MOSFET in Linear Mode

Place a 4-wire (4) across points G and H in project #674, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the star LED (70) beating and see the lamp (76) beating dimly. Move the magnet (7) away from the reed switch (83) and the star LED (70) and lamp (76) will go off. To operate a depletion p-channel MOSFET in the linear region, it is required that $V_{GS} > V_{th}$ (not in cut-off mode) and $V_{DS} > V_{GS} - V_{th}$. So applying a gate-source voltage that is $|V_{th}|$ below the drain-source voltage $V_{DS}$ as shown in the figure from project #672 will enable the transistor to operate in linear mode.

## 676. Magnet-controlled Low Siren and Lamp

Build the circuit shown. Press the switch (62) and place the magnet (7) near the reed switch (83). You will hear the siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95). Move the magnet (7) away from the reed switch (83) and the siren and lamp (76) will go off. The siren audio signal from the 3-in-1 (11) produces voltage variations through the motor (95) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the motor (95).




[ 676 - 682 ]

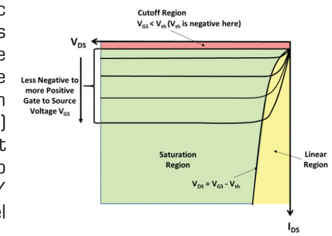
**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 677. Depletion P-channel MOSFET in Saturation Mode

Place the touch plate (80) across points C and D in project #676, press the switch (62) and place the magnet (7) near the reed switch (83). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95). Move the magnet (7) away from the reed switch (83) and the gun shots and lamp (76) will go off. A depletion p-channel MOSFET will be in saturation mode if $V_{GS} > V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. This means that the gate-source voltage has to be more negative than the drain-source voltage by at least $|V_{th}|$ to keep the transistor in the linear region, otherwise the transistor will go into saturation.

## 678. Depletion P-Channel MOSFET Characteristic Chart

Place a 4-wire (4) across points A and B in project #676, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear a fire siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95). Move the magnet (7) away from the reed switch (83) and the fire siren and lamp (76) will go off. The figure on the right shows a typical depletion p-channel MOSFET characteristic chart. Note that typically the specs for such transistor types use $V_{GS}$ and $V_{DS}$ (as opposed to $V_{SG}$ and $V_{SD}$ per discussion in previous projects), which are negative voltages. The operation of the depletion p-channel MOSFET is very similar to that of the enhancement p-channel MOSFET with the main differences being that with depletion p-channel MOSFETs, decreasing the gate-source voltage (i.e. making it more negative) will eventually push the transistor into cut-off mode, whereas with enhancement p-channel MOSFETs, increasing the gate-source voltage (i.e. making it less negative to positive) will eventually push the transistor going into cut-off mode. But from a linear/saturation region operation point of view, the depletion and enhancement p-channel MOSFETs work the same.




## 679. Applications of MOSFETs

Place a 4-wire (4) across points E and F in project #676, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear space battle sounds at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95). Move the magnet (7) away from the reed switch (83) and the sounds of space battle and lamp (76) will go off. Integrated Circuits (ICs) such as microprocessors, microcontrollers, and memory devices contain thousands to millions MOSFET transistors, providing the basic switching functions required to implement logic gates and data storage.

## 680. Bulk or Body of MOSFET

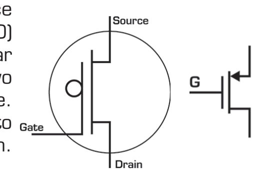
Place a 4-wire (4) across points G and H in project #676, press the switch (62) and place the magnet (7) near the reed switch (83). You will hear music at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95). Move the magnet (7) away from the reed switch (83) and the music and lamp (76) will go off. In the figures from projects #617 and #619, you may have noticed a fourth terminal call the source substrate. This is actually the body, or sometimes called the bulk, of the transistor. The characteristics of a MOSFET, and in particular the turn on/off voltage threshold $V_{th}$, is dependent on and can be adjusted by the voltage level at the bulk terminal.

## 681. Body Effect

Replace the motor (95) with the heart LED (69) and replace the lamp (76) with the star LED (70) in project #676, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) and star LED (70) flickering. Move the magnet (7) away from the reed switch (83) and the heart LED (69) and star LED (70) will go off. Application of a source voltage relative to the bulk terminal will affect the occupancy of the channel in MOSFET that in turn impacts the gate voltage necessary to establish the channel. The change in channel strength by application of voltage across the source-bulk is called the "body effect". For many applications the source is just connected directly to the bulk instead of applying a bias voltage.

## 682. Symbol for Common Bulk Enhancement P-Channel MOSFET

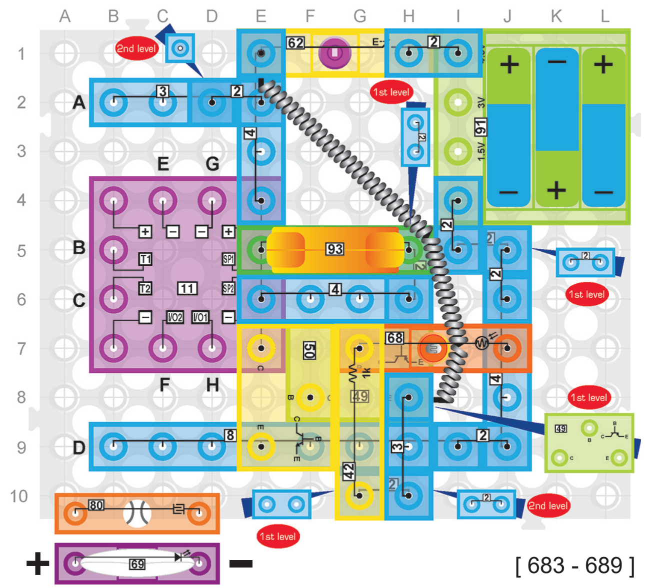
Place a 4-wire (4) across points G and H in project #681, press the switch (62) and place the magnet (7) near the reed switch (83). You will see the heart LED (69) and star LED (70) beating. Move the magnet (7) away from the reed switch (83) and the heart LED (69) and star LED (70) will go off. When the source to bulk terminals are made common, then there are two different symbols typically used to identify an enhancement p-channel MOSFET with no bulk (i.e. common bulk) as shown to the right. The figure on the left uses a circle on the gate terminal to indicate that it's a p-channel MOSFET and thus negative voltages are used for typical operation.



## 683. Light-controlled High Volume Siren – NPN & PNP Switch

Build the circuit shown. Press the switch (62) and you will hear the siren at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off. While light is shining on the photoresistor (68), the resistance of the photoresistor (68) is low, which lowers the voltage level seen by the base of the PNP transistor (49), enabling current to flow out of the base of the PNP transistor (49), that turns on the PNP transistor (49) enabling current to flow from the emitter to the collector of the PNP transistor (49) and into the base of the NPN transistor (50), which turns on the NPN transistor (50) enabling current to flow from the "–" terminal of the 3-in-1 (11) module to ground, which makes the siren sound.

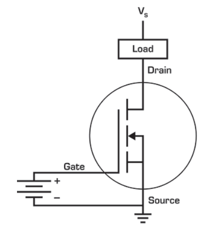
When you block light from getting to the photoresistor (68), this increases the resistance of the photoresistor (68), which raises the voltage level at the base of the PNP transistor (49), turning off the PNP transistor (49), which then turns off the NPN transistor (50) disabling the current flow from the "–" terminal of the 3-in-1 (11) module to ground, and then the siren turns off.




[ 683 - 689 ]

## 684. Typical Operation for Enhancement N-channel MOSFET

Place the touch plate (80) across points C and D in project #683 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93) while light is shining on the photoresistor (68). The figure on the right shows the typical operating circuit for an enhancement n-channel MOSFET.




## 685. Enhancement N-channel MOSFET in Cut-off Mode

Place a 4-wire (4) across points A and B in project #683 and press the switch (62). You will hear a fire siren at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off. An enhancement n-channel MOSFET is operating in cutoff mode when $V_{GS} < V_{th}$, where for a n-channel MOSFET the threshold voltage $V_{th}$ is a positive number. As discussed in project #617, an enhancement n-channel MOSFET is nominally OFF (with an open circuit at the gate), and as long as the voltage between the gate-source is less than $V_{th}$, it will be in this OFF or cut-off region.

## 686. Enhancement N-channel MOSFET in Linear Mode

Place a 4-wire (4) across points E and F in project #683 and press the switch (62). You will hear space battle sounds at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. To operate an enhancement n-channel MOSFET in the linear region, it is required that $V_{GS} > V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. So applying a gate-source voltage that is $V_{th}$ greater than the drain-source supply voltage $V_{DS}$, as shown in the figure from project #684, will enable the transistor to operate in linear mode.

## 687. Enhancement N-channel MOSFET in Saturation Mode

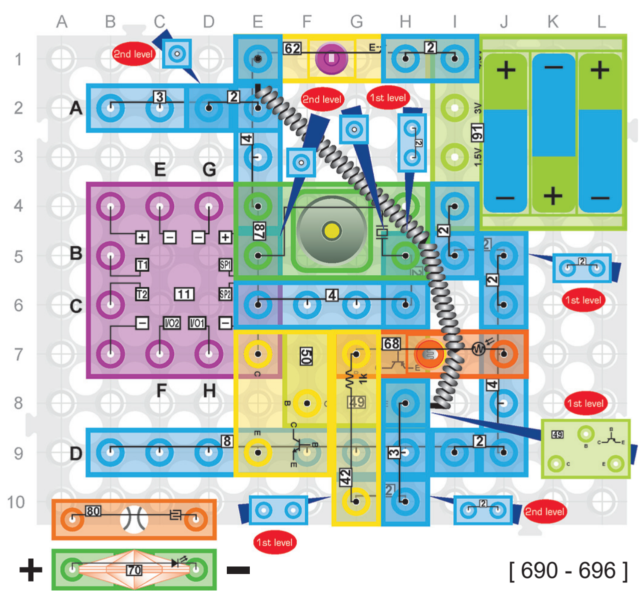
Place a 4-wire (4) across points G and H in project #683 and press the switch (62). You will hear music at high volume from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off. An enhancement n-channel MOSFET will be in saturation mode if $V_{GS} < V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. This means that the gate-source voltage has to be larger than the drain-source voltage by at least $V_{th}$ to keep the transistor in the linear region, otherwise the transistor will go into saturation.

## 688. Light-controlled Flickering Light – NPN & PNP Switch

Replace the speaker (93) with the heart LED (69) in project #683. Press the switch (62) and you will see the heart LED (69) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) will go off. This project lets you turn on and off the flickering heart LED (69), just like you turned on and off the siren as discussed in project #683. But now the siren audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the siren audio levels and frequencies of the siren audio signal change quickly, the heart LED (69) flashes quickly.

## 689. Light-controlled Heartbeat NPN & PNP Switch

Place a 4-wire (4) across points G and H in project #688. Press the switch (62) and you will see the heart LED (69) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) will go off. This project lets you turn on and off the beating heart LED (69), just like you turned on and off the siren as discussed in project #683. But now the music audio output signal from the 3-in-1 (11) module is going through the heart LED (69), and since the music audio levels and frequencies of the music audio signal change more slowly, the heart LED (69) flashes more slowly like a heartbeat.



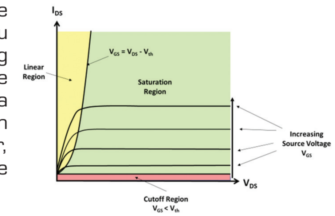
[ 690 - 696 ]

## 690. Light-controlled Medium Volume Siren

Build the circuit shown. Press the switch (62) and you will hear the siren at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off. As discussed in project #283, the reason the volume from the buzzer (87) is lower than that from the speaker is because the buzzer (87) is a high input impedance device which limits the current through it.

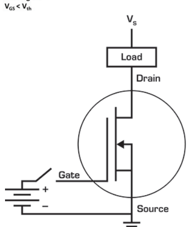
## 691. Enhancement N-Channel MOSFET Characteristic Chart

Place the touch plate (80) across points C and D in project #690 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots will go off. The figure on the right shows a typical enhancement n-channel MOSFET characteristic chart. Per the discussions in the several previous projects, $V_{GS}$ has to be greater than $V_{th}$ to turn on the transistor, and the gate to source voltage has to be at least $V_{th}$ more than the drain to source voltage to stay in the linear region.




## 692. Typical Operation for Depletion N-channel MOSFET

Place a 4-wire (4) across points A and B in project #690 and press the switch (62). You will hear a fire siren at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off. The figure to the right shows the typical operating circuit for a depletion n-channel MOSFET.




## 693. Depletion N-channel MOSFET in Cut-off Mode

Place a 4-wire (4) across points E and F in project #690 and press the switch (62). You will hear space battle sounds at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. A depletion n-channel MOSFET is operating in cutoff mode when $V_{GS} > V_{th}$, where for a n-channel MOSFET the threshold voltage $V_{th}$ is a positive number. As discussed in project #619, a depletion n-channel MOSFET is nominally ON (with an open circuit at the gate), and as long as the voltage between the gate and source does not become too large, it will stay ON. To turn OFF a depletion mode n-channel MOSFET and put it in cut-off mode, a voltage can be applied across the gate-source as shown in the figure in project #692. When this voltage is becomes greater than $V_{th}$, then the transistor will go into cut-off mode.

## 694. Depletion N-channel MOSFET in Linear Mode

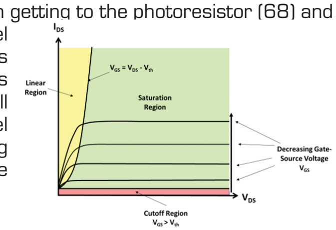
Place a 4-wire (4) across points G and H in project #690 and press the switch (62). You will hear music at medium volume from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off. To operate a depletion n-channel MOSFET in the linear region, it is required that $V_{GS} < V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. So applying a gate-source voltage that is $V_{th}$ greater than the drain-source supply voltage $V_{DS}$, as shown in the figure from project #692, will enable the transistor to operate in linear mode.

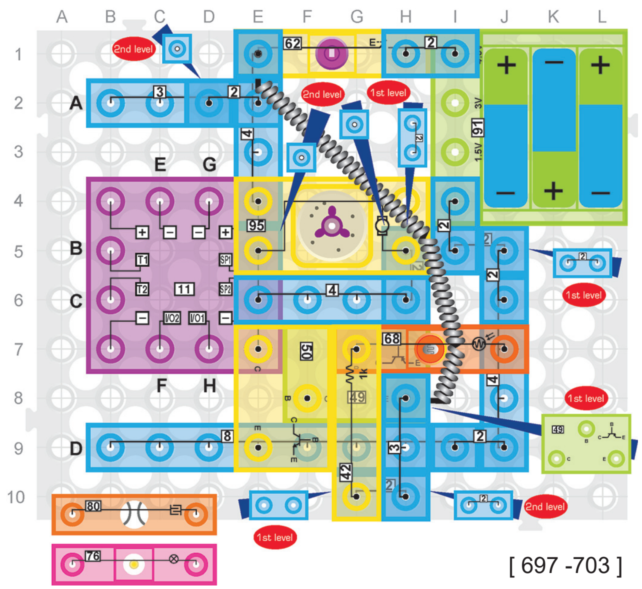
## 695. Depletion N-channel MOSFET in Saturation Mode

Replace the speaker (93) with the star LED (70) in project #690. Press the switch (62) and you will see the star LED (70) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) will go off. A depletion n-channel MOSFET will be in saturation mode if $V_{GS} < V_{th}$ (not in cut-off mode) and $V_{DS} < V_{GS} - V_{th}$. This means that the gate-source voltage has to be larger than the drain-source voltage by at least $V_{th}$ to keep the transistor in the linear region, otherwise the transistor will go into saturation.

## 696. Depletion N-Channel MOSFET Characteristic Chart

Place a 4-wire (4) across points G and H in project #695. Press the switch (62) and you will see the star LED (70) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) will go off. The figure to the right shows a typical depletion n-channel MOSFET characteristic chart. The operation of the depletion n-channel MOSFET is very similar to that of the enhancement n-channel MOSFET with the main differences being that with depletion n-channel MOSFETs, increasing the gate-source voltage will eventually push the transistor into cut-off mode, whereas with enhancement n-channel MOSFETs, decreasing the gate-source voltage will eventually push the transistor going into cut-off mode. But from a linear/saturation region operation point of view, the depletion and enhancement n-channel MOSFETs work the same.





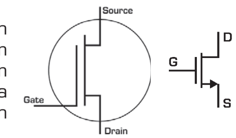
[ 697 -703 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 697. Light-controlled Low Volume Siren

Build the circuit shown. Press the switch (62) and you will hear the siren at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren will go off. As discussed in project #192, the shell of the motor (95) can act like the cone in a speaker, which is why you hear the siren from the motor (95). The volume from the motor (95) is much lower than that from the speaker (93) because the cone in the speaker (93) is designed acoustically to more efficiently transfer the energy from the vibrations in the cone to airwaves.

## 698. Symbol for Common Bulk Enhancement N-Channel MOSFET



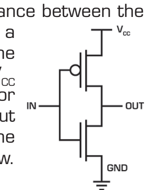

Place the touch plate (80) across points C and D in project #697 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots will go off. When the source to bulk terminals of a MOSFET transistor are made common, then there are two different symbols typically used to identify an enhancement n-channel MOSFET with no bulk (i.e. common bulk) as shown on the right.

## 699. Complementary Metal Oxide Semiconductors (CMOS)

Place a 4-wire (4) across points A and B in project #697 and press the switch (62). You will hear a fire siren at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren will go off. CMOS stands for Complementary Metal Oxide Semiconductor and refers to both a particular style of digital circuitry design and a family of processes used to implement integrated circuits. CMOS uses both p-type and n-type MOSFETs to implement logic gates and other digital circuits.

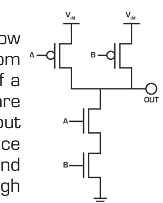
## 700. CMOS NOT Gate

Place a 4-wire (4) across points E and F in project #697 and press the switch (62). You will hear space battle sounds at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds will go off. The figure on the right shows how a NOT gate is implemented in CMOS. When the voltage at input (IN) is low, the NMOS transistor (bottom of the figure) is OFF and creating high resistance between the output (OUT) and ground, limiting the current that can flow from the output to ground. On the other hand, with a low input voltage, the PMOS transistor (top of the diagram) is ON and creating low resistance between $V_{CC}$ and the output, allowing current to flow from $V_{CC}$ to the output. This combination leads to a small voltage drop between $V_{CC}$ and the output, which makes the output high. Conversely, when the voltage at input (IN) is high, the NMOS transistor is ON and creating low resistance between the output (OUT) and ground, allowing current to flow from the output to ground. The high input voltage turns the PMOS transistor ON and creates high resistance between $V_{CC}$ and the output. This combination leads to a small voltage drop between the output and ground, which makes the output low. So a low input results in a high output and a high input results in a low output (inversion or a NOT gate).



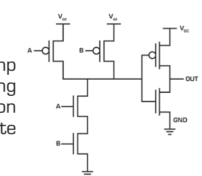

## 701. CMOS NAND Gate

Place a 4-wire (4) across points G and H in project #697 and press the switch (62). You will hear music at low volume from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music will go off. The figure on the right shows the implementation of a NAND gate in CMOS. When both inputs A and B are high, then both NMOS transistors (bottom of the figure) are ON, while both PMOS transistors (top of the figure) are OFF. This pulls the output to ground resulting in a low output state. When either or both inputs A and B are low, then at least one NMOS transistor is OFF (so high resistance between output and ground) and at least one PMOS transistors is ON (low resistance between output and $V_{dd}$) and this pulls the output to $V_{dd}$ resulting in a high output state. So the output is low if and only if both inputs are high (a NAND gate).



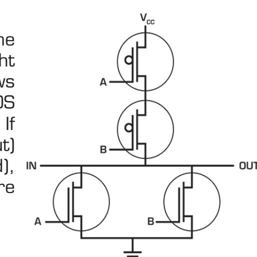

## 702. CMOS AND Gate

Replace the speaker (93) with the lamp (76) in project #697. Press the switch (62) and you will see the lamp (76) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the lamp (76) will go off. The figure on the right shows the implementation of an AND gate in CMOS. Simply put, an AND gate in CMOS is implemented by implementing a NAND gate followed by a NOT gate.



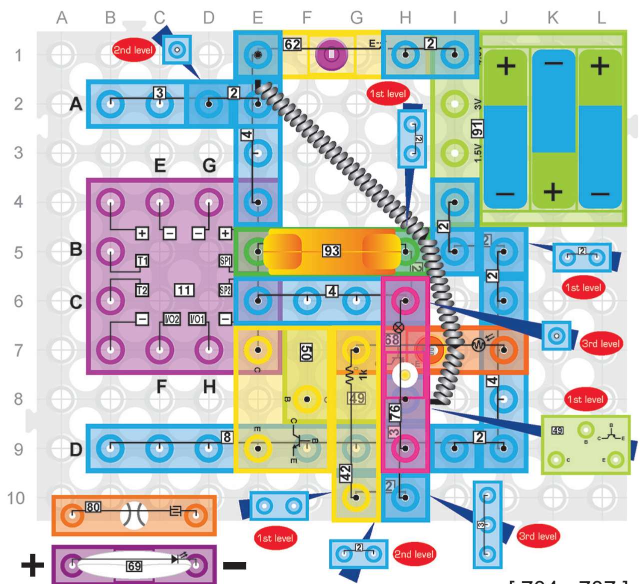
## 703. CMOS NOR Gate

Place a 4-wire (4) across points G and H in project #702. Press the switch (62) and you will see the lamp (76) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the lamp (76) will go off. The figure on the right shows the implementation of a NOR gate in CMOS. When both inputs A and B are low, then both PMOS transistors are ON and both NMOS transistors are OFF, pulling the output to $V_{CC}$ (high output state). If either input is high, then at least one PMOS is OFF (leading to high resistance from $V_{CC}$ to the output) and at least one NMOS transistor is on (leading to low resistance between the output and ground), which pulls the output to ground (low output state). So the output is high if and only if both inputs are low (a NOR gate).



## 704. Light-controlled High Volume Siren and Lamp

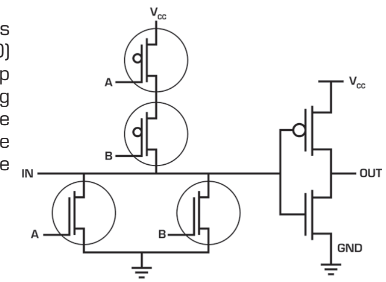
Build the circuit shown. Press the switch (62) and you will hear the siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off. Synchronizing light and sound is a very common application of circuits like this for movies, plays and light shows.




[ 704 - 707 ]

## 705. CMOS OR Gate

Place the touch plate (80) across points C and D in project #704 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off. The figure to the right shows the implementation of an OR gate in CMOS. Simply put, an OR gate in CMOS is implemented by implementing a NOR gate followed by a NOT gate.




## 706. Duality of CMOS

Place a 4-wire (4) across points A and B in project #704 and press the switch (62). You will hear a fire siren at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off. One of the important characteristics of CMOS is how it uses the duality properties of PMOS and NMOS transistors to insure that the output of the circuit is tied either to $V_{CC}$ or ground, but never both. This is done by always having a series group of PMOS transistors from $V_{CC}$ to the output paired with a parallel group of NMOS transistors from the output to ground, and a parallel group of PMOS transistors from $V_{CC}$ to the output paired with a series group of NMOS transistors from the output to ground. It can be proven using De Morgan's Law (see next project) that this will always insure that the for any input combination, the output will be tied to either $V_{CC}$ or ground but never both.

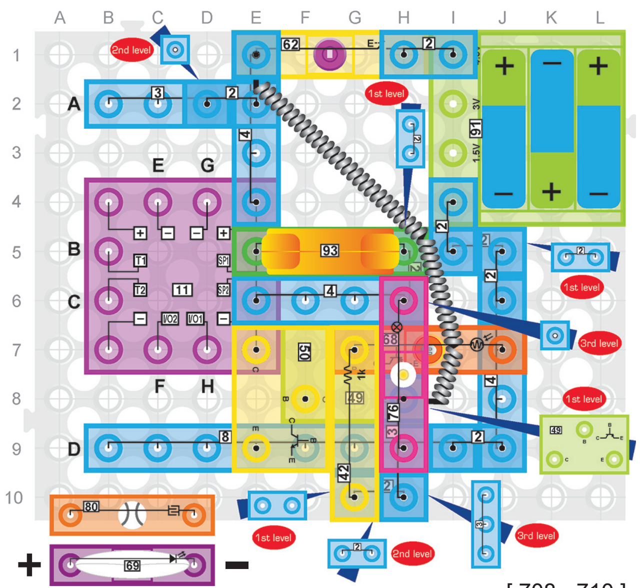
## 707. De Morgan's Law

Place a 4-wire (4) across points E and F in project #704 and press the switch (62). You will hear space battle sounds at high volume from the speaker (93) and see the lamp (76) flickering dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off. Boolean algebra was discussed in project #145. In terms of Boolean algebra, De Morgan's Law states that:

$$\overline{A * B} = \overline{A} + \overline{B}$$

$$\overline{A + B} = \overline{A} * \overline{B}$$

where an overbar stands for the NOT function. You can check for yourself that De Morgan's Law proves out by trying all cases. For example, if A = 1 and B = 0, then A*B = 0 and the NOT of A*B is 1. Similarly, the NOT of A is 0 and the NOT of B is 1, so (NOT of A) + (NOT of B) = 0 + 1 = 1. Try any other combinations of A and B being 0 or 1 and you will see that both of the formulas above hold true.



[ 708 - 710 ]

## 708. What De Morgan's Law Means to CMOS

Place a 4-wire (4) across points G and H in project #704 and press the switch (62). You will hear music at high volume from the speaker (93) and see the lamp (76) beating dimly with the sound from the speaker (93) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off.

Based on the previous two projects, we can now show why pairing a group of PMOS transistors in parallel with a group of NMOS transistors and series (and vice versa) provides duality. Note that series combinations of transistors is like a multiply function because both have to be ON (both have to be 1) for the output to be 1. Likewise, a parallel combination of transistors is like an add function because both have to be OFF (both have to be 0) for the output to be 0. Also note that PMOS functions like the NOT of NMOS and vice versa in CMOS circuits (see project #700).

So using De Morgan's Laws, if you implement a series combination of PMOS transistors with inputs A and B, then the output of the series of PMOS transistors would be A*B. Now we want to make sure that whatever the output for the series of PMOS transistors, the output of the NMOS grouping of transistors is the opposite (so that the output is not ties to $V_{CC}$ and ground at the same time). Per De Morgan's Law, the opposite of A*B is NOT A + NOT B. This is exactly the result we will get by grouping the NMOS transistors in parallel since each NMOS transistor produces the opposite output of the PMOS transistors.

## 709. Advantages of CMOS

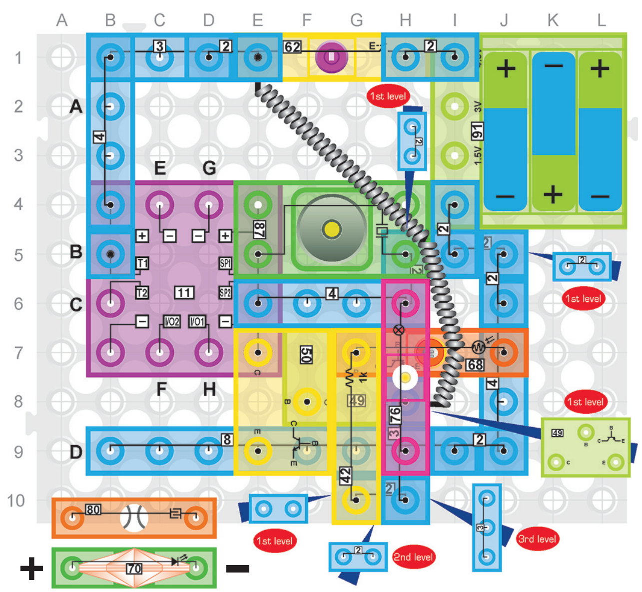
Replace the speaker (93) with the heart LED (69) in project #704. Press the switch (62) and you will see the heart LED (69) and lamp (76) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and lamp (76) will go off.

In addition to providing a simple way to implement digital logic as shown in the previous several projects, CMOS also has advantages in terms of dissipated power since it only dissipates power when switching. Recall that when the input to a CMOS NOT gate is high, the output is low (no current). And when the output of a CMOS device is high, the input is low (0 voltage). Since power is V*I and one is always 0, no power is dissipated in the static state. It's only during switching states that power is dissipated in CMOS.

## 710. Transistor Biasing

Place a 4-wire (4) across points G and H in project #709. Press the switch (62) and you will see the heart LED (69) and lamp (76) beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and lamp (76) will go off.

As seen in many of the previous projects, transistors operate in different modes depending on the voltages and currents across, into and out of the transistor terminals. In order to insure a transistor is operating in the mode and region desired, it is necessary to set voltage and current levels appropriately, typically through resistive circuits. This is called biasing the transistor.




[ 711 - 715 ]

## 711. Light Controlled Medium Siren and Lamp

Build the circuit shown. Press the switch (62) and you will hear the siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off. The siren audio signal from the 3-in-1 (11) produces voltage variations through the buzzer (87) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the buzzer (87).

## 712. Transistor Operating Point

Place the touch plate (80) across points C and D in project #711 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off.

Depending on the application, there are many different operating points for a transistor. For instance, it has already been discussed that if the intention is to use the transistor as a switch, then operating in saturation mode may be most appropriate, while if the intention is to provide current gain, then operating in active or linear mode is most appropriate.

In order to determine how to bias a transistor, it is first necessary to understand what operating point is desired for the application. Operating point (also known as quiescent point or Q) is basically the point on the characteristic curves shown in previous projects where you want the transistor to be operating. For simplicity, the discussion in following projects will focus on biasing NPN transistors as an example.

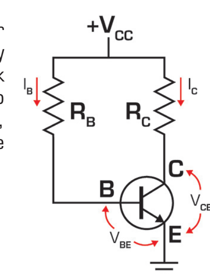
## 713. Base Biasing

Place a 4-wire (4) across points A and B in project #711 and press the switch (62). You will hear a fire siren at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off.

For setting a desired Q-Point of the transistor, this first step is to put a resistor between the supply voltage (B+) and the collector of the NPN transistor to set the collector current to a constant and steady value with an open circuit at its base. There are many different methods of transistor biasing, but some of the most popular are called base biasing. Five common base biasing circuits include fixed base biasing, collector feedback biasing, dual feedback biasing, emitter feedback biasing and voltage divider biasing.

## 714. Fixed Base Biasing

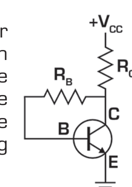
Place 4-wire (4) across points E and F in project #711 and press the switch (62). You will hear space battle sounds at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off. The figure on the right shows a fixed base biasing circuit. In this biasing method, the transistors base current, $I_B$, remains constant for a given supply voltage $V_{CC}$. This also fixes the operating point Q. Fixed base biasing is dependent on the gain of the transistor (β).

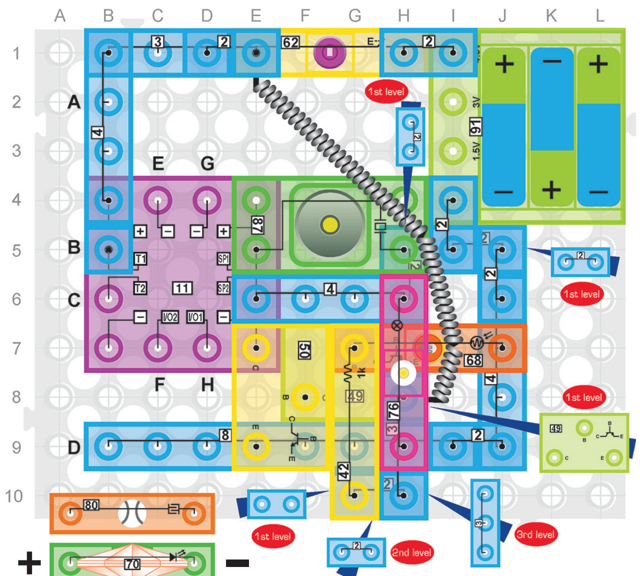



## 715. Collector Feedback Biasing

Place a 4-wire (4) across points G and H in project #711 and press the switch (62). You will hear music at medium volume from the buzzer (87) and see the lamp (76) flickering dimly with the sound from the buzzer (87) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off.

The figure on the right shows a collector feedback biasing circuit. The collector to base feedback resistor ensures that the transistor is always biased in active mode regardless of β since the bias voltage is a function of the collector voltage. If the collector current increases, the collector voltage drops, reducing the base voltage and current which in turn reduces the collector current to keep the operating point fixed. This type of feedback is called negative feedback since a change in collector current results in feedback through the base that causes an opposite change in the collector current, which is why this circuit keeps the operating point fixed.



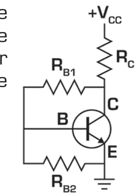


[ 716 - 717 ]

## 716. Dual Feedback Biasing

Replace the buzzer (87) with the star LED (70) in project #711. Press the switch (62) and you will see the star LED (70) flickering and see the lamp (76) flickering dimly while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) and lamp (76) will go off.

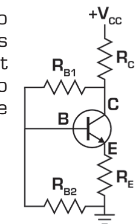
The siren audio signal from the 3-in-1 (11) produces voltage variations through the star LED (70) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the star LED (70). The figure on the right shows a dual feedback biasing circuit. Adding a resistor between the base and emitter ($R_{B2}$) to the circuit in the previous project increases the current flowing into the base, which will improve stability with respect to variations in β.

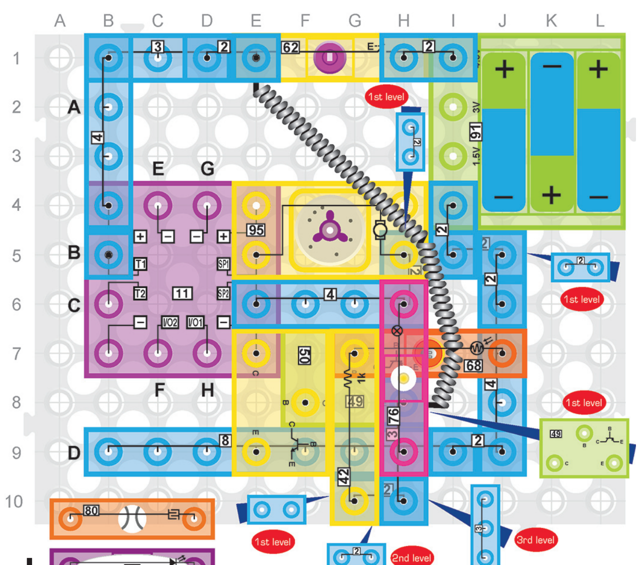



## 717. Emitter Feedback Biasing

Place a 4-wire (4) across points G and H in project #716. Press the switch (62) and you will see the star LED (70) beating and see the lamp (76) beating dimly while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the star LED (70) and lamp (76) will go off.

The figure on the right shows an emitter feedback biasing circuit. Adding another resistor from emitter to ground ($R_E$) to the circuit in the previous project results both emitter and collector feedback which stabilizes the collector current even more. However, the downside of emitter feedback is reduced gain β because what is called "degenerative feedback". An increase in current flowing from the emitter causes a voltage drop to appear across $R_E$ which reduces the base-emitter voltage, thus reducing current into the base, limiting the current increase out the emitter, which reduces β.



[ 718 - 719 ]

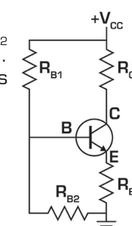
## 718. Light-controlled Low Siren and Lamp

Build the circuit shown. Press the switch (62) and you will hear the siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the siren and lamp (76) will go off. The siren audio signal from the 3-in-1 (11) produces voltage variations through the motor (95) and to the lamp (76) which are synchronized since the lamp (76) is connected to one end of the motor (95).

## 719. Voltage Divider Biasing

Place the touch plate (80) across points C and D in project #718 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the gun shots and lamp (76) will go off.

The figure on the right shows a voltage divider biasing circuit. In this circuit the two resistors $R_{B1}$ and $R_{B2}$ form a voltage divider circuit that divides the supply voltage ($+V_{CC}$) that sets the voltage at the base terminal. The benefit of this type of biasing is that it's independent of changes in β since the voltages at the transistors base, emitter, and collector are determined by external circuit values.

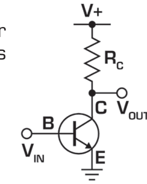


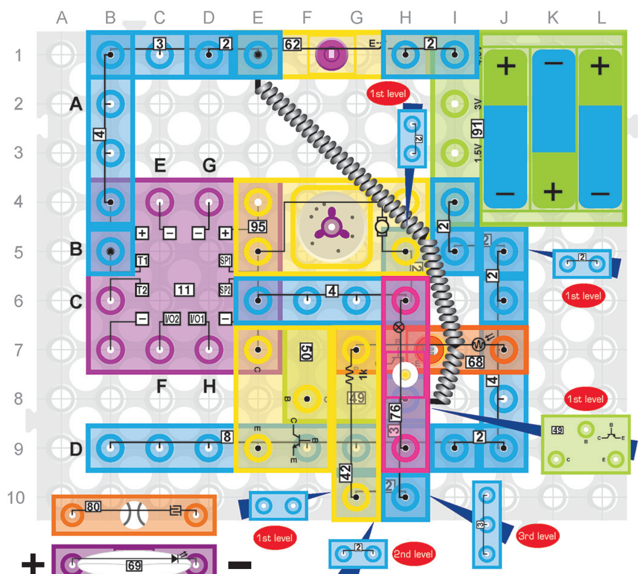

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 720. Common Emitter Circuit Configurations

Place a 4-wire (4) across points A and B in project #719 and press the switch (62). You will hear a fire siren at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the fire siren and lamp (76) will go off.

The figure on the right shows the basic common emitter NPN circuit. This is called common emitter because the base is the input, the collector is the output and the emitter is common to both (i.e. in this circuit the emitter is a common ground for both the input and output).



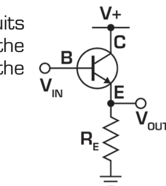

[ 720 - 724 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 721. Common Collector Circuit Configurations

Place a 4-wire (4) across points E and F in project #719 and press the switch (62). You will hear space battle sounds at low volume from the motor (95) and see the lamp (76) flickering dimly with the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the space battle sounds and lamp (76) will go off.

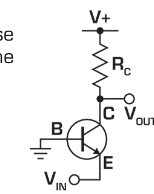
The figure on the right shows the basic common collector NPN circuit (note that common collector circuits are also commonly referred to as emitter follower circuits). This is called common collector because the base is the input, the emitter is the output and the collector is common to both (i.e. in this circuit the collector is a common supply V+ for both the input and output).




## 722. Common Base Circuit Configurations

Place a 4-wire (4) across points G and H in project #719 and press the switch (62). You will hear music at low volume from the motor (95) and see the lamp (76) flickering dimly with the sound from the motor (95) while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the music and lamp (76) will go off.

The figure on the right shows the basic common base NPN circuit. This is called common base because the emitter is the input, the collector is the output and the base is common to both (i.e. in this circuit the base is a common ground for both the input and output).




## 723. Current Gain of Common Emitter Circuits

Replace the motor (95) with the heart LED (69) and replace the lamp (76) with the star LED (70) in project #719. Press the switch (62) and you will see the heart LED (69) and star LED (70) flickering while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and star LED (70) will go off. The current gain ($I_{OUT}/I_{IN}$) is straightforward for the common emitter configuration shown in the figure for project #720 as it's simply the $\beta$ of the transistor. So assuming the transistor has a high gain $\beta$ (e.g. 100 or more), and it's operated in the forward active mode, then the current gain for the common emitter configuration will be high.

## 724. Current Gain of Common Collector Circuits

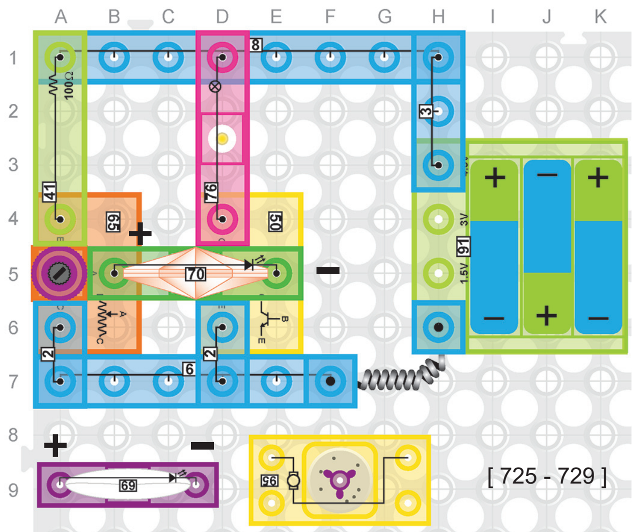
Place a 4-wire (4) across points G and H in project #723. Press the switch (62) and you will see you will see both LEDs beating while light is shining on the photoresistor (68). Go into a dark room or block light from getting to the photoresistor (68) and the heart LED (69) and star LED (70) will go off. The current gain ($I_{OUT}/I_{IN}$) is straightforward for the common collector configuration shown in the figure for project #721 as it's simply the $\beta$ of the transistor. So assuming the transistor has a high gain $\beta$ (e.g. 100 or more), and it's operated in the forward active mode, then the current gain for the common collector configuration will be high.

## 725. Seeing the NPN Transistor Turn On

Build the circuit shown. Turn the knob of the variable resistor (65) fully clockwise and the lamp (76) and star LED (70) will be off. Slowly turn the knob on the variable resistor (65) counter-clockwise. You will see at some point the bottom of the star LED (70) starts to light, and then as you continue to turn the knob counter-clockwise the lamp (76) will eventually light. Continue to turn the knob counter-clockwise and the star LED (70) will slowly become bright while the lamp (76) will quickly become bright.

When the knob on the variable resistor is fully clockwise, there is very high resistance between collector-base and very low resistance between base-emitter, which means very low voltage at the base of the NPN transistor (50) and thus the NPN transistor (50) is off and both the star LED (70) and lamp (76) are off. As you turn the knob counter-clockwise, the resistance between collector-base decreases, increasing the voltage at the base of the NPN transistor (50) and once this voltage reaches around 0.6V, the NPN transistor (50) starts to turn on, and current begins to flow from base to emitter, which is when you see the bottom of the star LED (70) light up.

Even though the NPN transistor (50) is on at this point, there is not quite enough current from collector to emitter to light the lamp (76). But as you continue to turn the knob counter-clockwise, the current slowly increases into the base of the NPN transistor (50) (which is why the star LED (70) slowly gets brighter), and this causes the current between the collector-emitter to increase rapidly (due to the gain $\beta$ of the transistor), and thus you see the lamp (76) get bright quickly.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 726. Verifying the Direction of Current Flow in the NPN Transistor

Reverse the direction of the star LED (70) and repeat the experiment in project #725. Now you see that the star LED (70) and lamp (76) do not turn on. The star LED (70) in this case blocks the flow of current into the base of the NPN transistor (50). This shows that to turn on an NPN transistor in the forward active mode, current needs to flow into the base and to the emitter.

## 727. Current Gain of Common Base Circuits

Replace the lamp (76) with the motor (95) in project #725. Turn the knob of the variable resistor (65) fully clockwise and the motor (95) and star LED (70) will be off. Slowly turn the knob on the variable resistor (65) counter-clockwise. You will see at some point the bottom of the star LED (70) starts to light, and then as you continue to turn the knob counter-clockwise the motor (95) will eventually start to spin. Continue to turn the knob counter-clockwise and the star LED (70) will slowly become bright while the motor (95) will quickly start to spin at high speed.

The current gain ($I_{out}/I_{in}$) for the common base configuration shown in the figure for project #722 is actually less than 1. This is because the emitter current (which is the input current) is the sum of the base current and the collector current (which is the output current). So the output current will be slightly less than the input current (assuming high $\beta$ and transistor is in forward active mode), and thus the current gain for the common base configuration is low (actually negative gain, or loss).

## 728. Demonstrating Lower Turn on Voltage of heart LED (69)

Replace the star LED (70) with the heart LED (69) in project #725. Turn the knob of the variable resistor (65) fully clockwise and the lamp (76) and heart LED (69) will be off. Slowly turn the knob on the variable resistor (65) counter-clockwise. You will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to turn the knob counter-clockwise the lamp (76) will eventually light. Continue to turn the knob counter-clockwise and the heart LED (69) will slowly become bright while the lamp (76) will quickly become bright. Notice that you don't have to turn the knob counter-clockwise as much to make the heart LED (69) light as you did in project #725 to make the star LED (70) light. This is because the heart LED (69) has a lower turn on voltage than the star LED (70) (as discusses in project #79), so as you turn the knob counter-clockwise, the base voltage reaches the turn on voltage of the heart LED (69) sooner than that of the star LED (70).

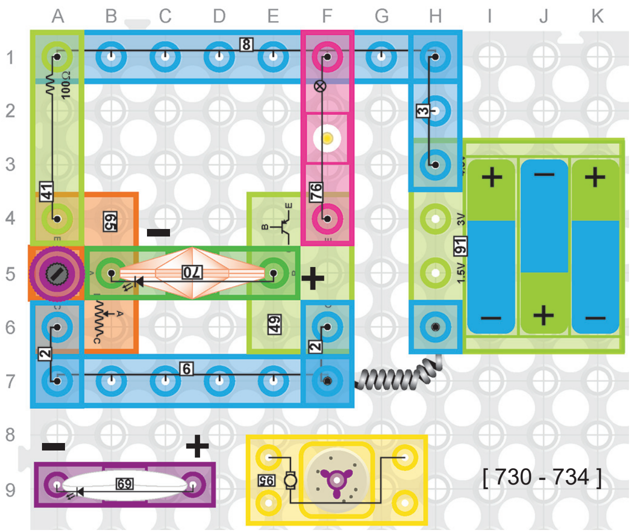
## 729. Voltage Gain of Common Emitter Circuits

Replace the lamp (76) with the motor (95) in project #728. Turn the knob of the variable resistor (65) fully clockwise and the motor (95) and heart LED (69) will be off. Slowly turn the knob on the variable resistor (65) counter-clockwise. You will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to turn the knob counter-clockwise the motor (95) will eventually start to spin. Continue to turn the knob counter-clockwise and the heart LED (69) will slowly become bright while the motor (95) will quickly start to spin at high speed.

Consider the voltage gain for the common emitter circuit shown in figure #720 to be the ratio of the change in output voltage (call it $\Delta V_{OUT}$) to a change in the input voltage (call it $\Delta V_{IN}$). So voltage gain = $\Delta \mathbf{V}_{OUT}/\Delta \mathbf{V}_{IN}$. Now we know that the ratio of the change in output current (call it $\Delta I_{OUT}$) to a change in the input current (call it $\Delta I_{IN}$) is equal to $\beta$. We also know through Ohm's Law that the change in output voltage is $\Delta \mathbf{V}_{OUT} = \Delta \mathbf{I}_{OUT} * \mathbf{R}_C$ and the change in input voltage is $\Delta \mathbf{V}_{IN} = \Delta \mathbf{I}_{IN} * \mathbf{R}_B$, where $R_B$ is the resistance of the source. This means that the voltage gain is:

$$\Delta V_{OUT}/\Delta V_{IN} = (\Delta I_{OUT} * R_C)/(\Delta I_{IN} * R_B) = (\Delta I_{OUT}/\Delta I_{IN}) * (R_C/R_B) = \beta * (R_C/R_B).$$

So the voltage gain of the common emitter configuration depends on the ratio of the collector resistor to the impedance of the input source. Normally the collector resistor $R_C$ is kept modestly small (e.g. 5kΩ) so as not to limit the output current too much, and so the ratio of ($R_C/R_B$) could be small if the impedance of the input source is high. But a large $\beta$ can make up for this. So we will say that the voltage gain of the common emitter configuration is medium.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 730. Seeing the PNP Transistor Turn On

Build the circuit shown. Turn the knob of the variable resistor (65) fully counter-clockwise and the lamp (76) and star LED (70) will be off. Slowly turn the knob on the variable resistor (65) clockwise. You will see at some point the bottom of the star LED (70) starts to light, and then as you continue to turn the knob counter-clockwise the lamp (76) will eventually light. Continue to turn the knob counter-clockwise and the star LED (70) will slowly become brighter while the lamp (76) will quickly become brighter.

When the knob on the variable resistor is fully counter-clockwise, there is very high resistance between base-collector and very low resistance between emitter-base, which means very high voltage at the base of the PNP transistor (49) and thus the PNP transistor (49) is off and both the star LED (70) and lamp (76) are off. As you turn the knob clockwise, the resistance between base-collector decreases, decreasing the voltage at the base of the PNP transistor (49) and once this voltage is about 0.6V below the ~4.5V battery voltage, the PNP transistor (49) starts to turn on, and current begins to flow from emitter to base, which is when you see the bottom of the star LED (70) light up.

Even though the PNP transistor (49) is on at this point, there is not quite enough current from emitter to collector to light the lamp (76). But as you continue to turn the knob clockwise, the current slowly increases out of the base of the PNP transistor (49) (which is why the star LED (70) slowly gets brighter), and this causes the current between the emitter-collector to increase rapidly (due to the gain $\beta$ of the transistor), and thus you see the lamp (76) get brighter quickly.

## 731. Verifying the Direction of Current Flow in the PNP Transistor

Reverse the direction of the star LED (70) and repeat the experiment in project #730. Now you see that the star LED (70) and lamp (76) do not turn on. The star LED (70) in this case blocks the flow of current out of the base of the PNP transistor (49). This shows that to turn on a PNP transistor in the forward active mode, current needs to flow out of the base from the emitter.

## 732. Slower Motor Top Speed

Replace the lamp (76) with the motor (95) in project #730. Turn the knob of the variable resistor (65) fully counter-clockwise and the motor (95) and star LED (70) will be off. Slowly turn the knob on the variable resistor (65) clockwise. You will see at some point the bottom of the star LED (70) starts to light, and then as you continue to turn the knob clockwise the motor (95) will eventually start to spin. Continue to turn the knob clockwise and the star LED (70) will slowly become bright while the motor (95) will quickly start to spin at higher speed.

You may have noticed that the top speed of the motor (95) in this PNP transistor (49) circuit is slower than the top speed of the motor (95) in the NPN transistor (50) circuit in project #727. This is because the internal resistance of the motor (95) in this circuit limits the current that can flow from emitter out the base, whereas in the NPN transistor (50) circuit in project #727, the motor (95) is in the collector path and not limiting the base to emitter current.

## 733. Voltage Gain of Common Collector Circuits

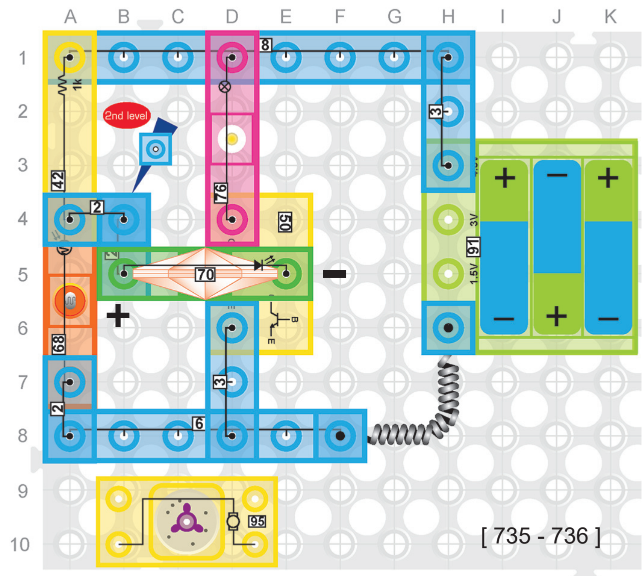
Replace the star LED (70) with the heart LED (69) in project #730. Turn the knob of the variable resistor (65) fully counter-clockwise and the lamp (76) and heart LED (69) will be off. Slowly turn the knob on the variable resistor (65) clockwise. You will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to turn the knob clockwise the lamp (76) will eventually light. Continue to turn the knob clockwise and the heart LED (69) will slowly become brighter while the lamp (76) will quickly become brighter.

Recall from project #466 that there is approximately a 0.6V drop from base to emitter of an NPN transistor (50). So for the common collector circuit shown in the figure in project #721, we see that the output voltage will be about 0.6V lower than the input voltage. So for typical input voltages (5V and higher), the voltage gain for the common collector configuration will be less than 1, but close to one for high input voltages. This still means that the voltage gain for the common collector configuration is low (and actually negative meaning a loss).

## 734. Voltage Gain of Common Base Circuits

Replace the lamp (76) with the motor (95) in project #733. Turn the knob of the variable resistor (65) fully counter-clockwise and the motor (95) and heart LED (69) will be off. Slowly turn the knob on the variable resistor (65) clockwise. You will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to turn the knob clockwise the motor (95) will eventually start to spin. Continue to turn the knob clockwise and the heart LED (69) will slowly become brighter while the motor (95) will quickly start to spin at higher speed.

The voltage gain for the common base circuit shown in figure #722 is the same as it is for the common emitter configuration (the only difference is the polarity of the input voltage is reversed). So the voltage gain of the common base configuration is again $\beta*(R_C/R_B)$, and thus the voltage gain of the common base configuration is considered medium.




> ⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 735. Turning On the Lamp with Darkness

Build the circuit shown. While light is shining on the photoresistor (68), the star LED (70) and lamp (76) will be off. Slowly move your hand over the photoresistor (68) blocking the light and you will see at some point the bottom of the star LED (70) starts to light, and then as you continue to block more light from entering the photoresistor (68) the lamp (76) will eventually light. Continue to block all light from entering the photoresistor (68) and the star LED (70) will slowly become bright while the lamp (76) will quickly become bright.

When there is light shining on the photoresistor (68), there is very low resistance between base-emitter (much lower than the 1kΩ resistor (42) from collector to base), which means very low voltage at the base of the NPN transistor (50) and thus the NPN transistor (50) is off and both the star LED (70) and lamp (76) are off. As you start to block light from entering the photoresistor (68), the resistance between base-emitter increases, increasing the voltage at the base of the NPN transistor (50) and once this voltage reaches around 0.6V, the NPN transistor (50) starts to turn on, and current begins to flow from base to emitter, which is when you see the bottom of the star LED (70) light up.

Even though the NPN transistor (50) is on at this point, there is not quite enough current from collector to emitter to light the lamp (76). But as you continue to block light from entering the photoresistor (68), the current slowly increases into the base of the NPN transistor (50) (which is why the star LED (70) slowly gets brighter), and this causes the current between the collector-emitter to increase rapidly (due to the gain β of the transistor), and thus you see the lamp (76) get bright quickly.

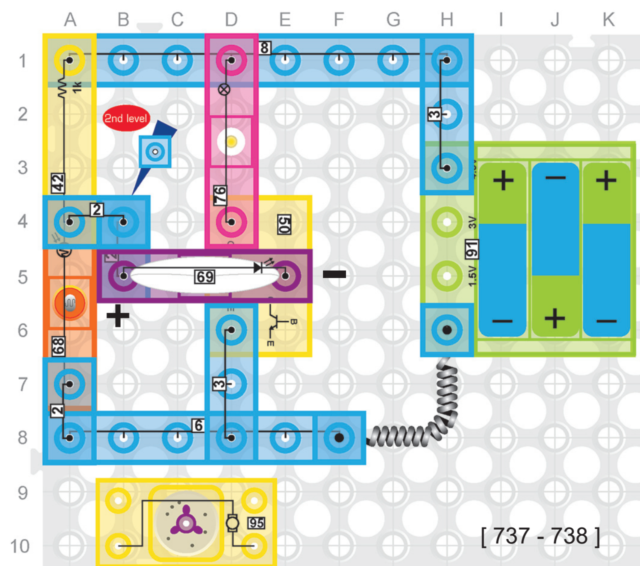
## 736. Power Gain of Common Emitter Circuits

Replace the lamp (76) with the motor (95) in project #735. While light is shining on the photoresistor (68), the star LED (70) and motor (95) will be off. Slowly move your hand over the photoresistor (68) blocking the light and you will see at some point the bottom of the star LED (70) starts to light, and then as you continue to block more light from entering the photoresistor (68) the motor (95) will eventually start to spin. Continue to block all light from entering the photoresistor (68) and the star LED (70) will slowly become bright while the motor (95) will quickly start to spin at high speed.

Recall from project #28 that power is the product of voltage and current. So from projects #723 and #729, we get that the power gain of the common emitter configuration is:

$$\text{Power Gain} = \text{Voltage Gain} * \text{Current Gain} = \beta*(R_C/R_B)*\beta = \beta^2*(R_C/R_B).$$

This shows that the power gain for the common emitter configuration is very high (actually the highest of the three configurations as we will see after projects #737 and #738).




> ⚠ **WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 737. Power Gain of Common Collector Circuits

Build the circuit shown. While light is shining on the photoresistor (68), the heart LED (69) and lamp (76) will be off. Slowly move your hand over the photoresistor (68) blocking the light and you will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to block more light from entering the photoresistor (68) the lamp (76) will eventually light. Continue to block all light from entering the photoresistor (68) and the heart LED (69) will slowly become bright while the lamp (76) will quickly become bright.

From projects #724 and #733, we get that the power gain of the common collector configuration is:

$$\text{Power Gain} = \text{Voltage Gain}*\text{Current Gain} = (\sim 1)*\beta = \sim\beta.$$

This shows that the power gain for the common collector configuration is good, but not as high as in the common emitter configuration, so we will call the power gain of the common collector configuration medium.

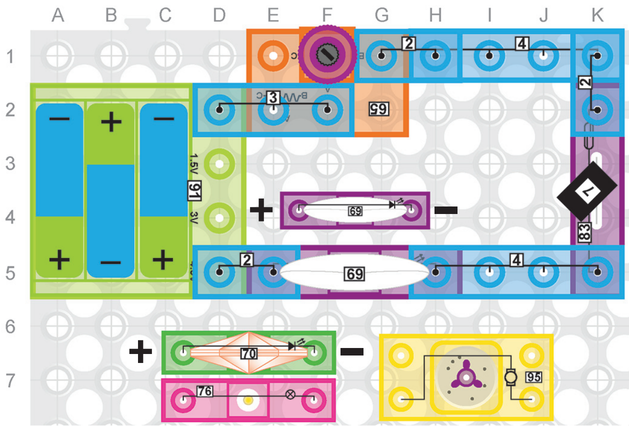
## 738. Power Gain of Common Base Circuits

Replace the lamp (76) with the motor (95) in project #737. While light is shining on the photoresistor (68), the heart LED (69) and motor (95) will be off. Slowly move your hand over the photoresistor (68) blocking the light and you will see at some point the bottom of the heart LED (69) starts to light, and then as you continue to block more light from entering the photoresistor (68) the motor (95) will eventually start to spin. Continue to block all light from entering the photoresistor (68) and the heart LED (69) will slowly become bright while the motor (95) will quickly start to spin at high speed.

From projects #727 and #734, we get that the power gain of the common base configuration is:

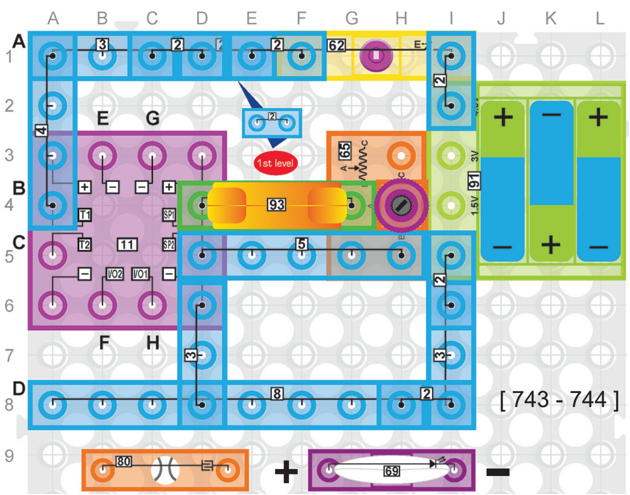
$$\text{Power Gain} = \text{Voltage Gain} * \text{Current Gain} = \beta*(R_C/R_B)*(\sim 1)*\beta = \sim\beta*(R_C/R_B).$$

This shows that the power gain for the common base configuration is dependent on $(R_C/R_B)$, which can be low (if the impedance of the input is high) or similar to the power gain of the common collector (if the impedance of the input is low). So we will call the power gain of the common base configuration medium-low.



[ 739 - 742 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.



[ 743 - 744 ]

## 739. Variable Heart LED Intensity

Build the circuit shown and place the magnet (7) on the reed switch (83). As you adjust the knob on the variable resistor (65) clockwise, the heart LED (69) intensity will decrease. As you adjust the knob on the variable resistor (65) counter-clockwise, the heart LED (69) intensity will increase.

As you turn the knob on the variable resistor (65) clockwise, this increases the resistance between points A and B on the variable resistor (65), increasing the resistance in the circuit and limiting the current through the heart LED (69) which is why the heart LED (69) gets dim. As you turn the knob on the variable resistor (65) counter-clockwise, this decreases the resistance between points A and B on the variable resistor (65), decreasing the resistance in the circuit, increasing the current through the heart LED (69) which is why the heart LED (69) gets bright.

## 740. Video Game Joysticks

Replace the heart LED (69) with the star LED (70) in project #739 and place the magnet (7) on the reed switch (83). As you adjust the knob on the variable resistor (65) clockwise, the star LED (70) intensity will decrease. As you adjust the knob on the variable resistor (65) counter-clockwise, the star LED (70) intensity will increase.

Variable resistors can be used as a joystick to convert the knob adjustments on the variable resistor to varying positions of an object on the screen in a video game (remember those old video pong games?).

## 741. Dual Gang Potentiometer

Replace the heart LED (69) with the lamp (76) in project #739 and place the magnet (7) on the reed switch (83). As you adjust the knob on the variable resistor (65) clockwise, the lamp (76) intensity will decrease. As you adjust the knob on the variable resistor (65) counter-clockwise, the lamp (76) intensity will increase.

A dual gang potentiometer consists of two potentiometers combined on the same shaft. So by turning the shaft, two separate channels can be adjusted identically simultaneously. This comes in handy when you need two outputs to be adjusted exactly the same way, such as the volume of stereo speakers.

## 742. Servomotor

Replace the heart LED (69) with the motor (95) in project #739 and place the magnet (7) on the reed switch (83). As you adjust the knob on the variable resistor (65) clockwise, the speed at which the motor (95) spins will decrease. As you adjust the knob on the variable resistor (65) counter-clockwise, the speed at which the motor (95) spins will increase.

Potentiometers are used in servomotors. A servomotor uses position feedback to control its motion and final position. The position sensing can be performed by a potentiometer. The measured position is compared to the selected position to create an error signal that is feedback to rotate the motor in either direction, as needed to bring the shaft closer to the selected position.

## 743. Variable Speaker Volume Siren

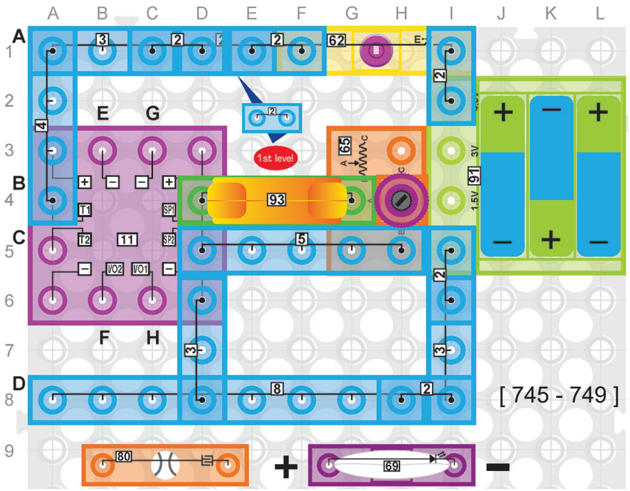
Build the circuit shown. Press the switch (62) and you will hear the siren. Turn the knob on the variable resistor (65) clockwise and the volume from the speaker (93) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the speaker (93) will increase.

Turning the knob on the variable resistor clockwise increases the resistance between points A and B on the variable resistor (65), which increases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This reduces the current through the speaker (93), thereby reducing the volume from the speaker (93). Turning the knob on the variable resistor (65) counter-clockwise decreases the resistance between points A and B on the variable resistor (65), which decreases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This increases the current through the speaker (93), thereby increasing the volume from the speaker (93).

## 744. Input Impedance of Common Emitter

Place the touch plate (80) across points C and D in project #743 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots from the speaker (93). Turn the knob on the variable resistor (65) clockwise and the volume from the speaker (93) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the speaker (93) will increase.

For a given input voltage in the common emitter configuration, the input current is generally low to produce a high output current (due to the β gain). This would normally mean a high input impedance (i.e. given input voltage / low input current = high input resistance or impedance). However there is no emitter resistor in the common emitter configuration to limit the base to emitter current, so we will say that the input impedance in the common emitter configuration is medium.




## 745. Input Impedance of Common Collector

Place a 4-wire (4) across points A and B in project #743 and press the switch (62). You will hear a fire siren from the speaker (93). Turn the knob on the variable resistor (65) clockwise and the volume from the speaker (93) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the speaker (93) will increase.

The input impedance of the common collector configuration is similar to that of the common emitter except that now there is an emitter resistor that further limits the current from base to emitter. So the input impedance of the common collector configuration is high.

## 746. Input Impedance of Common Base

Place a 4-wire (4) across points E and F in project #743 and press the switch (62). You will hear space battle sounds. Turn the knob on the variable resistor (65) clockwise and the volume from the speaker (93) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the speaker (93) will increase.

For a given input voltage in the common base configuration, the input current is generally high since it's the emitter current. This would means a low input impedance (i.e. given input voltage / high input current = low input resistance or impedance). So the input impedance in the common base configuration is low.

## 747. Output Impedance of Common Emitter

Place a 4-wire (4) across points G and H in project #743; press the switch (62) and you will hear music. Turn the knob on the variable resistor (65) clockwise and the volume from the speaker (93) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the speaker (93) will increase.

The common emitter configuration produces high output current (high current gain due to $\beta$) but with medium output voltage ($\beta$*($R_C$/$R_B$) voltage gain). So medium output voltage / high output current leads to medium output resistance for the common emitter configuration.

## 748. Output Impedance of Common Collector

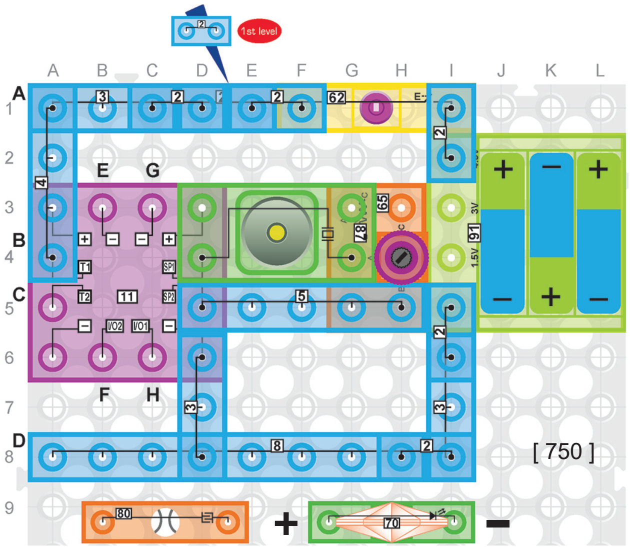
Replace the speaker (93) with the heart LED (69) in project #743. Press the switch (62) and you will see the heart LED (69) flickering. Turn the knob on the variable resistor (65) clockwise and the brightness of the heart LED (69) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the heart LED (69) will increase.

The common collector configuration produces high output current (high current gain due to $\beta$) but with low output voltage (less than unity voltage gain). So low output voltage / high output current leads to low output resistance for the common collector configuration.

## 749. Output Impedance of Common Base

Place a 4-wire (4) across points G and H in project #748. Press the switch (62) and you will see the heart LED (69) beating. Turn the knob on the variable resistor (65) clockwise and the brightness of the heart LED (69) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the heart LED (69) will increase.

The common base configuration produces low output current (less than unity current gain) but with medium output voltage ($\beta$*($R_C$/$R_B$) voltage gain). So medium output voltage / low output current leads to high output resistance for the common base configuration.




## 750. Variable Buzzer Volume Siren

Build the circuit shown. Press the switch (62) and you will hear the siren. Turn the knob on the variable resistor (65) clockwise and the volume from the buzzer (87) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the buzzer (87) will increase.

Turning the knob on the variable resistor clockwise increases the resistance between points A and B on the variable resistor (65), which increases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This reduces the current through the buzzer (87), thereby reducing the volume from the buzzer (87). Turning the knob on the variable resistor counter-clockwise decreases the resistance between points A and B on the variable resistor (65), which decreases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This increases the current through the buzzer (87), thereby increasing the volume from the buzzer (87).

## 751. Comparison of Common Configuration Circuits

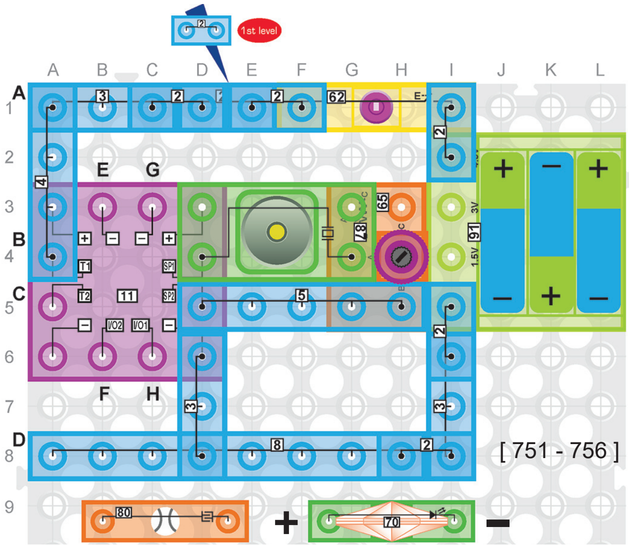
Place the touch plate (80) across points C and D in project #750 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots from the buzzer (87). Turn the knob on the variable resistor (65) clockwise and the volume from the buzzer (87) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the buzzer (87) will increase. The table below provides a comparison of the common emitter, common collector and common base configurations.

| | Common Emitter | Common Collector | Common Base |
|---|---|---|---|
| Current Gain | High | High | Low |
| Voltage Gain | Medium | Low | Medium |
| Power Gain | High | Medium | Medium-Low |
| Input Impedance | Medium | High | Low |
| Output Impedance | Medium | Low | High |

## 752. Applications of Common Emitter Circuits

Place a 4-wire (4) across points A and B in project #750 and press the switch (62). You will hear a fire siren from the buzzer (87). Turn the knob on the variable resistor (65) clockwise and the volume from the buzzer (87) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the buzzer (87) will increase.

Because the power gain of the common emitter configuration is higher than that of the common collector and common base configurations, common emitter circuits are probably the most popular circuits for use in audio amplifiers.




## 753. Applications of Common Collector Circuits

Place a 4-wire (4) across points E and F in project #750 and press the switch (62). You will hear space battle sounds from the buzzer (87). Turn the knob on the variable resistor (65) clockwise and the volume from the buzzer (87) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the buzzer (87) will increase.

Although common collector circuits generally have lower power gain than common emitter circuits, often times the input source to an amplifier has high impedance (e.g. the audio output from a smartphone) and the output of the amplifier is being connected to a low impedance device (e.g. the input to a low ohm speaker). Common collector circuits are an interesting choice in these situations to provide input and output impedance matching (see projects #294 and #295).

## 754. Applications of Common Base Circuits

Place a 4-wire (4) across points G and H in project #750 and press the switch (62). You will hear music from the buzzer (87). Turn the knob on the variable resistor (65) clockwise and the volume from the buzzer (87) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the buzzer (87) will increase. Common base circuits are mainly used when low input impedance is important. Examples of use of common base circuits includes microphone amplifiers and UHF/VHF TV antenna amplifiers.

## 755. Junction Impedance for Silicon Transistors

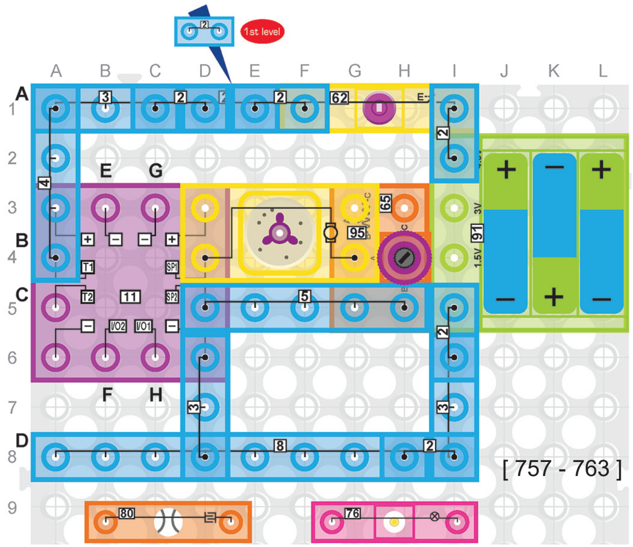
Replace the buzzer (87) with the star LED (70) in project #750. Press the switch (62) and you will see the star LED (70) flickering. Turn the knob on the variable resistor (65) clockwise and the brightness of the star LED (70) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the star LED (70) will increase.

When analyzing transistor circuits like the common configurations discussed in previous projects, one very important characteristic that must be taken into account is the junction impedance of the transistor. Transistors are non-linear devices, and depending on the current flowing out the emitter (for NPN) or in from the emitter (for PNP), the effective impedance of the emitter for silicon based transistors has been empirically measured to be approximately 26/(direct current through the junction in mA) ohms.

## 756. Example Junction Impedance Calculation

Place a 4-wire (4) across points G and H in project #755. Press the switch (62) and you will see the star LED (70) beating. Turn the knob on the variable resistor (65) clockwise and the brightness of the star LED (70) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the star LED (70) will increase. Consider the voltage divider biasing circuit from project #719 and assume $R_C$ = 1kΩ, $R_E$ = 100Ω, $R_{B1}$ = 10kΩ, $R_{B2}$ = 1kΩ, and $+V_{CC}$ = 10V.

First we can calculate the voltage at the base to be 10V*1kΩ/(1kΩ +10kΩ) = 0.91V. Assuming this is a silicon transistor, then the emitter voltage will be about 0.6V less, or about 0.31V. Since there is a 100Ω resistor connected to the emitter, the direct current coming out of the emitter is 0.31V/100Ω = 3.1 mA. From projects #755, this means that the junction impedance is about 26/3.1 = 8.4Ω. This means that the effective emitter resistance is closer to 108.4Ω (not 100Ω) in this circuit.




**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 757. Variable Motor Volume Siren

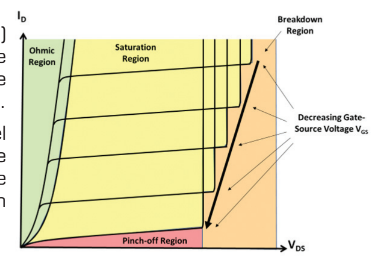
Build the circuit shown. Press the switch (62) and you will hear the siren. Turn the knob on the variable resistor (65) clockwise and the volume from the motor (95) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the motor (95) will increase. Turning the knob on the variable resistor clockwise increases the resistance between points A and B on the variable resistor (65), which increases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This reduces the current through the motor (95), thereby reducing the volume from the motor (95). Turning the knob on the variable resistor counter-clockwise decreases the resistance between points A and B on the variable resistor (65), which decreases the resistance in the circuit path between speaker outputs SP1 and SP2 on the 3-in-1 (11). This increases the current through the motor (95), thereby increasing the volume from the motor (95).

## 758. Operating Regions of JFET Transistors

Place the touch plate (80) across points C and D in project #757 and press the switch (62). When you rub your finger up and down on the touch plate (80) you will hear gun shots. Turn the knob on the variable resistor (65) clockwise and the volume from the motor (95) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the motor (95) will increase. Projects #434 and #513 introduced JFET transistors. Just like MOSFETs and BJTs, JFET transistors also have operating regions. The four operating regions for JFETS are called Ohmic, Pinch-off, Saturation and Breakdown regions.

## 759. Characteristic Chart for N-channel JFET

Place a 4-wire (4) across points A and B in project #757; press the switch (62) and you will hear a fire siren. Turn the knob on the variable resistor (65) clockwise and the volume from the motor (95) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the motor (95) will increase.




The figure on the right shows an example characteristic chart for an n-channel JFET. Note that the curves in the chart correspond to gate-source voltages (unlike in NPN transistor characteristic charts that show base current curves), and are negative in value and shown decreasing (becoming more negative) as you go down the chart.

## 760. Pinch-off Region of an N-channel JFET

Place a 4-wire (4) across points E and F in project #757 and press the switch (62). You will hear space battle sounds. Turn the knob on the variable resistor (65) clockwise and the volume from the motor (95) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the motor (95) will increase. Recalling the figure from project #513 for an n-channel JFET, as the gate-source voltage decreases, this increases the area of the depletion layer shown in the figure. At some point, the depletion area becomes large enough to "pinch off" the n-channel between source and drain. When $V_{GS}$ is sufficiently negative to make this happen, then the transistor goes into the pinch off region and the drain current $I_D$ is close to zero.

## 761. Ohmic Region of an N-channel JFET

Place a 4-wire (4) across points G and H in project #757 and press the switch (62). You will hear music. Turn the knob on the variable resistor (65) clockwise and the volume from the motor (95) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the volume from the motor (95) will increase. The ohmic region of an n-channel JFET is shown in the figure in project #759. In this region, the drain current changes nearly linearly with changes in the drain-source voltage. This is called the ohmic region because this is the only mode of the transistor where changes in voltage lead to linearly proportional changes in current, just as prescribed by Ohm's Law. The transistor is essentially acting as a voltage-controlled resistor in this region.

## 762. Saturation Region of an N-channel JFET

Replace the motor (95) with the lamp (76) in project #757. Press the switch (62) and you will see the lamp (76) flickering. Turn the knob on the variable resistor (65) clockwise and the brightness of the lamp (76) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the lamp (76) will increase. The saturation region of an n-channel JFET is shown in the figure in project #759. In this region, the transistor becomes a good conductor (fixed at maximum drain current $I_D$), with little effect from the drain-source voltage $V_{DS}$, and with the maximum drain current controlled by the gate-source voltage $V_{GS}$. The transistor essentially acts like a switch in the saturation region.

## 763. Breakdown Region of an N-Channel JFET

Place a 4-wire (4) across points G and H in project #762. Press the switch (62) and you will see the lamp (76) beating. Turn the knob on the variable resistor (65) clockwise and the brightness of the lamp (76) will decrease. Turn the knob on the variable resistor (65) counter-clockwise and the brightness of the lamp (76) will increase. The breakdown region of an n-channel JFET is shown in the figure in project #759. In this region, the drain-source voltage $V_{DS}$ has become so large that the resistive n-channel breaks down, leading to uncontrollable drain current levels $I_D$.

## 764. Varying Space Battle Sounds

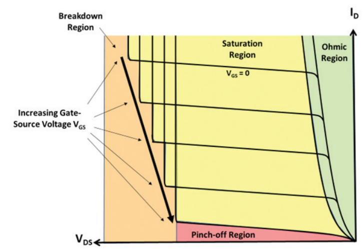
Build the circuit shown and turn on the switch (62). You will hear sounds of space battle in high volume. Now rub your finger on the touch plate (80) and you will hear different sounds of space battle. Keep rubbing your finger on the touch plate (80) and the sounds of space battle will continue to change and cycle through various sounds.

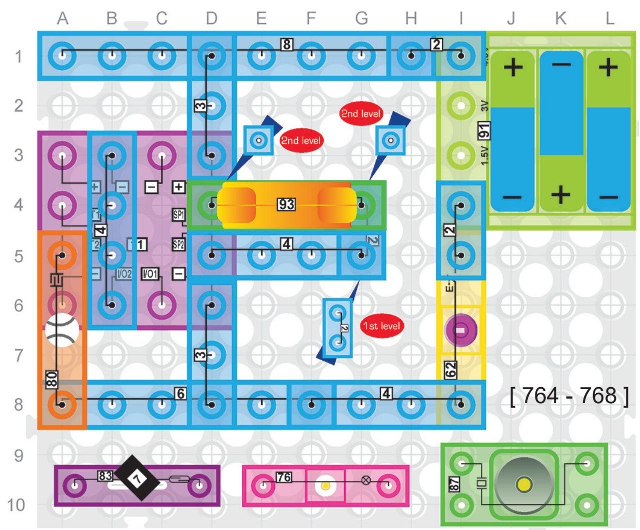
The T1 input pin on the 3-in-1 (11) is a high input impedance control input that is active low. High input impedance means that even the small conduction through your finger can provide enough current to activate the input. When your finger crosses over multiple plated paths on the touch plate (80), this creates a path between the T1 input and ground, which activates the input since it is active low.

## 765. Characteristic Chart for P-channel JFET

Replace the switch (62) with the reed switch (83) in project #764 and place the magnet (7) on the reed switch (83). You will hear sounds of space battle in high volume. Now rub your finger on the touch plate (80) and you will hear different sounds of space battle. Keep rubbing your finger on the touch plate (80) and the sounds of space battle will continue to change and cycle through various sounds.

The figure below shows an example characteristic chart for an p-channel JFET. Note that the curves in the chart correspond to gate-source voltages (unlike in PNP transistor characteristic charts that show base current curves), and are positive in value and shown increasing as you go down the chart.




[ 764 - 768 ]

## 766. Light Space Battle

Replace the speaker (93) with the lamp (76) in project #764 and press the switch (62). You will see the lamp (76) flickering. Now rub your finger on the touch plate (80) and you will see a different flickering pattern from the lamp (76). Keep rubbing your finger on the touch plate (80) and the flickering patterns will continue to change and cycle through various patterns.

In this circuit, as you rub your finger on the touch plate (80) you are changing the audio signal to the various space battle audio signals. This leads to various voltage changing patterns at the SP1 and SP2 output pins from the 3-in-1 (11), which is what you are seeing on the lamp (76).

## 767. Pinch-off Region of an P-channel JFET

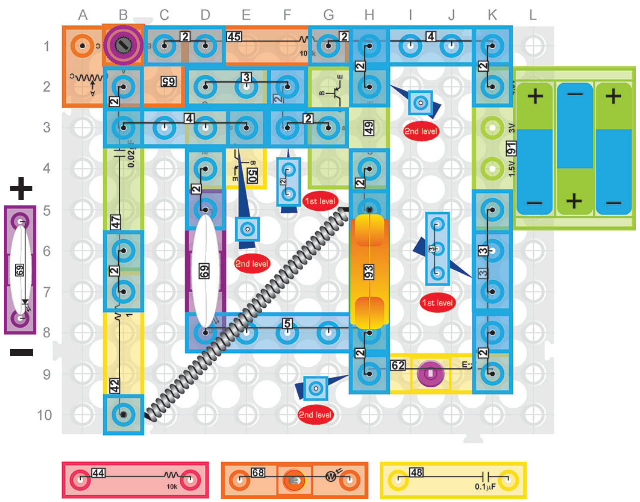
Replace the switch (62) with the reed switch (83) in project #766 and place the magnet (7) on the reed switch (83). You will see the lamp (76) flickering. Now rub your finger on the touch plate (80) and you will see a different flickering pattern from the lamp (76). Keep rubbing your finger on the touch plate (80) and the flickering patterns will continue to change and cycle through various patterns.

Recalling the figure from project #434 for a p-channel JFET, as the gate-source voltage increases, this increases the area of the depletion layer shown in the figure. At some point, the depletion area becomes large enough to "pinch off" the p-channel between source and drain. When $V_{GS}$ is sufficiently large to make this happen, then the transistor goes into the pinch off region and the drain current $I_D$ is close to zero.

## 768. Ohmic Region of an P-channel JFET

Replace the speaker (93) with the buzzer (87) in project #764 and turn on the switch (62). You will hear sounds of space battle in medium volume. Now rub your finger on the touch plate (80) and you will hear different sounds of space battle. Keep rubbing your finger on the touch plate (80) and the sounds of space battle will continue to change and cycle through various sounds.

The ohmic region of a p-channel JFET is shown in the figure in project #765. In this region, the drain current changes nearly linearly with changes in the drain-source voltage. This is called the ohmic region because this is the only mode of the transistor where changes in voltage lead to linearly proportional changes in current, just as prescribed by Ohm's Law. The transistor is essentially acting as a voltage controlled resistor in this region.



[ 769 - 772 ]

## 769. Medium Pitch Oscillator Circuit

Build the circuit shown. Press the switch (62) and you will hear a medium pitch buzzing or tone. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

The tone you are hearing is due to the 2-stage transistor circuit turning on and off creating sudden change or burst in current through the speaker (93), similar to what was discussed in project #541. When you turn on the switch (62), the 0.02μF capacitor (47) begins to charge up through the 100kΩ resistor (45) and variable resistor (65). When the voltage of the 0.02μF capacitor (47) reaches the turn on voltage of the NPN transistor (50) (approximately 0.6V above the emitter voltage level), a little current starts to flow to the base of the 2-stage transistor. A little current to the base of the NPN transistor (50) starts a little current to flow through the 2-stage transistor circuit, out the collector of the PNP transistor (49), into the 1kΩ resistor (42), through the 0.02μF capacitor (47) and back into the base of the NPN transistor (50). This in turn increases the current flow through the 2-stage transistor circuit providing a feedback loop that quickly provides a burst of current through the speaker (93).

Now once the 2-stage transistor circuit is on, this brings down the voltage at the PNP transistor (49) emitter, causing the 0.02μF capacitor (47) to discharge through the 100kΩ resistor (45), which reduces the voltage at the base of the NPN transistor (50), reducing the current flowing into the base of the NPN transistor (50) and eventually this causes the 2-stage transistor circuit to turn off. But this brings back up the voltage at the PNP transistor (49) emitter that causes the 0.02μF capacitor (47) to start charging up again which starts the whole process over again.

The circuit continues to oscillate through this process, and hence this is a called an oscillator circuit. Every time the 2-stage transistor circuit turns on and off, bursts of current start and stop going through the speaker (93), and due to the low capacitance of the 0.02μF capacitor (47), all this happens at a very fast rate so that what you hear from the speaker sounds like a tone rather than clicking and popping.

## 770. Lower Pitch Oscillator Circuit

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #769. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #769. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

Increasing the resistance from 1kΩ to 10kΩ increases the RC time constant in the circuit, so it takes longer for the capacitor to charge and discharge. This leads to longer delays between switch on and switch off of the 2-stage transistor circuit, which means longer delays between bursts of current through the speaker (93), which is why the pitch of the tone is lower.

## 771. Higher Pitch Oscillator Circuit

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #769. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #769. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease.

While light is shining on the photoresistor (68), there is very low resistance through the photoresistor (68) (around 100Ω–200Ω per project #299). Decreasing the resistance from 1kΩ to a few hundred ohms has the effect of decreasing the RC time constant in the circuit, so it takes less time for the capacitor to charge and discharge. This leads to shorter delays between switch on and switch off of the 2-stage transistor circuit, which means shorter delays between bursts of current through the speaker (93), which is why the pitch of the tone is higher. Increasing the resistance by covering the photoresistor (68) increases the RC time constant and thus the pitch of the tone is lower.

## 772. Lowering the Pitch by Increasing Capacitance

Replace the 0.02μF capacitor (47) with the 0.1μF capacitor (48) in the circuit in project #769. Press the switch (62) and you will hear a low pitch buzzing or tone. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

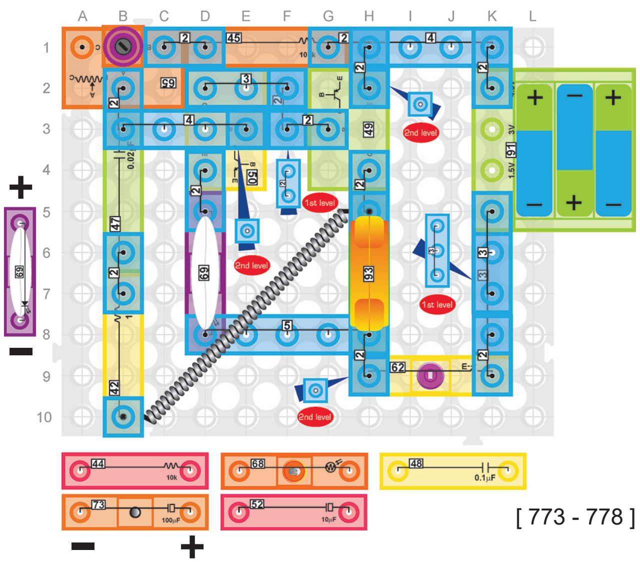
Due to the increased capacitance, it takes longer for the 0.1μF capacitor (48) to charge and discharge than it did for the 0.02μF capacitor (47) to charge and discharge. This means the 2-stage transistor circuit will turn on and off less frequently, which means that the bursts of current through the speaker (93) occur less frequently which is why the tone from the speaker (93) has a lower pitch.

## 773. Adjusting the Pitch of the Tone

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #772. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #772. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

As you turn the knob on the variable resistor (65) counter-clockwise, this lowers the resistance between points A and B on the variable resistor (65). This lowers the RC time constant of the of the charging and discharging path through the 100kΩ resistor (45). A lower RC time constant means that the 0.1μF capacitor (48) charges and discharges more quickly, which means the 2-stage transistor circuit turns on and off more frequently. This means the bursts of current through the speaker (93) occur more frequently, and thus the pitch of the tone increases when you turn the knob of the variable resistor (65) counter-clockwise.

As you turn the knob on the variable resistor (65) clockwise, this increases the resistance between points A and B on the variable resistor (65). This increases the RC time constant of the of the charging and discharging path through the 100kΩ resistor (45). A larger RC time constant means that the 0.1μF capacitor (48) charges and discharges more slowly, which means the 2-stage transistor circuit turns on and off less frequently. This means the bursts of current through the speaker (93) occur less frequently, and thus the pitch of the tone decreases when you turn the knob of the variable resistor (65) clockwise.



[ 773 - 778 ]

## 774. Saturation Region of an P-channel JFET

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #772. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #772. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will increase.

The saturation region of a p-channel JFET is shown in the figure in project #765. In this region, the transistor becomes a good conductor (fixed at maximum drain current $I_D$), with little effect from the drain-source voltage $V_{DS}$, and with the maximum drain current controlled by the gate-source voltage $V_{GS}$. The transistor essentially acts like a switch in the saturation region.

## 775. Quick Flashing and Clicking

Replace the 0.02μF capacitor (47) with the 10μF capacitor (52) in the circuit in project #769. Press the switch (62) and you will see the heart LED (69) flash quickly and the speaker (93) clicking often. Turn the knob on the variable resistor (65) and you see the frequency of the flashing and clicking vary.

The 10μF capacitor (52) increases the RC time constant in the circuit, making it longer for the 10μF capacitor (52) to charge and discharge to the point where you can actually see and hear the instants in time when the 2-stage transistor circuit is turning on and off.

## 776. Breakdown Region of an P-Channel JFET

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #775. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #775. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

The breakdown region of a p-channel JFET is shown in the figure in project #765. In this region, the drain-source voltage $V_{DS}$ has become so large that the resistive p-channel breaks down, leading to uncontrollable drain current levels $I_D$.

## 777. Advantages of JFET Transistors

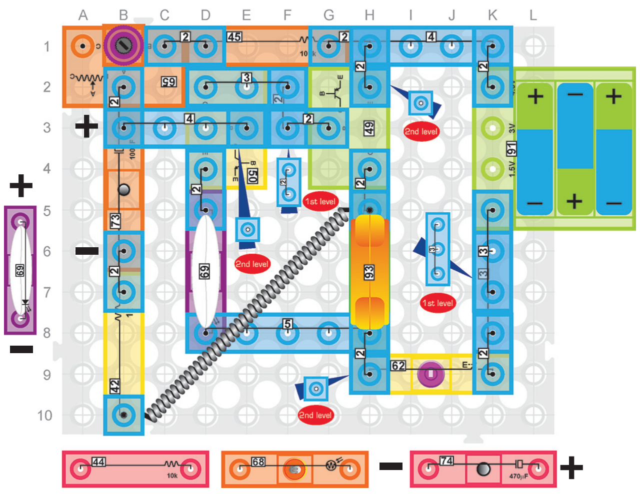
Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #775. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #775. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease.

Some of the key benefits of JFET transistors over BJT transistors are that JFET transistors all have high input impedance, JFETs have lower noise, JFETs have no offset voltage at zero drain current, JFETs are voltage controlled and JFETs have better thermal characteristics.

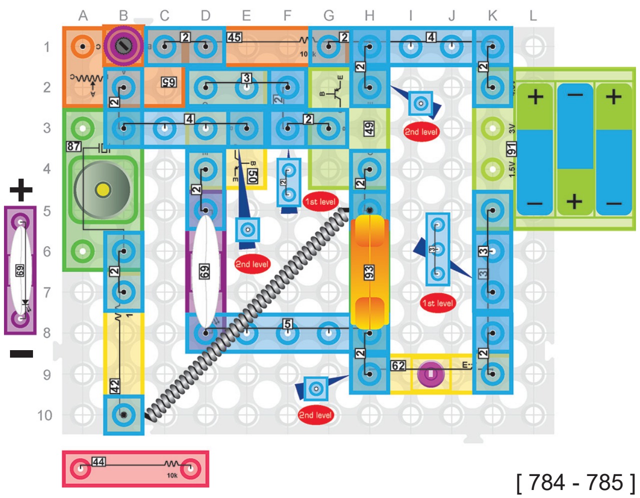
## 778. Flashing Heart and Clicking Speaker

Replace the 0.02μF capacitor (47) with the 100μF capacitor (73) in the circuit in project #769. Press the switch (62) and you will see the heart LED (69) flash and the speaker (93) click at a slow rate. Turn the knob on the variable resistor (65) and you see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary.

This circuit works the same way as the circuit in project #769, only now with such a large capacitor in the circuit (100μF), the time between on and off cycles of the 2-stage transistor circuit is so slow that it doesn't sound like a tone anymore and you can actually see and hear the instants in time when the 2-stage transistor circuit turns on and off.



[ 779 - 783 ]



[ 784 - 785 ]

### 779. Longer Flashes of Heart

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #778. Press the switch (62) and you will see the heart LED (69) flash and the speaker (93) click at a slightly slower rate than in project #778, and the length of the heart LED (69) flashes is longer. Turn the knob on the variable resistor (65) and you will see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary.

The 10kΩ resistor (44) in this circuit increases the RC time constant compared to that in project #778, which increases the time it takes for the 100μF capacitor (73) to charge and discharge which is why it stays on longer in this project than in the previous project.

### 780. Relaxation Oscillator

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #778. Press the switch (62), go into a bright room and you will see the heart LED (69) flash and the speaker (93) click at a slightly faster rate than in project #778, and the length of the heart LED (69) flashes is shorter.

Turn the knob on the variable resistor (65) and you will see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary. Cover the photoresistor (68) from light and the heart LED (69) flashes will be longer and the frequency of the heart LED (69) flashes and speaker (93) clicks will decrease slightly. This type of transistor/capacitor/resistor circuit that repeats itself is called a relaxation oscillator.

### 781. Applications of JFET Transistors

Replace the 100μF capacitor (73) with the 470μF capacitor (74) in project #778. Press the switch (62) and you will see the heart LED (69) flash and the speaker (93) click at a very slow rate. Turn the knob on the variable resistor (65) and you see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary.

Due to the high input impedance of JFET transistors, they are often used as buffer amplifiers and are used in voltmeters to provide and input buffer stage.

### 782. Disadvantages of JFET Transistors

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #781. Press the switch (62) and you will see the heart LED (69) flash and the speaker (93) click at a slightly slower rate than in project #781, and the length of the heart LED (69) flashes is longer. Turn the knob on the variable resistor (65) and you will see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary.

Although the analysis of JFET transistors focused on DC performance, the AC performance of transistors is also important. It turns out that one of the disadvantages of JFET transistors is that their gain is more limited to a smaller range of frequencies than BJT transistors.

### 783. Applications of Relaxation Oscillators

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #781. Press the switch (62), go into a bright room and you will see the heart LED (69) flash and the speaker (93) click at a slightly faster rate than in project #781, and the length of the heart LED (69) flashes is shorter. Turn the knob on the variable resistor (65) and you will see the frequency and length of the heart LED (69) flashing vary and the frequency of the clicks from the speaker (93) vary.

Cover the photoresistor (68) from light and the heart LED (69) flashes will be longer and the frequency of the heart LED (69) flashes and speaker (93) clicks will decrease slightly. Relaxation oscillators like the one in this circuit are sometimes used to produce low frequency signals for applications like blinking traffic lights, electronic beeping clock alarms, and actual clock signals in digital circuits.

### 784. Buzzer Capacitance

Build the circuit shown. Press the switch (62) and you will hear a high pitch buzzing or tone. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. In this circuit, the buzzer (87) is acting like a capacitor since it has internal capacitance. Given that the pitch of the tone you hear is very high (even higher than when the 0.02μF capacitor (47) was in the circuit), you can assume that the capacitance of the buzzer is very small (less than 0.02μF).

### 785. Delay by Capacitance

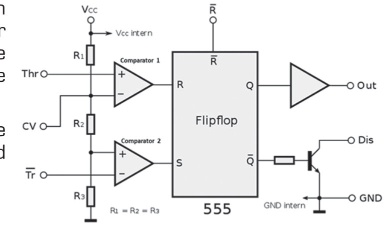
Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #784. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #784. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

The reason you hear a high pitch tone in this circuit was explained in project #769. One of the key reasons that this circuit oscillates is because of the time it takes for the capacitor (in this case the capacitance in the buzzer (87)) to charge up and charge down. Essentially, capacitance adds delay in a circuit. Sometimes this is bad (e.g. if you want fast switching times), but sometimes this is good (e.g. if you want to build a delay circuit for applications like those discussed in project #783).

## 786. 555 Timer

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #784. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #784. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease.

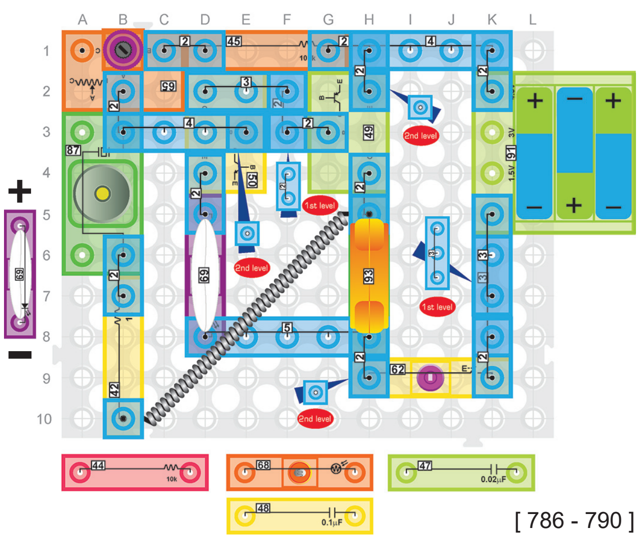
Another way to implement a relaxation oscillator is using a 555 timer chip. The internals of a 555 timer chip includes transistors, resistors, comparators and a flip flop as shown in the figure on the right.




## 787. Adding Capacitance to Buzzer

Add the 0.02μF capacitor (47) on top of the buzzer (87) using the two 1-wire (1) parts in project #784. Press the switch (62) and you will hear a lower pitch buzzing or tone than you heard in project #784. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

Placing the 0.02μF capacitor (47) on top of the buzzer (87) puts it in parallel with the buzzer (87), so the capacitance of the buzzer (87) and 0.02μF capacitor (47) add. With more capacitance in the circuit, this increases the RC time constant in the circuit, so it takes longer for the circuit to charge and discharge. This leads to longer delays between switch on and switch off of the 2-stage transistor circuit, which means longer delays between bursts of current through the speaker (93), which is why the pitch of the tone is lower.



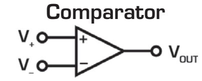
[ 786 - 790 ]

## 788. Comparator

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #787. Press the switch (62) and you will hear a lower pitch buzzing or tone than you heard in project #787. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

The symbol and logic table for a comparator is shown on the right. Basically, if the "+" input voltage to the comparator is higher than the "–" input voltage, then the output of the comparator goes high, and if the "+" input voltage to the comparator is lower than the "–" input voltage, then the output of the comparator goes low.

**Comparator**



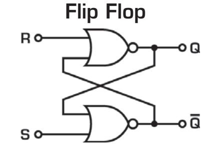

| Input | Output |
|---|---|
| + Input > – Input | High |
| + Input < – Input | Low |

## 789. Flip Flop

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #787. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #787. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease.

A flip flop was shown as part of the 555 timer diagram in project #786. The best way to understand the logic for a flip flop is using nor gates as shown on the right. Basically, whenever S = 1 (S stands for "SET"), then the output Q = 1 and whenever R = 1 (R stands for "RESET") then Q = 0. The intention is that either S or R be 1 but not both at the same time (i.e. you are either setting the output to 1 or resetting the output to 0). During transitions between S = 1 and R = 1 it is assumed that you go through the S = 0 and R = 0 state first before switching, and as shown on the right, this has the effect of keeping the output the same until the switch is made.

**Flip Flop**




| S | R | Q | $\overline{Q}$ |
|---|---|---|---|
| 0 | 0 | * | * |
| 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 1 | 0 | 0 |

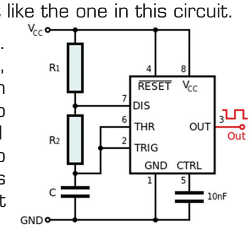
* When S = R = 0 after S = 1 and R = 0, then Q = 1 and $\overline{Q}$ = 0

When S = R = 0 after S = 0 and R = 1, then Q = 0 and $\overline{Q}$ = 1

## 790. Astable 555 Timer Circuit (I)

Add the 0.1μF capacitor (48) on top of the buzzer (87) using the two 1-wire (1) parts in project #784. Press the switch (62) and you will hear a lower pitch buzzing or tone than you heard in project #787 due to the higher capacitance of the 0.1μF capacitor (48) being added to that of the buzzer (87) capacitance. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Now that the comparator and flip flop devices have been explained, we can look at the a circuit using the 555 timer from project #786 as shown below to create an oscillator circuit like the one in this circuit.

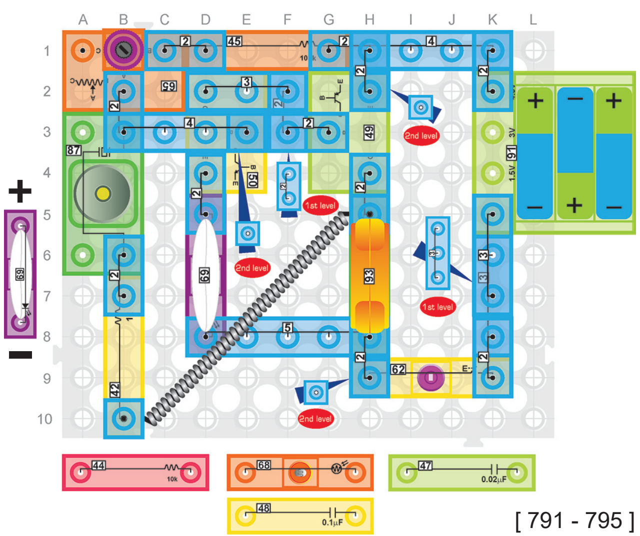
In the diagram shown on the right, initially assume no charge on the capacitor in the lower left. This means that the Threshold and Trigger inputs are at 0V. From the figure in project #786, we see that the "–" input to comparator 1 is 2/3 of $V_{CC}$ (since it's assumed that $R_1 = R_2 = R_3$ in the figure which divides the input voltage $V_{CC}$ by 3 across each resistor). Since the "+" input to comparator 1 is at 0V (since the Threshold input is at 0V initially), the output of comparator 1 is low (R = 0). Similarly, since the "+" input to comparator 2 is 1/3 of $V_{CC}$ and the "–" input to comparator 2 is at 0V (since the Trigger input is at 0V initially), the output of comparator 1 is high (S = 1). Since S = 1, and R = 0, initially the output of the 555 timer (which is the output of the flip flop) is Q = 1.



## 791. Astable 555 Timer Circuit (II)

Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #790. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #790. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

Continuing analysis of the astable 555 timer circuit in the previous project, once the output Q = 1, this also sets $\overline{Q}$ = 0. This sets the input to the base of the transistor shown in the figure in project #786 low, and thus the Discharge output in the figure in the previous project is allowed to increase. Over time, the capacitor in the lower left of the figure in the previous project begins to charge up and this increases the voltage level of the Threshold and Trigger inputs. When the charge on the capacitor goes above 1/3 of $V_{CC}$ (and thus the Trigger input goes above 1/3 of $V_{CC}$), then the output of comparator 2 goes low (S = 0). At this point in time, S = 0 and R = 0. Project #789 showed that a transition from S = 1, R = 0 to S = 0, R = 0 keeps the output at Q = 1. This also keeps $\overline{Q}$ = 0 which keeps the transistor off and allows the capacitor to continue to charge up.




[ 791 - 795 ]

## 792. Astable 555 Timer Circuit (III)

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #790. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #790. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease. Continuing analysis of the astable 555 timer circuit in the previous project, over time the voltage across the capacitor in the lower left of the figure in project #790 will increase to be above 2/3 of $V_{CC}$ (and thus the Threshold input goes above 2/3 of $V_{CC}$). At this point, the output of comparator 1 in the figure in project #786 becomes high (R = 1). So now S = 0 and R = 1 which sets the output of the 555 timer to Q = 0.

## 793. Astable 555 Timer Circuit (IV)

Add the 0.02μF capacitor (47) and 0.1μF capacitor (48) on top of the buzzer (87) using the two 1-wire (1) parts in project #784. Press the switch (62) and you will hear a lower pitch buzzing or tone than you heard in project #790 due to the added capacitance of the 0.02μF capacitor (47) being added in parallel with the 0.1μF capacitor (48). Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary.

Continuing analysis of the astable 555 timer circuit in the previous project, once Q = 0 this also means that $\overline{Q}$ = 1 which sets the base input to the transistor in the figure in project #786 high, turning on the transistor and bringing the Discharge output voltage down near ground. With the Discharge voltage near ground, this starts to discharge the capacitor in the lower left of the figure in project #790 through the resistor R2. As the capacitor discharges, at some point this lowers the Threshold input to below 2/3 of $V_{CC}$, which causes the output of comparator 1 to go low (R = 0). So at this point, S = 0 and R = 0. Project #789 showed that a transition from S = 0, R = 1 to S = 0, R = 0 keeps the output at Q = 0. This also keeps $\overline{Q}$ = 1 which keeps the transistor on and allows the capacitor to continue to discharge through $R_2$.

## 794. Astable 555 Timer Circuit (V)

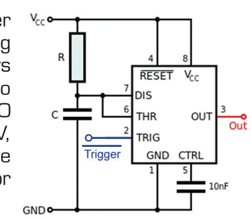
Replace the 1kΩ resistor (42) with the 10kΩ resistor (44) in the circuit in project #793. Press the switch (62) and you will hear a lower pitch buzzing or tone than in project #793. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Continuing analysis of the astable 555 timer circuit in the previous project, as the capacitor in the lower left of the figure in project #786 continues to discharge, eventually this will lower the Trigger input below 1/3 of $V_{CC}$. This then causes the output of comparator 2 to go high (S = 1), which causes the output of the 555 timer to go high Q = 1. At this point, we are back to the S = 1 and R = 0 state, which is where we started in project #790, and the whole process starts again. This results in an oscillatory or astable output like a square wave shown in the figure in project #790.

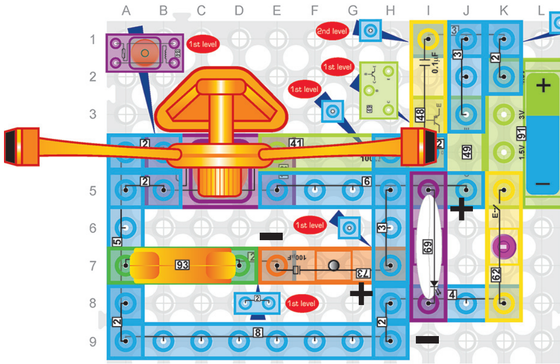
## 795. Monostable 555 Timer Circuit

Replace the 1kΩ resistor (42) with the photoresistor (68) in the circuit in project #793. Press the switch (62), go into a bright room and you will hear a higher pitch buzzing or tone than in project #793. Turn the knob on the variable resistor (65) and you will hear the pitch of the tone vary. Cover the photoresistor (68) from light and the pitch of the tone will decrease.

The figure on the right shows how to create a monostable circuit using the 555 timer. In this circuit, the Trigger input is generally connected to $V_{CC}$ through a resistor so that the input is high which keeps S = 0 in the flip flop of the 555 timer. Assuming an initial state of S = 0, R = 0 and Q = 0, this circuit will stay at Q = 0 until the Trigger input is pulled low. Note that with Q = 0, the transistor in the 555 timer is on, keeping the capacitor discharged at 0V, which keeps R = 0.

So with the Trigger not set, S = 0 and R = 0 and the output stays at Q = 0. Now once the Trigger is set low, this sets S=1, which changes the output to Q = 1 (since S = 1 and R = 0). Assuming the Trigger is released immediately, this leads to an S = 0, R = 0 state and thus the output stays at Q = 1. With Q = 1, the transistor in the 555 timer turns off, which allows the capacitor to charge up. Once the capacitor voltage goes above 2/3 of $V_{CC}$, this sets R = 1, with sets Q = 0 again. With Q = 0 now, this turns on the transistor which brings the capacitor voltage to 0V, which makes R = 0 and S = 0 and we are back to the initial state of R = 0, S = 0, and Q = 0. The length of time that the output stays high when the trigger is set can be adjusted by the resistor and capacitor in the figure shown on the right.



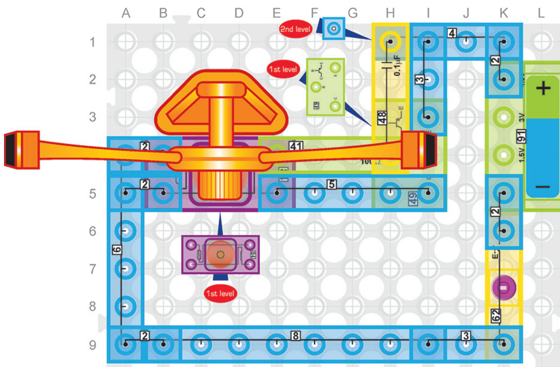


[ 796 ]

## 796. Faraday's Law of Induction

Build the circuit to the left, turn on the switch (62) and start rotating the blade of the windmill (90) with your fingers. You will see the windmill (90) continue to rotate for a while, the heart LED (69) will be flashing and you will hear sounds from the speaker (93).

Faraday's law of induction predicts how magnetic fields interact with electric circuits to produce an electromotive force (EMF). This phenomenon, called electromagnetic induction, is the basis for how transformers, inductors, motors and generators work.

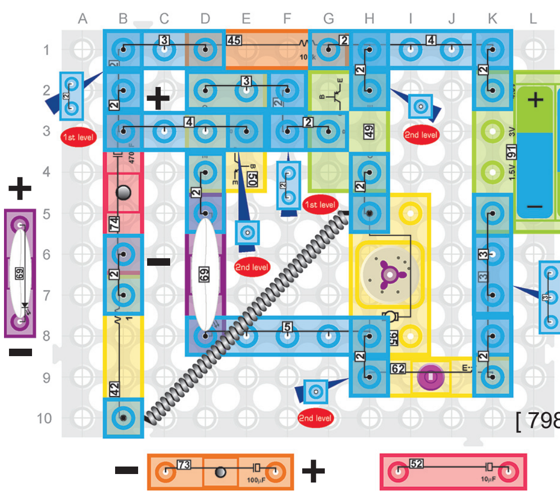


[ 797 ]

## 797. Centrifugal Force

Build the circuit to the left, turn on the switch (62) and start rotating the blade of the windmill (90) with your fingers. You will see the windmill (90) continue to rotate quickly for a while.

Have you ever tried swinging a ball or a yo-yo at the end of a string? Doing this you will notice an outward force trying to pull the ball or yo-yo away from the axis of rotation (i.e. where your finger holds the string assuming you hold your finger in place). This apparent outward force is called centrifugal force.



[ 798 - 800 ]

**WARNING:** Moving parts. Do not touch the motor during operation. Do not lean over the motor.

## 798. Delayed Motor

Build the circuit shown. Press the switch (62) and the motor (95) will not spin initially. Wait a while and eventually the motor (95) will start spinning and keep spinning.

In this circuit, initially the 2-stage transistor circuit is off and it takes time for the 470μF capacitor (74) to charge up the 100kΩ resistor (45). At some point, the charge of the 470μF capacitor (74) reaches the turn on voltage for the NPN transistor (50) which turns on the 2-stage transistor circuit, enabling current to flow out the collector of the PNP transistor (49) and through the motor (95) which makes the motor (95) spin. However, unlike in the oscillatory circuits in previous experiments, current through the motor (95) does not bring down the voltage at the emitter of the PNP transistor (49) (it stays around 4.5V) and thus the 470μF capacitor (74) stays charged and keeps the 2-stage transistor circuit on.

## 799. Reduced Delay Motor

Replace the 470μF capacitor (74) with the 100μF capacitor (73) in the figure in project #798. Press the switch (62) and the motor (95) will not spin initially. Wait a little while and the motor (95) will start spinning and keep spinning.

The motor (95) starts spinning sooner in this project than in the previous project because it takes less time for the smaller 100μF capacitor (73) to charge up and turn on the 2-stage transistor circuit.

## 800. Applications of 555 Timer Monostable Circuit

Replace the 470μF capacitor (74) with the 10μF capacitor (52) in the figure in project #798. Press the switch (62) and there will be a short delay before the motor (95) starts to spin.

The capacitance of the 10μF capacitor (52) is small so it doesn't take long for the capacitor to charge and turn on the 2-stage transistor circuit which turns on the motor (95). Monostable circuits like the one in project #795 are used in all kinds of delay circuit applications like an egg timer or the timer you set on your microwave.

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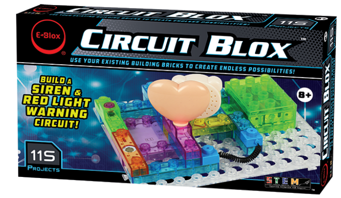


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