E-Blox®

Circuit Blox™

USE YOUR EXISTING BUILDING BRICKS TO CREATE ENDLESS POSSIBILITIES!

INSTRUCTION MANUAL

395 Projects

STEM
Science Technology Engineering Mathematics
Innovate Integrate and Inspire ™

E-Blox®

Circuit Blox™ 395

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 16 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?

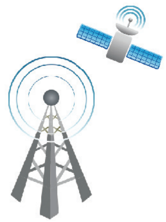
A: A few major Sciences are Biology, Chemistry, Astronomy, and Physics.

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?

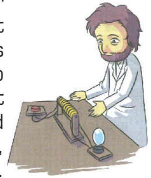
Q: What is technology and who used technology in the past?

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?

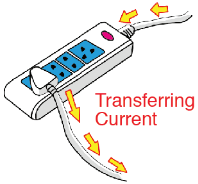
A: Let me tell you a story about a girl named Becky. She was only 10 years old when she was attempting to do her homework in her mom's car. As it got darker outside, she had the idea that there should be a way to make her paper easier to see in the dark. She began playing around with phosphorescent materials, 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?

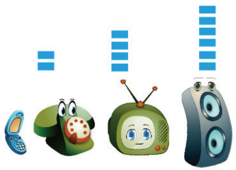
A: Engineering is the application of Science, Technology, and Mathematics to make products that are useful to people. Engineers are skillful in using their knowledge to make products. For example, surge protectors transfer current from the electrical wall outlet to the electrical appliances plugged into 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?

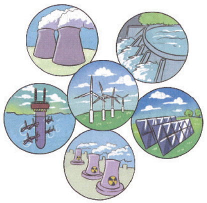
A: Engineers must design the products to be the most appealing at the best price. Product appearance helps marketing sell the product. Product performance is also important and engineers are given specifications by marketing to meet their requirements. Safety is always very important. An audio device 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

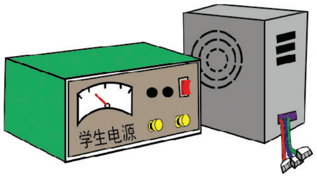
Q: How do Engineers help protect our environment?

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)

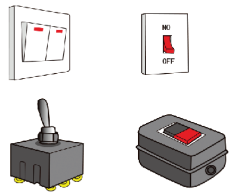
13. Ohm's Law

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.

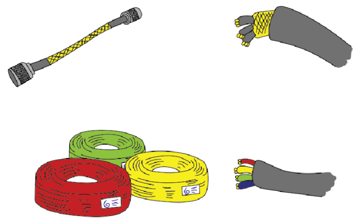


15. Using Mathematics to Calculate Fuses

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

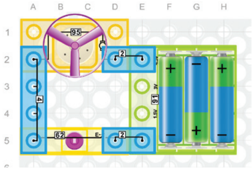
Conductive paths are used to connect circuits and transfer electricity. If the voltage on one end of the conductor is lower than on the other end when current is flowing, then the conductor has resistance. The voltage drop on the conductor divided by the current in the conductor is the Resistance of 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)

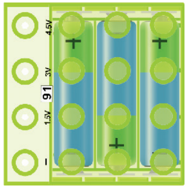
17. Circuit Blox™

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.



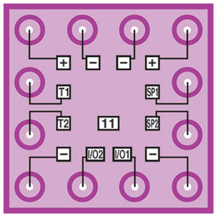
18. Short Circuits in Circuit Blox™

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.



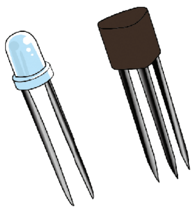
19. Sound and Light

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.



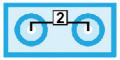
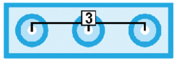
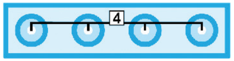
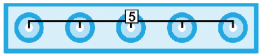
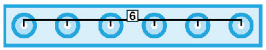
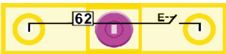
20. Semiconductors

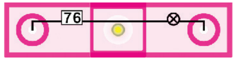
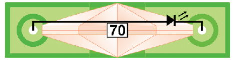
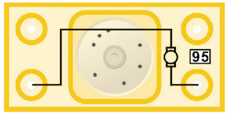
Semiconductors have properties that can control current flowing through a conductor similar to a faucet controlling the flow of water in a pipe. A diode acts like a check valve in a water pipe by only letting current flow in one direction. A Light Emitting Diode (LED) produces light when very little 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.

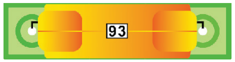
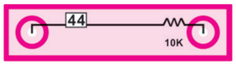


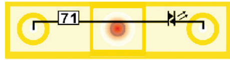
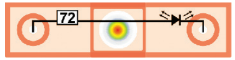
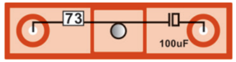
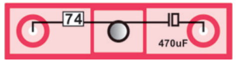
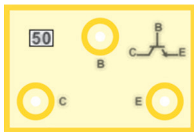
Parts List (colors and styles may vary) Symbols and Numbers

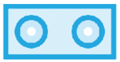
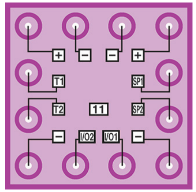
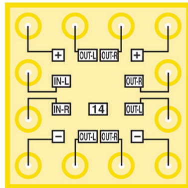
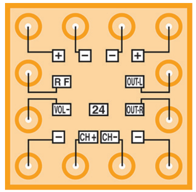
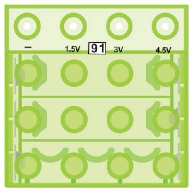
Important: If any parts are missing or damaged, **DO NOT RETURN TO RETAILER.** Call toll-free (855) MY EBLOX (693-2569) or e-mail us at: support@myeblox.com. Customer Service: 880 Asbury Dr., Buffalo Grove, IL 60089 U.S.A.

Qty.	Name	Symbol	Part #
4	1-wire Block		6EB2X01
8	2-wire Block		6EB2X02
4	3-wire Block		6EB2X03
4	4-wire Block		6EB2X04
1	5-wire Block		6EB2X05
1	6-wire Block		6EB2X06
2	Press Switch		6EB2X61
1	Switch		6EB2X62

Qty.	Name	Symbol	Part #
1	Lamp		6EB2X76
1	Heart LED		6EB2X69
1	Star LED		6EB2X70
1	Reed Switch		6EB2X83
1	Motor		6EB2X95
3	Motor Shaft Cap		6EB2X60A
3	Motor Top		6EB2X64

Qty.	Name	Symbol	Part #
1	Spring Wire		6EB2X09
1	Speaker		6EB2X93
1	100Ω Resistor		6EB2X41
1	1kΩ Resistor		6EB2X42
1	5.1kΩ Resistor		6EB2X43
1	10kΩ Resistor		6EB2X44
1	100kΩ Resistor		6EB2X45

Qty.	Name	Symbol	Part #
1	Photo Resistor		6EB2X68
1	Bi-directional LED		6EB2X71
1	Colorful LED		6EB2X72
1	100µF Capacitor		6EB2X73
1	470µF Capacitor		6EB2X74
1	NPN Transistor		6EB2X50

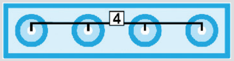
Qty.	Name	Symbol	Part #
1	Buzzer		6EB2X78
3	Fan Blade		6EB2X60
1	Base Grid		6EB2X39
1	Magnet		6EB2X07
1	Fiber Optic Tree		6EB2X40
3	Level Block		6EB2X100
3	Level Block		6EB2X200
1	Three-in-One		6EB2X11
1	Power Amplifier		6EB2X14
1	FM Radio		6EB2X24
1	Battery Holder		6EB2X91
1	Battery Cover		6EB2X91C

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

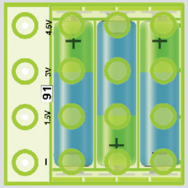
E-Blox® Circuit Blox™ parts contain a PC board with connectors so you can build the different electrical and electronic circuits in the projects. Each block has a function: there are switch blocks, a light block, battery block, wire blocks, etc. These blocks are different colors and have numbers on them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



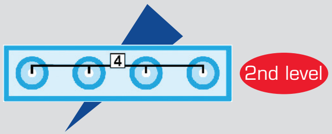
You need a power source to build each circuit. The part is marked 91 and requires three (3) 1.5V "AA" batteries (not included). The four connections are marked –, 1.5V, 3V, and 4.5V.

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.

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 **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 **bi-directional LED (71)** is like the others but has red and blue LEDs connected in opposite directions.

The **colorful LED (72)** slowly changes colors (red-green-blue) when connected to a power source.

The **alarm (78)** converts electricity into sound by making mechanical vibrations. These vibrations create variations in air pressure which travel across the room. You "hear" sound when your ears feel these air pressure variations.

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.

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.

About Your E-Blox® Circuit Blox™ Parts

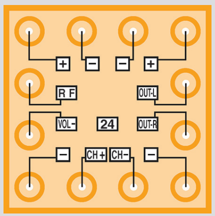
The blue **level blocks (100 & 200)** are non-conductive and just used as building blocks.

A **fiber optic tree (40)** is used with the LED to enhance the light effects.

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.

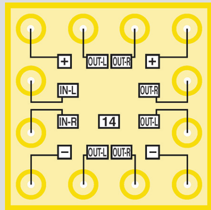
The **FM radio (24)** contains an integrated FM radio circuit. Refer to the figure below for the pin-out description:



See project #116 for an example of proper connections.

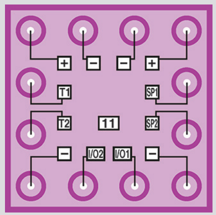
FM Radio:
(+) - power from batteries
(–) - power return to batteries
RF - antenna input
VOL - volume adjust connection
CH+ - tune up
CH– - tune down
OUT-L - left channel output connection
OUT-R - right channel output

The **power amplifier IC (14)** block is a module containing an integrated circuit amplifier and supporting components that are always needed with it. A description of it is given here for those interested:



Power Amplifier IC:
(+) - power from batteries
(–) - power return to batteries
OUT-L - left channel output connection
OUT-R - right channel output
IN-L - left channel input
IN-R - right channel input

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.

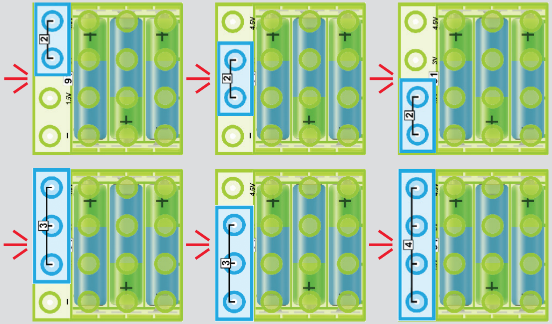
DON'T leave a circuit unattended when it is turned on.

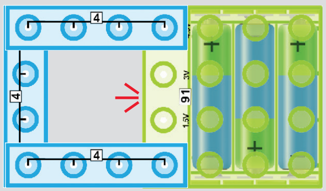
DON'T touch the motor when it is spinning at high speed.

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.

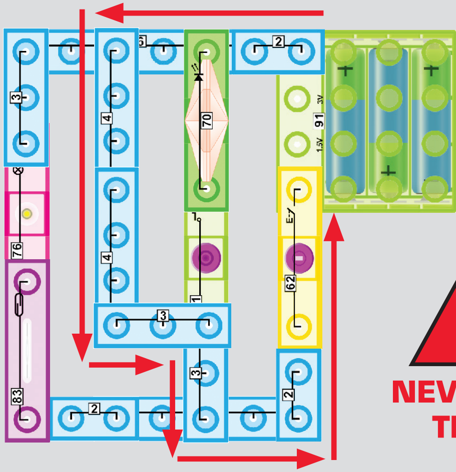
NEVER DO THIS!





NEVER DO THIS!

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!

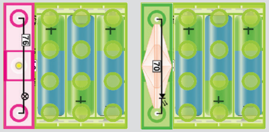
WARNING: SHOCK HAZARD! Never connect E-Blox® Circuit Blox™ to the electrical outlets in your home in any way!

Advanced Troubleshooting (adult supervision recommended)

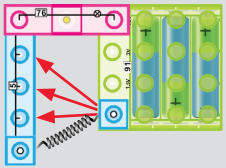
E-Blox® is not responsible for parts damaged due to incorrect wiring.

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

1. Lamp (76), LEDs (69-72), 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:

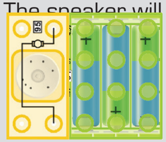


Spring Wire test - Build the circuit shown below. The lamp (76) should light.

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.

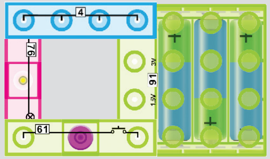


4. Switch (62), Press switch (61), Reed Switch (83): Use this circuit to test each switch and the touch plate (80). The lamp (76) should light. If the lamp doesn't light, then the switch is bad.

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.



5. Three-In-One (11): Siren & Machine Gun - Build project #49, you should hear a siren sound from the speaker.

Space Battle - Build project #52, you should hear a space battle sound from the speaker.

Music - Build project #47, you should hear a music from the speaker.

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

Project Listings

Project Listings

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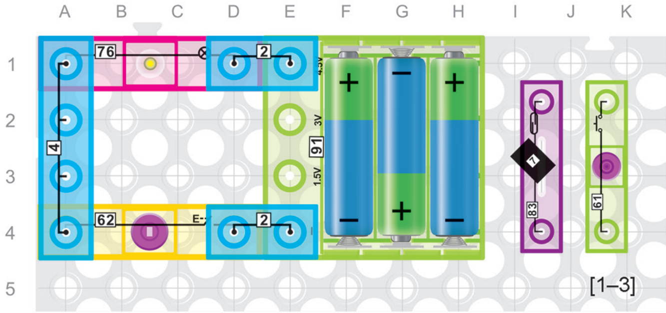
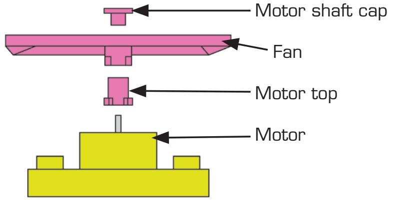
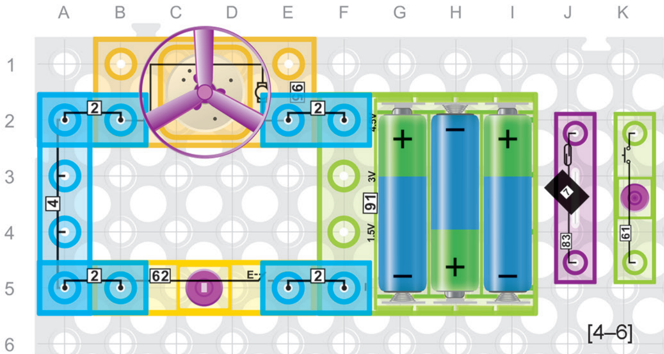
Project Listings





⚠ 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. 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 will spin as long as the switch is pressed. Electrical energy from the batteries has been changed to mechanical energy by the motor (95).

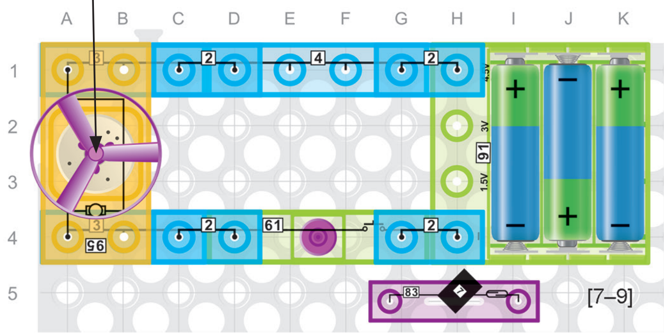
5. Proximity Sensor

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.

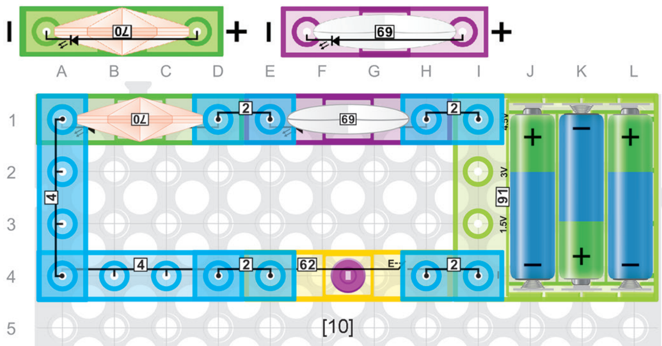
6. Newton's First Law of Motion

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. 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.

Reminder: Remove the shaft cap (60A) before launching the flying saucer.



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



7. 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 does not fly, make sure the batteries are fresh, the motor (95) is in the correct direction and give the fan 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 forces it to rise.

8. Magnet-controlled Flying Saucer

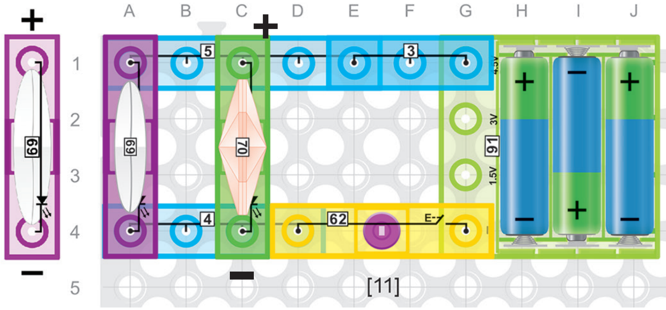
Replace the press switch (61) with the reed switch (83) and move the magnet (7) towards the reed switch (83). Wait for a few seconds then move the magnet (7) away to launch the saucer. A reed switch is typically made from two or more ferrous reeds encased within a small glass tube-like envelope, which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

9. 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 (60) blade push the fan in the downward direction.

10. LEDs in Series

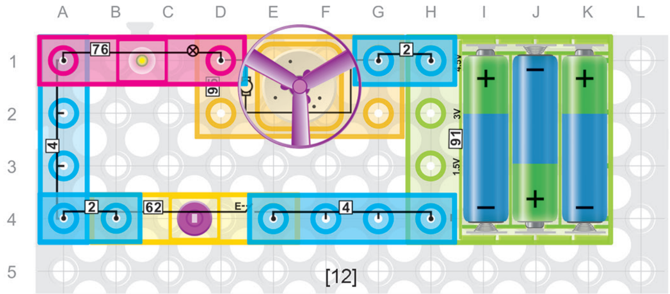
Build the circuit shown on the left and turn on the switch (62). The heart LED (69) and the star LED (70) will both light (make sure both LED modules are in the circuit in the correct direction based on the markings show in the diagram), but they are both dim. This is because these LED modules have internal 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.



[11]

11. LEDs in Parallel

Build the circuit 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. Thus, 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.

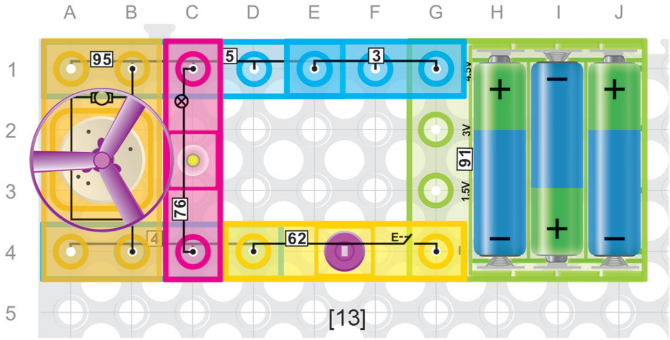


[12]

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

12. Disadvantage of Series Circuits

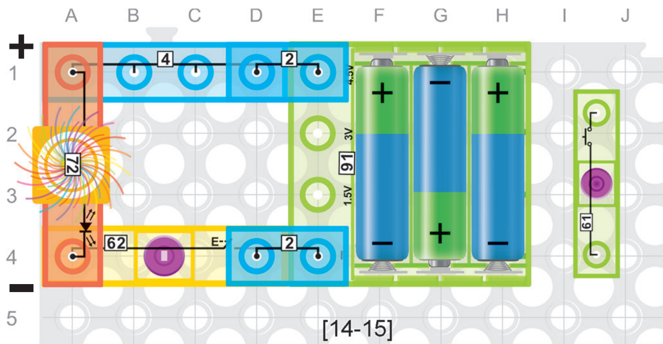
Build the circuit on the left, press the switch (62) and the fan blade (60) of the motor (95) will start running while the lamp (76) is on. Try disconnecting the lamp (76) from the circuit and notice that the motor (95) stops spinning. This is one of the disadvantages of series circuits. Since there is only one current path running through the lamp (76) and the motor (95), removing one of these components creates an open circuit that disables current from flowing through the other component. Think about those old Christmas lights where one light going out made them all go out!



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

13. Advantage of Parallel Circuits

Build the circuit on the left, press the switch (62) and the fan blade (60) of the motor (95) will start running while the lamp (76) is on. Try disconnecting the lamp (76) from the circuit and notice that the motor (95) keeps spinning. This is one of the advantages of parallel circuits. Since there are separate current paths running through the lamp (76) and the motor (95), 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!).

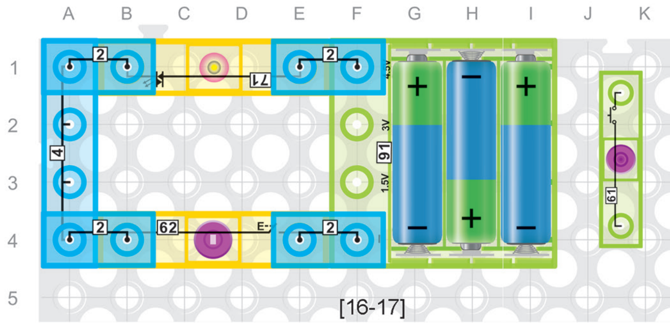


14. Fiber Optics

Build the circuit on the left and place the fiber optic tree (40) on the colorful LED (72). Press the switch (62), the colorful LED (72) will turn on and you will see the fiber optic tree (40) change colors with the LED's colors. If you look at the tips of the fibers at the top of the tree you will see bright light emitting from the fibers. This demonstrates how fibers carry light, and the simplest form of fibers (called single mode fibers) can actually carry light over 60 miles or more.

15. Fiber Optic Communication

Replace the switch (62) with the press switch (61), press the press switch (61) and the colorful LED (72) will flash on and off. Hold the press switch (61) and the colorful LED (72) will stay on while the fiber optic tree (40) changes colors with the colorful LED (72). By pressing the press switch (61) ON and OFF for different periods of time you can simulate a digital communication signal (light ON means a digital 1 was sent while light OFF means a digital 0 was sent).

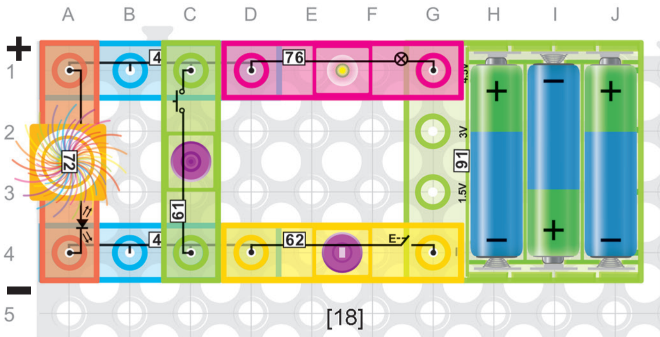


16. The Bi-directional LED

Build the circuit above, press the switch (62) and you will see the bi-directional LED (71) turn on red. Now install the bi-directional LED (71) in the reverse direction and when you press the switch (62) the bi-directional LED (71) will turn on blue. Bi-directional LEDs 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, which determines which color LED lights.

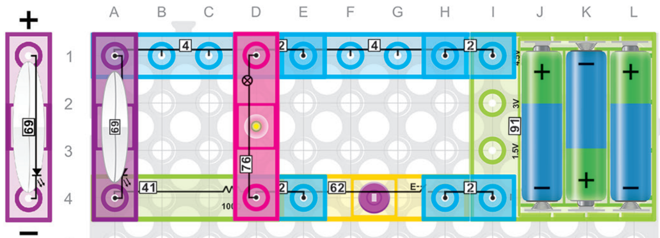
17. Bi-directional LED Sensor

Replace the switch (62) with the press switch (61), press the press switch (61) and the bi-directional LED (71) will flash on and off. If you hold the press switch (61), the bi-directional LED (71) will turn on red. Install the bi-directional LED (71) in the reverse direction, then hold the press switch (61) and you will see the bi-directional LED (71) turn on Blue. Bi-directional LEDs can be used as sensors that indicate which direction current is flowing.



18. Simulating a Short Circuit

Build the circuit above making sure the colorful LED (72) is in the correct direction. Press the switch (62) to turn on both the colorful LED (72) and the lamp (76). Press the press switch (61) and the colorful LED (72) will turn OFF but the lamp (76) will get brighter. 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 colorful LED (72)) which causes the colorful LED (72) to stop working. Typically, short circuits occur due to unintended contacts of components that result in accidental diversion of the current.



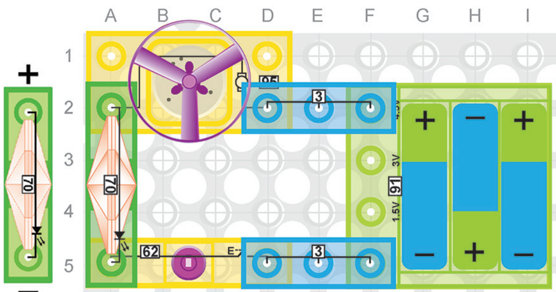
[19]

19. Resistors

Build the circuit shown on the left, then turn on the switch (62) and you will see the heart LED (69) and the lamp (76) will be on at the same time. The heart LED (69) is a little dimmer than it was in project #11 due to the presence of the 100 Ohm (Ω) resistor (41) that is connected in series with the heart LED (69). Resistors get their name because they are designed to resist the flow of current. The 100Ω resistor (41) in this circuit limits the flow of current through the heart LED (69) which is why it is dimmer than in project #11.

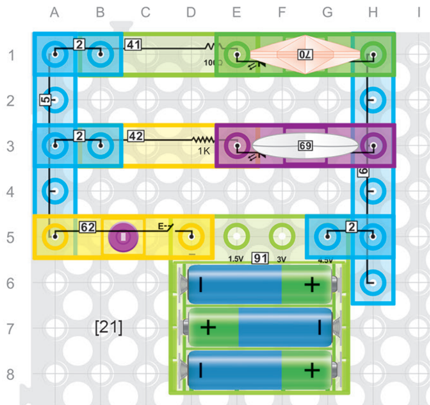
20. Power 'ON' Indicator

Build the circuit shown on the right, press the switch (62) and the fan blade (60) of the motor (95) will start running while the star LED (70) is on. Without the fan blade (60) it is difficult to see if the motor (95) is 'ON' when far from the circuit. With the LED (70) in parallel with the motor (95), a visual indicator that the motor (95) is 'ON' can be seen from a distance. Red LEDs are often used on electrical devices to show they are 'ON'. Wasted "Watts" cost money and is bad for the environment.

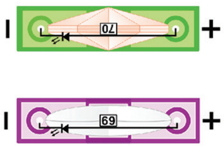


[20]

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

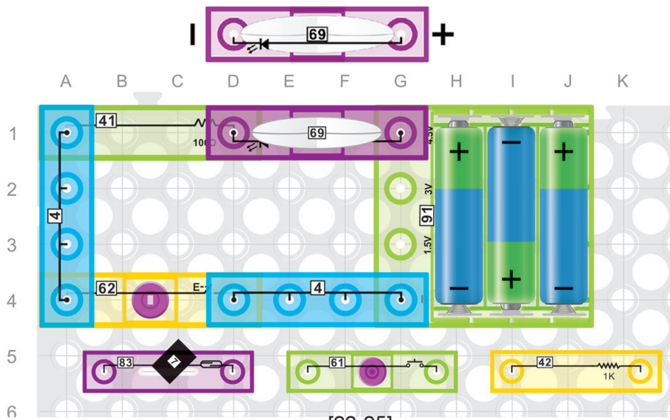


[21]



21. Ohms of Resistance

Build the circuit shown on the left, then 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. But the heart LED (69) is much dimmer than the star (LED). This is because the heart LED (69) has the 1kΩ resistor (42) in series with it, while the star LED (70) has only the 100Ω resistor (41) in series with it. Larger resistors (higher Ohms (Ω)) means more resistance, allowing less current to flow, while smaller resistors (lower Ohms (Ω)) means less resistance allowing more current to flow.



[22-25]

22. LED, the Check Valve Light

Build the circuit shown on the left making sure the heart LED (69) is in the correct direction. Press the switch (62) to turn it ON and OFF. Reverse the heart LED (69) and repeat. Notice that the heart LED (69) does not light when in the circuit in the reverse direction, demonstrating how LEDs only allow current to flow in one direction.

23. Alarm Switches

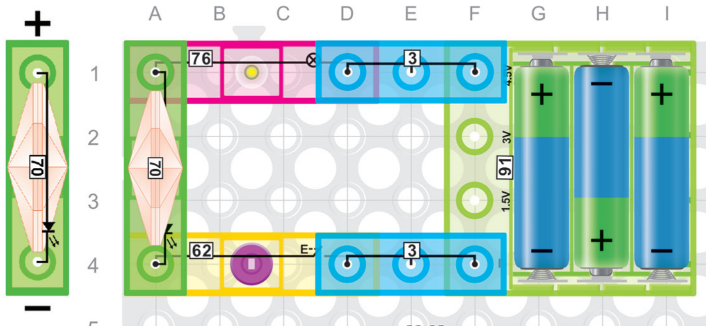
Replace the switch (62) with the reed switch (83). Move the magnet (7) towards the reed switch (83) and the heart LED (69) will turn ON. Move the magnet (7) away and the heart LED (69) will turn OFF. House alarms sometimes use reed switches to detect when a door or window is open.

24. Reed Switch vs. Mechanical Switch

Replace the reed switch (83) with the press switch (61). Press and hold the press switch (61). The heart LED (69) will be on while you hold down the press switch (61) and will go off when you release the press switch (61). 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. 1k Ohm Resistor

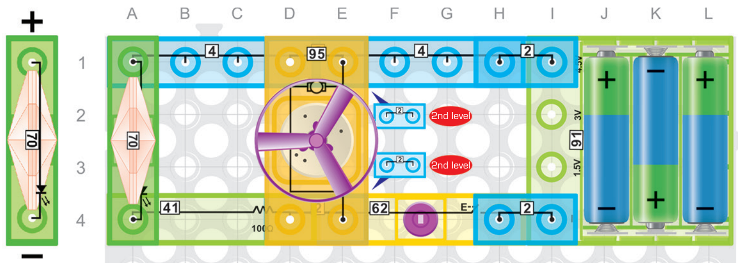
Replace the 100 Ohm (Ω) resistor (41) with the 1kΩ resistor (42). You will find that the heart LED (69) is dimmer. The letter “k” in 1kΩ stands for kilo, which is a prefix that stands for 1000. So 1kΩ is equal to 1000Ω, which is 10 times greater than 100Ω, which is why the heart LED (69) gets dimmer when you replace the 100Ω resistor (41) with a 1kΩ resistor (42).



[26]

26. Electronic Efficiency

Electronic Efficiency is defined as the Useful Power Output divided by the Total Power Input. Build the circuit shown on the left and press the switch (62). The star LED (70) will light, but the lamp (76) will not light brightly. 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.

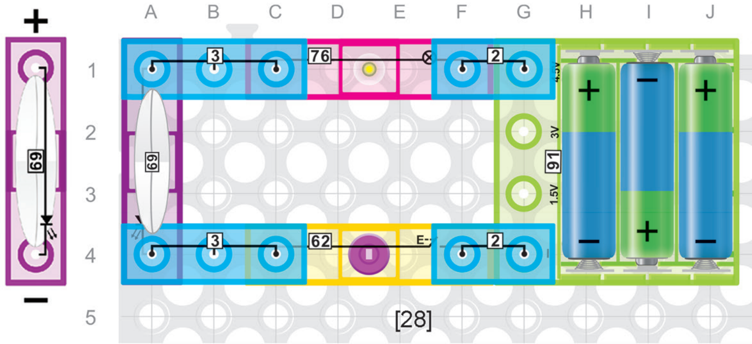


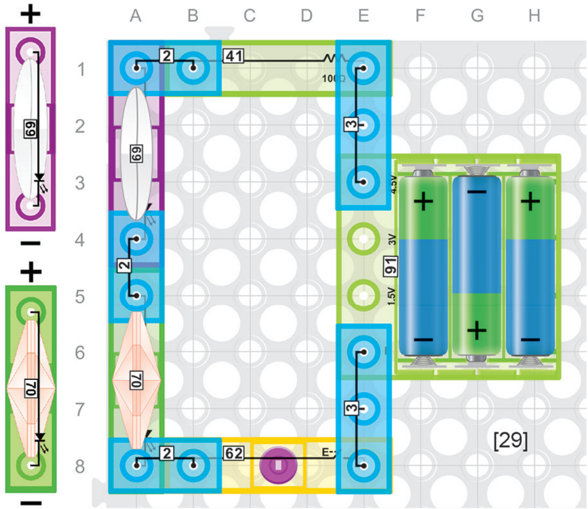
[27]

27. Inertia

Build the circuit shown on the left and place the fan (60) on the motor (95). Press the switch (62) and the star LED (70) will light up and the fan (60) will start spinning. Turn OFF the switch (62) and the fan will keep spinning for a little while, but the star LED (70) 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 star LED (70) does not.

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





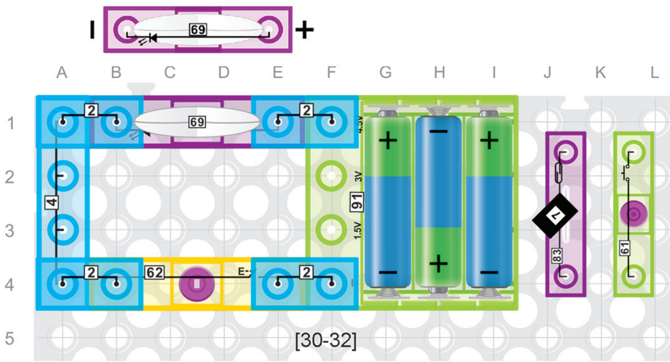
28. Ohm's Law

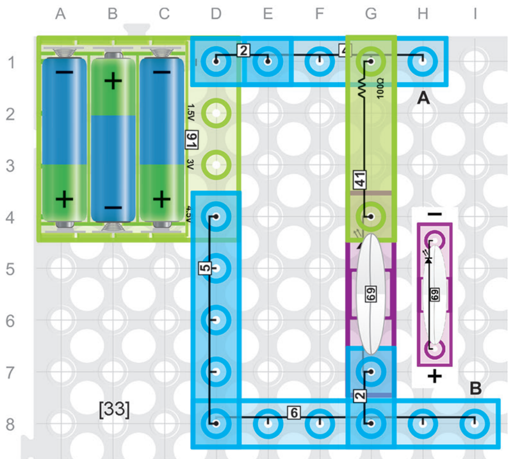
Using Ohm's Law, the resistance of each part could be calculated. Build the circuit shown on the left. In this circuit the heart LED (69) and the lamp (76) are in series so they see the same current. If you had a voltmeter and measured the voltage drop across each component, you would see that the voltage drop across the heart LED (69) is much greater than the voltage drop across the lamp (76).

According to Ohm's Law, V=I*R, where V stands for Voltage, I stands for Current and R stands for Resistance. It has been discussed that the heart LED (69) has a relatively high internal resistance built into it to protect the LED from being damaged by too much current flowing through it. The lamp (76) does not have as high an internal resistance. Since the heart LED (69) and lamp (76) are in series, the current flowing through each will be the same. Thus, Ohm's law tells us that the voltage drop across the heart LED (69) will be greater than that across the lamp (76) (assuming I is constant in Ohm's law, a higher R leads to a higher V). Because of the higher voltage drop across the heart LED (69), there is not enough voltage across the lamp (76) to make it light.

29. Advantages of Series Circuits

Build the circuit shown on the left. The heart LED (69) and the star LED (70) are in series and thus are dim due to the internal resistance in both LED modules limiting the current in the circuit. 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.





30. Light Emitting Diode

Build the circuit shown on the left. Turn ON the switch (62) and the heart LED (69) will light. 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.

31. Detecting Fluid Levels

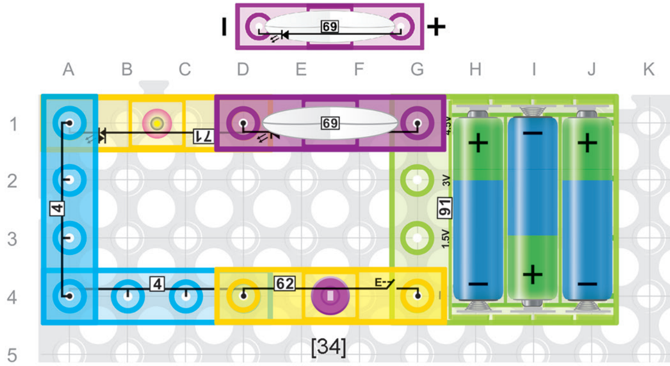
Replace the switch (62) with the reed switch (83). Move the magnet (7) near the reed switch (83) and the heart LED (69) will light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will go off. Reed switch circuits like this can be used to detect fluid levels for coffee makers, 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.

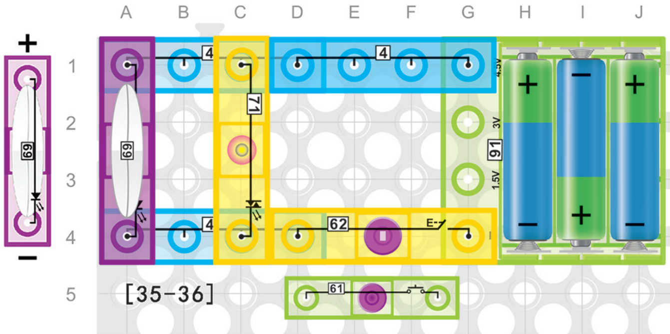
32. Ship to Ship Morse Code

Replace the reed switch (83) with the press switch (61). Press the press switch and the heart LED (69) will flash ON and OFF. 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.

33. 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 all the current to flow through it, bypassing the heart LED (69) and the heart LED (69) will turn off. If the object is a very poor conductor, then very little current will flow through it while most of the current will flow through the heart LED (69) making it light.





34. Red and Blue Light Wavelength

Build the circuit shown on the left, press the switch (62) and the heart LED (69) will light and the bi-directional LED (71) will be red. Reverse the direction of the bi-directional LED (71) and it will be blue. LEDs 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, while blue light has a wavelength of around 470 nanometers. A nanometer is 1 billionth of a meter.

35. ON-OFF Switch

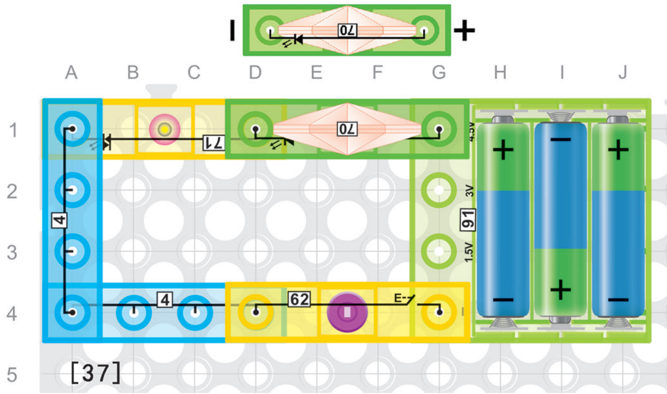
Build the circuit shown on the left, press the switch (62), and you will see the heart LED (69) and the bi-directional LED (71) turn on at the same time. The switch (62) is commonly called an on/off switch since it just turns the circuit on or off from one location. For that reason, it's also referred 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 current flow through the switch. When you change it to OFF, the gate snaps open. It opens the circuit and interrupts the flow of current.

36. Details of Morse Code

Replace the switch (62) with the press switch (61). Press and release the press switch (61) and you will see the heart LED (69) and bi-directional LED (71) flash On and Off. As discussed in project #32, 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.

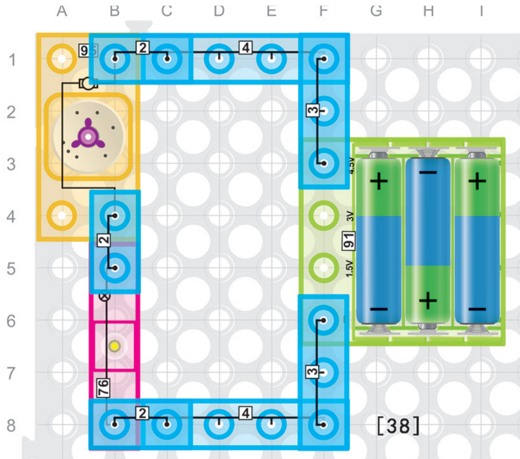
Morse Code

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 ●–●	



37. Toy Lights

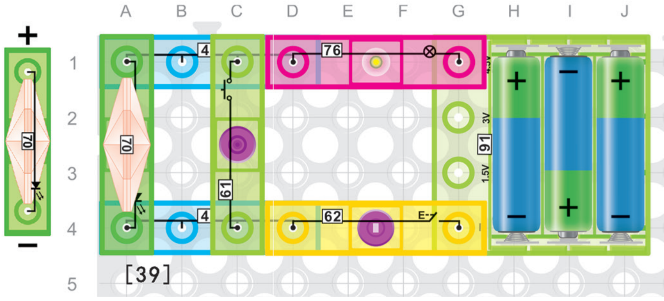
Build the circuit shown on the left, press the switch (62) and the bi-directional LED (71) and star LED (70) will turn on. Press the switch (62) again and the LEDs will turn off. Circuits like this are used in lots of battery operated infant toys where lights go ON and OFF as the child presses the button.

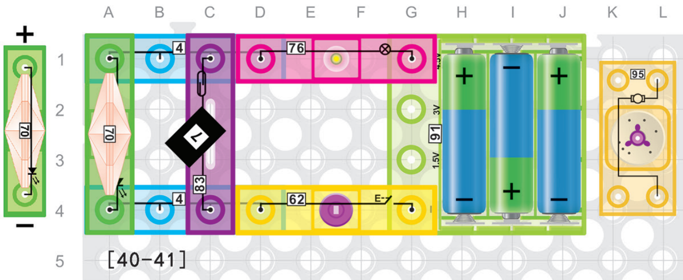


38. Power

Build the circuit shown on the left and the motor (95) will spin while the lamp (76) is on. Power is defined as voltage times current and is measured in Watts. If you measured the internal 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 series in this circuit, they see the same current. If the internal resistance (R) and current (I) through each component are the similar, then Ohm's law (V = I*R) tells us that the Voltage (V) across each component is similar. This shows that the power of each component (V*I) is also similar.

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.

39. Light Power

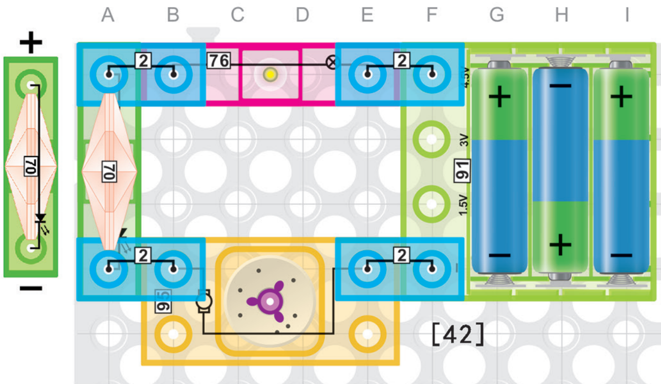
Build the circuit to the left, press the switch (62) and the star LED (70) will be bright but the lamp (76) will be very dim. Light power can be measured in Watts or Lumens. Watts refer to how much energy the bulb uses while Lumens are a measure of the bulb's light output intensity.

40. Battery Power

Build the circuit shown on the left, then turn on the switch (62) and you will see the star LED (70) is on. If you touch the reed switch (83) with magnet (7), the star LED (70) will go off, but the lamp (76) will turn on. 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. Motors and Magnetic Fields

Replace the lamp (76) with the motor (95) and press the switch (62). Now you can control whether the star LED (70) or the motor (95) is on by moving the magnet (7) close to or away from the reed switch (83). 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.



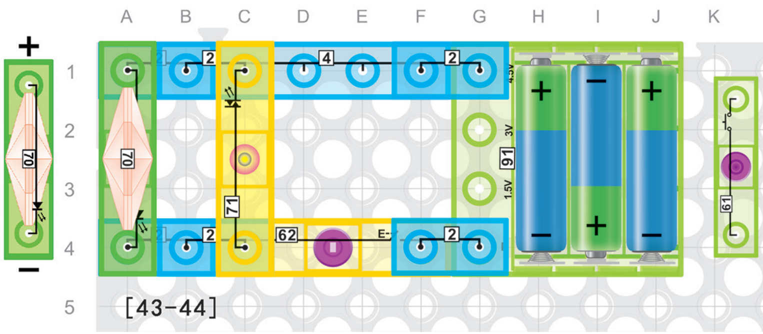
WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.

42. Kirchhoff's Voltage Law

Build the circuit shown on the left and you will see the star LED (70) is on, but the lamp (76) is very dim and the and the motor (95) does not spin or spins very slowly. This is because the voltage across the lamp (76) and motor (95) is small compared to the voltage across the star LED (70). 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:

$$V_{F4 \to F1} + V_{F1 \to A1} + V_{A1 \to A4} + V_{A4 \to F4} = 0$$

This shows that the voltage drop across the battery module (91) must equal the voltage drop across the lamp (76) plus the voltage drop across the star LED (70) plus the voltage drop across the motor (95). If you had a voltmeter and measured the voltage drop across the star LED (70) it would be around 3.5V or greater. So Kirchoff's voltage law says that there's less than 1V left to distribute across the lamp (76) and motor (95) which is why they don't function properly.



43. Kirchhoff's Current Law

Build the circuit shown on the left, turn on the switch (62) and you will see that the Star LED (70) is on and the bi-directional LED (71) is blue. 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 C1 represents a node. If a positive current is coming into a node and a negative current is leaving a node, then:

$$I_{battery} + I_{bi\text{-}directional\ LED} + I_{star\ LED} = 0$$

This shows that the current flowing into node C1 from the battery (91) must equal the current flowing out of node C1 to the bi-directional LED (71) plus the current flowing out of node C1 to the star LED (70).

44. Red and Blue Light Frequency

Replace the switch (62) with the press switch (61), press the press switch (61) and you will see that the star LED (70) is on and the bi-directional LED (71) is blue. Release the press switch (61) and the star LED (70) and bi-directional LED (71) will turn off. Project #34 discussed the wavelength of light. Light can also be characterized in frequency, which is inversely related of wavelength. Specifically,

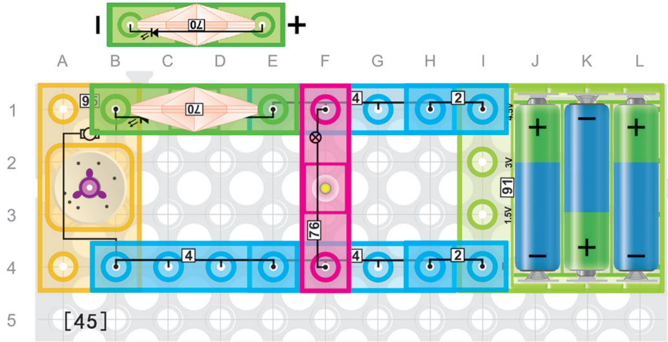
Frequency = (Speed of light)/Wavelength

Light travels at a constant speed of 300 million meters/second (that's fast!). So based on the wavelengths of red and blue light discussed in project #34, we see that:

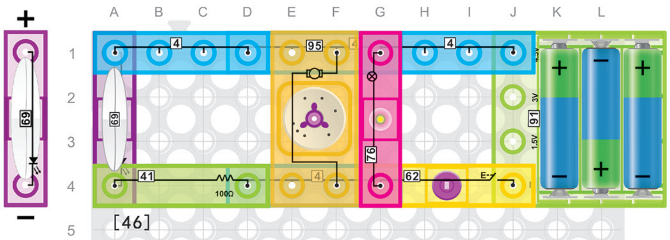
Frequency of Red Light = $(3*10^8)/(665*10^{-9})$ = ~451 THz

Frequency of Blue Light = $(3*10^8)/(470*10^{-9})$ = ~638 THz

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



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.

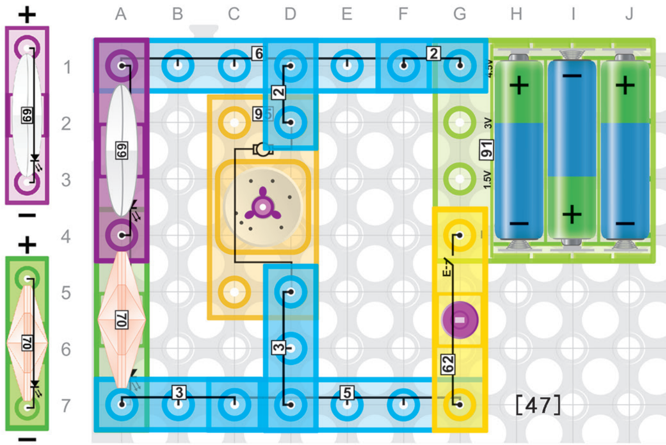
45. Motor Speed

Build the circuit shown on the left and you will see the lamp (76) and the star LED (70) are on while the motor (95) does not spin or spins slowly. Because the motor (95) is in series with the star LED (70), and the star LED (70) has a large voltage drop of about 3.5V, the voltage across the motor (95) is small and thus it spins slowly.

46. Reversing a DC Motor

Build the circuit shown on the left, turn on switch (62) and you will see the heart LED (69) and lamp (76) turn on, and the motor (95) spin at the same time. Turn off the switch (62) and put the motor (95) in backwards, reversing its direction (95 should be upside down now). Press the switch (62) and the motor (95) now spins in the opposite direction.

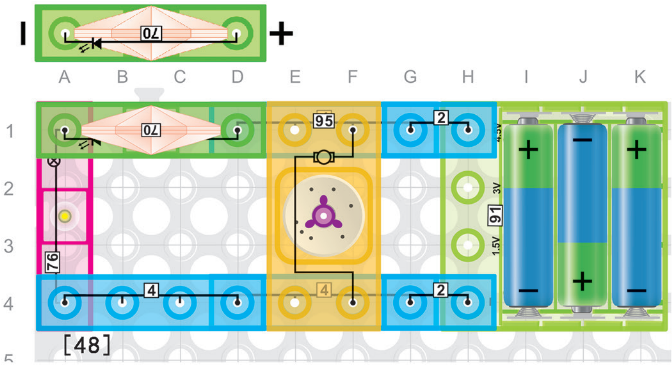
Notice that the direction the motor (95) spins is related to the direction the current flows through the motor (95). This is because the force created on the motor shaft is related to the direction that the current flows through the magnetic field in the motor (95). You can look up Fleming's left hand rule for more details on the relationship between the current flow, magnetic field, and force that creates motion.



47. First Electric Motor

Build the circuit shown on the left, turn on the switch (62) and you can see the motor (95) start spinning, and the two LEDs are turned on dimly at the same lime. 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?

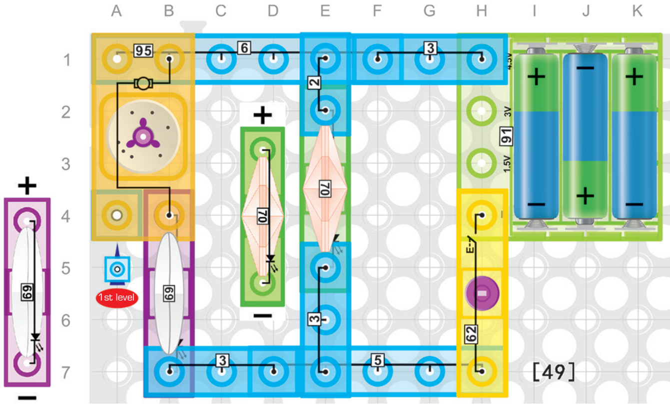
WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.



48. The Dynamo and Generator

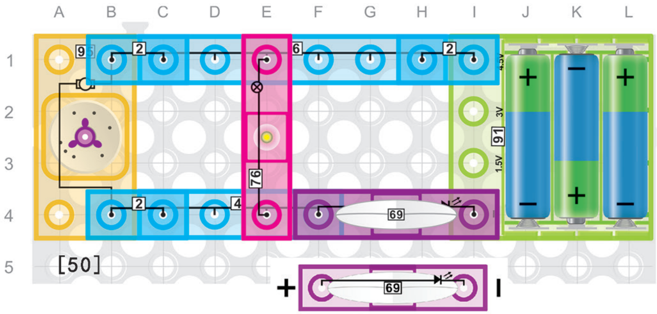
Build the circuit shown on the left and you will see the motor (95) spin and the star LED (70) turn on, but the lamp (76) will be very dim. Because the lamp (76) and the star LED (70) are connected in series, the current that passes though the lamp is limited by the internal resistance in the star LED (70). It was discussed in project #4 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.

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



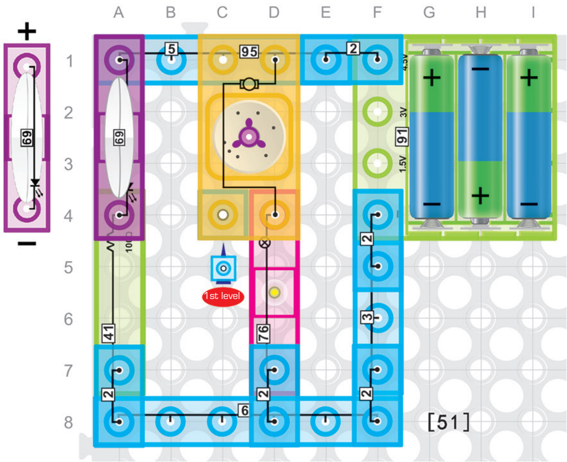
49. Uses of Motors

Build the circuit shown on the left, turn on the switch (62) and the heart LED (69) and star LED (70) will light, but the motor (95) does not spin. The heart LED (69) in series with the motor (95) is limiting the current path through the motor (95) which is why it does not spin. 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?



50. History of LEDs

Build the circuit shown on the left and you see the heart LED (69) light, but the motor (95) does not spin and the lamp (76) does not 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.

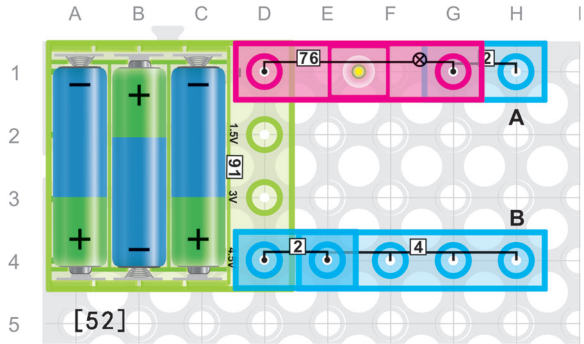


51. Ohms

Build the circuit and you will see the heart LED (69) and lamp (76) will light and the motor (95) spin at the same time. Because the lamp (76) and motor (95) are in parallel with the heart LED (69), the internal resistance of the heart LED (69) does not significantly limit the current path through the lamp (76) and motor (95).

Recall from project #28 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.

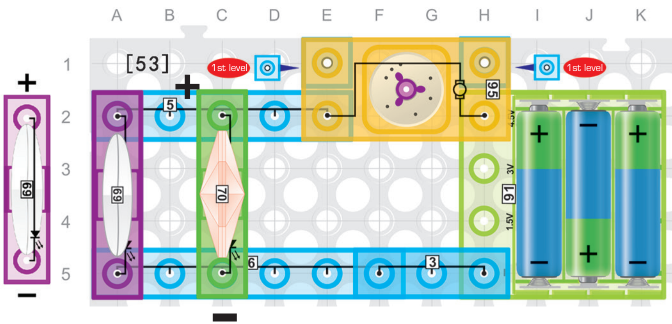
WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.



52. 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 all the current to flow through it and the lamp (76) will light. If the object is a very poor conductor, then very little current will flow through it and the lamp (76) will not light.

This conductivity tester is similar to the one in project #33 but here the light coming on means a good conductor, while in project #33 the light coming on meant a poor conductor.



53. Calculating Equivalent Resistance

Build the circuit shown on the left 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:

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

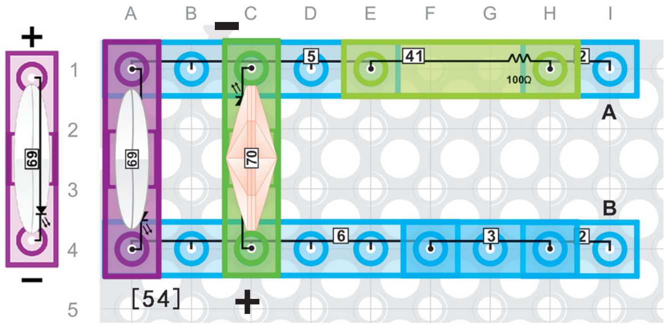
where V is the voltage across both the star LED (70) and heart LED (69), which is the same since they are connected in parallel. Thus, the total current can be written as:

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

Solving for V yields:

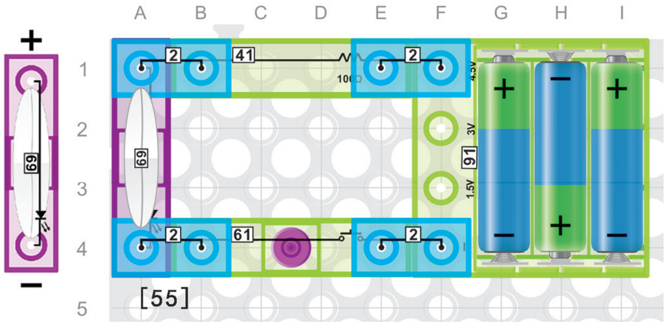
$$V = I_{tot}*R_{star}*R_{heart}/(R_{heart} + R_{star})$$

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 $R_{star} = R_{heart} = R$, 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.



54. Polarity Tester

Build the circuit shown on the 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) will light. This circuit acts as a tester to see which side of a battery is the positive side and which is the negative side.

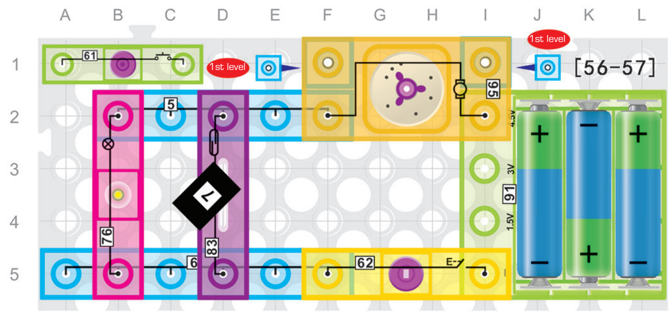


55. Help!

Build the circuit shown on the left, press and release 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 #36) 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



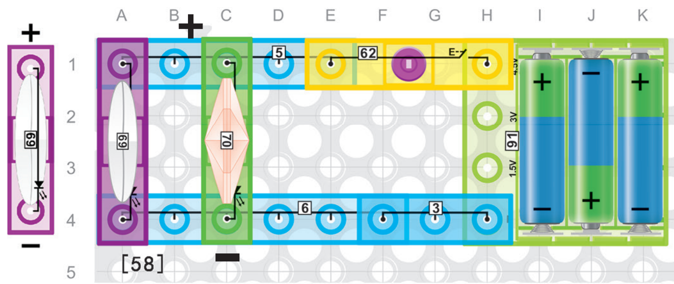
56. Brushless Motors

Build the circuit shown on the left, turn on the switch (62) and you will see the lamp (76) and the motor (95) spin at the same time. Now if you move the magnet (7) near the reed switch (83), you will see the lamp (76) go off while the motor (95) is running faster. Reed switches can actually be used to create what are called brushless motors.

57. Motor Speed Selection Circuit

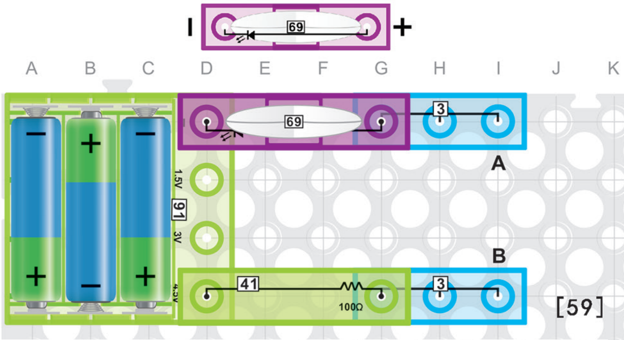
Replace the reed switch (83) with the press switch (61). Turn on the switch (62) and you will see the lamp (76) is on and the motor (95) spin. If you press the press switch (61), you will see the lamp (76) is off while the motor (95) is spinning faster. This circuit demonstrates how speeds of a remote control toy car can be controlled.

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

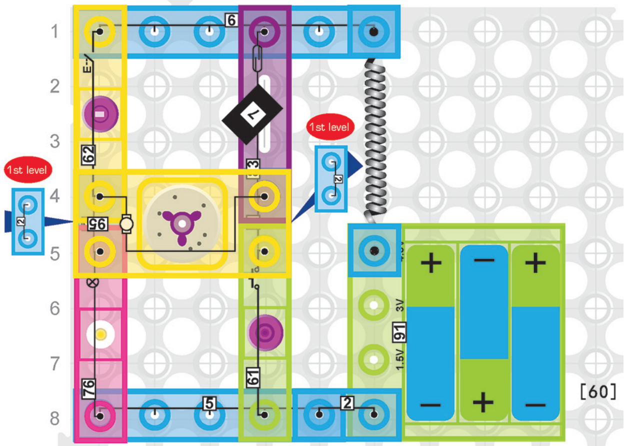


58. Voltage and Current in Parallel Circuits

Build the circuit shown on the left, turn on the switch (62) and you will see the two LEDs light at the same time. Turn off the switch (62) and the LEDs will go off. If you think about Kirchhoff's laws in projects #42 & #43, you can conclude that the voltage across components in parallel is the same, while the current through components in parallel are usually different.



[59]



[60]

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

59. Internal Resistance of Heart LED

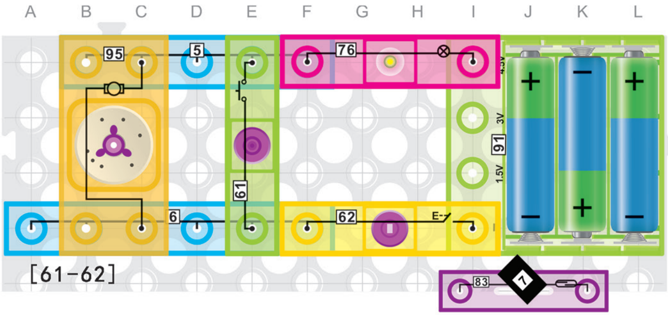
Build the circuit shown on the left and put a 4-wire (4) across the points A and B. If you have a voltmeter, you can measure the voltage across the heart LED (69) and 100Ω resistor (41) (Ω is the symbol representing Ohms) and see that about 3.3V is across the heart LED (69) and only about 1.2V is across the 100Ω resistor (41). 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.

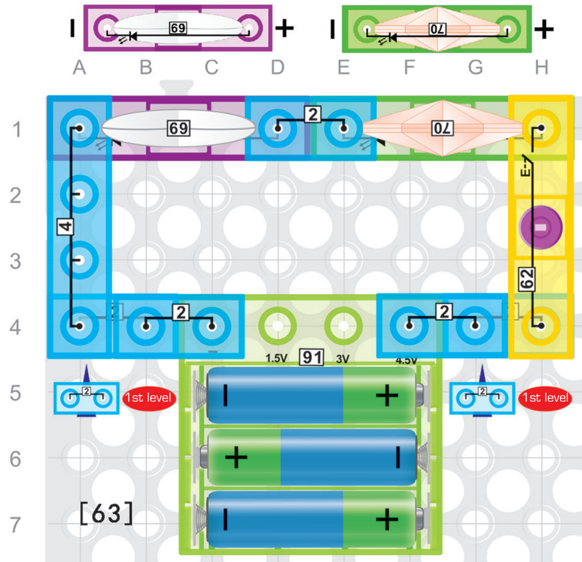
Actual LEDs have very little resistance but do require a certain “turn on” voltage to light, which is color dependent. Red light is one of the easier colors to light and requires only about 1.8V to turn on the LED. So this means that the internal resistor will see about 1.5V of the 3.3V across the heart LED (69). Since the heart LED (69) and 100Ω resistor (41) are in series, the same current is running through each. Since the internal resistance of the heart LED (69) and the 100Ω resistor (41) are both seeing the same current, and we calculated they both are seeing about 1.2-1.5V across each of them, Ohm’s law (R = V/I) tells us that the internal resistance of the heart LED (69) must be very close to 100Ω.

60. Revisiting Fleming’s Left Hand Rule

Build the circuit shown on the left, touch the reed switch (83) with the magnet (7) and you will see the motor (95) spin and the lamp (76) is turned on. Move away the magnet (7), then turn on the switch (62). The lamp (76) will be on again and if you press the press switch (61) now the motor (95) will spin in the opposite direction.

Fleming’s left hand rule was mentioned in project #46. 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 see that if the current is reversed (like in this project), then the force is in the opposite direction which is why the motor spins in the opposite direction.





61. Light Dimmer

Build the circuit shown on the left, turn on the switch (62) and you will see the lamp (76) ON and the motor (95) spin at the same time. Now press the press switch (61) and the lamp (76) gets brighter while the motor 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.

62. Fused Motor

Replace the press switch (61) with the reed switch (83). Now you can control the brightness of the lamp (76) by using the magnet (7). Also, the motor (95) goes off when you place the magnet (7) near the reed switch (83).

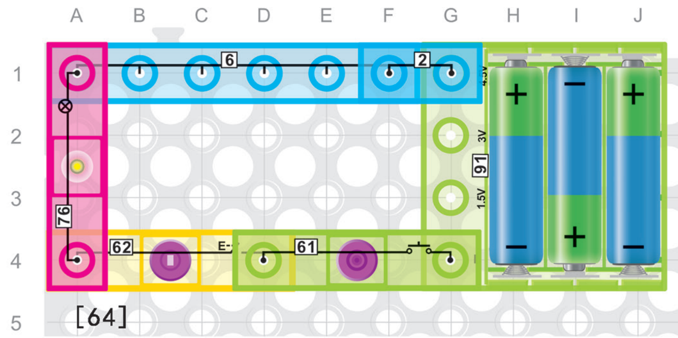
Motors are designed with fuses to limit the current that can be seen by the motor to prevent fires. When you move the magnet (7) near the reed switch (83), you are simulating a motor fuse popping to protect a motor from too much current.

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

63. Voltage and Current in Series Circuits

Build the circuit shown on the left, turn on the switch (62) and you will see the two LEDs light at the same time. Turn off the switch (62) and the LEDs will go off.

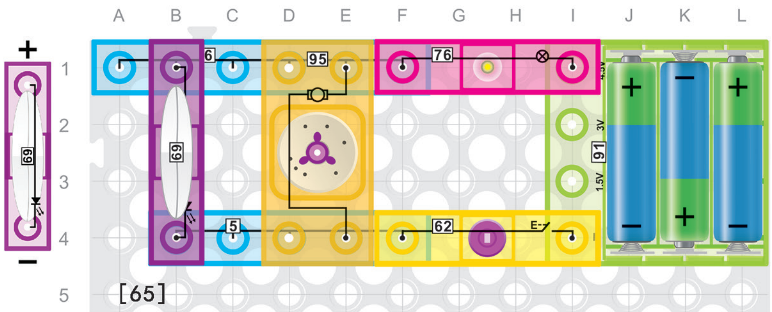
If you think about Kirchhoff's laws in projects #42 & #43, you can conclude that the current through components in series is the same, while the voltage across components in series are usually different.



64. 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).



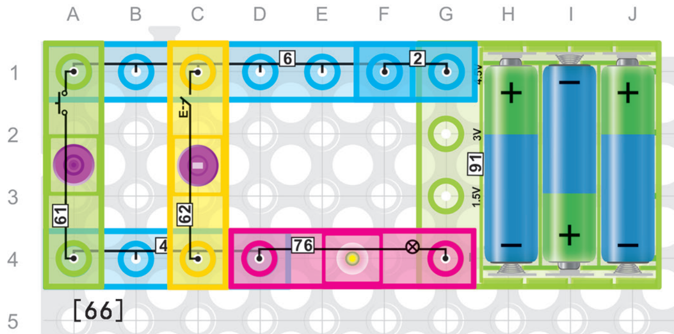
65. Internal Resistance of the Motor

Build the circuit shown on the left. Turn on the switch (62) and you will see the lamp (76) light, the motor (95) spin, and the heart LED (69) turn on dimly.

Motors that are spinning (in the ON state) have very low internal resistance (less than that of the heart LED (69)). Since the motor (95) in this circuit is in parallel with the heart LED (69), the equivalent resistance of the parallel combination is much lower than when only the heart LED (69) is in the circuit.

Using Ohm’s law, you can show that this lower resistance leads to lowering the voltage across the motor (95) and heart LED (69), which is why the heart LED (69) is dim and the motor (95) speed is lower. This also shows that when other components are in series (like the lamp (76) in this project), then placing components in parallel can have an effect on each other.

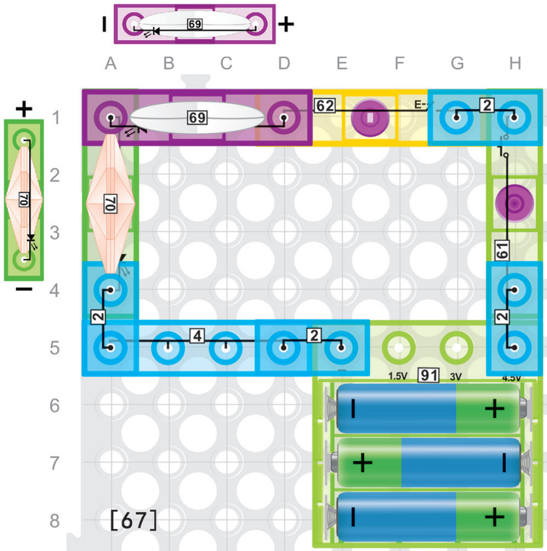
WARNING: Moving parts. Do not touch the motor during operation. Do not lean over the motor.



66. 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 the output is False only when all the inputs are False.

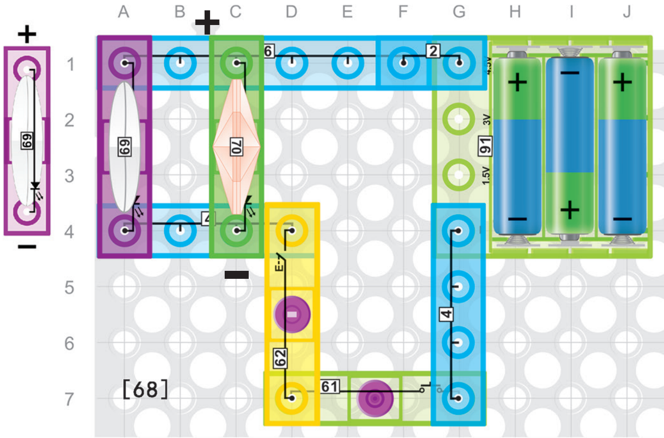
In this circuit, the output represented by the lamp (76) is ON (True) if either input represented by the press switch (61) or the switch (62) or both is ON (TRUE). The lamp (76) is OFF (False) only when both switches are OFF (False).



67. Direct Current and Alternating Current

Build the circuit, turn on the switch (62), and press the press switch (61) and you will see both LEDs are turned on. 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.

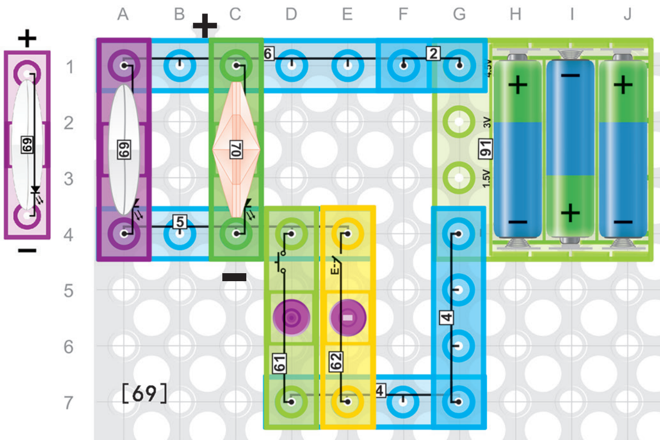
LEDs are generally driven by DC current, but the outlets in your house provide Alternating Current (AC). Alternating current changes the direction of the current like a sine wave. This is why you will usually see an AC to DC adaptor between your LED TV and the plug at the end of the cord for your LED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



68. Safety Circuit

Build the circuit shown on the left, turn on the switch (62) and press the press switch (61) and you will light up the LEDs at the same time.

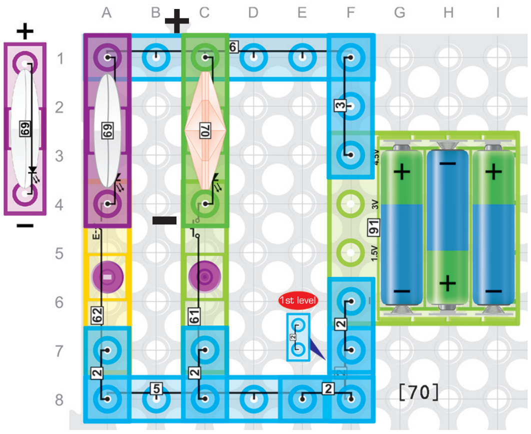
Sometimes, for safety reasons, it is required that two switches be ON before machinery will run.



69. Controlling Electrical Appliances

Build the circuit shown on the left. If you want to turn on the LEDs you just need to turn on the switch (62) or press the press switch (61). If you want to turn off the LEDs, you need to disconnect all the switches.

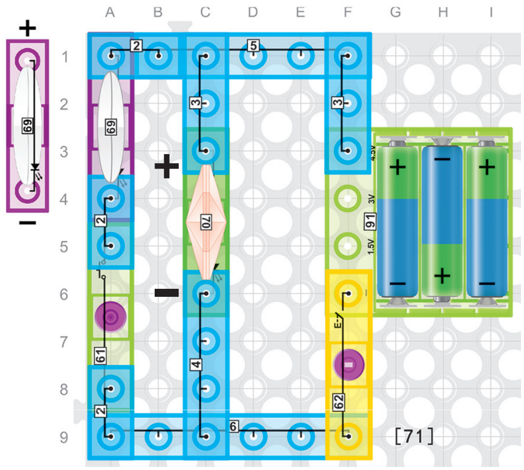
You might think this type of circuit could be used to have multiple switches in a room to control the same device(s). However, this type of circuit is not ideal because the switches do not toggle with each other. In your house, if you pushed the switch (62) ON to turn on your lights, then if you pressed the press switch (61) you would want your lights to go OFF. Your house uses three-way switches to do this, and not the circuit shown on the left.



70. Individually Controlled Electrical Appliances

Build the circuit, turn on the switch (62) and you will see the heart LED (69) is on. If you press the press switch (61), you will see the star LED (70) is on.

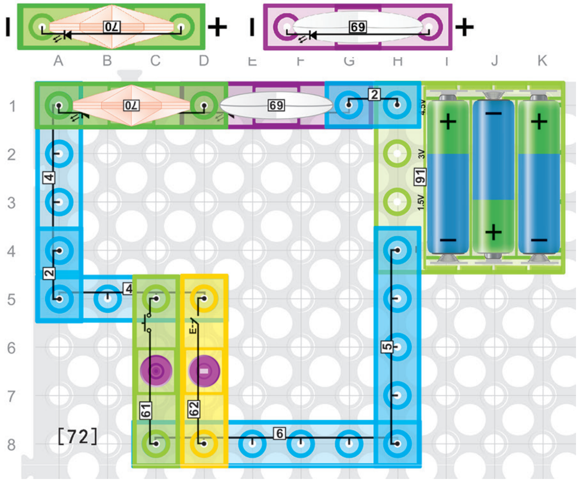
You might have a circuit in your family room like this where you have two switches on the wall where one switch turns on and off the lights in the room and one switch turns on and off the TV.



71. Switches on Appliances

Build the circuit, turn on the switch (62), and you will light up the star LED (70). You then need press the press switch (61) for the heart LED (69) to turn on.

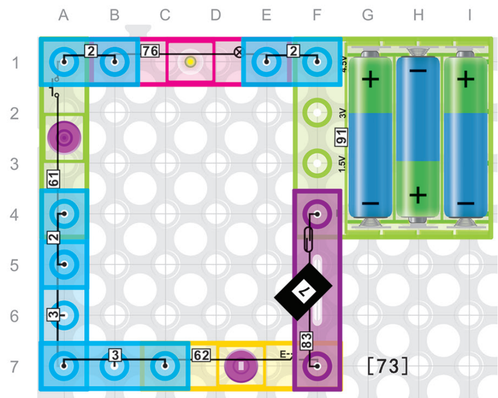
This type of circuit simulates how some appliances in your house may work. For instance, in your bedroom there may be a switch that turns on the lights embedded in the ceiling, and it turns on certain outlets in the room. But you still need to flip the switch on the lamp sitting your nightstand that is connected to those outlets to turn it on.



72. LEDs are less “Buggy”

Build the circuit shown on the left, turn on the switch (62) or the press switch (61) and you can light up both LEDs at the same time. If you want to turn off the two LEDs, you must turn off both the switches.

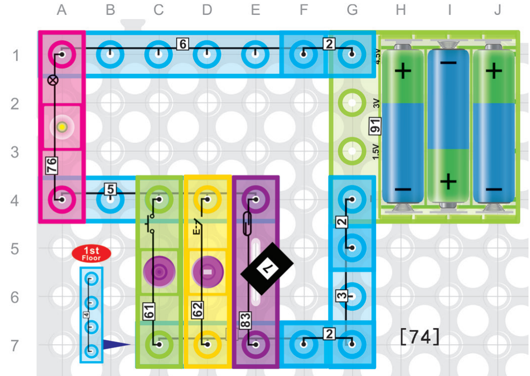
You may have noticed in the summertime at night, lots of bugs flying around your porch lights, especially if they are not LED lights but are incandescent lights. Try switching those incandescent lights to LED lights. LEDs don’t attract as many insects as other traditional light sources as they have very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



73. 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).

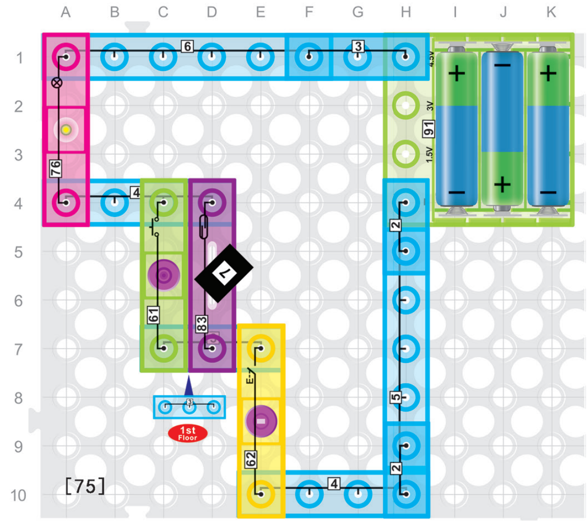
Electronic AND Gates can have two or more inputs but the function is still the same. All inputs must be True (ON) for the output to be True (ON).



74. Triple Input ‘OR’ Gate

Build the circuit shown on 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.

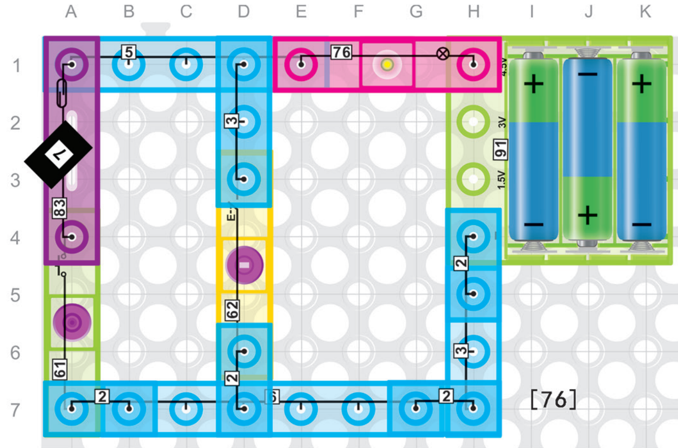
Electronic OR Gates can have two or more inputs but the function is still the same. All inputs must be False (OFF) for output to be False (OFF).



75. Series-Parallel Circuit Paths (I)

Build the circuit shown on 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.

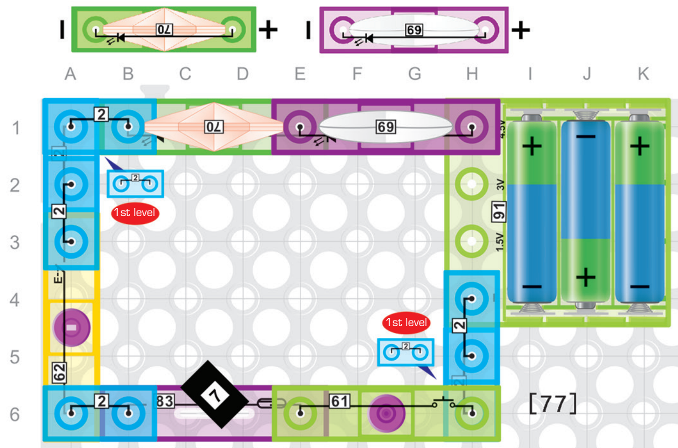
Since the switch (62) is in series with the other two switches that are in parallel, this makes a series-parallel circuit path for the lamp (76). This kind of circuit could be used in a hotel room where your key card must be inserted in a card holder near the door to enable a closed circuit, but you still need to turn on switches in the room to have certain lights or devices close the circuit and turn on.



76. Series-Parallel Circuit Paths (II)

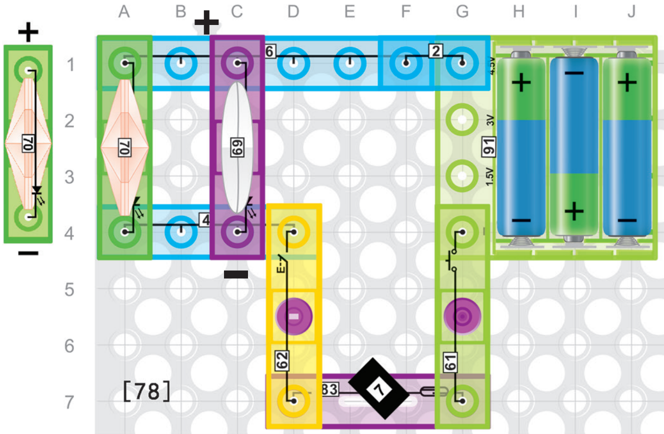
Build the circuit shown on the left. There are two ways to light the lamp (76) in this circuit. You can either press the switch (62) or place the magnet (7) next to the reed switch (83) and press the press switch (61).

Using the hotel analogy from the last project, 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.



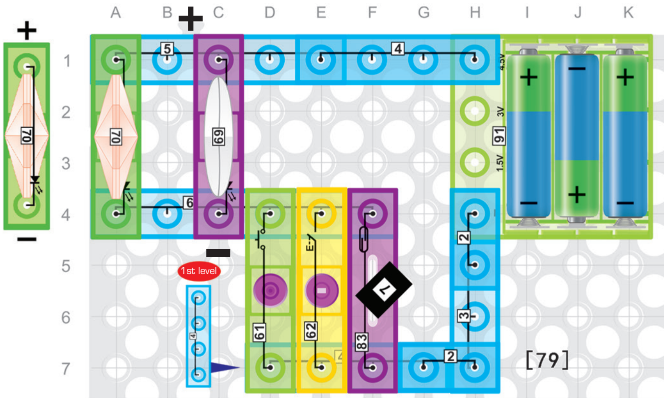
77. Three-person Rocket Launch

Build the circuit shown on the left. In this circuit, pretend the LEDs are 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.



78. Circuit Breakers

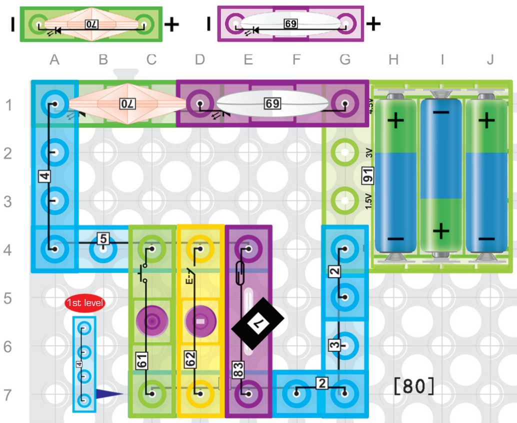
In this circuit, if you want to turn on the two LEDs, you need to turn on all the switches at the same time. This circuit could represent your house circuitry. Think of the reed switch (83) like the circuit breaker in your house, the switch (62) like a wall switch, and the press switch (61) like the 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.

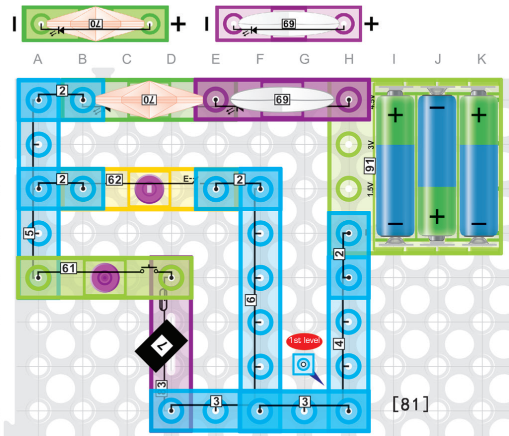


79. Reed Switches in Laptops

Build the circuit shown on the left. If you turn on any one of the switches, you can see the two LEDs are on at the same time. But if you want to turn off the LEDs, you need to turn off all the switches.

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?





80. Reed Switches for Speed Sensors

Build the circuit shown on the left. If you turn on any one of the switches, you can see the two LEDs are on at the same time. But if you want to turn off the LEDs, you need to turn off all the switches.

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.

81. AND Gate and OR Gate Logic

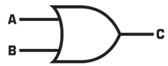
In this circuit, if you want to turn on the two LEDs you can press the switch (62), or you can press the press switch (61) and the reed switch (83) at the same time.

AND gates and OR Gates have been discussed in projects #64 and #66. The diagram and logical tables for the 2-input AND Gate and 2-input OR Gate are shown below.

AND Gate

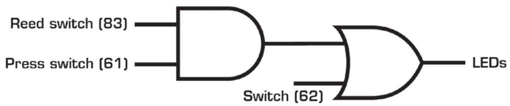
Inputs		Output
A	B	C
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

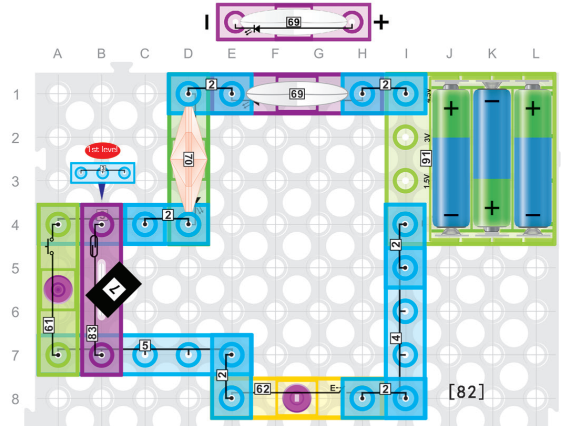
OR Gate

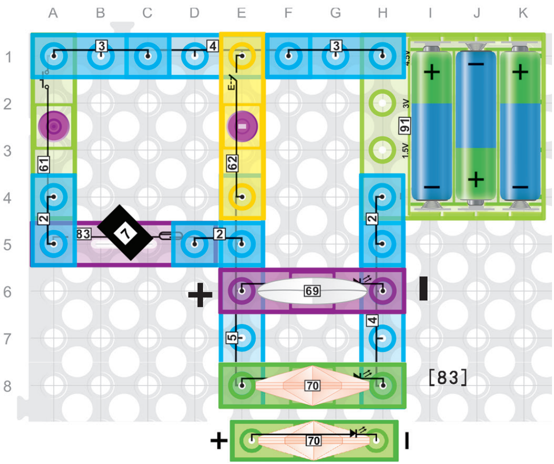


Inputs		Output
A	B	C
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

Using these diagrams, you could represent the logic in this circuit as shown below.

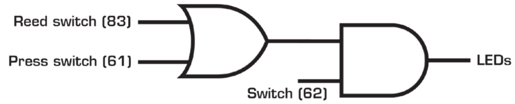






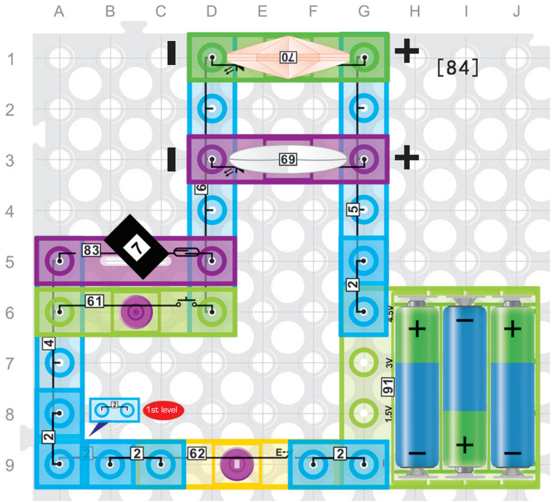
82. More AND/OR Gate Logic

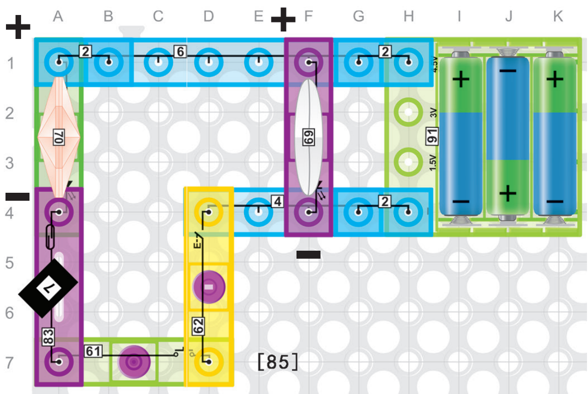
Build the circuit shown on the left and turn on the switch (62). Now touch the reed switch (83) with the magnet (7) or press the press switch (61) and you will light up both LEDs. If you want to turn off the LEDs, you can either turn off the switch (62) or turn off both the press switch (61) and the reed switch (83). Using the logical diagrams from project #81, you could represent the logic in this circuit as shown below.



83. Applications of the Press Switch

In this circuit, if you want to turn on both the LEDs you can turn on the switch (62), or turn on the reed switch (83) and the press switch (61) at the same time. Some of the common applications of the press switch (61) are for doorbells, keys on your keyboard, and laser pointers.





84. LED Efficiency

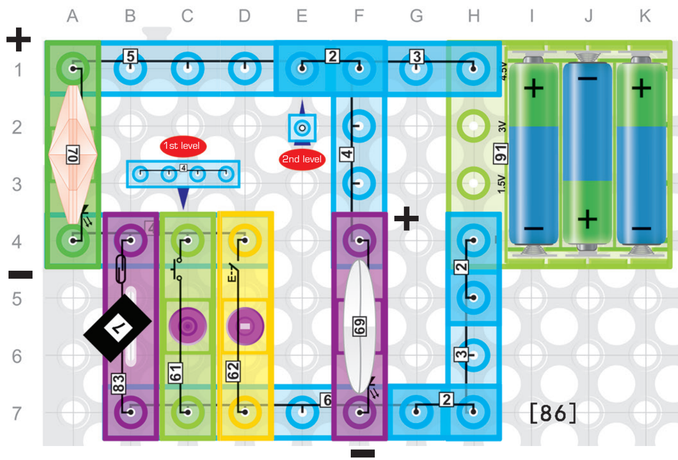
Build the circuit shown on the left, then turn on the switch (62). If you touch the reed switch (83) or press the press switch (61), you will then light up the two LEDs at the same time. If you want to turn off the two LEDs, you can turn off the press switch (61) and the reed switch (83) or turn off the switch (62).

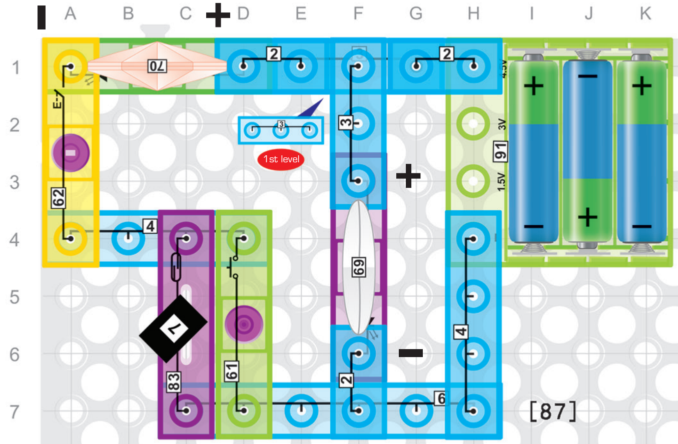
An incandescent lamp converts about 9-10% of the energy fed to it into light, whereas LEDs convert at least 50% of that incoming energy they consume to light, the rest being lost to heat generation. So LEDs are much more efficient than incandescent lamps.

85. Instant ON

Build the circuit shown on the left and you will see the heart LED (69) is on. Turn on the switch (62) and place the magnet (7) near the reed switch (83). Now when you press the press switch (61) the star LED (70) comes on.

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.

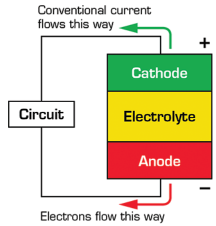




86. Batteries

Build the circuit to the left and you will see that the heart LED (69) is on. Now if you turn on any switch, you will see the star LED (70) is on too.

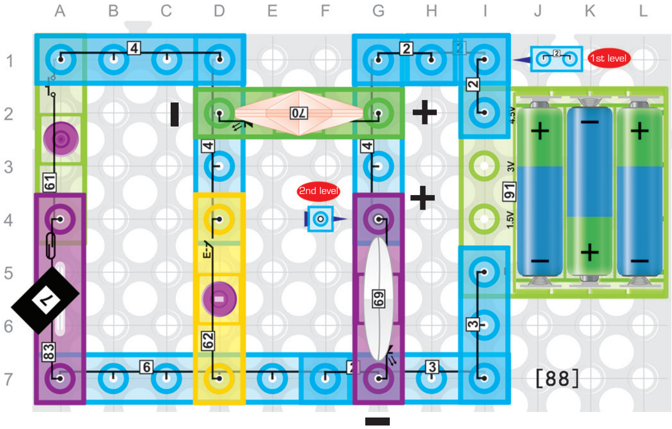
Ever wonder how the batteries in your circuit work? Batteries have three parts, an anode (–), a cathode (+), and the electrolyte, as shown in the figure below. When the cathode and anode are hooked up to an electrical circuit, a chemical reaction occurs in the battery causing a buildup of electrons at 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).



87. Direction that Current Flows

Build the circuit shown and you will see the heart LED (69) is on. If you want to turn on the star LED (70), you can turn on the switch (62) and either press the press switch (61) or touch the reed switch (83) with the magnet (7).

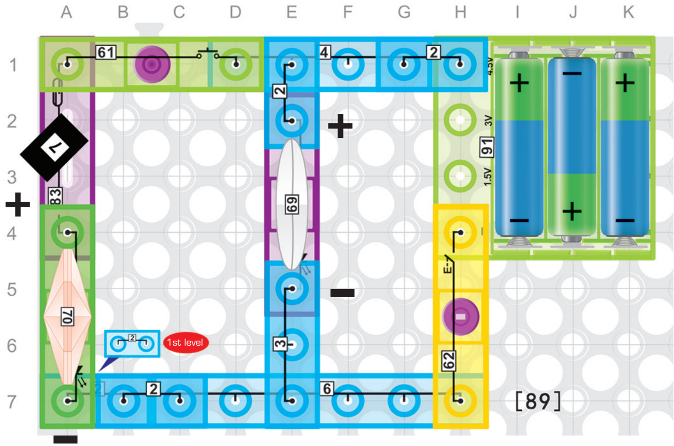
Based on the discussion on batteries in the previous project, you could say that current is flowing from the "–" terminal of the battery to the "+" terminal of the battery since electrons are moving that direction. In fact, some in the industry will refer to this as "electron flow notation". However, 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.



88. Forward & Reverse Bias

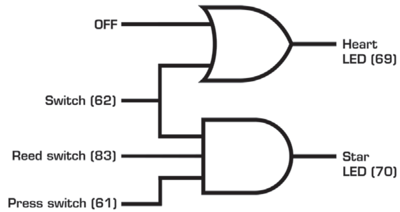
Build the circuit shown on the left and you will see the heart LED (69) is on. If you want to turn on the star LED (70), you can turn on the switch (62), or you can press the press switch (61) and move the magnet (7) near the reed switch (83). Note that the LEDs must be in the circuit in the direction 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.

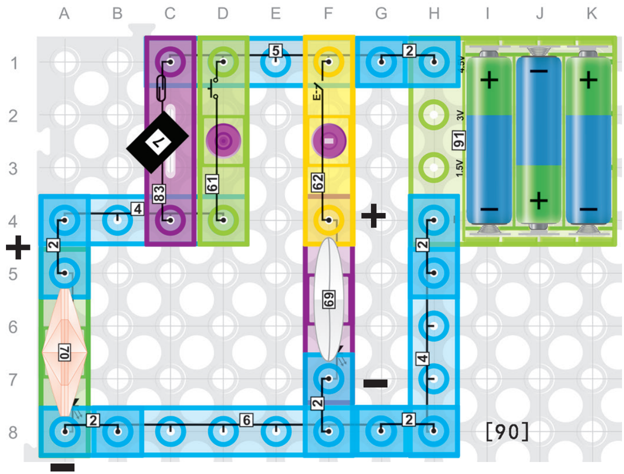
LEDs are typically made of two types of semiconductor materials side-by-side. One material has an excess of electrons and the other material has a depletion of electrons (excess of holes). By doing this, even a small "forward bias" voltage can be applied in one direction and current will flow making the LED light. However, even large "reverse bias" voltages are not enough to enable current to flow in the other direction through the LED.

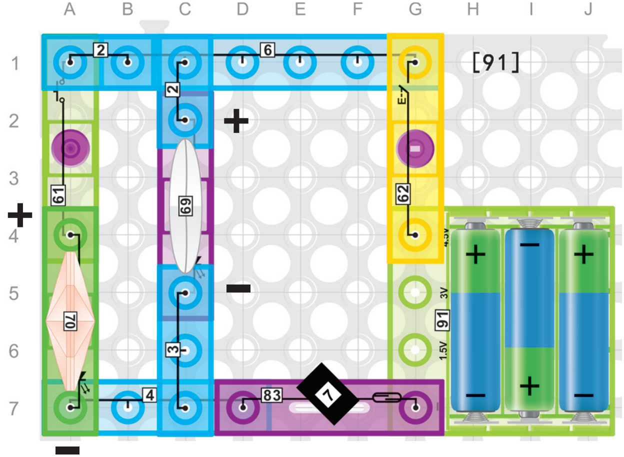


89. More AND/OR Gate Logic

Build the circuit, turn on the switch (62) and you will see the heart LED (69) is on. If you want to turn on the star LED (70), you can press the press switch (61) and touch the reed switch (83) with the magnet (7) at the same time. The logic diagram for this circuit is shown below.







90. Measuring Current

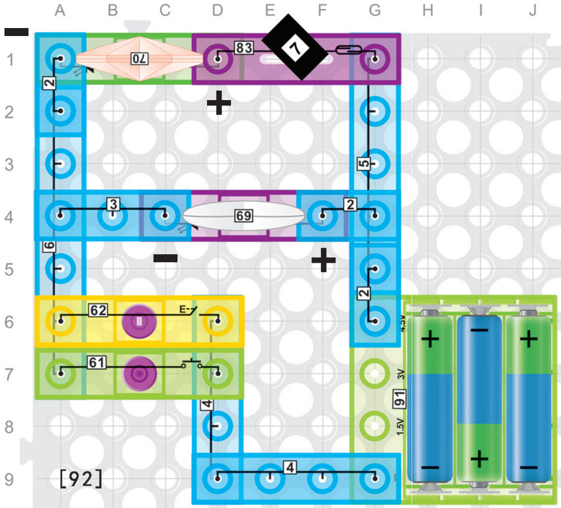
Build the circuit shown, turn on the switch (62) and you will see the heart LED (69) is on. If you want to turn on the star LED (70), you just need to press the press switch (61) or hold the magnet (7) near the reed switch (83).

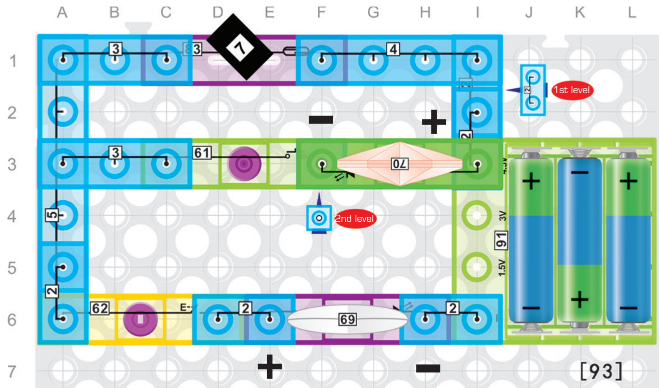
If you wanted to know how much current is flowing in different parts of this circuit, you could use an Ammeter. An Ammeter is an instrument used to measure the Amps of current flowing in a circuit. If you hooked up an ammeter to the current path of the heart LED (69), you would see about 27mA (pronounced 27 milli-Amps, which represents 27 thousandths of an Amp) of current flowing when the switch (62) is ON. If you hooked up an ammeter to the current path of the star LED (70), you would see about 57mA of current flowing when you press the press switch (61). Can you figure out why more current flows through the star LED (70)?

91. Calculating Internal Resistance of the LEDs

Build the circuit shown on the left, turn on the switch (62) and the reed switch (83) and you will see the heart LED (69) is on. Now press the press switch (61) and the star LED (70) will be turned on too. The LEDs in this project are in parallel just like they were in project #90 so we would get the same ammeter measurements as discussed in project #90.

You may have figured out by now that the reason more current flows through the star LED (70) is because it has a lower internal resistance. Recall from project #59 that the actual LEDs inside the heart LED (69) and star LED (70) require a "turn on" voltage to light. This is approximately 1.8V for red light, but white light requires about 2.5V. So the internal resistor in the heart LED (69) will see about 2.7V (since the batteries provide about 4.5V, minus the 1.8V drop across the red LED), and from the previous project the heart LED (69) sees 27mA of current, and thus based on Ohm's Law (R=V/I) the internal resistance of the heart LED (69) is about R=2.7/0.027 = 100Ω. The internal resistor in the star LED (70) will see about 2V, and from the previous project the star LED (70) sees 57mA of current, and thus based on Ohm's Law the internal resistance of the star LED (70) is about 2/0.057 = 35Ω.





92. Revisiting Kirchhoff's Current Law

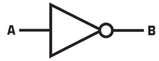
Build the circuit shown on the left, turn on the switch (62) or press the press switch (61) and you will light up the heart LED (69). If you want to light up the star LED (70), then you also need to move the magnet (7) near the reed switch (83).

The LEDs in this project are in parallel just like they were in project #91 so we would get the same ammeter measurements as discussed in project #91. If you hooked up an ammeter to the current path coming out of the battery (91), you would measure about 84 mA. This shows that the current being drawn from the battery (91) is equal to the sum of the currents through the star LED (70) and heart LED (69) (Kirchhoff's Current Law in action!).

93. NOT Gate

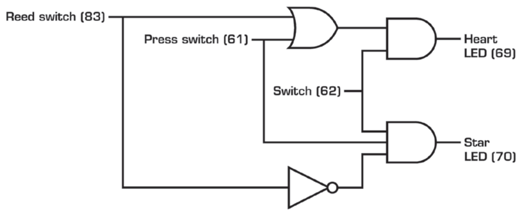
Build the circuit shown, turn on the switch (62) and press the press switch (61) and you will see both the LEDs are on. If you touch the reed switch (83) with the magnet (7), you will see that the star LED (70) goes off, but the heart LED (69) is brighter. This is because by activating the reed switch (83) you are bypassing the star LED (70) so the heart LED (69) 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 on the right. 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).

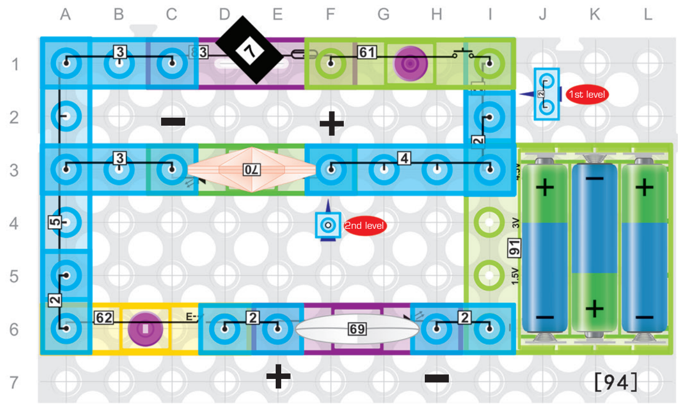
NOT Gate



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.

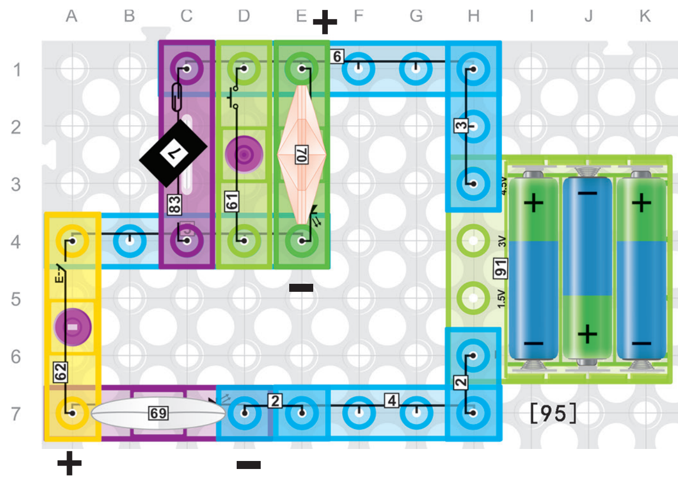




94. Measuring Voltage

Build the circuit to the left, turn on the switch (62) and you will see the two LEDs are turned on. Now press the press switch (61) and touch the reed switch (83) with the magnet (7) and you will see the star LED (70) goes off, but the heart LED (69) will be brighter.

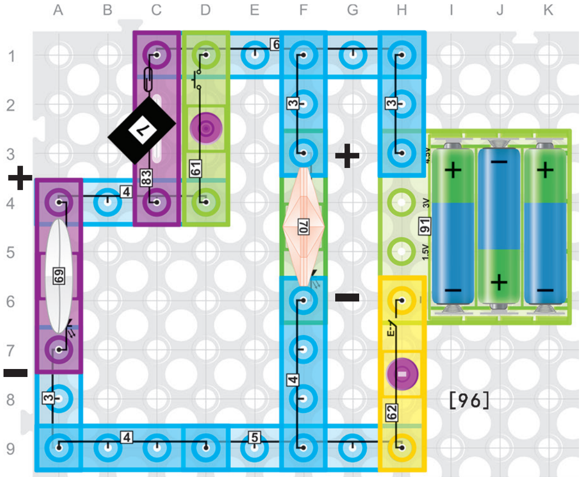
A Voltmeter is used to measure voltage. Since the LEDs in this circuit are in series, they each don't see the full 4.5V from the battery (91). If you used a voltmeter you would see that when the switch (62) is on and the press switch (61) is off, then the voltage across the heart LED (69) is about 1.9V 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!).

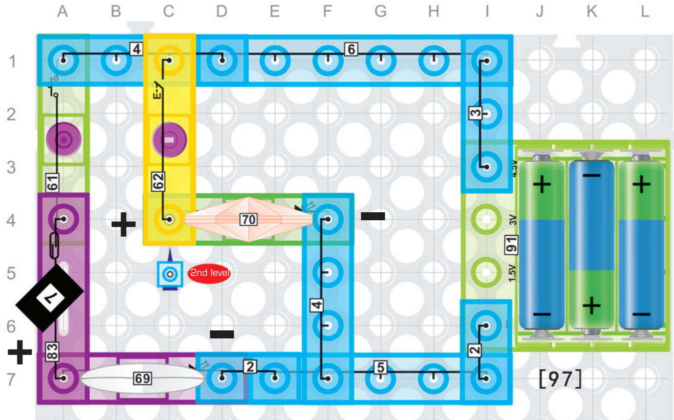


95. Internal Resistance of the LED Modules

Build the circuit shown on the left, turn on the switch (62), and you will see the two LEDs are turned on at the same time. Now press the press switch (61) or touch the reed switch (83) with the magnet (7) and the star LED (70) will go off, but the heart LED (69) will be brighter.

In project #91 it was discussed that white light requires higher voltage to turn on the internal LED than red light. Thus, less voltage remains across the internal resistor in the star LED (70) than in the heart LED (69). Based on Ohm's law (I=V/R), in order to get the same current through the star LED (70) as the heart LED (69), the internal resistor in the star LED (70) must be smaller than in the heart LED (69). This is exactly what we saw in project #91 and is why the star LED (70) module is designed with a smaller internal resistor than the heart LED (69) module.





96. Conservation of Energy

Build the circuit shown on the left, turn on the switch (62) and you will see the star LED (70) is on. Now if you touch the reed switch (83) with the magnet (7), or press the press switch (61), the heart LED (69) will be on too. 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.

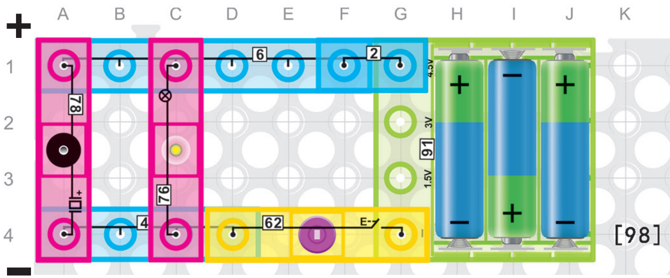
97. Different Color LED Turn On Voltages

Build the circuit shown on the left, turn on the switch (62) and you will see the star LED (70) is on. Press the press switch (61) and touch the reed switch (83) with the magnet (7) and the heart LED (69) will be on too.

In project #44 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 ΔV (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 $6.626*10^{-34}$.

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

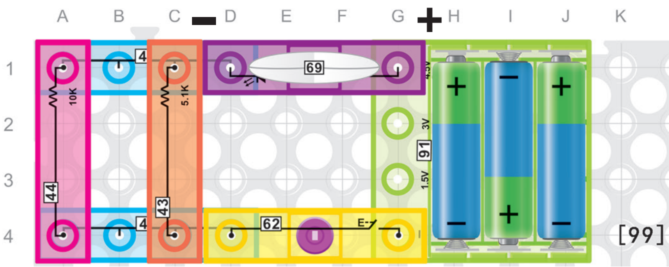
Conservation of energy lets us say that the energy lost by the electron is equal to the energy of the emitted photon, so $q*\Delta V = hf$. So the Conservation of Energy tells us that for the same light intensity, higher frequencies require a larger ΔV, which is why the star LED (70) producing white light (which contains all colors) requires a higher "turn on" voltage than the heart LED (69) producing red light.



98. Fire Drill Alarm

Build the circuit shown on the left making sure the alarm (78) is in the correct direction. Press the switch (62) and you will hear the alarm (78) and see the lamp (76) light.

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 then turned OFF when the fire drill is over.

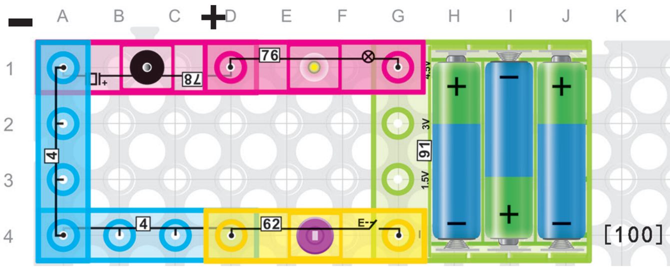


99. Resistors in Parallel

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 #53, two resistors in parallel have an equivalent resistance of:

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

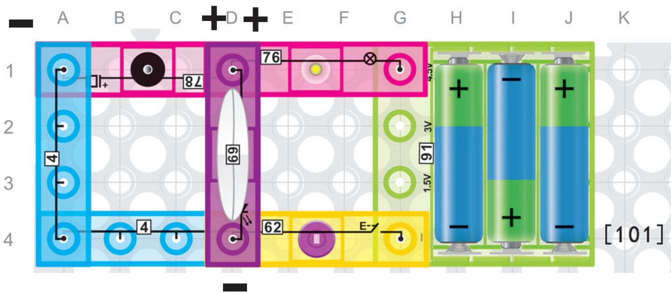
In this case $R_{equivalent}$ = (5.1k * 10k)/(5.1k + 10k) = 3.4kΩ. So as you can see, the equivalent resistance of the parallel combination of the two resistors is less than the value of either resistor, so when you pull one of the resistors out of the circuit it actually increases the resistance in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



100. Sound Waves

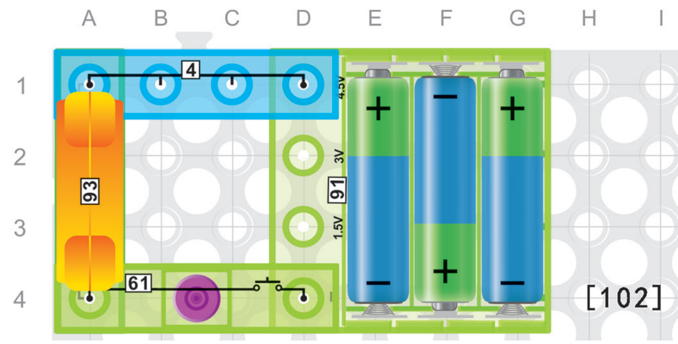
Build the circuit, turn on the switch (62) and you will hear the warning sounds from the alarm (78), but the lamp (76) is off. The internal resistance of the alarm (78) limits the current in this circuit preventing the lamp (76) from lighting. The alarm (78) makes sound by creating sound waves, much like light waves, but at much longer wavelengths and much lower frequencies.

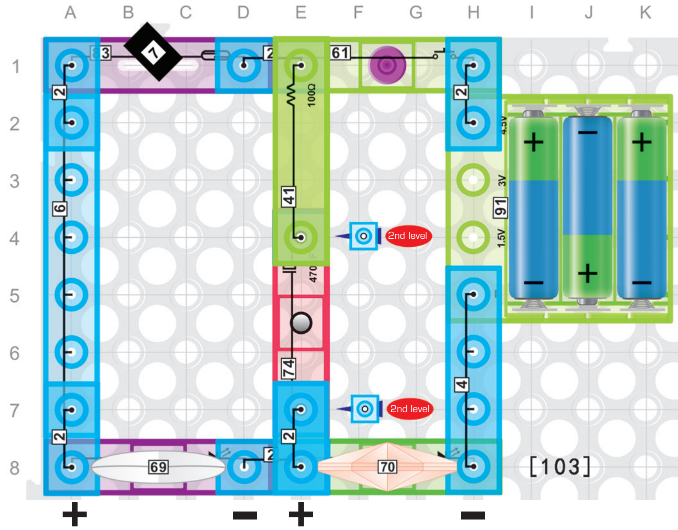
Frequency is the inverse of wavelength (frequency = 1/wavelength) and is measured in Hertz (Hz). The human ear can hear sound waves between about 20 Hz and 20 kHz (20,000 Hz).



101. Visual and Audio Alarm

Build the circuit shown on the left. In this circuit, the alarm (78) and the heart LED (69) are connected in parallel, and they are both connected in series with the lamp (76). This is called series-parallel circuit. 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.





102. Sound Waves

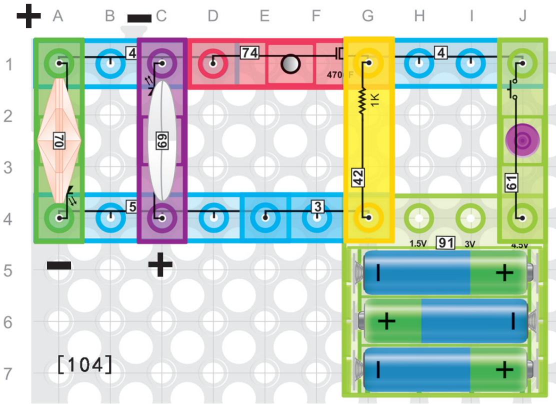
Build the circuit shown, press and release the press switch (61) several times and you will hear some clicks and pops from the speaker (93).

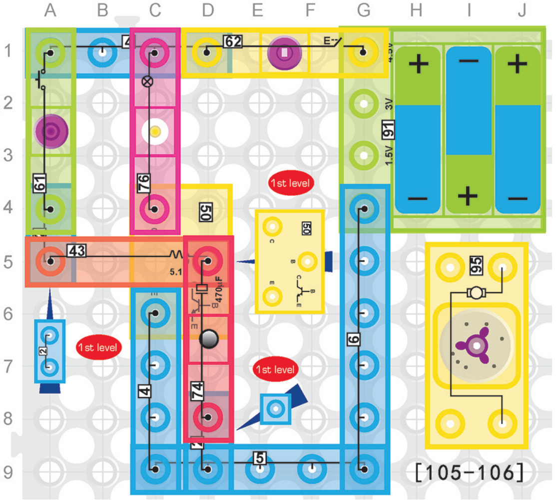
In order to translate an electrical signal into an audible sound, speakers contain electromagnets made from a metal coil that creates a magnetic field when an electric current flows through it. The coil is designed such that reversing the direction of the current in the coil flips the polarity of the 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.

103. 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 typical 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.





104. 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).

105. NPN Transistor – a Current Switch

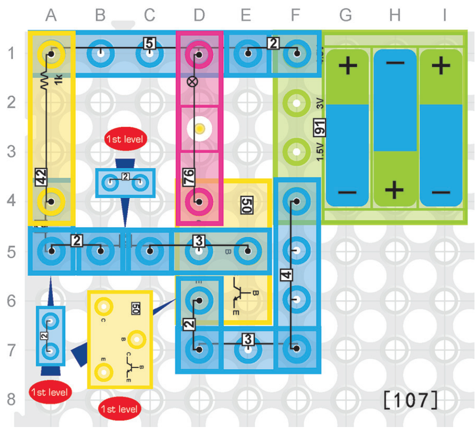
Build the circuit shown on the left and turn on the switch (62); the lamp (76) is still off. Press and hold the press switch (61) and you will see the lamp (76) turns on after a short delay. Make sure your 470μF capacitor (74) is fully discharged before you start this project (you can discharge the 470μF 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)).

106. Delay Circuit

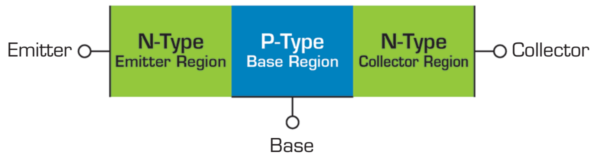
Replace the lamp (76) with the motor (95) in the previous project; the motor (95) is still off. Press and hold the press switch (61) and you will see the motor (95) turns on after a short delay. Make sure your 470μF capacitor (74) is fully discharged before you start this project (you can discharge the 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.

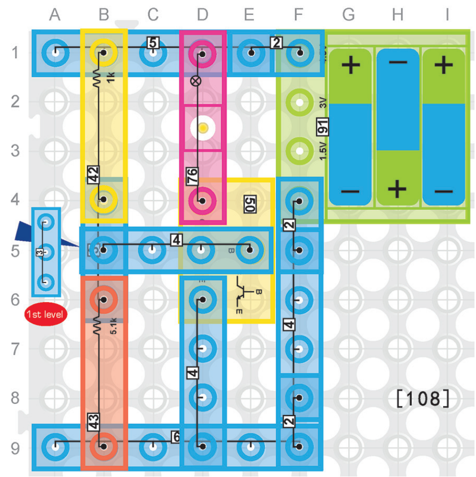


107. NPN Transistor Basics

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 are called P-type layers. This is shown in the diagram below.

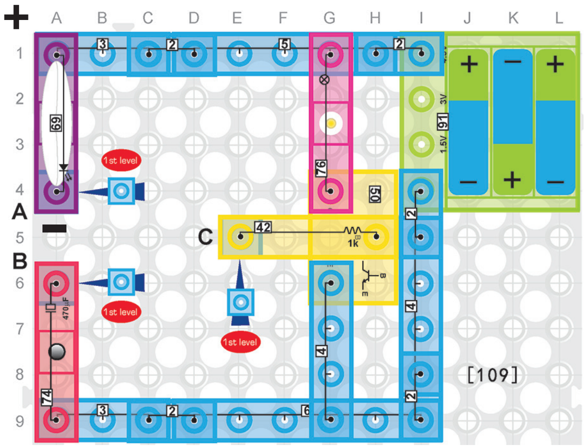


Roughly speaking, the NPN transistor (50) is designed so that conventional current can easily flow from the Base region (P-type) to the Emitter region (N-type) when the Base is at a high enough voltage above the Emitter. Once current begins flowing from Base to Emitter, then it becomes much easier for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



108. Voltage Divider

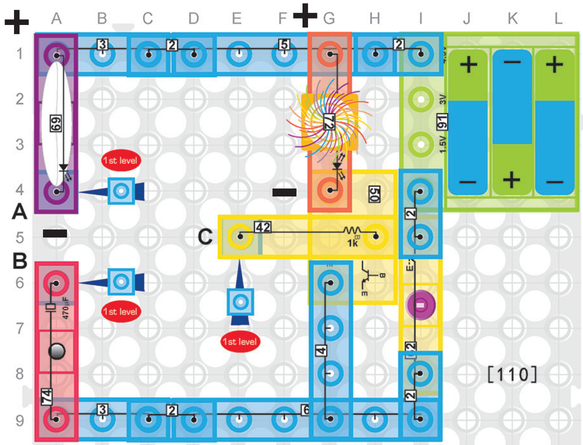
Build the circuit shown on the left and the lamp (76) will be on. This type of circuit is often used to hold the voltage level at the Base of the NPN transistor (50) at a constant level to set a particular operating point for the NPN transistor (50).



109. 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.

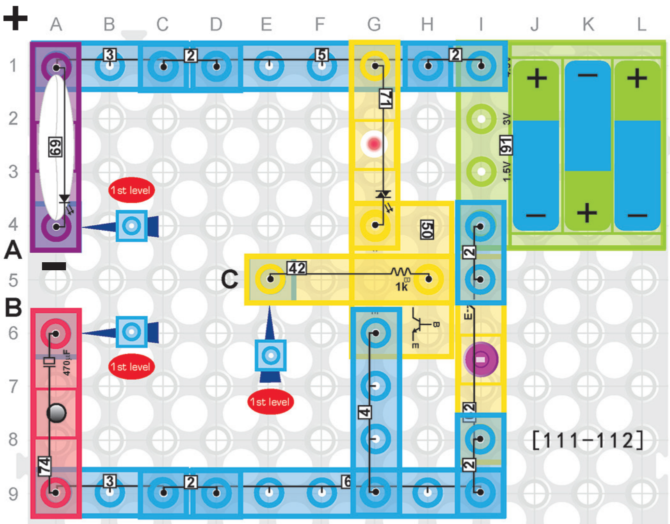
Now remove the spring wire (9) from points A and B and connect the spring wire (9) between points B and C. The lamp (76) will turn on for a while and then fade out. This is because when the 470µF capacitor (74) is charged, it stores electrical energy. While this electrical energy is being discharged through the Base of the NPN transistor (50), current is enabled to flow from Collector to Emitter lighting up the lamp. 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.



110. Capacitor Discharge

Build the circuit shown on the left, connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) will 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 fiber tree (40) light for a while and fade to be very dim as the 470µF capacitor (74) discharges. Notice in this case, though, that the colorful LED (72) will stay dim for a long time. This is because it takes a long time for the 470µF capacitor (74) to fully discharge, and even a small current through the colorful LED (72) is enough to light it dimly.



111. Capacitor Basics

Build the circuit shown on the left, connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) will 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 bi-directional LED (71) light red for a while and fade to be very dim as the 470μF capacitor (74) discharges.

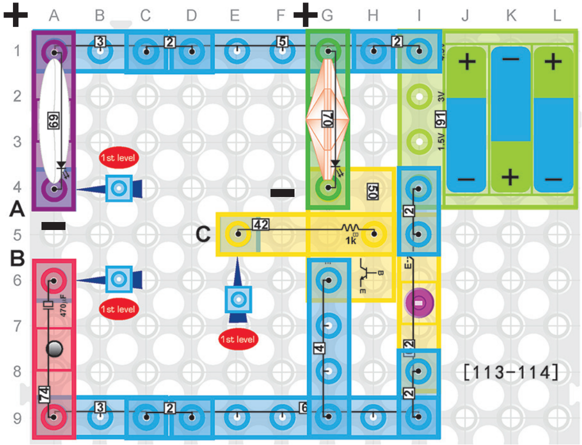
Capacitors are made of two plates separated by an insulating material between them. When a battery or voltage source is placed across the leads of a capacitor, one plate builds up a positive charge (like a build-up of a holes) while the other plate builds up a negative charge (build-up of electrons). 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.

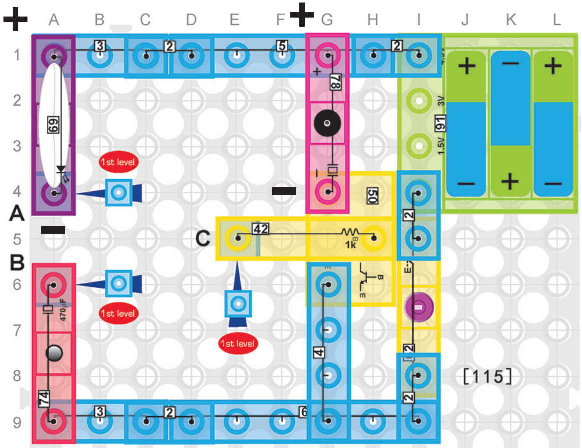
112. Capacitance

Reverse the direction of the bi-directional LED (71) in the previous project. Connect points A and B with the spring wire (9) and then turn on the switch (62). The heart LED (69) will light red 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 bi-directional LED (71) light blue for a while and fade to be very dim 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.





113. Measure of Electric Charge - The Coulomb

Build the circuit shown, connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) will 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.

114. Measure of Capacitance - The Farad

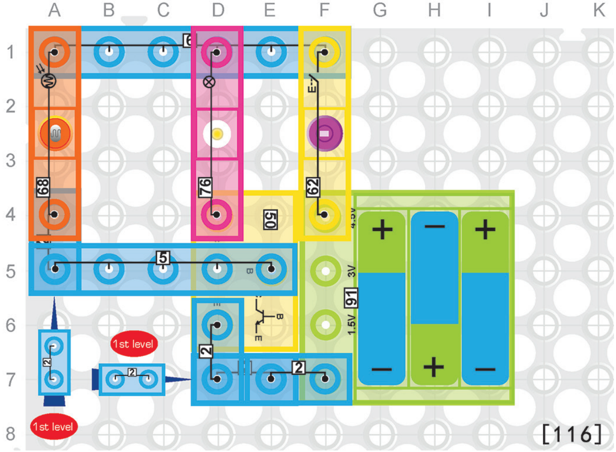
Remove the spring wire (9) from points A and B in project #113 and place the spring wire (9) across points B and C. You will see the star LED (70) light for a while and fade to be very dim as the 470μF capacitor (74) discharges.

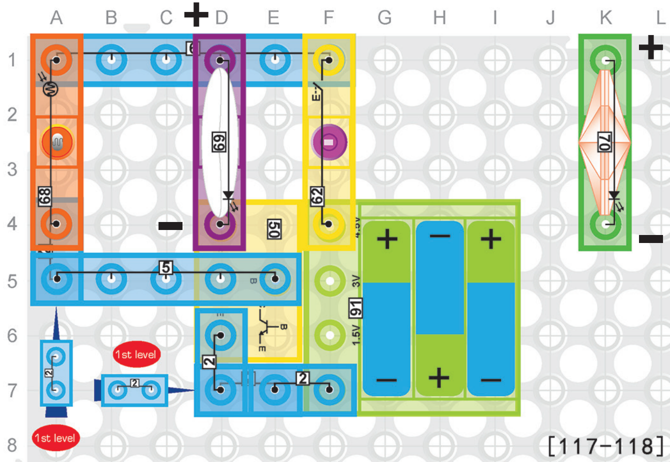
The capacitance of a capacitor is measured in Farads. A capacitor is said to have 1 Farad of capacitance when a potential difference of 1 Volt across its plates will charge it with 1 Coulomb of electricity.

115. Approximation for Capacitance of a Capacitor

Build the circuit shown on the left, connect points A and B with the spring wire (9), then turn on the switch (62). The heart LED (69) will 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 hear the alarm (78) for a while and then fade out as the 470μF capacitor (74) discharges.

It was discussed in project #112 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 ε is the permittivity of the dielectric between the plates (permittivity is the ability of a substance to store electrical energy in an electric field).





116. Photoresistor

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

A photoresistor (68) is designed to have low resistance when there is light shining on it, and high resistance when no light is shining on it.

117. Photoresistor Basics

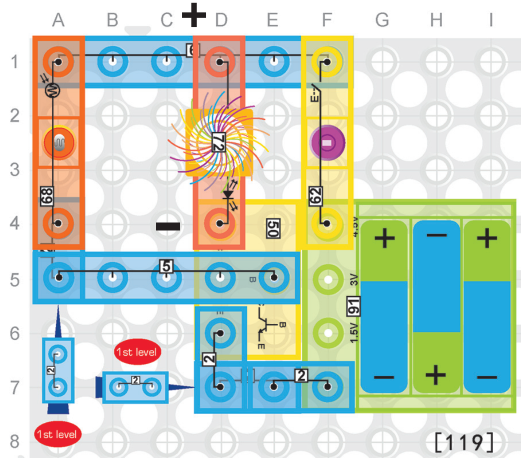
Build the circuit shown and turn on the switch (62). Whenever light shines on the photoresistor (68), the heart LED (69) will be bright. Cover the photoresistor (68) with your finger and the heart LED (69) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the heart LED (69).

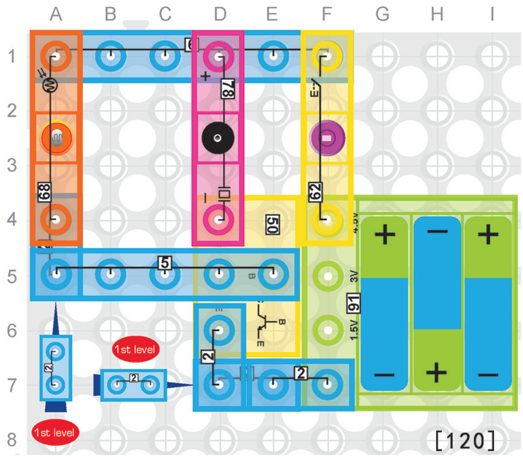
A photoresistor is made of semiconductor material that has high resistance in the dark. But when light shines on a photoresistor, electrons in the semiconductor material get enough energy to jump into the conduction band. The resulting free electrons conduct electricity, thereby lowering resistance.

118. Resistance of a Photoresistor

Replace the heart LED (69) with the star LED (70) in project #117 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 resistance of a photoresistor (68) can vary by device, but typically a photoresistor (68) can have several MΩ (pronounced meg-ohms which is 1 million Ohms) when in the dark and can have as low as 100 Ohms of resistance or even less in bright light.





119. Latency of a Photoresistor

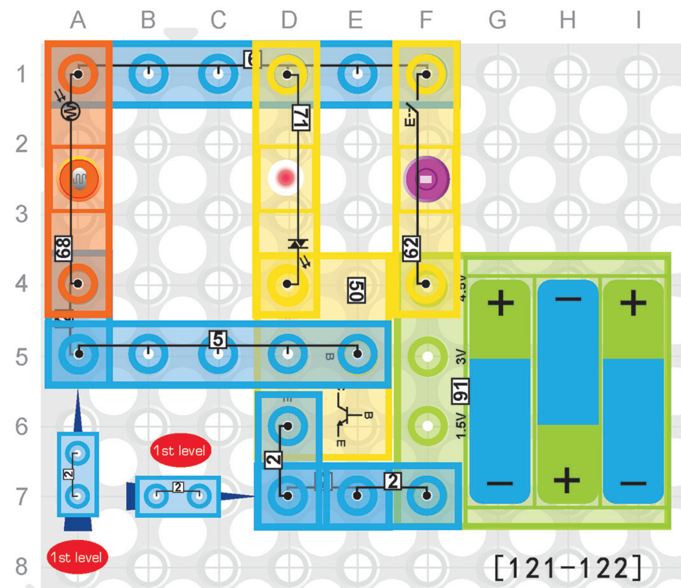
Build the circuit shown on the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the colorful LED (72) will light the fiber tree (40). Cover the photoresistor (68) with your finger and the colorful LED (72) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the colorful LED (72).

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.

120. Wake Up Alarm

Build the circuit shown on the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the alarm (78) sounds. Cover the photoresistor (68) with your finger and the alarm (78) will go off.

This circuit could be used as a wake-up alarm, where the alarm (78) goes off when the sun shines into your room.



121. Advantages of Photoresistors

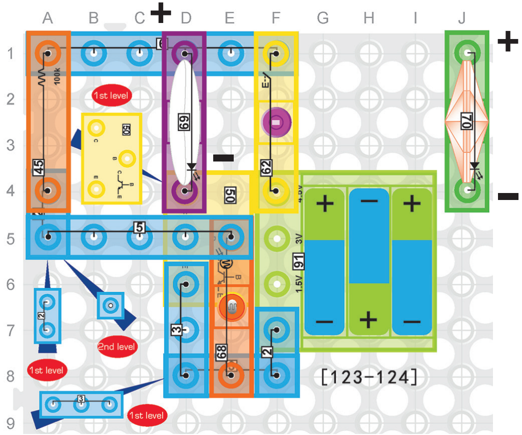
Build the circuit shown on the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the bi-directional LED (71) will be bright red. Cover the photoresistor (68) with your finger and the bi-directional LED (71) may get a little dimmer, but even the little current entering the Base of the NPN transistor (50) is enough to allow enough current to flow from the Collector to the Emitter to light the bi-directional LED (71).

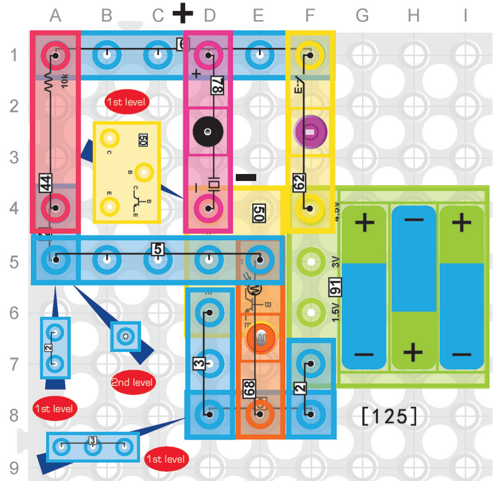
The advantages of photoresistors are that they are small in size and thus can be carried or placed in just about anywhere easily, and they are low cost.

122. Disadvantages of Photoresistors

Reverse the direction of the bi-directional LED (71) in project #121. Whenever light shines on the photoresistor (68), the bi-directional LED (71) will be bright blue. Cover the photoresistor (68) with your finger and the bi-directional LED (71) 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 bi-directional LED (71).

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.





123. 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. You may need to take your circuit into a dark room to see the heart LED (69) light.

This circuit does the reverse of the circuit in project #116 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 NPN transistor (50) 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 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).

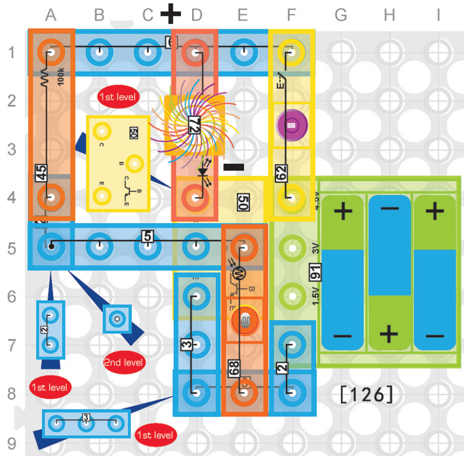
124. Street Lights

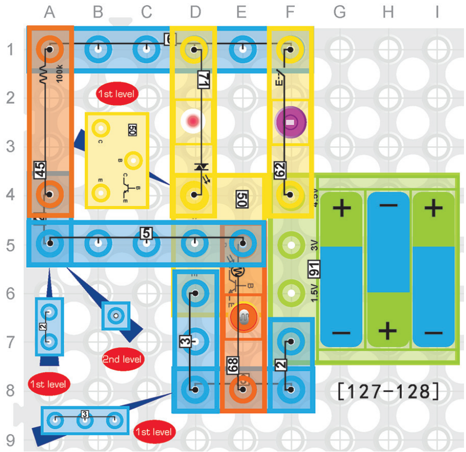
Replace the heart LED (69) with the star LED (70) and turn on the switch (62). Whenever light shines on the photoresistor (68), the star LED (70) will be off. Cover the photoresistor (68) with your finger and the star LED (70) will turn on. This circuit could be used to control street lights, where during 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.

125. Audio Compressors

Build the circuit to the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the alarm (78) will be off. Cover the photoresistor (68) with your finger and the alarm (78) with sound.

Photoresistors are sometimes used as audio compressors to reduce the gain of an amplifier when the audio signal level is above a threshold. This can be done by using an LED that indicates changes in audio signal levels, and feed this into a photoresistor that adjusts the gain in the amplifier (transistor) based on the LED brightness (which indicates audio signal level). Due to the slow response time of the photoresistor (68), it is believed that this technique can provide smooth audio compression.





126. The Colorful LED

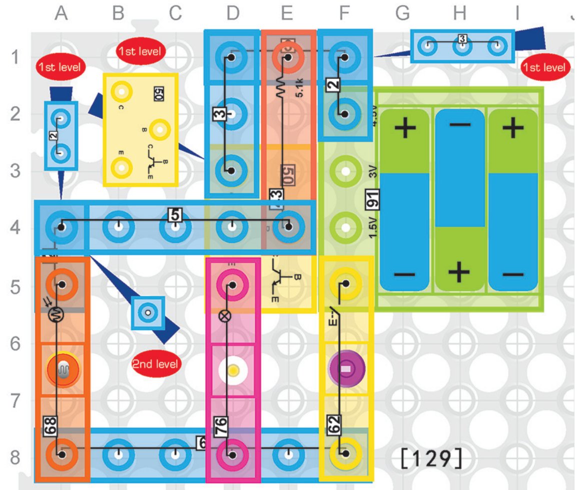
Build the circuit shown and turn on the switch (62). Whenever light shines on the photoresistor (68), the colorful LED (72) will be off. Cover the photoresistor (68) with your finger and the colorful LED (72) will turn on and light the fiber tree (40). The colorful LED (72) is made of three LEDs (one 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, the colorful LED (72) 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 colorful LED (72) 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%.

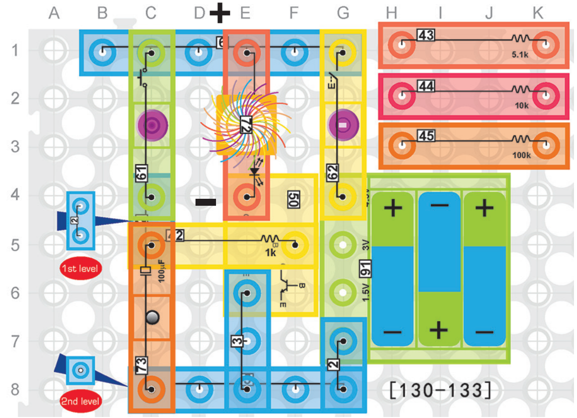
127. Angular Light Intensity

Build the circuit shown on the left and turn on the switch (62). Whenever light shines on the photoresistor (68), the bi-directional LED (71) will be off. Cover the photoresistor (68) with your finger and the bi-directional LED (71) will turn on red. While it may appear that the bi-directional LED (71) is brighter than the heart LED (69), 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. If you look from the side at the bi-directional LED (71), you will see it looks very dim, just like looking at the side of the heart LED (69).

128. 4-Band Resistor

Reverse the direction of the bi-directional LED (71) in project #127 and turn on the switch (62). Whenever light shines on the photoresistor (68), the bi-directional LED (71) will be off. Cover the photoresistor (68) with your finger and the bi-directional LED (71) will turn on blue. Although the resistor values in your Circuit Blox™ 395 set are labeled (e.g. 100kΩ in this project), physical resistors are often labeled using a color code. Below is a picture of a 4-band resistor. The first three bands on the left define the resistance value of the resistor, while the last band on the right defines the tolerance of the resistor.





129. 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) (like in the previous several projects). 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.

130. 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 colorful LED (72) light the fiber tree (40). Release the press switch (61) and the colorful LED (72) 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.

131. Resistor in RC Circuit

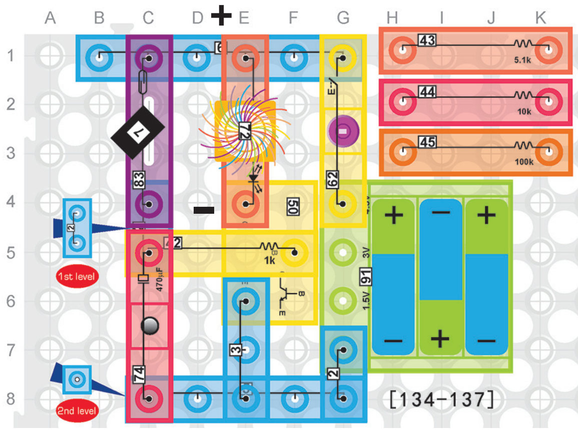
Replace the 1kΩ resistor (42) in project #130 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the colorful LED (72) light the fiber tree (40). Release the press switch (61) and the colorful LED (72) will stay bright for a little while and then turn dim. This RC circuit has a larger 5.1kΩ resistor (43) compared to project #130, which limits the current and thus discharges the 100μF capacitor (73) more slowly.

132. Delayed Lights

Replace the 1kΩ resistor (42) in project #130 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the colorful LED (72) light the fiber tree (40). Release the press switch (61) and the colorful LED (72) 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.

133. RC Time Constant

Replace the 1kΩ resistor (42) in project #130 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the colorful LED (72) light the fiber tree (40). Release the press switch (61) and the colorful LED (72) will stay bright for many seconds before turning dim. Through use of Kirchhoff's Current Law, 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 capacitor decays as an exponential function with a time constant of R*C.



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

134. 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 colorful LED (72) light the fiber tree (40). Move the magnet (7) away from the reed switch (83) and the colorful LED (72) 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*(470 x 10^{-6}) = 0.47 second. If the 1kΩ resistor and 470μF capacitor (74) represented the only resistance and capacitance in the circuit, then 0.47 second would represent the time for the voltage on the 470μF capacitor (74) to reduce from its maximum value to ~63% of its maximum value.

135. Relative RC Time Constant

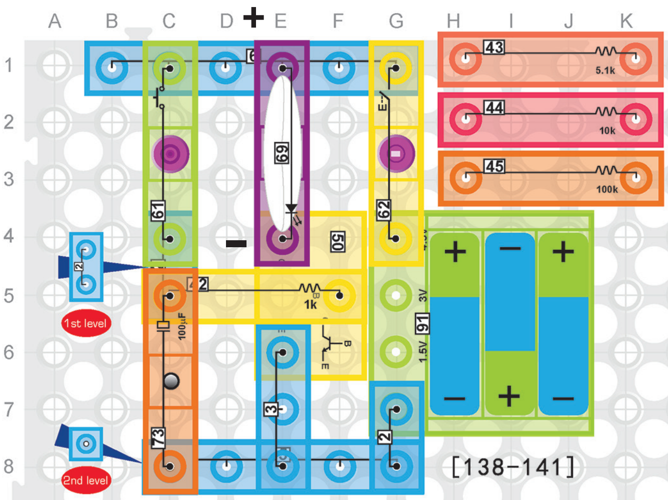
Replace the 1kΩ resistor (42) in project #134 with the 5.1kΩ resistor (43) and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the colorful LED (72) light the fiber tree (40). Move the magnet (7) away from the reed switch (83) and the colorful LED (72) will stay bright for a while and then turn dim. The time constant of this circuit is 5100*(470 x 10^{-6}) = 2.4 seconds. The colorful LED (72) will likely take longer than 2.4 seconds to dim in this circuit due to other resistance and capacitance not accounted for in the circuit, but relatively speaking it should take about 5 times longer for the colorful LED (72) to dim in this circuit compared to the previous circuit.

136. Intermittent Windshield Wipers

Replace the 1kΩ resistor (42) in project #134 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 colorful LED (72) light the fiber tree (40). Move the magnet (7) away from the reed switch (83) and the colorful LED (72) will stay bright for a several seconds and then turn dim. This circuit could be used to create the delay for your windshield wipers.

137. Resistor Color Code Table

Replace the 1kΩ resistor (42) in project #134 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 colorful LED (72) light the fiber tree (40). Move the magnet (7) away from the reed switch (83) and the colorful LED (72) will stay bright for a long time before turning dim. Project #128 introduced the 4-band resistor. The first three bands define the resistance of the resistor using the table shown on the left. So for instance, a 100Ω resistor would have the colors brown, black and brown as the first three bands (10 x 10^1 = 100).



138. 1kΩ Resistor

Build the circuit shown on the right 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 ($10 \times 10^2 = 1{,}000$).

139. 5.1kΩ Resistor

Replace the 1kΩ resistor (42) in project #138 with the 5.1kΩ resistor (43) 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 for a little while and then turn dim.

The 5.1kΩ resistor (43) in this circuit would have the colors green, brown and red as the first three bands ($51 \times 10^2 = 5{,}100$).

140. 10kΩ Resistor

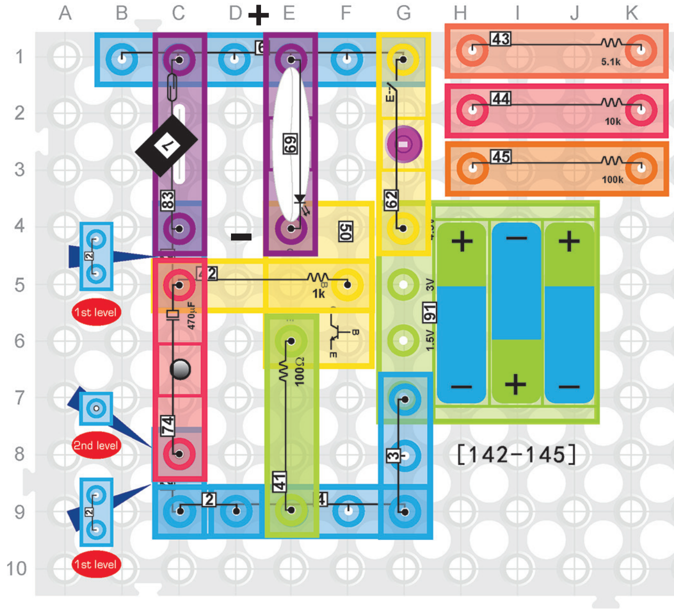
Replace the 1kΩ resistor (42) in project #138 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) light. Release the press switch (61) and the heart LED (69) will stay bright for a while and then turn dim.

The 10kΩ resistor (44) in this circuit would have the colors brown, black and orange as the first three bands ($10 \times 10^3 = 10{,}000$).

141. 100kΩ Resistor

Replace the 1kΩ resistor (42) in project #138 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 ($10 \times 10^4 = 100{,}000$).



142. The Number *e*

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 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 project #133, 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.

143. Time Constant τ

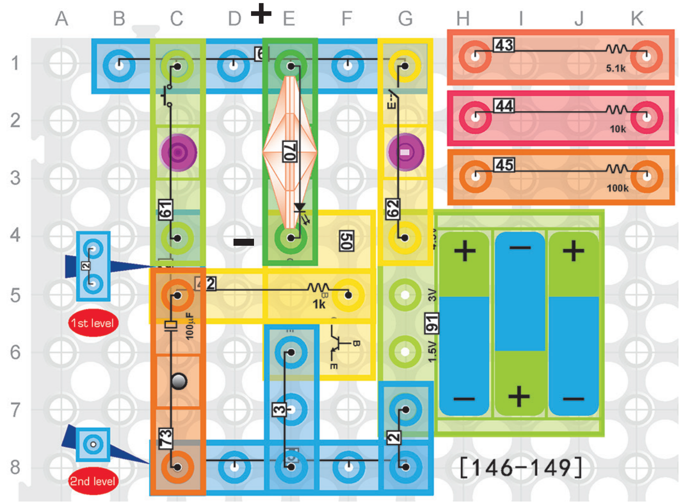
Replace the 1kΩ resistor (42) in project #142 with the 5.1kΩ resistor (43) and turn on the switch (62). Place the magnet (7) near the reed switch (83) and you will see the heart LED (69) light. Move the magnet (7) away from the reed switch (83) and the heart LED (69) will stay bright for a while and then turn dim. As discussed in project #133, 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 $t = \tau = R*C$, then the signal has decayed by $e^{-1} = 0.367$ or by approximately 37% below its maximum value.

144. τ for 10kΩ Resistor and 470μF Capacitor

Replace the 1kΩ resistor (42) in project #142 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 $10{,}000*470e^{-6} = 4.7$ seconds.

145. τ for 100kΩ Resistor and 470μF Capacitor

Replace the 1kΩ resistor (42) in project #142 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 $100{,}000*470e^{-6} = 47$ seconds.



146. 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 $1{,}000 * 100e^{-6} = 0.1$ second.

147. τ for 5.1kΩ Resistor and 100μF Capacitor

Replace the 1kΩ resistor (42) in project #146 with the 5.1kΩ resistor (43) 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 for a little while and then turn dim.

The τ for this circuit is $5{,}100 * 100e^{-6} = 0.51$ second.

148. τ for 10kΩ Resistor and 100μF Capacitor

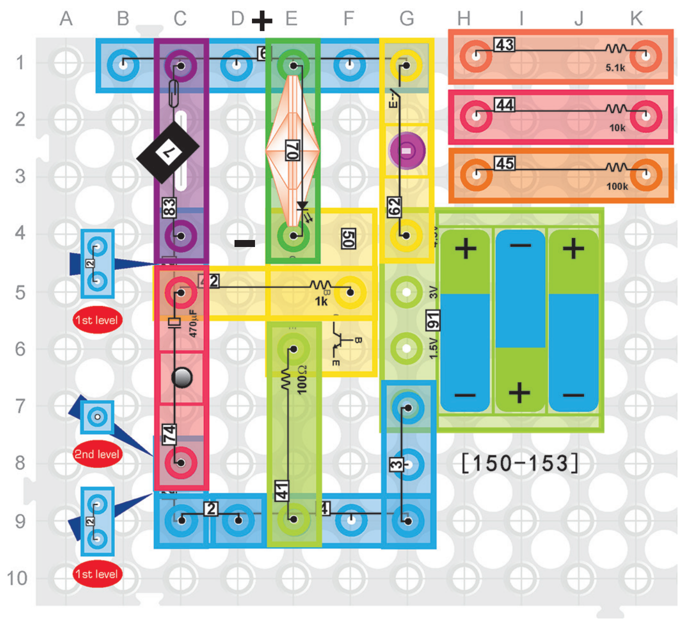
Replace the 1kΩ resistor (42) in project #146 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the star LED (70) light. Release the press switch (61) and the star LED (70) will stay bright for a while and then turn dim.

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

149. τ for 100kΩ Resistor and 100μF Capacitor

Replace the 1kΩ resistor (42) in project #146 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 $100{,}000 * 100e^{-6} = 10$ seconds.



150. 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.

151. Transistor Gain with 5.1kΩ Resistor

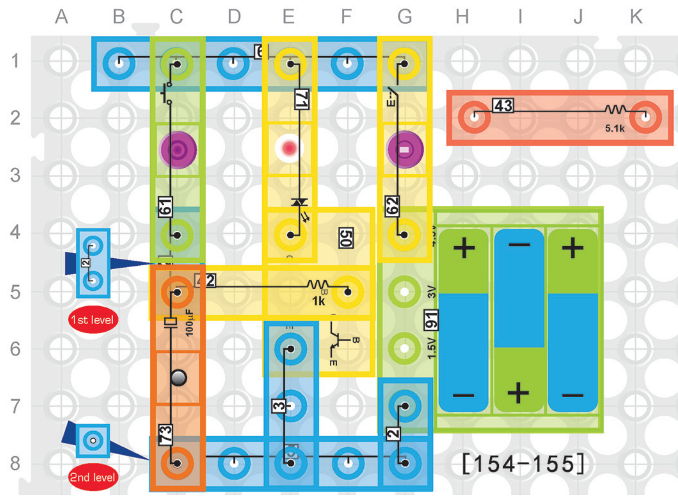
Replace the 1kΩ resistor (42) in project #150 with the 5.1kΩ resistor (43) and turn on the switch (62). Place the magnet (7) near the switch (83) and you will see the star LED (70) light. Move the magnet (7) away from the reed switch (83) and the star LED (70) will stay bright for a while and then turn dim. If you had an ammeter and measured the current going into the Base it would be around 0.75 mA, while the current coming out of the Emitter would be about 41 mA. This yields a β = 41/0.75 = 55.

152. Transistor Gain with 10kΩ Resistor

Replace the 1kΩ resistor (42) in project #150 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.

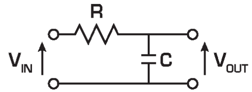
153. Transistor Gain with 100kΩ Resistor

Replace the 1kΩ resistor (42) in project #150 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.



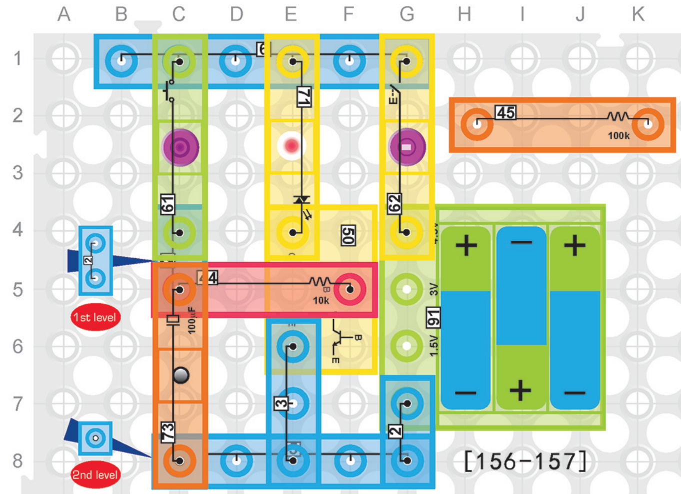
154. RC Low Pass Filter Circuit

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light red. Release the press switch (61) and the bi-directional LED (71) will stay bright briefly and then turn dim. 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).



155. RC Low Pass Filter Cutoff Frequency

Replace the 1kΩ resistor (42) in project #154 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light red. Release the press switch (61) and the bi-directional LED (71) will stay bright for a little while and then turn dim. 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 5.1kΩ resistor (43) and 100μF capacitor (73) in this project were used in an RC low pass filter, then the cutoff frequency would be $1/(2*3.14*5100*100e^{-6}) = 0.31$Hz. Only very low frequencies (near DC) would pass through such a circuit.

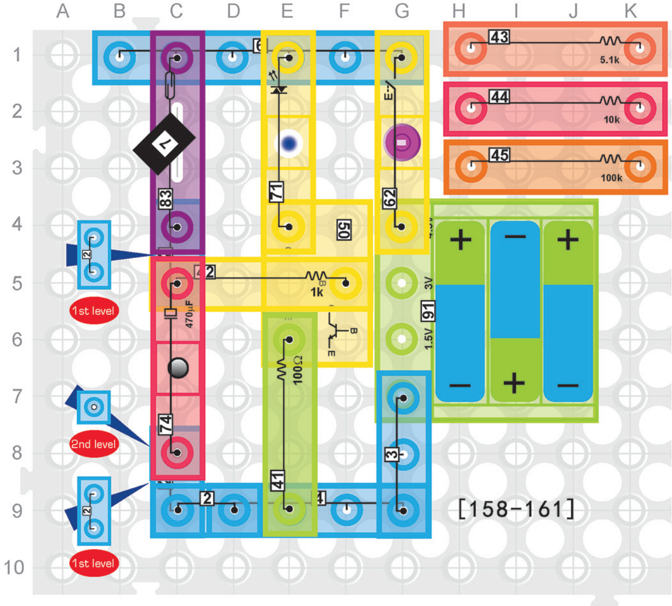


156. Cutoff Frequency of 10kΩ Resistor and 100μF Capacitor RC Circuit

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light red. Release the press switch (61) and the bi-directional LED (71) will stay bright for a while and then turn dim. 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 $1/(2*3.14*10{,}000*100e^{-6}) = 0.16$ Hz. Only very low frequencies (near DC) would pass through such a circuit.

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

Replace the 10kΩ resistor (44) in project #154 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light red. Release the press switch (61) and the bi-directional LED (71) will stay bright for many seconds before turning dim. 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 $1/(2*3.14*100{,}000*100e^{-6}) = 0.016$ Hz. Only very low frequencies (near DC) would pass through such a circuit.



158. 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 bi-directional LED (71) light blue. Release the press switch (61) and the bi-directional LED (71) will stay bright for a little while and then turn dim. 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 $1/(2*3.14*1{,}000*470e^{-6}) = 0.34$ Hz. Only very low frequencies (near DC) would pass through such a circuit.

159. Cutoff Frequency of 5.1kΩ Resistor and 470μF Capacitor RC Circuit

Replace the 1kΩ resistor (42) in project #158 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light blue. Release the press switch (61) and the bi-directional LED (71) will stay bright for a while and then turn dim. If the 5.1kΩ resistor (43) and 470μF capacitor (74) in this project were used in an RC low pass filter, then the cutoff frequency would be $1/(2*3.14*5{,}100*470e^{-6}) = 0.066$ Hz. Only very low frequencies (near DC) would pass through such a circuit.

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

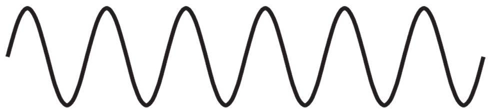
Replace the 1kΩ resistor (42) in project #158 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light blue. Release the press switch (61) and the bi-directional LED (71) will stay bright for several seconds and then turn dim. 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 $1/(2*3.14*10{,}000*470e^{-6}) = 0.034$ Hz. Only very low frequencies (near DC) would pass through such a circuit.

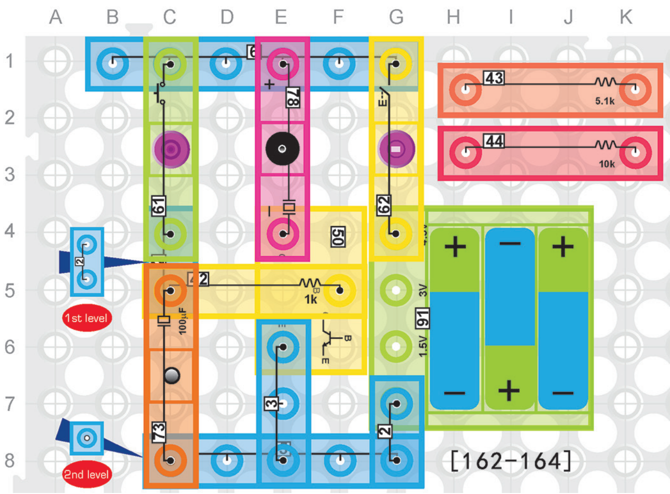
161. Cutoff Frequency of 100kΩ Resistor and 470μF Capacitor RC Circuit

Replace the 1kΩ resistor (42) in project #158 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) light blue. Release the press switch (61) and the bi-directional LED (71) will stay bright for a long time and then turn dim. 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 $1/(2*3.14*100{,}000*470e^{-6}) = 0.0034$ Hz. Only very low frequencies (near DC) would pass through such a circuit.

162. Sine Wave

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will hear the alarm (78) sound. Release the press switch (61) and the alarm (78) will sound briefly and then go off. The sound you hear from the alarm (78) is a tone. A pure tone is produced by a sinusoidal wave (called a sine wave), which is shown in the figure below.



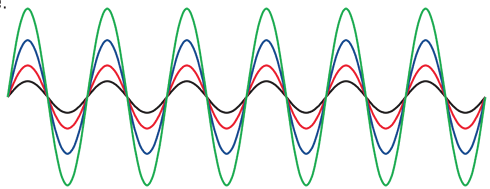


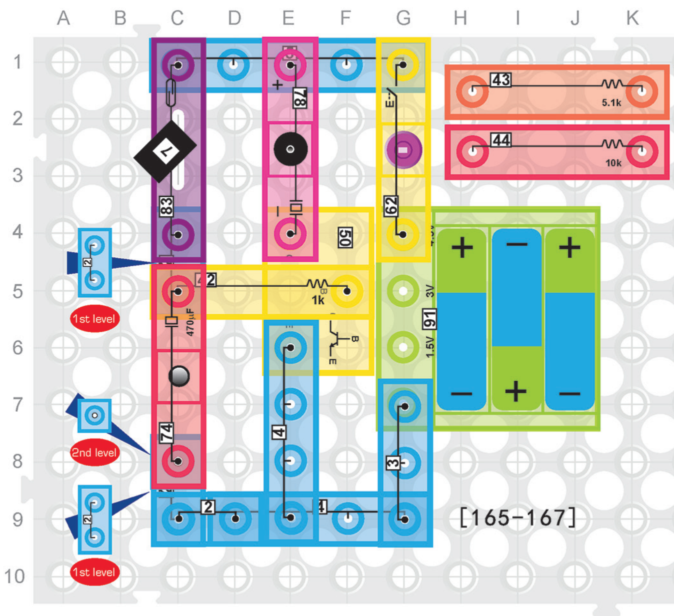
163. Formula for a Sine Wave

Replace the 1kΩ resistor (42) in project #162 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will hear the alarm (78) sound. Release the press switch (61) and the alarm (78) will sound for a little while and then go off. The sine wave producing the tone you hear from the alarm (78) 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.

164. Amplitude of a Sine Wave

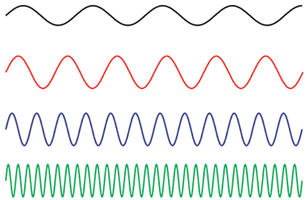
Replace the 1kΩ resistor (42) in project #162 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will hear the alarm (78) sound. Release the press switch (61) and the alarm (78) will sound for a while and then go off. A was defined as the amplitude of a sine wave in project #163. The below figure shows various sine waves with different amplitudes. The green sine wave has the largest amplitude and the black sine wave has the smallest amplitude.





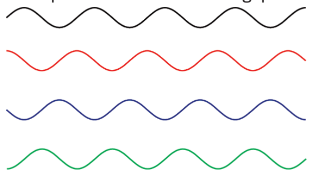
165. Frequency of Sine Wave

Build the circuit shown on the left and turn on the switch (62). Turn on the switch (62) and hold the magnet (7) near the reed switch (83) and you will hear the alarm (78) sound. Move the magnet (7) away from the reed switch (83) and the alarm (78) will sound for a little while and then go off. f_c was defined as the frequency of a sine wave in project #163. 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.



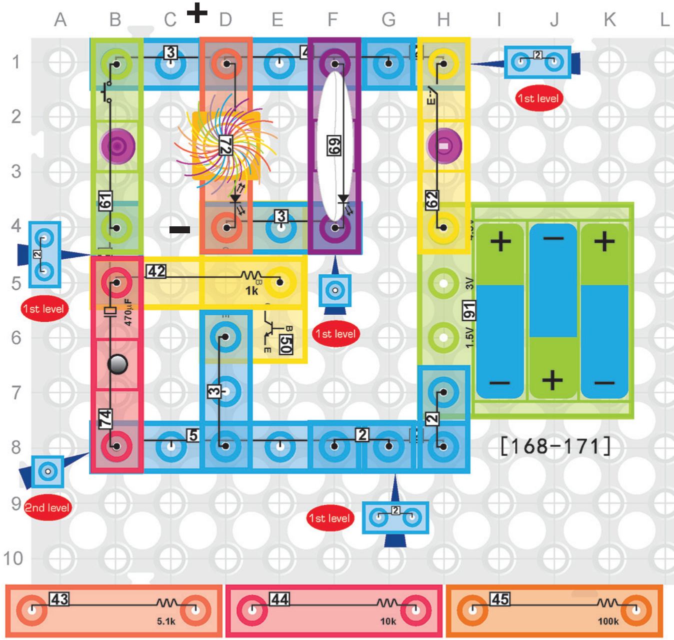
166. Phase of a Sine Wave

Replace the 1kΩ resistor (42) in project #165 with the 5.1kΩ resistor (43) and turn on the switch (62). Hold the magnet (7) near the reed switch (83) and you will hear the alarm (78) sound. Move the magnet (7) away from the reed switch (83) and the alarm (78) will sound for a while and then go off. θ was defined as the phase of a sine wave in project #163. The phase of a sine wave represents the starting point of the sine wave cycle. When $\theta = 0$, 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.



167. Speed of Sound

Replace the 1kΩ resistor (42) in project #165 with the 10kΩ resistor (44) and then turn on the switch (62). Hold the magnet (7) near the reed switch (83) and you will hear the alarm (78) sound. Move the magnet (7) away from the reed switch (83) and the alarm (78) will sound for a several seconds and then go off. 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.



168. Resistor Tolerance

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for a little while and then turn dim. In project #128 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.

169. 5.1kΩ Resistor Tolerance – Red Band

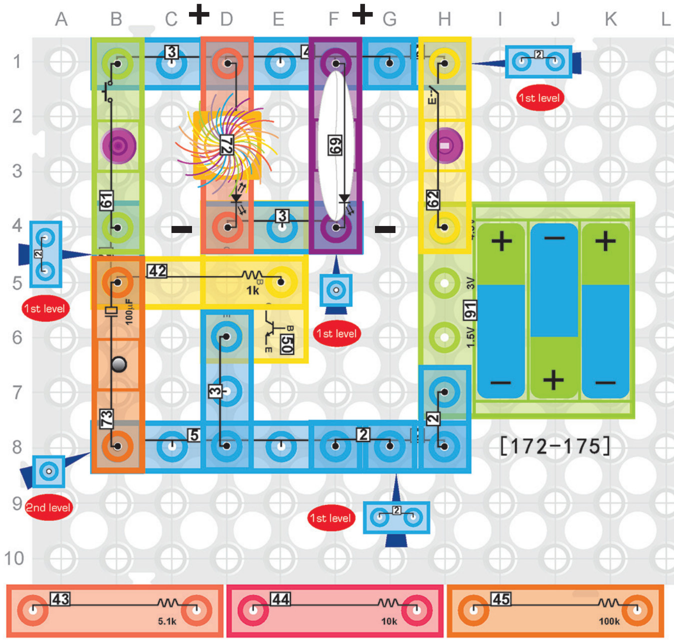
Replace the 1kΩ resistor (42) in project #168 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for a while and then turn dim. If we had a 5.1kΩ 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*5,100 = 4,998Ω to 1.02*5,100 = 5,202Ω.

170. 10kΩ Resistor Tolerance – Red Band

Replace the 1kΩ resistor (42) in project #168 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) 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.

171. 100kΩ Resistor Tolerance – Red Band

Replace the 1kΩ resistor (42) in project #168 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for a long time before turning dim. If we had a 100kΩ 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*100,000 = 98,000Ω to 1.02*100,000 = 102,000Ω.



172. 1kΩ Resistor Tolerance – Silver Band

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright briefly and then turn dim. If the 1kΩ resistor 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.

173. 5.1kΩ Resistor Tolerance – Silver Band

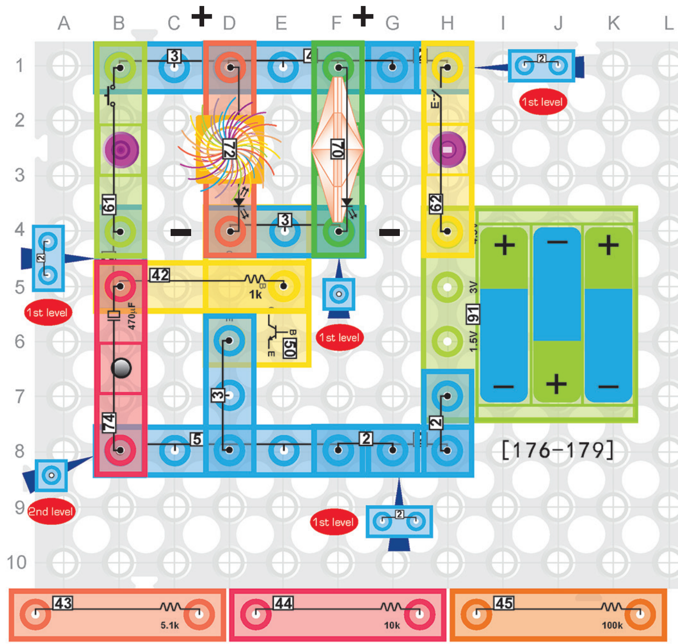
Replace the 1kΩ resistor (42) in project #172 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69) and colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for a little while and then turn dim. If we had a 5.1kΩ 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*5,100 = 4,845Ω to 1.05*5,100 = 5,355Ω.

174. 10kΩ Resistor Tolerance – Silver Band

Replace the 1kΩ resistor (42) in project #172 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for a while and then turn dim. If we had a 10kΩ 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*10,000 = 9,500Ω to 1.05*10,000 = 10,500Ω.

175. 100kΩ Resistor Tolerance – Silver Band

Replace the 1kΩ resistor (42) in project #172 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69) and colorful LED (72) will stay bright for several seconds before turning dim. If we had a 100kΩ resistor 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.



176. 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 colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for a little 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.

177. 5.1kΩ Resistor Tolerance – Gold Band

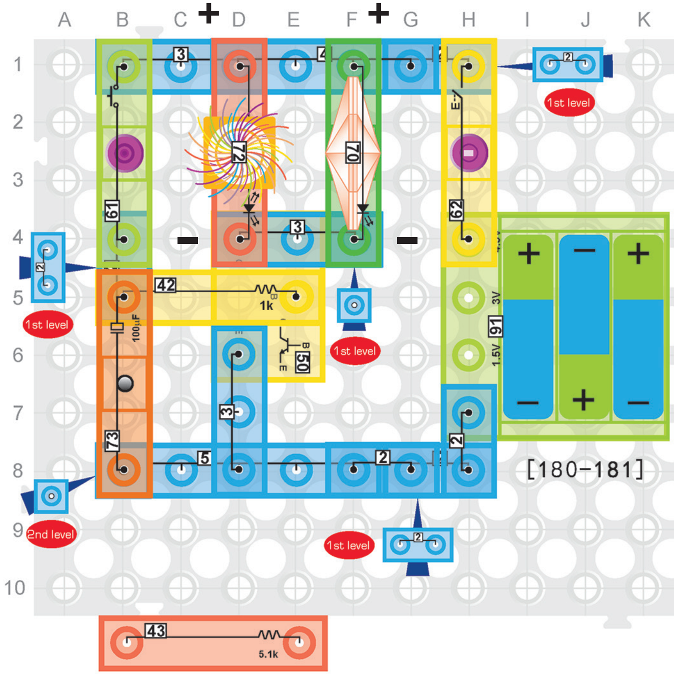
Replace the 1kΩ resistor (42) in project #176 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for a while and then turn dim. If we had a 5.1kΩ 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*5,100 = 4,590Ω to 1.1*5,100 = 5,610Ω.

178. 10kΩ Resistor Tolerance – Gold Band

Replace the 1kΩ resistor (42) in project #176 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 colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for several seconds and then turn dim. If we had a 10kΩ 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*10,000 = 9,000Ω to 1.1*10,000 = 11,000Ω.

179. 100kΩ Resistor Tolerance – Gold Band

Replace the 1kΩ resistor (42) in project #176 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 colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for several seconds before turning dim. If we had a 100kΩ resistor with a 4th band that is gold, then this would mean that the actual resistance of the resistor could be anywhere from 0.90*100,000 = 90,000Ω to 1.1*100,000 = 110,000Ω.



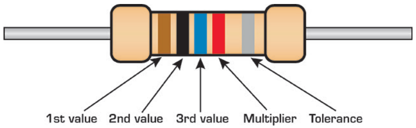
180. High Accuracy Resistors

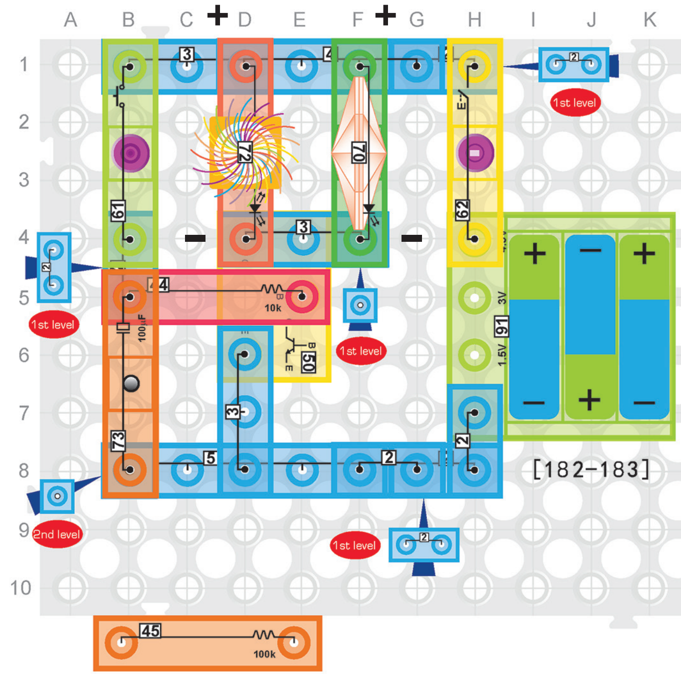
Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright briefly and then turn dim. Although most resistors use 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 below for all the possible 4th band color markings.

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%

181. 5-Band Resistors

Replace the 1kΩ resistor (42) in project #180 with the 5.1kΩ resistor (43) and turn on the switch (62). Press the press switch (61) and you will see the star LED (70) and colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for a little while and then turn dim. 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 below. This would be a 316*102 = 31,600Ω resistor that would be accurate to within 1% (31,284Ω to 31,916Ω).



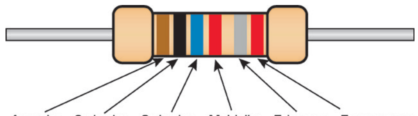


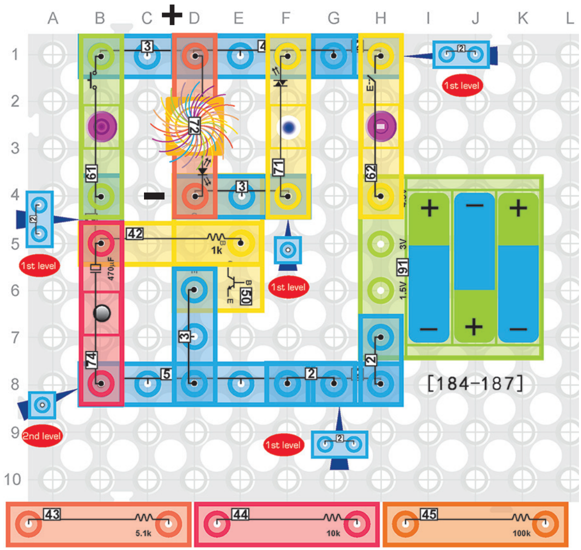
182. Resistor Temperature Effects

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 colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) 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.

183. 6-Band Resistors

Replace the 10kΩ resistor (44) in project #182 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 colorful LED (72) light. Release the press switch (61) and the star LED (70) and colorful LED (72) will stay bright for several seconds before turning dim. 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 below. This would be a 316*102 = 31,600Ω resistor that would be accurate to within 1% (31,284Ω to 31,916Ω) with 50ppm change per degree Centigrade.





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

184. Understanding PPM

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright briefly 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.

185. PPM Color Code

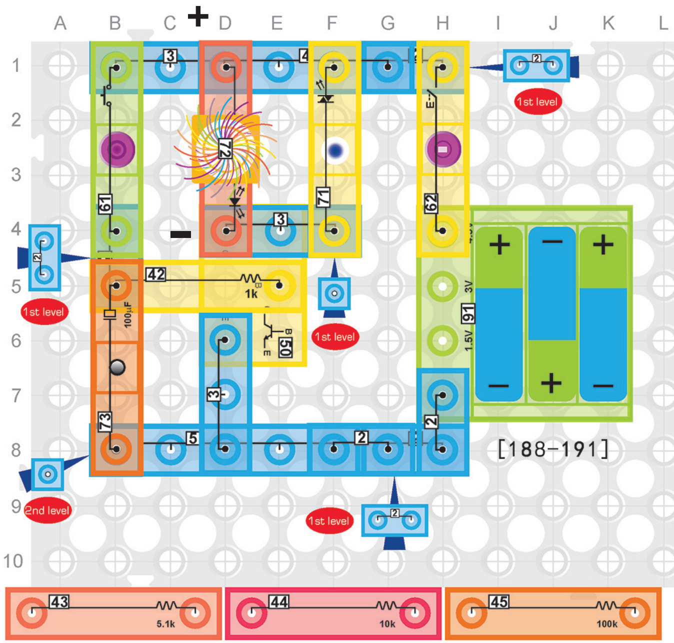
Replace the 1kΩ resistor (42) in project #184 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a little while and then turn dim. The table below shows the color coding for the Temperature Coefficient of Resistance (TCR) for 6 band resistors.

186. 10kΩ Resistor Temperature Tolerance Example

Replace the 1kΩ resistor (42) in project #184 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a while and then turn dim. If we had a 10kΩ resistor 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.

187. 100kΩ Resistor Temperature Tolerance Example

Replace the 1kΩ resistor (42) in project #184 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a long time before turning dim. If we had a 100kΩ resistor 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.



188. Fiber Optic Communication Underwater

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright briefly and then turn dim. One of the benefits of fiber optic transmission is that fibers can be placed under water. In fact, submarine communication cables (underwater cables) primarily use fiber and carry about 99% of data exchanged internationally.

189. Fiber Optic Communication – Near the Speed of Light

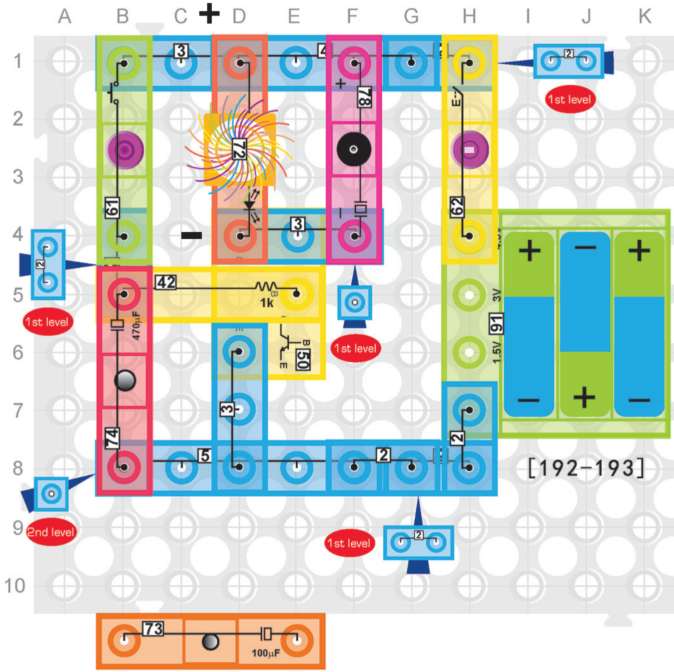
Replace the 1kΩ resistor (42) in project #188 with the 5.1kΩ resistor (43) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a little while and then turn dim. 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.

190. Advantages of Fiber Optics

Replace the 1kΩ resistor (42) in project #188 with the 10kΩ resistor (44) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) 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.

191. Disadvantages of Fiber Optics

Replace the 1kΩ resistor (42) in project #188 with the 100kΩ resistor (45) and then turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a long time 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.



192. Capacitor Polarity

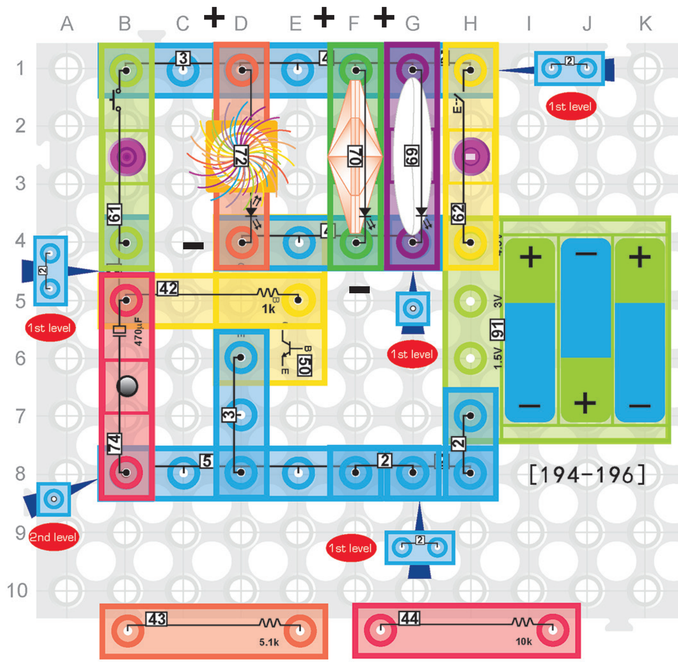
Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the colorful LED (72) light and the alarm (78) will sound. Release the press switch (61) and the colorful LED (72) will stay bright for a while then turn dim and the alarm (78) will stay on for a while then turn off.

The capacitors in your set have polarity, just like the LEDs. If you look closely at the capacitor in 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.

193. Capacitor Voltage Rating

Replace the 470μF capacitor (74) in project #192 with the 100μF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the colorful LED (72) light and the alarm (78) will sound. Release the press switch (61) and colorful LED (72) will stay bright briefly and then turn dim and the alarm (78) will sound briefly and then go off.

If you look closely at the 100μF capacitor (73) you will see that it has a voltage rating of 10V on the side. This capacitor 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.



194. Capacitor Tolerance

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70), and colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) 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 capacitance of the 470μF capacitor (74) should be between 0.8*470 = 376μF and 1.2*470 = 564μF.

195. Capacitor Operating Temperature

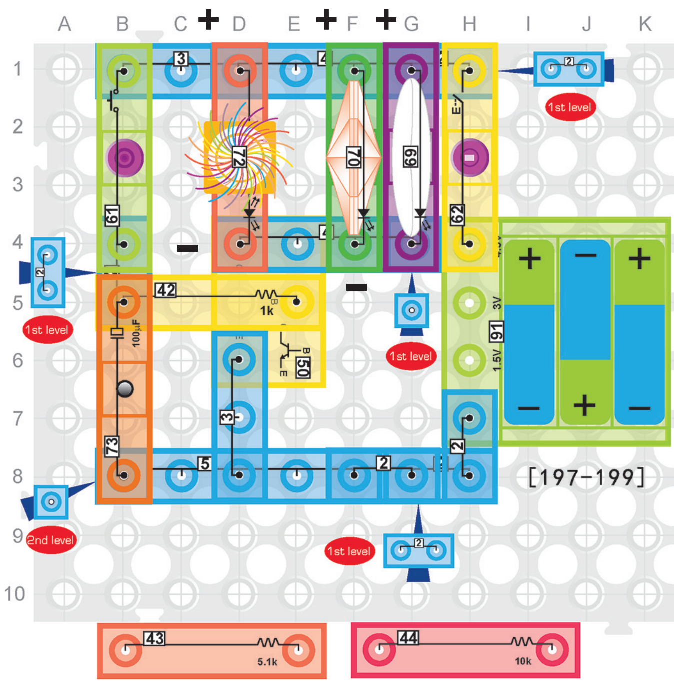
Replace the 1kΩ resistor (42) in project #194 with the 5.1kΩ resistor (43) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70), and colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) will stay bright for a while 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.

196. Ceramic Capacitors

Replace the 1kΩ resistor (42) in project #194 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) will stay bright for several seconds and then turn dim.

Even though the capacitors in your Circuit Blox™ 395 set are polarized, 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.



197. Electrolytic Capacitor

Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70), and colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) 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).

198. Tolerance of 100μF Capacitor

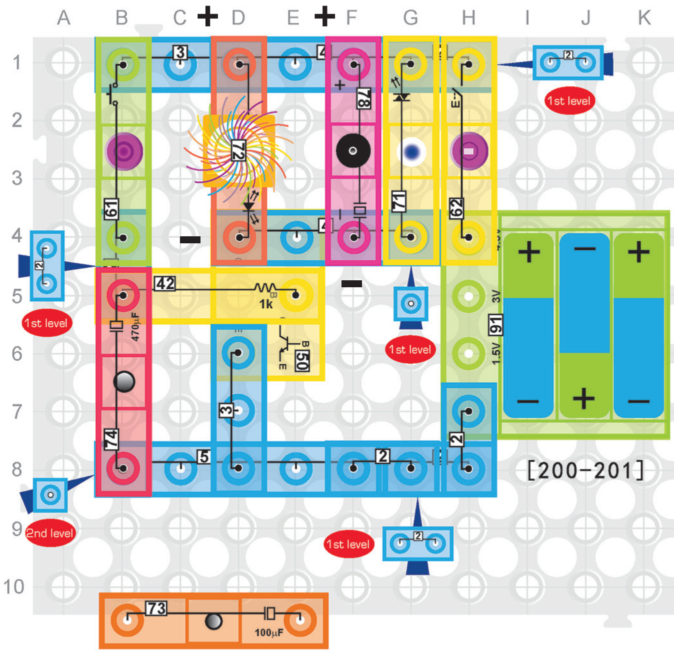
Replace the 1kΩ resistor (42) in project #197 with the 5.1kΩ resistor (43) and then turn on the switch (62). Press the press switch (61) and you will see the heart LED (69), star LED (70), and colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) will stay bright for a little while and then turn dim.

As discussed in project #194, 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.

199. Capacitors in Cameras

Replace the 1kΩ resistor (42) in project #197 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 colorful LED (72) light. Release the press switch (61) and the heart LED (69), star LED (70), and colorful LED (72) 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 the capacitor and when you press the button to take the picture, the sudden discharge of the capacitor is used to produce the flash.



200. Equalizer

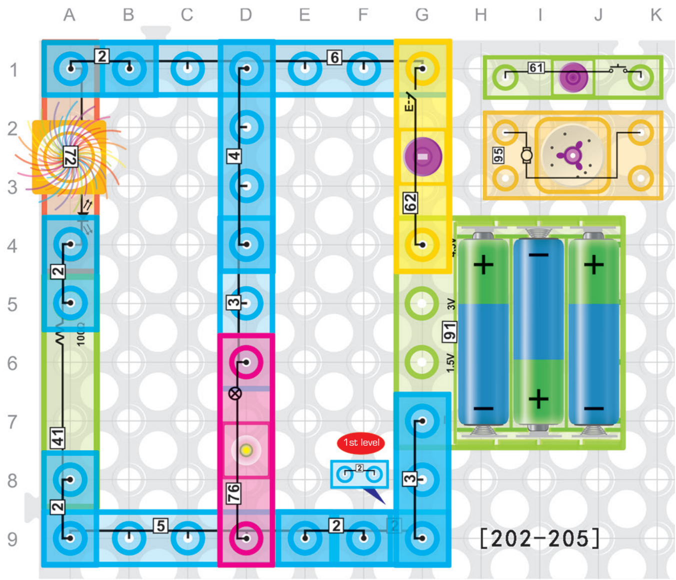
Build the circuit shown on the left and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light and hear the alarm (78) sound. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright for a while then turn dim and the alarm (78) will sound for a little while then turn off.

The sound from the alarm (78) is just 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.

201. Decibels

Replace the 470µF capacitor (74) in project #200 with the 100µF capacitor (73) and turn on the switch (62). Press the press switch (61) and you will see the bi-directional LED (71) and colorful LED (72) light and hear the alarm (78) sound. Release the press switch (61) and the bi-directional LED (71) and colorful LED (72) will stay bright briefly then turn dim and the alarm (78) will sound briefly then turn off.

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.



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

202. Relative Light Intensity

Build the circuit, turn on the switch (62), and the lamp (76) and the colorful LED (72) will be turned on at the same time. Decibels can also be used to compare light intensity levels. For instance, if the colorful LED (72) 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 colorful LED (72) and the lamp (76). You can find the log function on your typical scientific calculator.

203. Integrated Circuits (ICs)

Replace the switch (62) with the press switch (61) in project #202, then press the press switch (61) and the lamp (76) and the colorful LED (72) will be turned on at the same time.

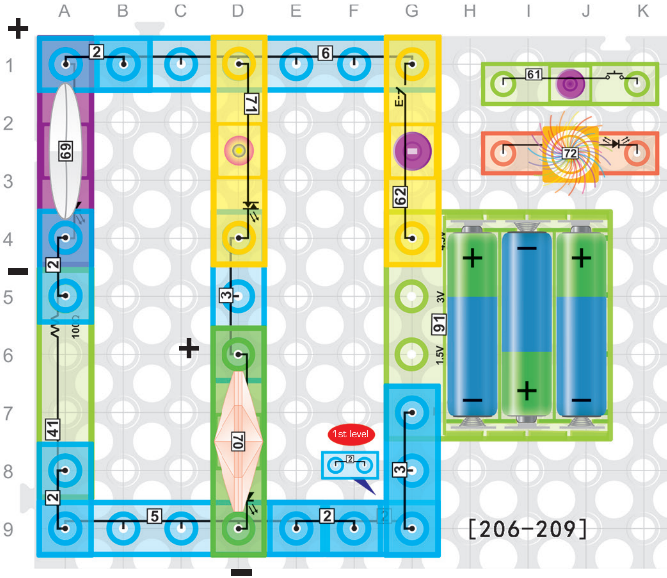
There is often the need to build simple as well as more complex circuits like this into very small devices (e.g. a garage door opener, a TV remote, etc.). Oftentimes this is done by making an Integrated Circuit (IC) board. ICs are small pieces of semiconducting material that is designed to provide the 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.

204. Fan/Motor Speed

Replace the lamp (76) in project #202 with the motor (95). Now If you turn on the switch (62) you will see the colorful LED (72) is on and the motor (95) is spinning too. Motor speed is measured in Revolutions per Minute, or RPMs. How fast do you think your motor (95) is spinning?

205. Poles in an AC Motor

In project #202, replace the switch (62) with the press switch (61), replace the lamp (76) with the motor (95). Now if you press the press switch (61) you will see the colorful LED (72) is shining 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.



206. IC Packaging

Build the circuit shown on the left, connect the switch (62), and the three LEDs will be turned on all at the same time. 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.

207. Making ICs – Step 1

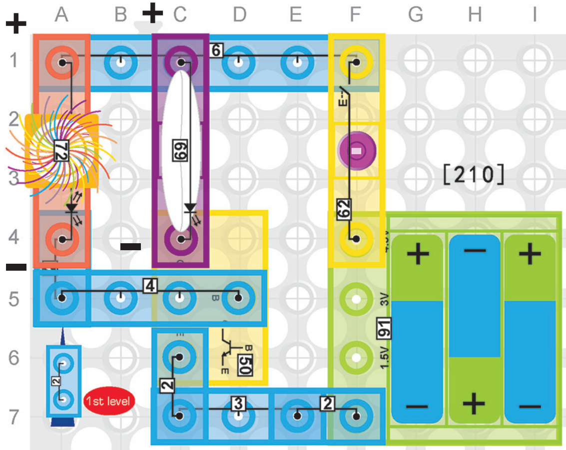
Replace the switch (62) with the press switch (61) in project #206, then press the press switch (61) and you will see the three LEDs will be turned on. To make ICs to support circuits like the one here and more complicated circuits, recall the discussions on how LEDs and transistors are made. The key 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.

208. Making ICs – Step 2

Replace the bi-directional LED (71) with the colorful LED (72) in project #206 and turn on the switch (62). Press the switch (62) and you will see the three LEDs will be turned on. 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.

209. Making ICs – Step 3

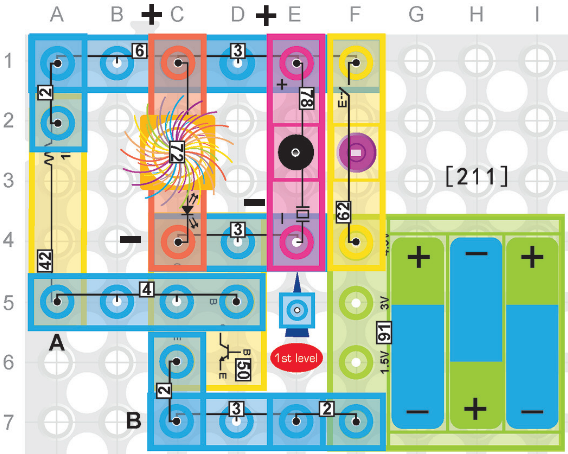
Replace the switch (62) with the press switch (61) in project #208, then press the press switch (61) and you will see the three LEDs will be turned on. The third step in making an IC for a circuit like this or more complicated circuits is to perform etching. Etching is the process of removing the photoresist 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.



210. Making ICs – Step 4

Build the circuit, then turn on the switch (62); you will see the heart LED (69) is on and the colorful LED (72) is shining too.

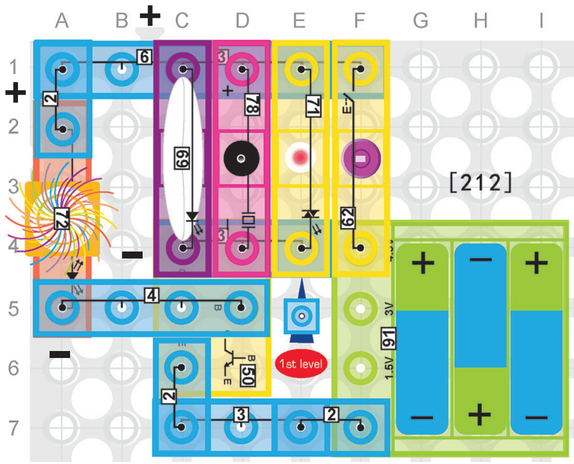
The fourth step in making an IC for a circuit like this or more complicated circuits is to perform doping. Doping is the process of heating the etched wafers with gases containing impurities to physically create the areas of n-type and p-type silicon. Steps 2 through 3 may be repeated a number of times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

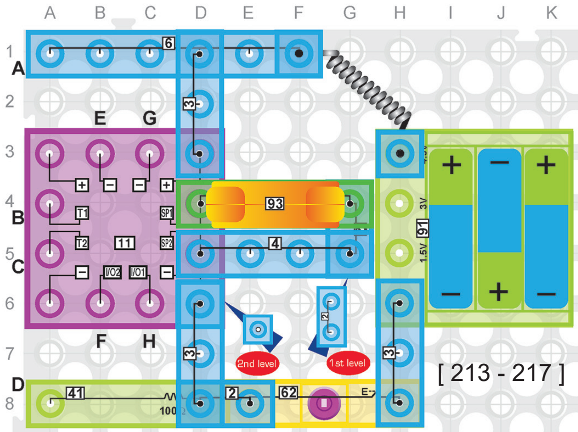


211. Making ICs – Step 5

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 colorful LED (72) will turn on and warning sounds will be heard from the alarm (78). 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.





212. Making ICs – Step 6

Build the circuit to the left, turn on the switch (62), and you will see all three LEDs will be on and also the alarm (78) will sound. 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 #206.

213. 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. As discussed previously, 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.

214. Machine Gun Sounds

Place a 4-wire (4) across points C and D in project #213, press the switch (62) and you will hear a gun shot and machine gun sounds. Sound technicians use electronics like this on the job to create all types of sounds.

215. Emergency Fire Siren

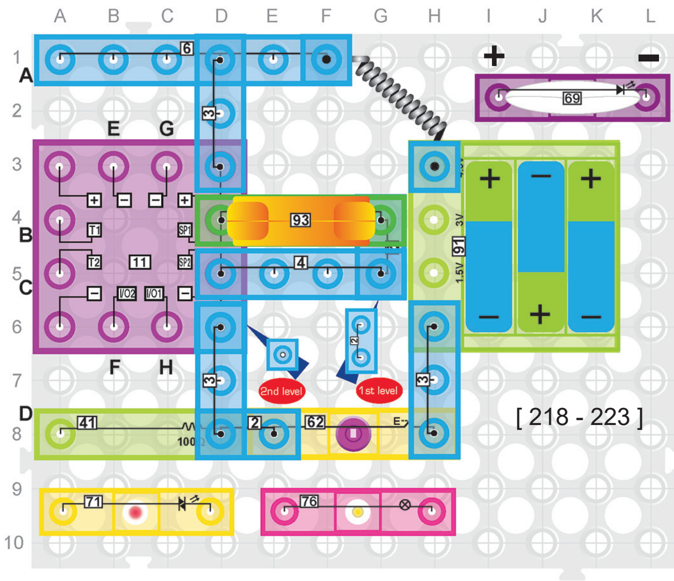
Place a 4-wire (4) across points A and B in project #213, press the switch (62) and you will hear the sound of an emergency fire siren. A siren like this is designed by an engineer to cover a large spectrum of sound so all people can hear it, even if they have hearing problems.

216. Space Battle Sounds

Place a 4-wire (4) across points E and F in project #213, 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".

217. Music

Place a 4-wire (4) across points G and H in project #213, 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.



218. Flickering Candle

Replace the speaker (93) with the lamp (76) in project #213, 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.

219. Flashing Quick Sale Sign

Replace the speaker (93) with the bi-directional LED (71) in project #213, then connect points C and D with a 4-wire (4). If you turn on the switch (62) you will see the bi-directional LED (71) is flashing quickly. An indicator like this could be used to show when a quick sale is available in a store.

220. Four Beats per Second

Replace the speaker (93) with the lamp (76) in project #213, 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.

221. Two Channel Monitor

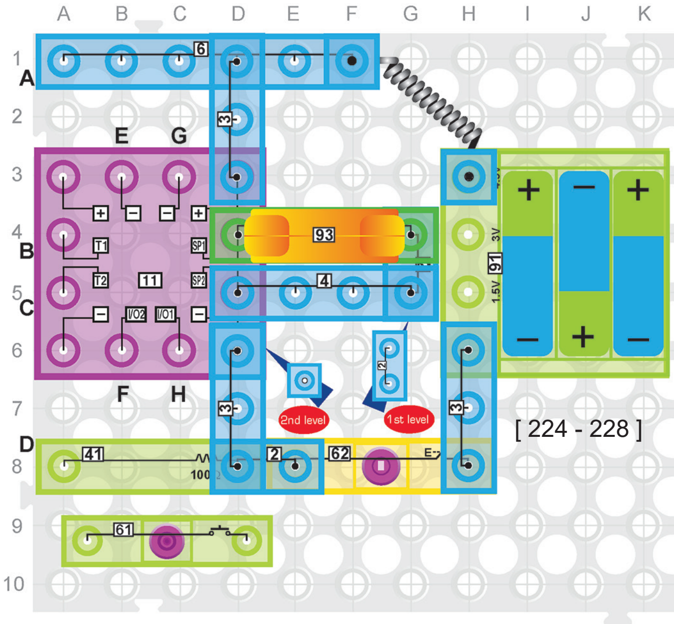
Replace the speaker (93) with bi-directional LED (71) in project #213, then connect points G and H using 4-wire (4). If you turn on the switch (62) you will see the bi-directional LED (71) is flashing slowly. Remove the 4-wire (4) from points GH and the bi-directional LED (71) flashes quickly. The light pulses from the bi-directional LED (71) 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.

222. Attention Please

Replace the speaker (93) with the heart LED (69) in project #213, 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.

223. Heartbeat

Replace the speaker (93) with the heart LED (69) in project #213, 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.



224. Moore's Law

Replace the switch (62) with the press switch (61) in project #213. Press the press switch (61) and you will hear the siren from the speaker (93). The 3-in-1 module (11) 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.

225. Sound Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #213. 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.

226. Types of Sound Recording and Reproduction

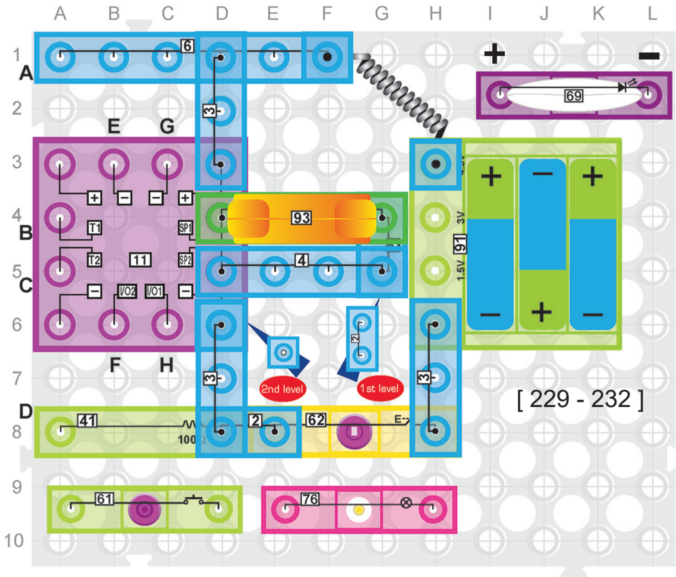
Replace the switch (62) with the press switch (61) in project #213. Place a 4-wire (4) across points A and B and when you press the press switch (61) you will hear the sound of an emergency fire siren. There are two types of sound recording and reproduction: analog and digital.

227. Analog Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #213. 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.

228. Digital Recording and Reproduction

Replace the switch (62) with the press switch (61) in project #213. 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.



229. Sampling

Replace the switch (62) with the press switch (61) and replace the speaker (93) with the lamp (76) in project #213. 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.

230. Nyquist Theorem

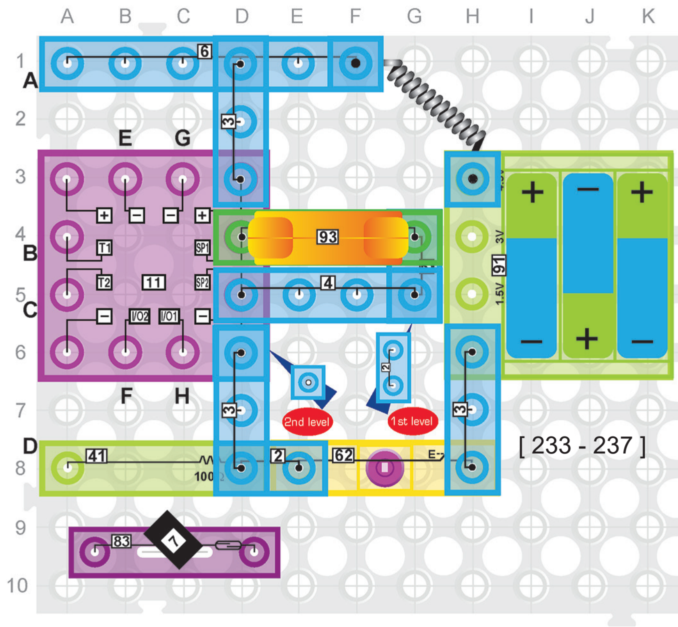
Replace the switch (62) with the press switch (61) and replace the speaker (93) with the lamp (76) in project #213. Connect points G and H using 4-wires (4), press the press switch (61) and you will see the lamp (76) flashing slowly. The Nyquist Theorem relates to the minimum sampling rate needed to 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.

231. 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 #213. 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.

232. 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 #213. 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 module (11) 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 heart LED (69).



233. Motion Detection Alarm

Replace the switch (62) with the reed switch (83) in project #213. 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.

234. No Touch Special Effects

Replace the switch (62) with the reed switch (83) in project #213. Place a 4-wire (4) across points C and D and when you hold the magnet (7) near the reed switch (83) you will hear a gun shot and machine gun sounds. This demonstrates how special sound effects can be activated and deactivated without physically having to touch a switch on the circuit.

235. Proximity Warning

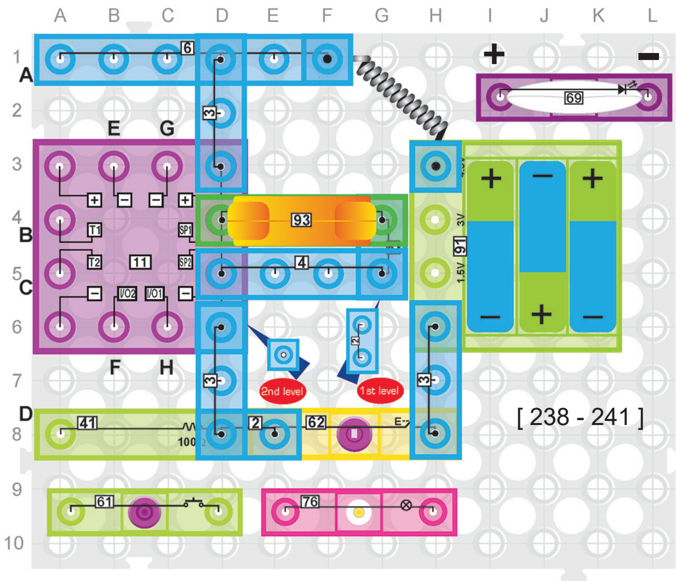
Replace the switch (62) with the reed switch (83) in project #213. Place a 4-wire (4) across points A and B and when you hold the magnet (7) near the reed switch (83) you will hear the sound of an emergency fire siren. The magnet (7) on the reed switch (83) could be like sensors on your car that activate a warning sound when it gets too close to an object.

236. Space Battle Sounds

Replace the switch (62) with the reed switch (83) in project #213. 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.

237. Proximity Music Interrupt

Replace the switch (62) with the reed switch (83) in project #213. 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.



238. Geiger Counter

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the lamp (76) in project #213. 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).

239. Proximity-controlled Sign

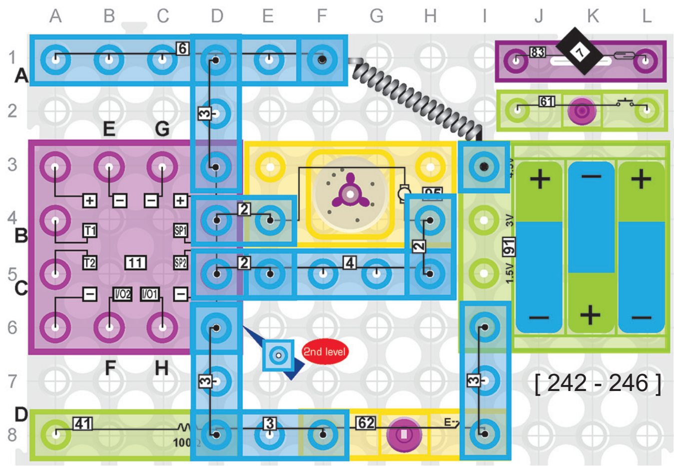
Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the lamp (76) in project #213. Connect points G and H using 4-wires (4), hold the magnet (7) near the reed switch (83) and you will see the lamp (76) flashing slowly. This circuit could simulate a person walking by a 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.

240. Flashing Alarm Light

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the heart LED (69) in project #213. 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 to simulate closing the door or window and now the light will go out indicating that you can set the alarm system.

241. A Pacemaker

Replace the switch (62) with the reed switch (83) and replace the speaker (93) with the heart LED (69) in project #213. 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.



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

242. 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 #41, current through the motor (95) creates a force on the shaft. It turns out this force is also being applied to the shell of the motor (95) and the shell of the motor (95) is acting like a cone in a speaker, which is creating the sound you hear.

243. Speed of an AC Motor

Place a 4-wire (4) across points C and D 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.

244. Motors in a Car

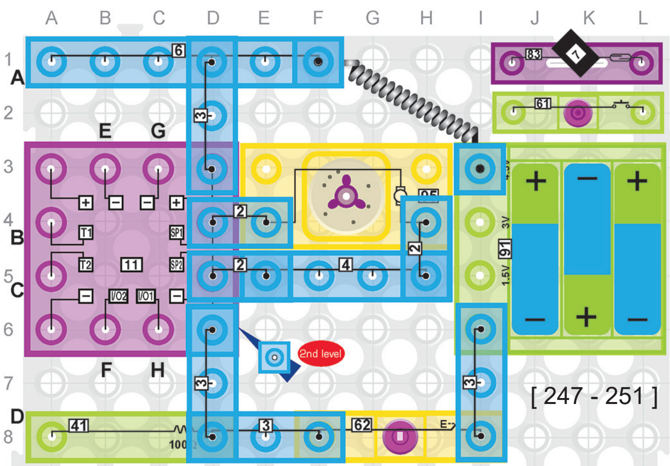
Place a 4-wire (4) across points A and B and when you press the switch (62) you will hear the faint sound of an emergency fire siren. Cars are a major consumer of motors. Did you know that an average car contains around 30 motors? See how many motors you can count in your car.

245. Engine vs. Motor

Place a 4-wire (4) across points E and F 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 #244. They are two different things. Motors run on electricity (from the batteries in these projects), while engines run on combustion.

246. Combustion for Car Engines

Place a 4-wire (4) across points G and H 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.



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

247. Gears

Replace the switch (62) with the press switch (61) in project #242, 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.

248. Gear Ratio

Replace the switch (62) with the press switch (61) in project #242, place a 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.

249. Helical Gears

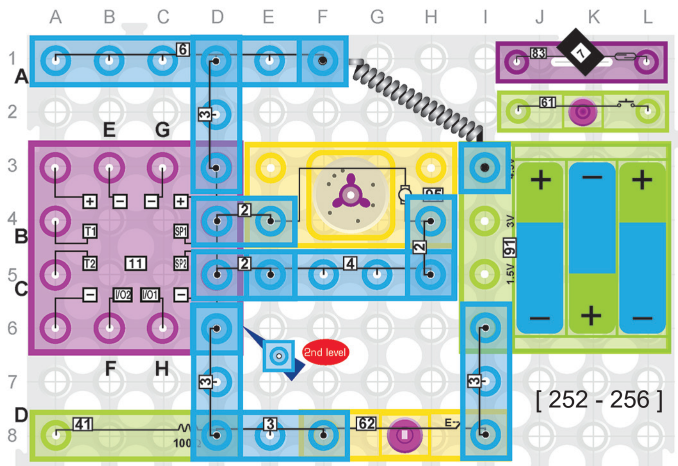
Replace the switch (62) with the press switch (61) in project #242, place a wire (4) across points A and B and when you press the press switch (61) you will hear the faint sound of an emergency fire siren. Your car uses helical gears. The leading edges of the teeth are set at an angle relative to the 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.

250. Gear Usages

Replace the switch (62) with the press switch (61) in project #242, place a 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.

251. Gear Applications

Replace the switch (62) with the press switch (61) in project #242, place a 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.

252. Magnets and Photons

Replace the switch (62) with the reed switch (83) in project #242, 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.

253. Magnet Material

Replace the switch (62) with the reed switch (83) in project #242, 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.

254. Animals and Magnets

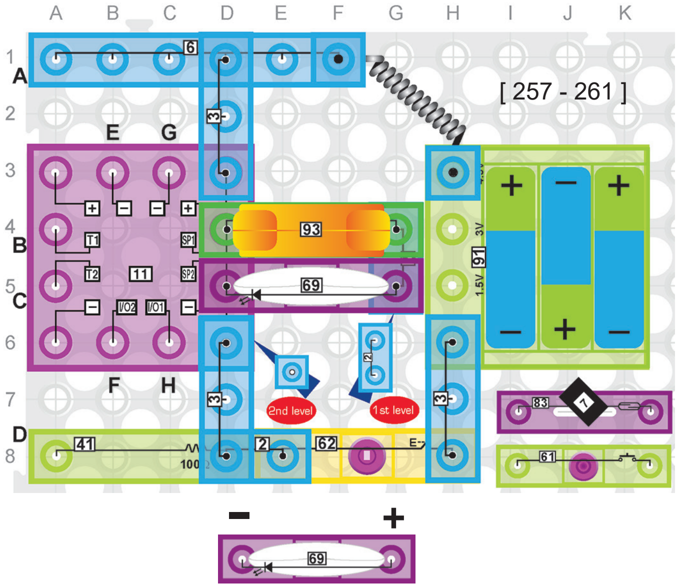
Replace the switch (62) with the reed switch (83) in project #242, place a 4-wire (4) across points A and B and when you hold the magnet (7) near the reed switch (83) you will hear the faint sound of an emergency fire siren. Some animals and bacteria have magnetite in their bodies. The chiton, a type 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.

255. Neutron Star

Replace the switch (62) with the reed switch (83) in project #242, 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?

256. Tesla

Replace the switch (62) with the reed switch (83) in project #242, 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.



257. Siren & Red Light Warning

Build the circuit shown on 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.

258. Gun with Flash on Shot

Connect points C and D with a 4-wire (4) in project #257, 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.

259. Fire Siren & Red Light Warning

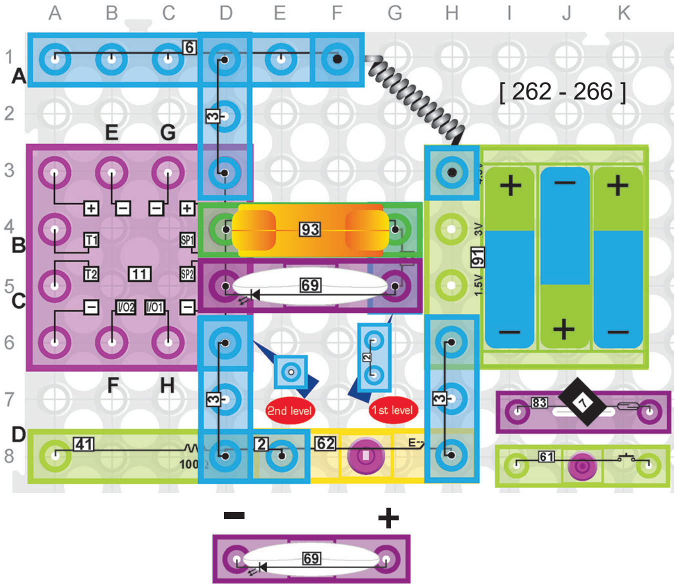
Connect points A and B with a 4-wire (4) in project #257, turn on the switch (62) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. The IC in the 3-in-1 (11) uses AND and NAND (Not AND) gate logic to make the fire engine siren sound when T1 is active AND I/O1 and I/O2 are NOT active.

260. 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 #257. 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).

261. Music with Red Beat

Connect points G and H with a 4-wire (4) in project #257, 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.

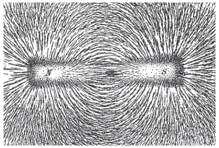


262. Magnet-controlled Fire Siren with Red Light Warning

Replace the switch (62) in project #257 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).

263. Magnetic Field of a Magnet

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 low volume and the heart LED (69) with flash at the same time. Iron filings can be used to show magnetic fields created by magnets (such as in the picture below).



264. Visual & Audio Warning

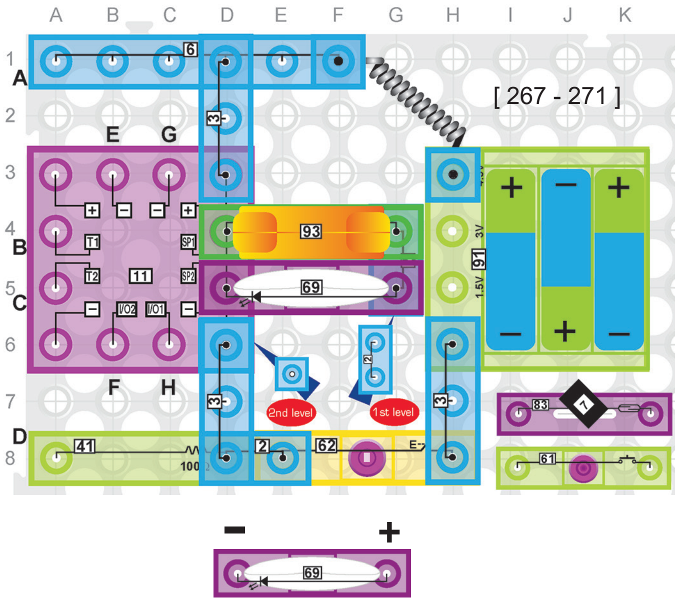
Connect points A and B with a 4-wire (4) in project #262, hold the magnet (7) near the reed switch (83) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. Police cars, fire trucks and fire engines all provide both audio and visual warnings in case of emergency.

265. Proximity Warning of an Alien Space Craft

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 low volume with the heart LED (69) flashing with each sound. This simulates a proximity warning from an alien space craft.

266. Surprise Birthday Song

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 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!



267. Distant Siren with Indicator

Replace the switch (62) in project #257 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.

268. Battle Far, Far Away

Connect points C and D with a 4-wire (4) in project #267. 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.

269. Non-Polarity Speaker

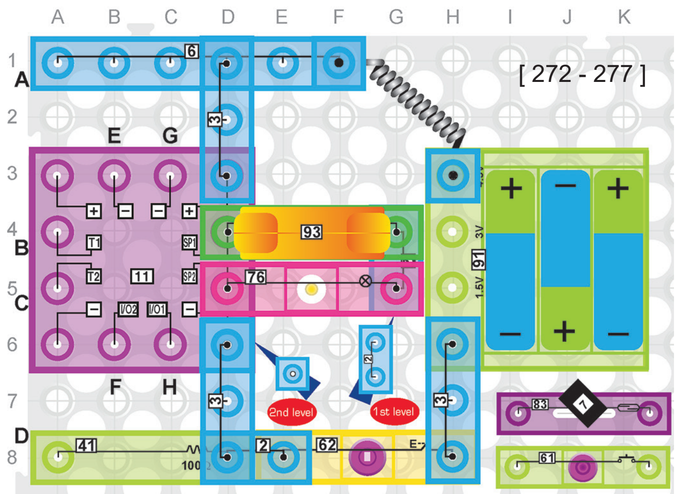
Connect points A and B with a 4-wire (4) in project #267. Press and hold the press switch (61) and you will hear a fire siren in low volume and the heart LED (69) will flicker at the same time. Try turning the speaker (93) around in this circuit. You will still hear the same sound. This shows that the speaker is a non-polarity component since it works both directions.

270. In a Galaxy Far, Far Away

Connect points E and F with a 4-wire (4) in project #267. 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.

271. Audio Spectrum Display

Connect points G and H with a 4-wire (4) in project #267. 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.



272. 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.

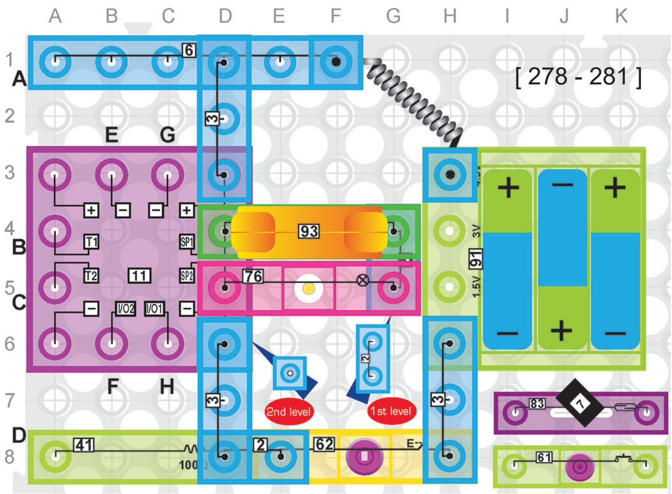
273. Bank Robbery
Connect points C and D with a 4-wire (4) in project #272, turn on the switch (62) and you will hear gun shots in medium volume and the lamp (76) with flash at the same time. The lamp (76) simulates flashes from the gun shots.

274. Sound Engineering Tricks
Connect points A and B with the press switch (61) in project #272, 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.

275. Engineering a Space Battle
Connect points E and F with a 4-wire (4) in project #272. 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.

276. Music Loudness Reduction
Connect points G and H with a 4-wire (4) in project #272, 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.

277. Sound in Water
Replace the switch (62) with the press switch (61) in project #272. 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 that air molecules so sounds can be passed more quickly between molecules.



278. Loudest Sound

Connect points C and D with a 4-wire (4) in project #277. 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?

279. Animal Hearing

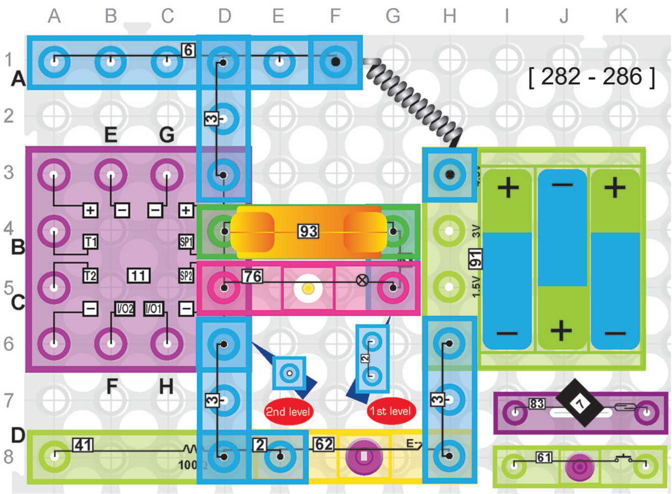
Connect points A and B with a 4-wire (4) in project #277. Press and hold the press switch (61) and you will hear a fire siren in medium volume and the lamp (76) will flash. Have you ever wondered why animals like dogs can hear things you cannot? Dogs have more sensitive ears that can hear things more 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!).

280. 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 #277. Press and hold the press switch (62) 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.

281. 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 #277. 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.



282. Flies and Sound

Replace the switch (62) with the reed switch (83) in project #272. 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!

283. Dolphins Hearing Underwater

Connect points C and D with a 4-wire (4) in project #282. Hold the magnet (7) near the reed switch (83) and you will hear gun shots in medium volume and the lamp (76) with flash at the same time. Did you know that dolphins can hear sounds under water that are up to 15 miles away? It must be pretty noisy for them under the sea!

284. Whale Voices

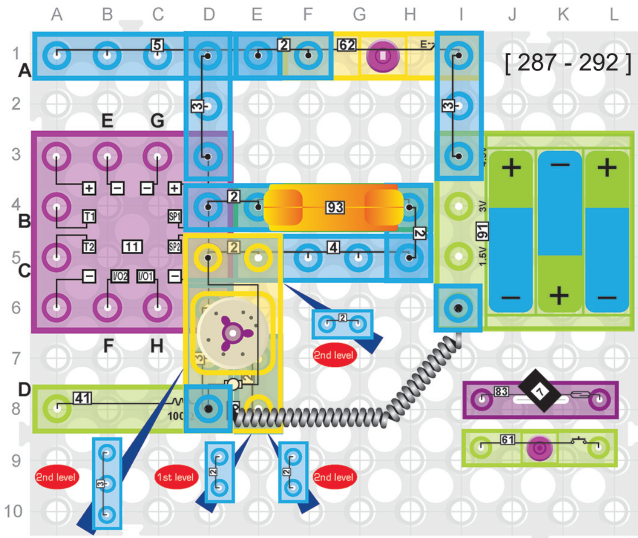
Connect points A and B with a 4-wire (4) in project #282. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren in medium volume and the lamp (76) will flash. Did you know that whale voices can travel over 400 miles underwater? They better be careful what they say!

285. Sound in a Vacuum

Connect points E and F with a 4-wire (4) in project #282. 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.

286. Is That My Voice?

Connect points G and H with a 4-wire (4) in project #282. 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!



287. 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.

288. Motor Syncing to Gun Shots

Connect points C and D with a 4-wire (4) in project #287, 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.

289. Motor Syncing to Fire Siren

Connect points A and B with a 4-wire (4) in project #287, 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 it's lowest pitch 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.

290. Electric Cars

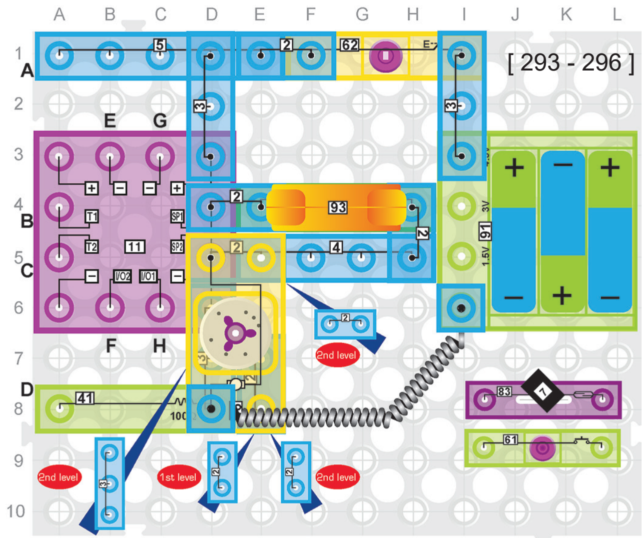
Connect points E and F with a 4-wire (4) in project #287, turn on the switch (62) and the sounds of space battle will turn on and the motor (95) will spin at the same time. Did you know that some electric cars are so quiet that they actually add noise for safety reasons? This is to protect people, particularly the blind, from not hearing a car coming.

291. Birthday Card

Connect points G and H with a 4-wire (4) in project #287, 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.

292. Robotic Sensor

Replace the switch (62) with the reed switch (83) in project #287. 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.



293. High Impedance Input

Connect points C and D with a 4-wire (4) in project #292. 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 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.

294. Active High Input – T1

Connect points A and B with a 4-wire (4) in project #292. 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.

295. Active Low Input – I/O2

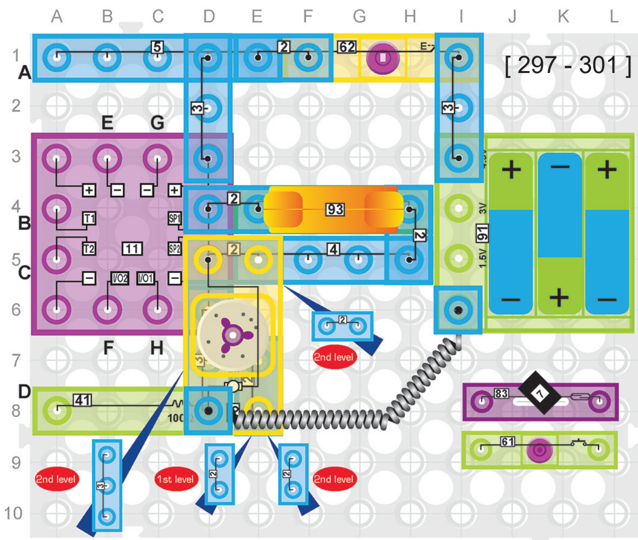
Connect points E and F with a 4-wire (4) in project #292. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on and the motor (95) will spin at the same time.

Connecting points E and F connects the I/O2 input to ground (OV). 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.

296. Active Low Input – I/O1

Connect points G and H with a 4-wire (4) in project #292. 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 (OV). 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.



297. Floating Inputs

Replace the switch (62) with the press switch (61) in project #287. 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 has tied these inputs to ground or 4.5V through a resistor, so they are not actually floating inputs.

298. Benefits of High Input Impedance

Connect points C and D with a 4-wire (4) in project #297. 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 #293, 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.

299. Output Impedance

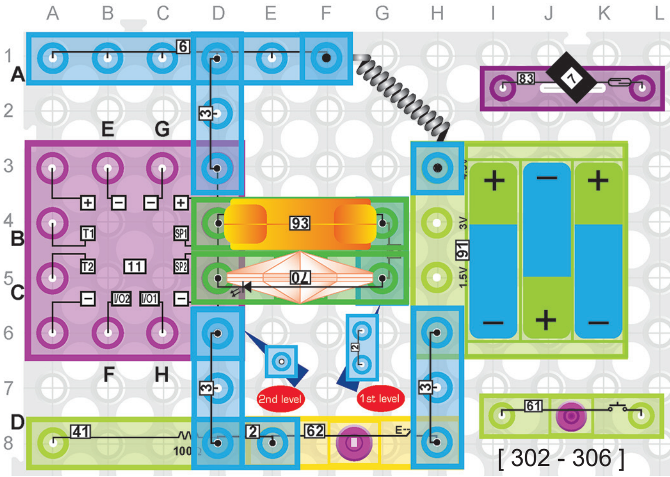
Connect points A and B with a 4-wire (4) in project #297. Press and hold the press switch (61) and you will hear a fire siren and the motor (95) will spin at the same time. The speaker outputs SP1 and SP2 have output impedance. Output impedance is a measure of the change in output voltage to the change in load current.

300. Thevinin's Theorem

Connect points E and F with a 4-wire (4) in project #297. 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 #53 showed an example of how an equivalent resistance can be calculated.

301. Admittance

Connect points G and H with a 4-wire (4) in project #297. 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.



302. 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.

303. Reactance

Connect points C and D with a 4-wire (4) in project #302, turn on the switch (62) and you will hear gun shots in medium volume and the star LED (70) will 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.

304. Relation between Reactance, Resistance, and Impedance

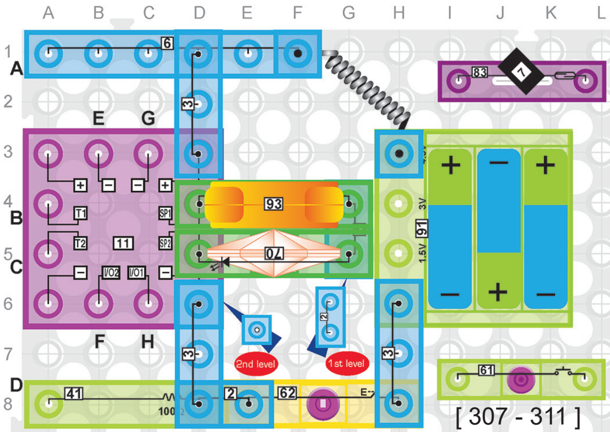
Connect points A and B with a 4-wire (4) in project #302, turn on the switch (62) and you will hear a fire siren in medium volume and the star LED (70) will flash. Impedance is the opposition to all types of current flow, due to resistance, capacitance and inductance. So you can think of impedance like the sum of resistance and reactance.

305. Conductance

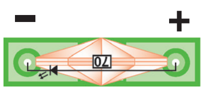
Connect points E and F with a 4-wire (4) in project #302. Turn on the switch (62) and the sounds of space battle will turn on in medium volume with the star LED (70) will flash. Conductance is the measure of ease in which current can flow through a circuit or input. Conductance is the inverse of resistance, that is conductance = 1/resistance.

306. Unit of Measure for Conductance: Siemens & Mhos

Connect points G and H with a 4-wire (4) in project #302, 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 measured 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.



[307 - 311]



307. Susceptance

Replace the switch (62) with the press switch (61) in project #302. 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.

308. Relation between Conductance, Susceptance, and Admittance

Connect points C and D with a 4-wire (4) in project #307. Press and hold the press switch (61) and you will hear gun shots in medium volume and the star LED (70) will 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.

309. Linear Circuits

Connect points A and B with a 4-wire (4) in project #307. 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 sine wave with the same frequency.

310. Superposition Principle

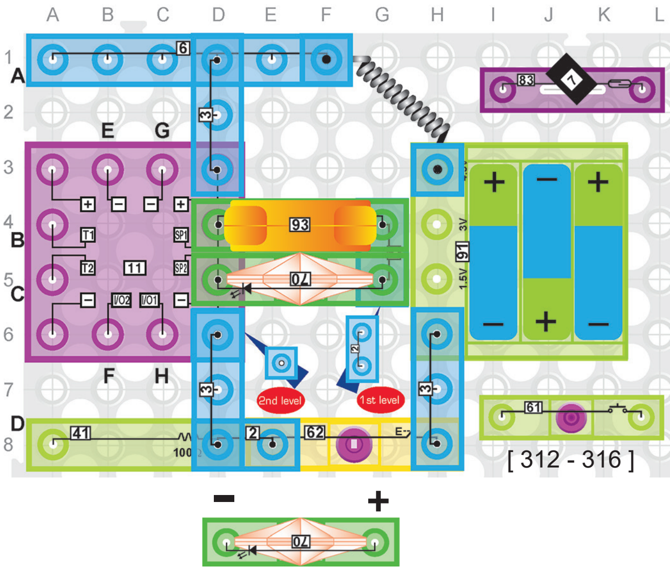
Connect points E and F with a 4-wire (4) in project #307. Press and hold the press switch (61) and the sounds of space battle will turn on in medium volume with the star LED (70) will flash. Another way to define a linear circuit is that it has to meet the superposition principle. The superposition principle 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.

311. Superposition Principle Equation

Connect points G and H with a 4-wire (4) in project #307. 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.



312. Linear Circuit Components

Replace the switch (62) with the reed switch (83) in project #302. 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.

313. Nonlinear Circuits

Connect points C and D with a 4-wire (4) in project #312. Hold the magnet (7) near the reed switch (83) and you will hear gun shots in medium volume and the star LED (70) will 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.

314. Nonlinear Circuit Components

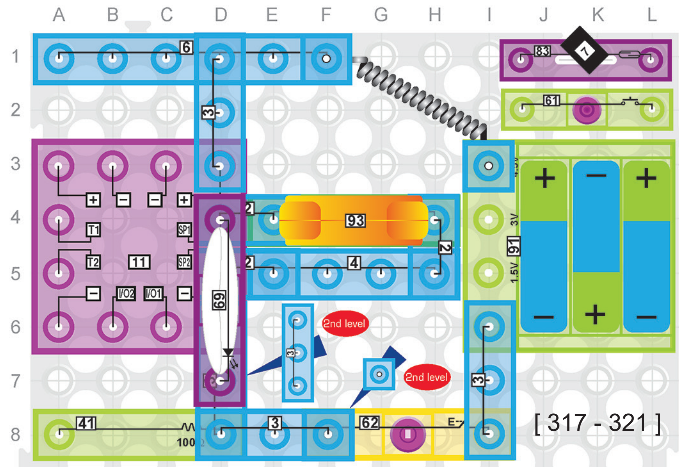
Connect points A and B with a 4-wire (4) in project #312. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren in medium volume and the star LED (70) will flash at the same time. Example of components in a circuit that will make it non-linear are diodes, transistors and transformers.

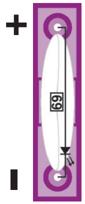
315. Active Elements

Connect points E and F with a 4-wire (4) in project #312. 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. Active elements are elements that can source power. For example, a voltage or current source like a power supply or battery are active elements.

316. Passive Elements

Connect points G and H with a 4-wire (4) in project #312. 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. Passive elements are elements that do not provide a source of energy. For example, resistors, capacitors and diodes are passive elements.





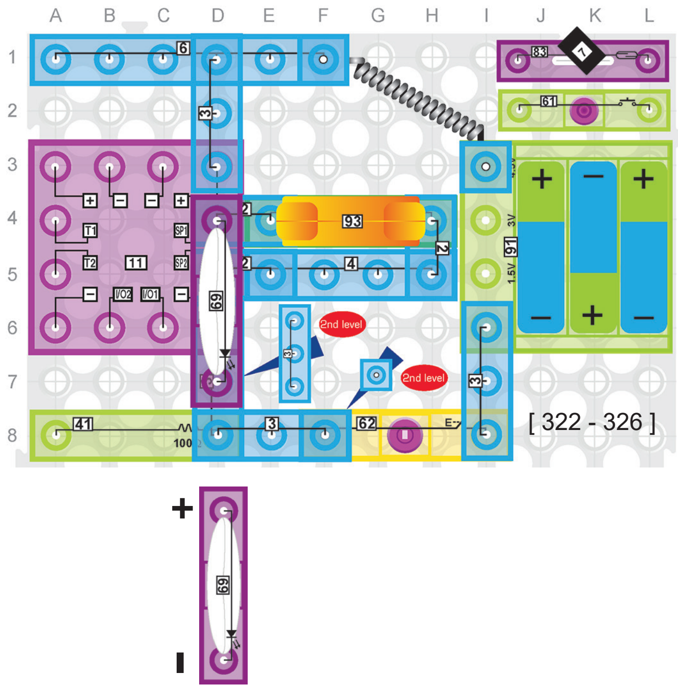
317. Orientation of IC
Build the circuit shown, turn on the switch (62) and you will hear the sounds of a police siren from the speaker (93). Also, you will see the heart LED (69) is flashing at the same time. If you ever looked at an IC you would see that there is a dot or notch on them. Since many 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.

318. Electrocardiogram
Connect points C and D with a 4-wire (4) in project #317. Turn on the switch (62) and you will hear gun shots and the heart LED (69) will flash at the same time. 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.

319. Output Impedance
Connect points A and B with the 4-wire (4) in project #317. 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.

320. Lightning
Connect points E and F with a 4-wire (4) in project #317. 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?

321. Electric EEL
Connect points G and H with a 4-wire (4) in project #317. 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 500V or more.



322. Work

Replace the switch (62) with the reed switch (83) in project #317. 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.

323. Formula for Work

Connect points C and D with a 4-wire (4) in project #322. Hold the magnet (7) near the reed switch (83) and you will hear gun shots and the heart LED (69) will flash at the same time. The formula for work is W = F*d, where W = work, F = force, and d = distance.

324. Newtons

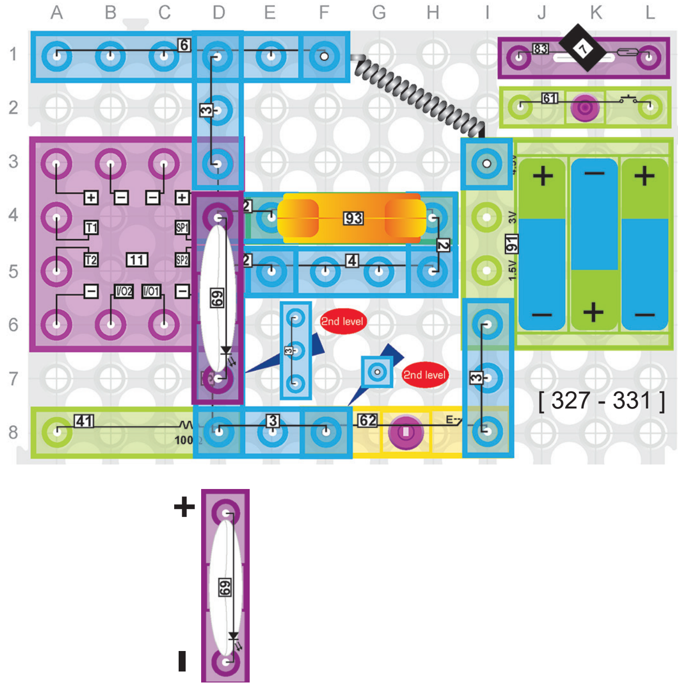
Connect points A and B with the 4-wire (4) in project #322. Hold the magnet (7) near the reed switch (83) and you will hear a fire siren and the heart LED (69) will flash at the same time. The Newton is the unit of measurement of force. One Newton is the force needed to accelerate one kilogram of mass at a rate of one m/s^2 in the direction of the applied force.

325. Newton's Second Law of Motion - Force

Connect points E and F with a 4-wire (4) in project #322. Hold the magnet (7) near the reed switch (83) and the sounds of space battle will turn on with 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 it's mass and acceleration. Specifically, Force = mass*acceleration (F=m*a).

326. Mass

Connect points G and H with a 4-wire (4) in project #322. 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.



327. Weight

Replace the switch (62) with the press switch (61) in project #317. 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.

328. Velocity

Connect points C and D with a 4-wire (4) in project #327. Press the press switch (61) and you will hear gun shots and the heart LED (69) will 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).

329. Acceleration

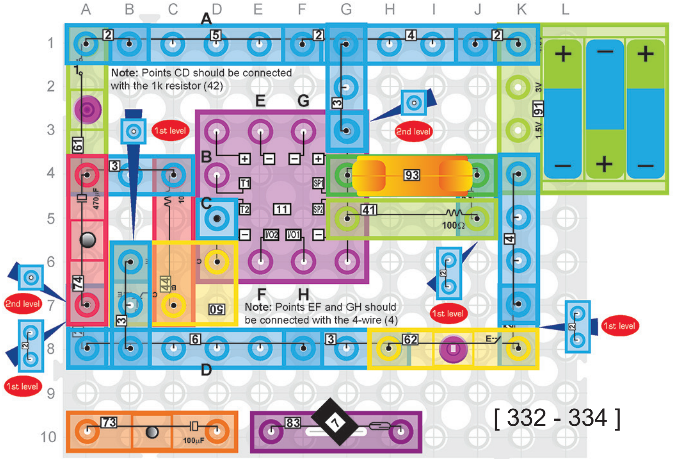
Connect points A and B with the 4-wire (4) in project #327. Press the press switch (61) and you will hear a fire siren and the heart LED (69) will flash at the same time. Acceleration is the rate of change of velocity and is measured in m/s^2.

330. Gravitational Acceleration

Connect points E and F with a 4-wire (4) in project #327. Press the press switch (61) and the sounds of space battle will turn on with 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.

331. Kinetic Energy

Connect points G and H with a 4-wire (4) in project #327. 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 $E_k = mv^2/2$.



332. Siren is Breaking up and Fading Out

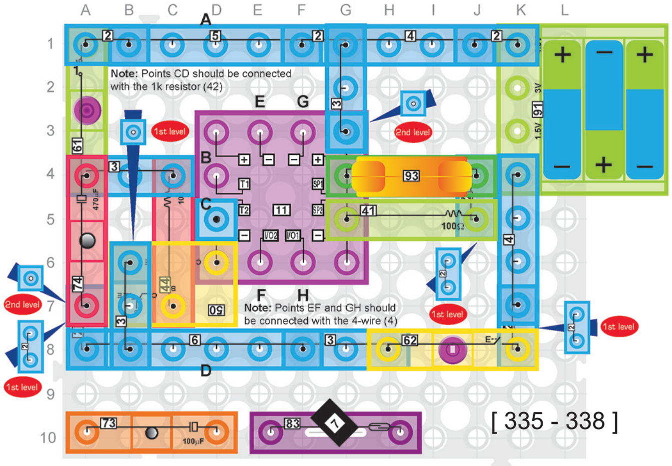
Build the circuit shown and turn on the switch (62). Press the press switch (61) for a while and you will hear the siren. Release the press switch (61) and wait for a while. You will eventually hear the siren start breaking up and fading out. This is because the 470μF capacitor (74) in the circuit is initially being charge when you press the press switch, 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.

333. Potential Energy

Connect points C and D with the 1kΩ resistor (42) in project #332. 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 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 #330.

334. Joules

Connect points A and B with the 4-wire (4) in project #332. 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.



335. Power

Connect points E and F with a 4-wire (4) in project #332. 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.

336. Watts

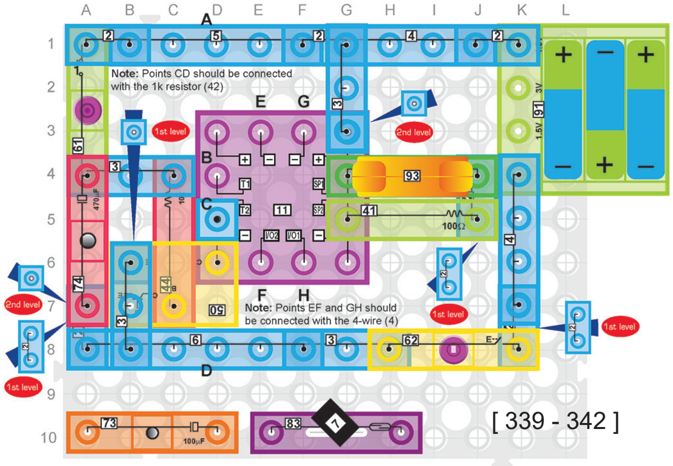
Connect points G and H with a 4-wire (4) in project #332. Press the press switch (61) for a while and you will hear music. Release the press switch (61) and wait for a while. You will eventually hear the music start breaking up and fading out. Watts is the unit of measure for power defined as 1 Joule per second.

337. Einstein's $E = mc^2$

Replace the press switch (61) with the reed switch (83) in project #332. 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 it's mass times the speed of light squared.

338. Alessandro Volta

Connect points C and D with the 1kΩ resistor (42) in project #337. 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.



[339 - 342]

339. Transformers

Connect points A and B with the 4-wire (4) in project #337. 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 voltages in electric power applications.

340. Inductors

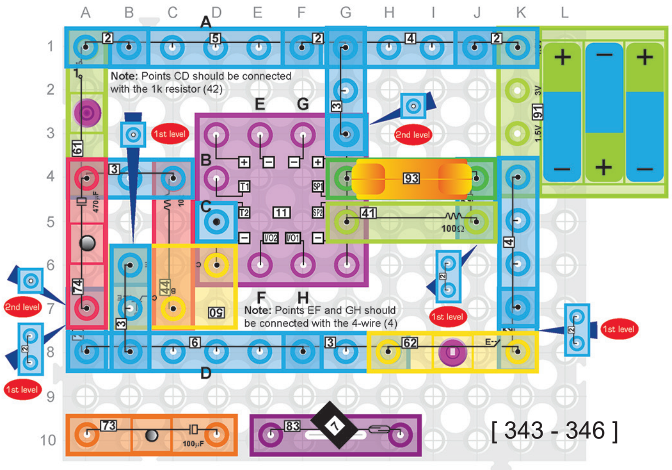
Connect points E and F with a 4-wire (4) in project #337. Hold the magnet (7) near the reed switch (83) for a while and you will hear space battle sounds. Move the magnet (7) away from the reed switch (83) and wait for a while. You will eventually hear the space battle sounds start breaking up and fading 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 preserve 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.

341. The Henry

Connect points G and H with a 4-wire (4) in project #337. 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 $kg*m^2/(s^2*A^2)$.

342. Faster Fade Out

Replace the 470μF capacitor (74) with the 100μF capacitor (73) in project #332. 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 #332 because the capacitance is smaller in the 100μF capacitor (73) in this circuit so it discharges more quickly.



[343 - 346]

343. Monolithic IC

Connect points C and D with the 1kΩ resistor (42) in project #342. 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.

344. Hybrid ICs

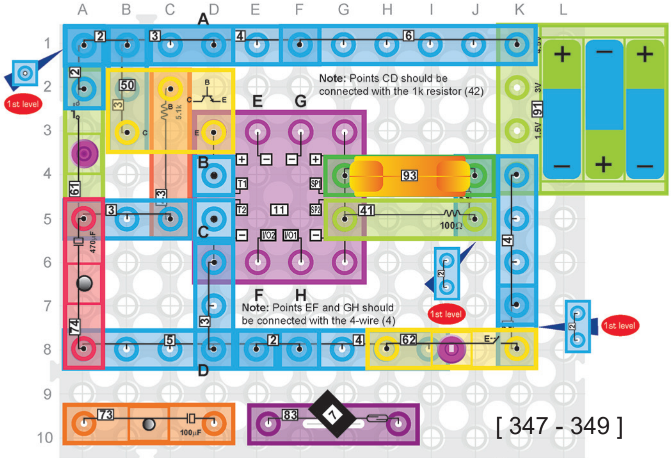
Connect points A and B with the 4-wire (4) in project #342. Press the press switch (61) for a while and you will hear the fire siren. Release the press switch (61) and wait for a while. You will eventually hear the fire siren start breaking up and fading out. More advanced circuits than in your 3-in-1 (11) may require several silicon chips, where the use of a Hybrid IC would incorporate multiple silicon chips into a single package.

345. Rectifier

Connect points E and F with a 4-wire (4) in project #342. 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.

346. Alkaline Batteries

Connect points G and H with a 4-wire (4) in project #342. 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. 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.



[347 - 349]

347. 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 5.1kΩ resistor (43) in this RC circuit, the siren should fade out slightly sooner than in project #332 where a 10kΩ resistor (44) is used because the RC time constant in this circuit is half the RC time constant of that in project #332.

348. Lithium Batteries

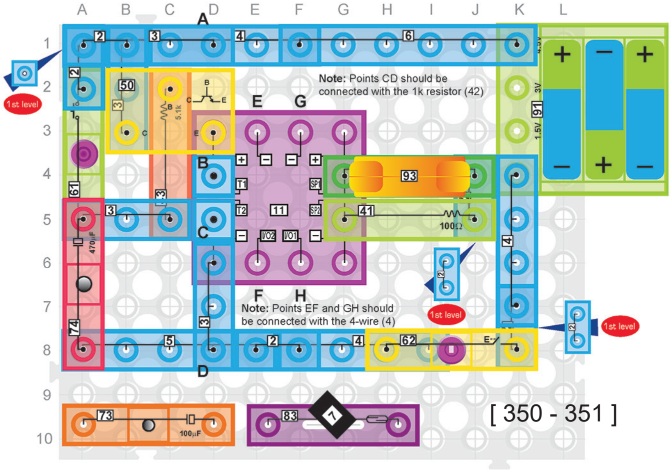
Connect points C and D with the 1kΩ resistor (42) in project #347. Press the press switch (61) for a while and you will hear gun shots in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). Release the press switch (61) and wait for a while. You will eventually hear the gun shots start breaking up and fading out.

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.

349. Pulse Code Modulation

Connect points A and B with the 4-wire (4) in project #347. Press the press switch (61) for a while and you will hear the fire 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 fire siren start breaking up and fading out.

As discussed in project #229, 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.

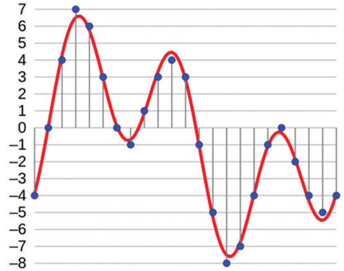


Decimal	Binary	Decimal	Binary
7	111	-1	1001
6	110	-2	1010
5	101	-3	1011
4	100	-4	1100
3	011	-5	1101
2	010	-6	1110
1	001	-7	1111
0	000	-8	1000

350. Quantization and Encoding

Connect points E and F with a 4-wire (4) in project #347. Press the press switch (61) for a while and you will hear space battle sounds 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 space battle sounds start breaking up and fading out.

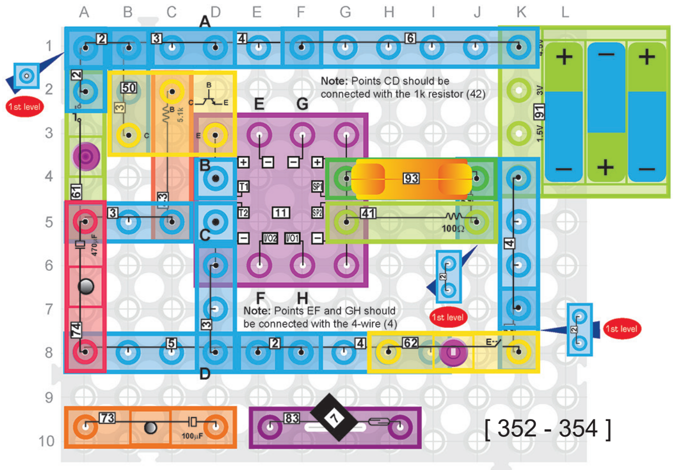
The picture below shows the process of quantization and encoding of the quantized values to a digital bit steam. Notice how the samples are “quantized” to one of 16 levels.



351. Decimal to Binary Conversion

Connect points G and H with a 4-wire (4) in project #347. Press the press switch (61) for a while and you will hear music 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 music start breaking up and fading out. The sample levels in project #350 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 shown on the left. 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.



352. ADC Converter

Replace the switch (62) with the reed switch (83) in project #347. Hold the magnet (7) near the reed switch (83) 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). 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.

353. DAC Converter

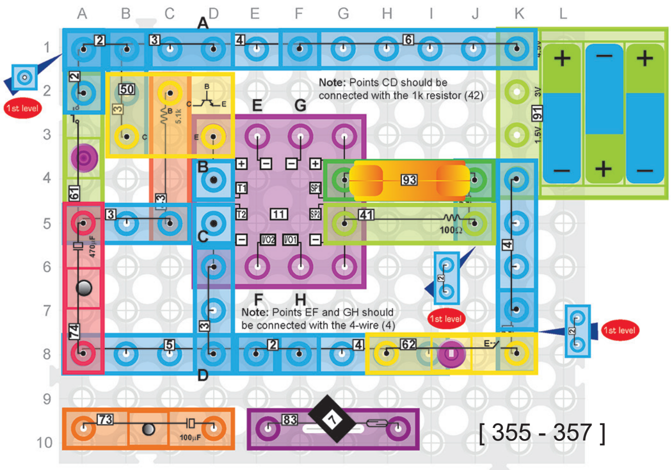
Connect points C and D with the 1kΩ resistor (42) in project #352. Hold the magnet (7) near the reed switch (83) for a while and you will hear gun shots in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). Move the magnet (7) away from the reed switch (83) 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.

354. Quantization Error

Connect points A and B with the 4-wire (4) in project #352. Hold the magnet (7) near the reed switch (83) for a while and you will hear the fire siren in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). 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 #350, 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.



355. Digital Signal Processing

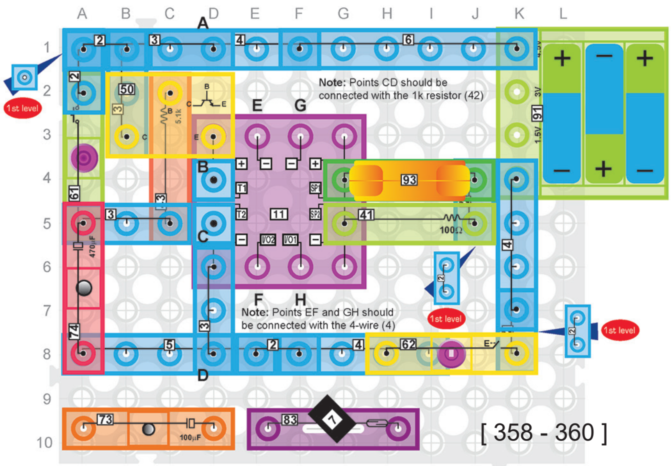
Connect points E and F with a 4-wire (4) in project #352. Hold the magnet (7) near the reed switch (83) for a while and you will hear space battle sounds in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). Move the magnet (7) away from the reed switch (83) 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.

356. Adaptive Pulse Code Modulation

Connect points G and H with a 4-wire (4) in project #352. Hold the magnet (7) near the reed switch (83) for a while and you will hear music in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). 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.

357. Even Shorter Siren Fade Out

Replace the 470μF capacitor (74) with the 100μF capacitor (73) in project #347. 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 100μF capacitor in this RC circuit, the siren should fade out sooner than in project #347 where a 470μF capacitor is used because the RC time constant in this circuit is about 1/5 the RC time constant of that in project #347.



358. BJT and FET

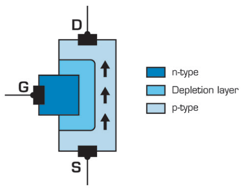
Connect points C and D with the 1kΩ resistor (42) in project #357. Press the press switch (61) for a while and you will hear gun shots in soft volume. This is because the 100Ω resistor (41) limits the current through the speaker (93). Release the press switch (61) and wait for a while. You will eventually hear the 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 #107, and Field Effect Transistors (FET).

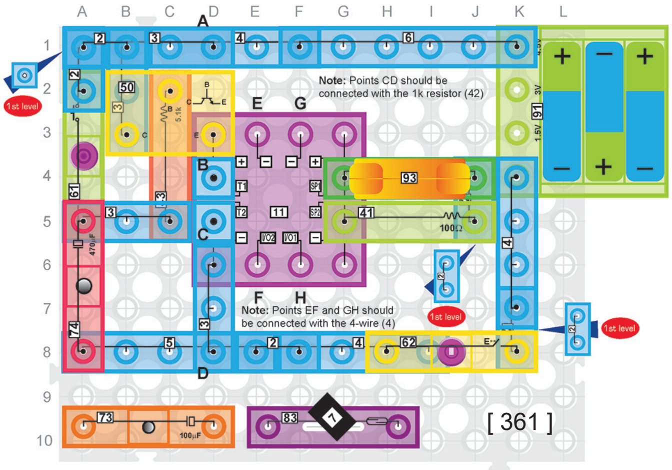
359. FETs

Connect points A and B with the 4-wire (4) in project #357. Press the press switch (61) for a while and you will hear the fire 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 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.

360. JFET

Connect points E and F with a 4-wire (4) in project #347. Press the press switch (61) for a while and you will hear space battle sounds 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 space battle sounds start breaking up and fading out. The makeup of a Junction Field Effect Transistor (JFET) is shown in the figure below. 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.



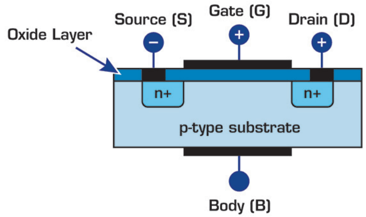


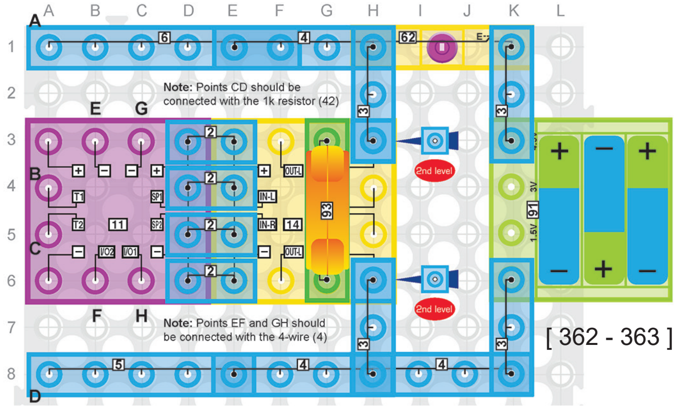
[361]

361. MOSFET

Connect points G and H with a 4-wire (4) in project #347. Press the press switch (61) for a while and you will hear music 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 music start breaking up and fading out.

The makeup of a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is shown in the figure below. MOSFET's operate the same as JFET's but the gate terminal is electrically isolated from the conductive channel.





[362 - 363]

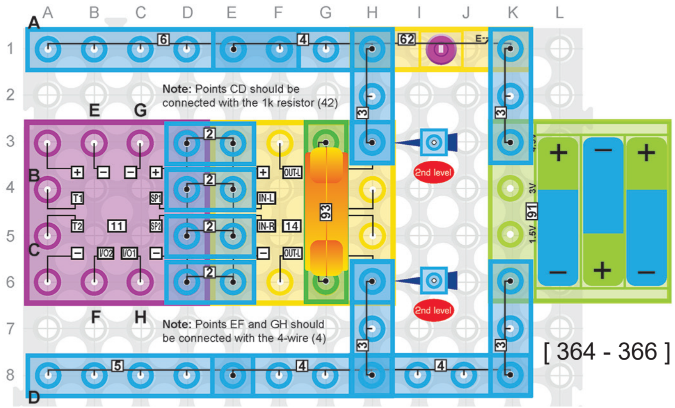
362. Amplified Siren

Build the circuit shown on the left, turn on the switch (62) and you will hear a very loud siren. Turn off the switch (62) and the siren will go off. In this circuit, the amplifier (14) is taking the output from the 3-in-1 (11), amplifying it using transistor circuits like the ones you have been learning about in previous projects, and then sending the amplified signal to the speaker (93).

363. Amplifier Gain

Connect points C and D with the 1kΩ resistor (42) in project #362. Turn on the switch (62) and you will hear very loud gun shots and machine gun sounds. Turn off the switch (62) and the sounds will go off.

If you had a voltmeter, you could measure the voltage across the 3-in-1 (11) speaker terminals SP1 and SP2 to be about 10mV (10 milli-volts or 0.01 volt), while if you measured the voltage across the amplifier (14) OUT-R terminals you would see about 1.9V. This means that the amplifier is increasing the sound signal strength by a factor of 190.



[364 - 366]

364. Distortion

Connect points A and B with the 4-wire (4) in project #362. Turn on the switch (62) and you will hear very loud fire siren. Turn off the switch (62) and the fire siren will go off. You may notice that the fire siren is so loud in this circuit that it sounds distorted.

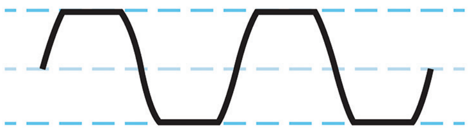
This is happening because fire siren waveform coming out of the 3-in-1 (11) is not just being amplified by the amplifier (14) but the waveform is being changed in some other way (i.e. the waveform is being distorted) from its original form by the amplifier (14). This can be due to several different things such as: 1. The input signal may be too large for the gain of the amplifier (14) so that the maximum output voltage from the amplifier (14) is exceeded, 2. The amplifier (14) may not be completely linear over the full frequency range of the fire siren signal, 3. Poor DC biasing is occurring in the amplifier (14) so that the amplification is not occurring over the full fire siren signal level.

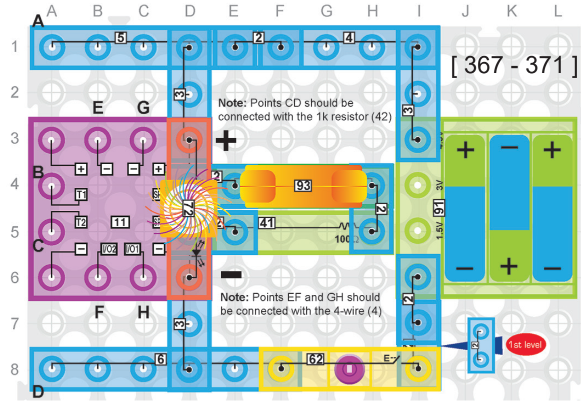
365. Amplifier Gain in dB

Connect points E and F with a 4-wire (4) in project #362. Turn on the switch (62) and you will hear very loud space battle sounds. Turn off the switch (62) and the sounds will go off. Based on the measurements from project #363, the amplifier gain in dB is about 10*log(190) = 22.8 dB.

366. Clipping

Connect points G and H with a 4-wire (4) in project #362. Turn on the switch (62) and you will hear very loud music. Turn off the switch (62) and the music will go off. You may also notice that the music in this project is very distorted. A couple of the reasons for the distortion mentioned in project #364 was due to the limitations in the maximum output voltage from the amplifier (14). When an amplifier is over driven and the amplified signal exceeds the maximum output voltage, then the signal will be “clipped” or capped at the maximum output voltage supported by the amplifier. This is called clipping and is shown in the figure below.





367. Low Volume Siren

Build the circuit to the left, turn on the switch (62) and you will hear a low volume siren and the colorful LED (72) will light the fiber tree (40). 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.

368. Lower Volume Machine Gun

Replace the 100Ω resistor (41) with the 1kΩ resistor (42) in project #367 and connect points C and D with the 100Ω resistor (41) in project #367. Turn on the switch (62) and you will hear lower volume gun shots and machine gun sounds and the colorful LED (72) will light the fiber tree (40). 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 #367.

369. Even Lower Volume Fire Siren

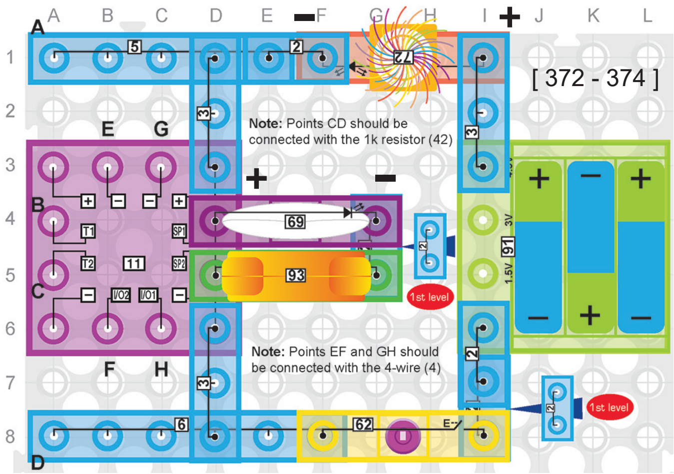
Replace the 100Ω resistor (41) with the 5.1kΩ resistor (43) in project #367 and connect points A and B with the 4-wire (4) in project #367.Turn on the switch (62) and you will hear an even lower volume fire siren. Turn off the switch (62) and the fire siren will go off and the colorful LED (72) will light the fiber tree (40). The 5.1kΩ resistor (43) limits the current more than the 1kΩ resistor (42) which is why the volume is even lower in this project than in projects #367 and #368.

370. Barely Audible Space Battle Sounds

Replace the 100Ω resistor (41) with the 10kΩ resistor (44) in project #367 and connect points E and F with a 4-wire (4) in project #367.Turn on the switch (62) and you will barely be able to hear space battle sounds and the colorful LED (72) will light the fiber tree (40). Turn off the switch (62) and the sounds will go off. The 10kΩ resistor (44) limits the current more than the 5.1kΩ resistor (43) which is why you can barely hear the space battle sounds in this project.

371. Can You Hear Music?

Replace the 100Ω resistor (41) with the 100kΩ resistor (45) in project #367 and connect points G and H with a 4-wire (4) in project #367. Turn on the switch (62). The colorful LED (72) will light the fiber tree (40), 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.



372. Siren Fading In and Out

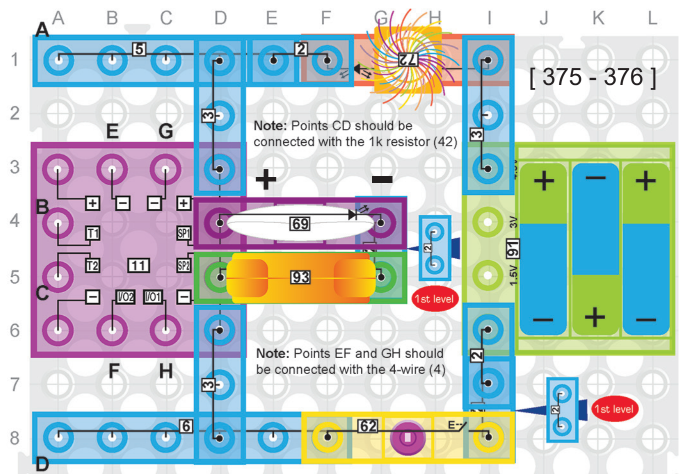
Build the circuit to the left, turn on the switch (62), and you will hear a low volume siren with the heart LED (69) and colorful LED (72) flashing. Listen as the colors change on the colorful LED (72). Can you detect a pattern? Turn off the switch (62) and the siren and LEDs will go off. In this circuit you may have noticed that the siren fades out as the colorful LED (72) turns green and blue but then the siren comes back when the LED turns red. As discussed in project #97, green and blue light have higher turn on voltages than red light. So when the colorful LED (72) is red, there is just enough voltage left for the 3-in-1 (11) to function correctly, but when the colorful LED (72) turns green and blue, there is not enough voltage left for the 3-in-1 (11) to function.

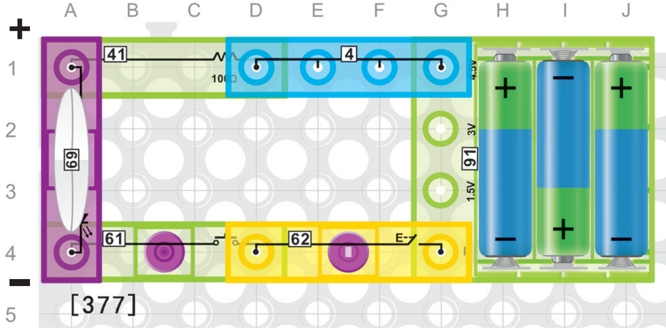
373. Changing Voltage

Connect points C and D with the 100Ω resistor (41) in project #372. Turn on the switch (62) and you will hear low volume gun shots and machine gun sounds with the heart LED (69) and colorful LED (72) flashing. Listen as the colors change on the colorful LED (72). Turn off the switch (62) and the sounds will go off. If you had a voltmeter and measured across the points D3 and D6 in this circuit, you would see that there is about 2.7V powering the 3-in-1 (11) when the colorful LED (72) is red, but only about 2.3V powering the 3-in-1 (11) when the colorful LED (72) is green or blue. As discussed in the previous project, 2.7V is enough to enable the 3-in-1 (11) to function properly, but 2.3V is not enough.

374. Changing Current

Connect points A and B with the 4-wire (4) in project #372. Turn on the switch (62) and you will hear a low volume fire siren with the heart LED (69) and colorful LED (72) flashing. Listen as the colors change on the colorful LED (72). Turn off the switch (62) and the fire siren will go off. If you had an Ammeter and measured the current coming out of node D6 towards the battery module (91) you would see that there is about 60mA of current flowing through the 3-in-1 (11) when the colorful LED (72) is red but only about 10mA when the colorful LED (72) is green or blue. As discussed in the previous project, 60mA is enough to enable the 3-in-1 (11) to function properly, but 10mA is not enough.





375. Battery Power When Red

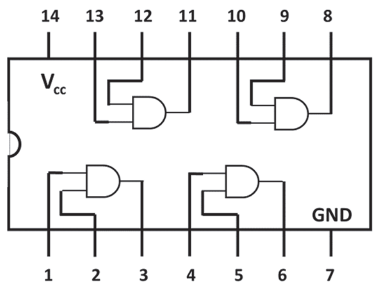
Connect points E and F with a 4-wire (4) in project #372. Turn on the switch (62) and you will hear low volume space battle sounds with the heart LED (69) and colorful LED (72) flashing. Turn off the switch (62) and the sounds will go off. Project #38 discussed that Power is calculated as V*I. In this circuit, when the colorful LED (72) is red the power drawn from the battery module (91) is 4.5V*60mA = 0.27 Watt.

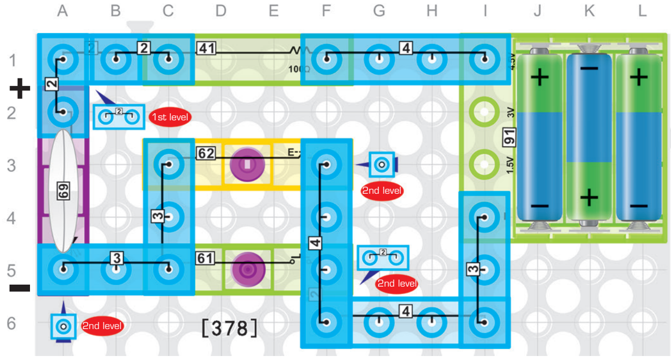
376. Battery Power when Green & Blue

Connect points G and H with a 4-wire (4) in project #372. Turn on the switch (62) and you will hear low volume music with the heart LED (69) and colorful LED (72) flashing. Turn off the switch (62) and the music will go off. When the colorful LED (72) is green or blue, the power drawn from the battery module (91) is 4.5V*10mA = 0.045 Watt. Interesting to note that the batteries drain more quickly with red light than with blue or green light.

377. AND Gate Revisited

Build the circuit shown on the left. Note that the heart LED (69) only turns on when both the switch (62) and press switch (61) are on. This was discussed as an AND Gate logic in project #64. 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.

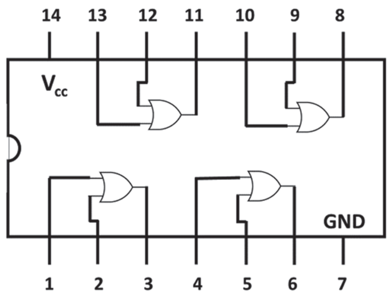


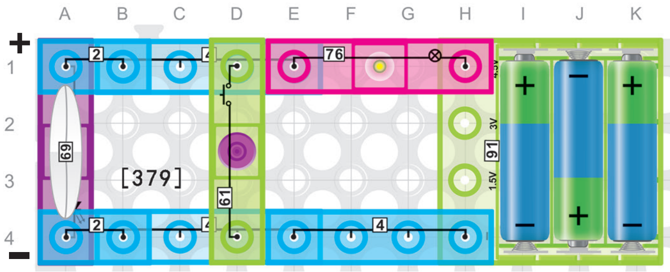


378. OR Gate Revisited

Build the circuit shown on the left. Note that the heart LED (69) turns on when either the switch (62) or the press switch (61) are on.

This was discussed as an OR Gate logic in Project #66. OR gates can also be purchased in ICs. Below is a picture of the pinout for one example IC that provides four OR gates.





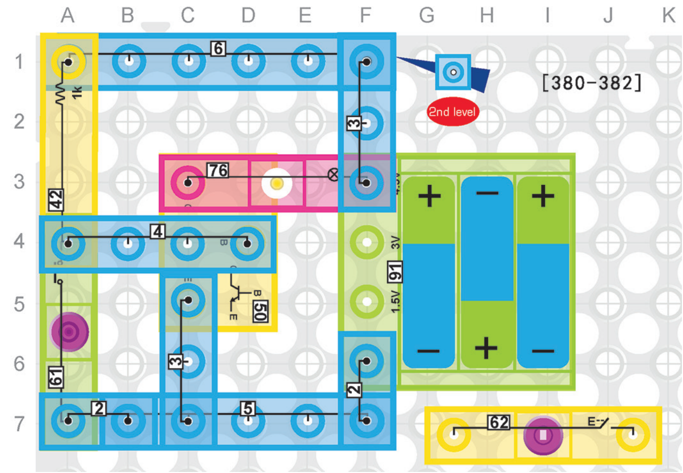
379. NOT Gate

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) turns off when the press switch (61) is on.

This was discussed as a NOT Gate in project #93, and this circuit now demonstrates how NOT Gate logic works.

380. NOT Gate Applications

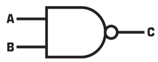
Build the circuit shown on the left. Note that the lamp (76) is on when the press switch (61) is off and the lamp (76) is off when the press switch (61) is on. You might have a circuit like this in your car, where the light in your car stays on while the door is open, but when you close the door, it's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



381. NAND Gate

Build the circuit from project #380 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

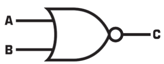


Inputs		Output
A	B	C
OFF	OFF	ON
OFF	ON	ON
ON	OFF	ON
ON	ON	OFF

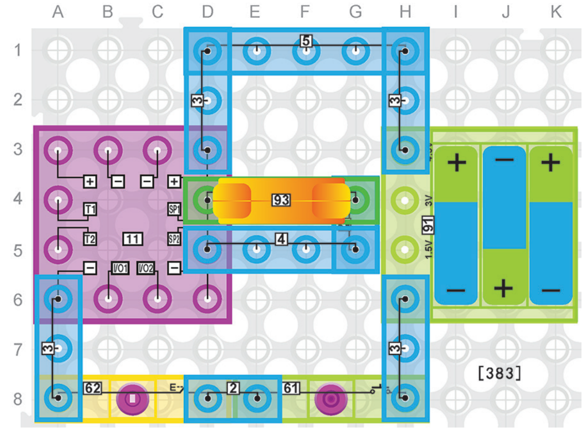
382. NOR Gate

Build the circuit from project #380 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

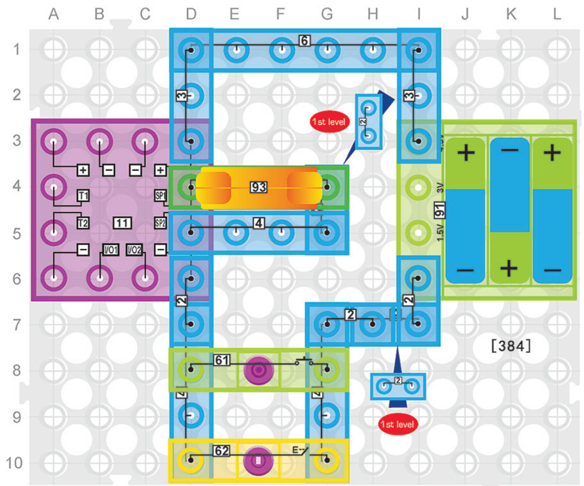


Inputs		Output
A	B	C
OFF	OFF	ON
OFF	ON	OFF
ON	OFF	OFF
ON	ON	OFF



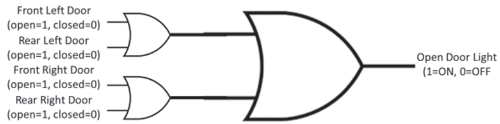
383. AND Gate Applications

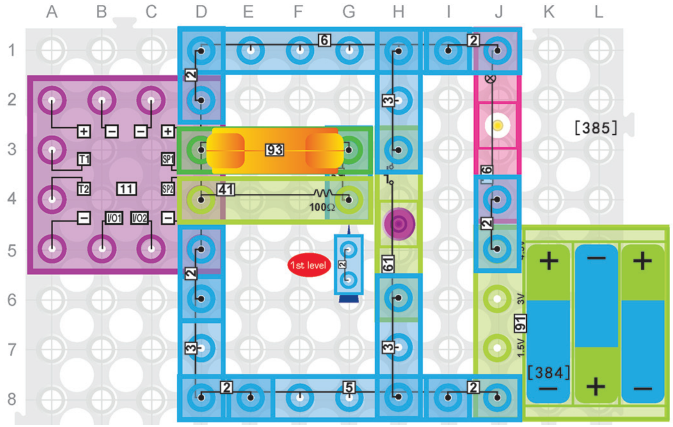
Build the circuit shown. Note that the siren sounds only when both the switch (62) and the press switch (61) are on. One of the most common applications of AND gates are as enabling circuits like this. So for instance, the press switch (61) in the circuit could represent a stream of digital date going 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.



384. OR Gate Applications

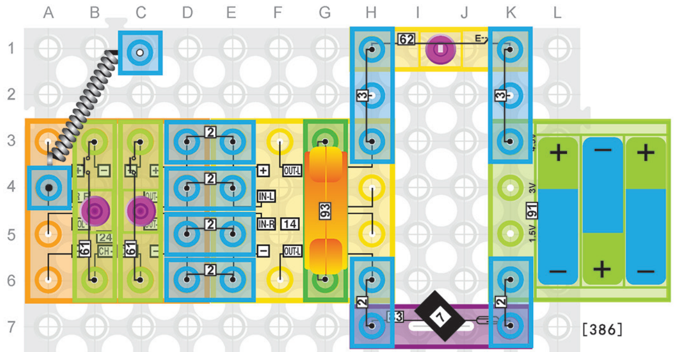
Build the circuit shown on the left. Note that the siren sounds when either the switch (62) or the press switch (61) are on. One application for OR gates would be the door open light in your car. Using a circuit like the one shown below, you can see that if any door is open (represented by a 1), then the output of the circuit produces a 1 (the door open light in dash comes on).





385. More NOT Gate Applications

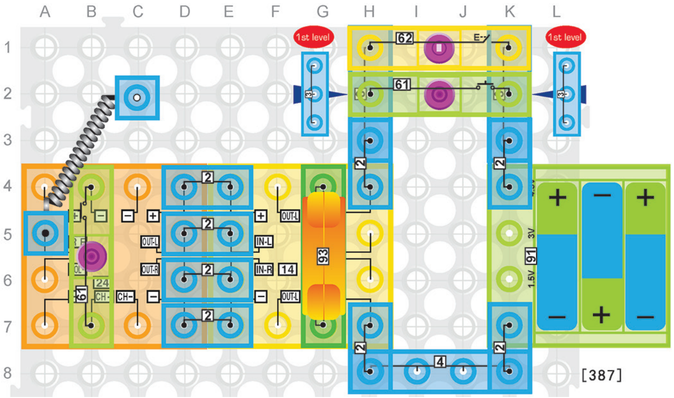
Build the circuit to the left. The lamp (76) lights and you will hear the sound of a siren. Note that the siren sounds while the press switch (61) is off, but when you press the press switch (61) the siren goes off. This type of circuit could act like a mute button for the sound on your TV.



386. FM Radio

Build the circuit to the left, turn on the switch (62), and move the magnet (7) near the reed switch (83) and you will hear some FM radio stations from the speaker (93). You may have to press one of the press switches (61) to get the FM receiver to scan for a channel. When you press one of the press switches (61), the FM receiver will scan for either a higher radio frequency (CH+) or a lower radio frequency (CH–).

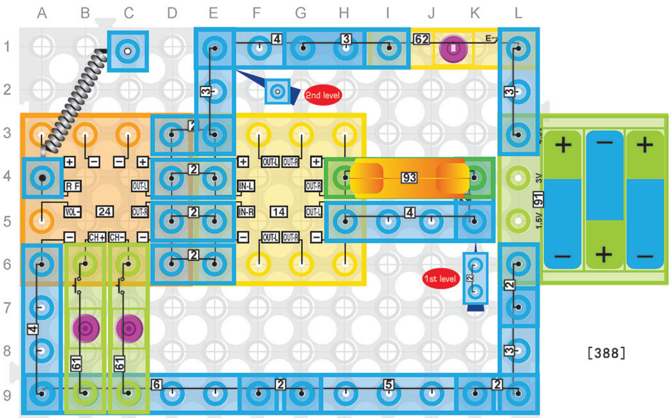
For best FM reception, hold the open end of the spring wire (9) in the air. The spring wire (9) is acting like an antenna in this circuit to receive FM radio signals that are typically sent from high power antennas on tall buildings in cities near you. You may find that by putting your finger on the pin on the loose end of the spring wire (9), you get even better reception. This is because your body also acts as an antenna.



387. FM Technology

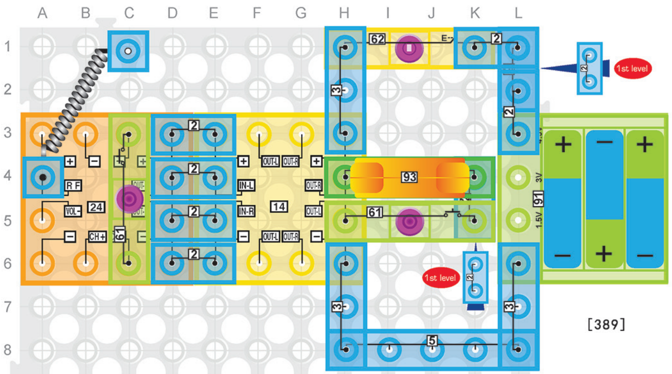
Build the circuit to the left, turn on the switch (62) or press the press switch (61) and you will hear some FM radio stations from the speaker (93). You may have to press the press switch (61) connected to CH+ to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air.

FM stands for Frequency Modulation, which means that the instantaneous frequency deviation (defined as the difference between the instantaneous frequency and carrier frequency of the radio signal) is proportional to the voltage level of the audio signal. The FM receiver collects the radio signal over the air through the spring wire (9), demodulates it (eliminates the carrier frequency to provide a baseband signal) and then uses a frequency detector to recover the audio signal.



388. FM Frequency Band

Build the circuit to the left, turn on the switch (62) and you will hear some FM radio stations from the speaker (93). You may have to press one of the press switches (61) to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air. When you press one of the press switches (61), the FM receiver scans for a radio station. In the FM band in the Americas, radio stations range from 88 MHz to 108 MHz.

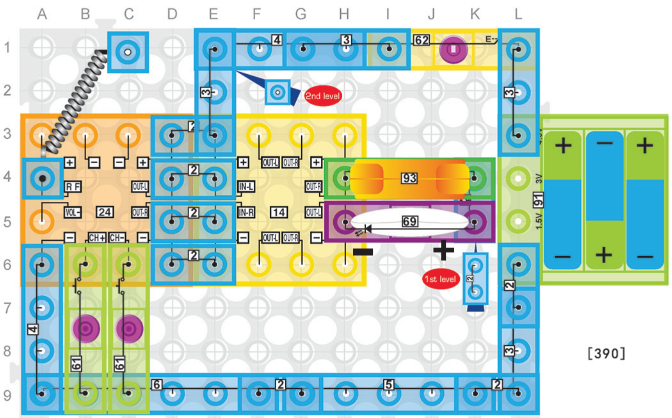


[389]

389. FM Radio Channels

Build the circuit to the left, turn on the switch (62) and press the press switch (61), and you will hear some FM radio stations from the speaker (93). You may have to press the press switch (61) connected to CH– to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air.

FM radio channels are spaced 200 kHz apart. This means that theoretically there could be about 100 FM channels in a given city/ area. The FM channels are actually numbered from channel 200 to channel 300 starting with channel 200 centered at 87.9 MHz, channel 201 at 88.1 MHz,...,up to channel 300 at 107.9 MHz. Have you ever noticed that all the FM radio channels you listen to ended in an odd number? Now you know why!

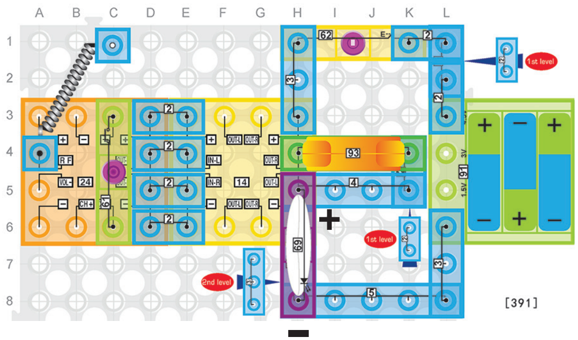


[390]

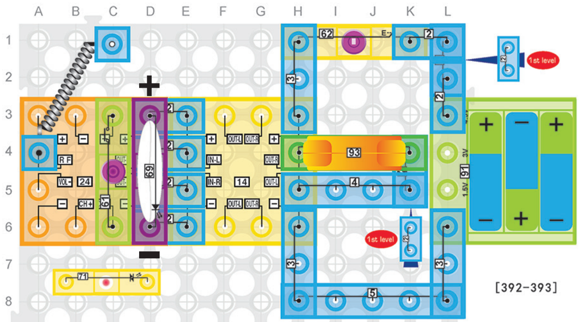
390. FM Radio in Lower Volume

Build the circuit to the left, turn on the switch (62), and you will hear some FM radio stations from the speaker (93) and see the heart LED (69) flash. You may have to press one of the press switches (61) to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air.

The volume from the speaker (93) is lower than in the previous project because the heart LED (69) introduces resistance which reduces the voltage levels seen across the Speaker[93].



[391]



[392-393]

391. FM Radio Audio Range

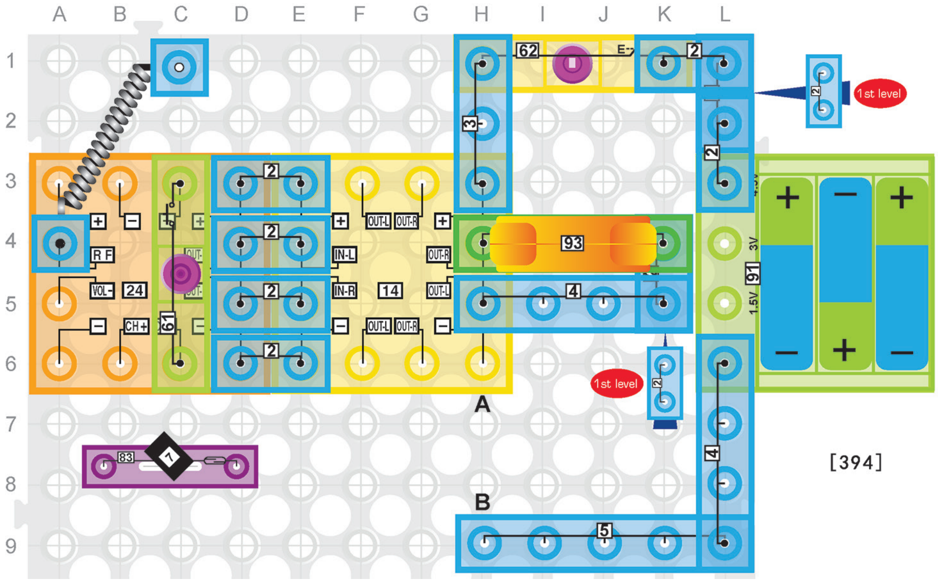
Build the circuit to the left, turn on the switch (62) and you will hear some FM radio stations from the speaker (93) and the heart LED (69) will flash with the sounds. You may have to press the press switch (61) connected to CH– to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air. Have you ever wondered why there are more music channels on FM radio stations than in AM radio stations? Because of the wide 200kHz channel bandwidth, FM radio channels are able to support audio frequencies up to around 15 kHz. AM radio has much narrower channels (10kHz) and thus can only support audio frequencies up to around 4.5 kHz. Since music typically has a lot of high frequency components, it will sound better on an FM radio station than on an AM radio station.

392. FM Channel Numbering

Build the circuit to the left, turn on the switch (62) and you will hear some FM radio stations from the speaker (93) and you will see the heart LED (69) light. You may have to press the press switch (61) connected to CH- to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air. The heart LED (69) acts like an ON-OFF indicator for the circuit. Project #389 discussed the channel numbering for FM radio. Are you curious why they started the numbering with channel 200 instead of channel 1? This was to avoid confusion with TV radio stations which use channel numbering up to 158.

393. FM Radio Wave Propagation

Replace the heart LED (69) with the bi-directional LED (71) in project #392, turn on the switch (62) and you will hear some FM radio stations from the speaker (93) and you will see the bi-directional LED (71) light. You may have to press the press switch (61) connected to CH- to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air. The bi-directional LED (71) acts like an ON-OFF indicator for the circuit. One of the reasons why FM radio uses the frequency bands 88-108MHz is because of the good radio wave propagation characteristics in this band. Even ignoring the effects of foliage like trees and buildings, radio waves propagate further at lower frequencies than at higher frequencies. In free space (no foliage) it has been shown through the Friis Transmission Formula that the pathloss (reciprocal of path gain) is given by $(4*\pi*d*f/c)^2$, where d is the distance between transmitting and receiving antennas, c is the speed of light and f is the carrier frequency of the signal. This formula clearly shows that in free space there is much larger pathlosses at higher frequencies.

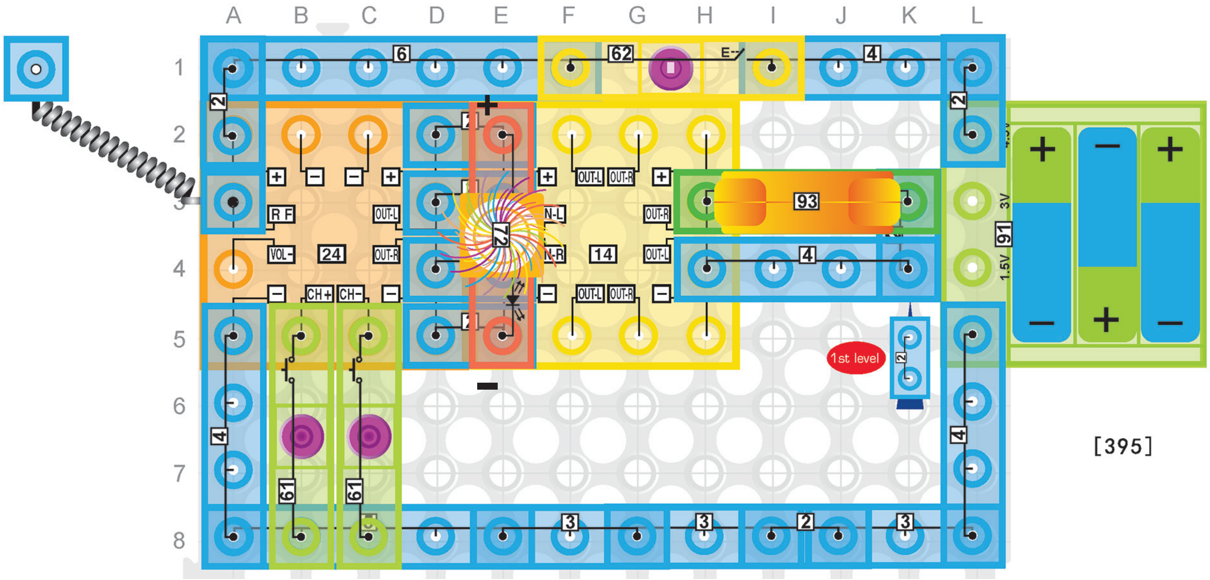


[394]

394. Pathloss Calculation

Build the circuit above, put the reed switch (83) across points A and B and turn on the switch (62). You won't hear any radio stations from the speaker (93) until you place the magnet (7) near the reed switch (83). You may have to press the press switch (61) connected to CH– to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air.

The previous projects discussed the propagation characteristics of radio waves and provided a formula for pathloss. To give you an idea of just how much pathloss is typical, consider trying to receive an FM radio station with your car antenna 1 mile (~1609 meters) away from the FM transmission antenna. Assuming you had line-of-site transmission (no trees or buildings between the antennas) and were using FM channel 200 at 87.9 MHz, the free space pathloss formula says there will be a pathloss of approximately $(4*3.1416*1609*87.9x10^6/3x10^8)^2$ = 35,096,763 or about 75 dB. That's a huge pathloss!



[395]

395. FM Transmission Power

Build the circuit above, turn on the switch (62) and you will hear some FM radio stations from the speaker (93) and the colorful LED (72) will light. You may have to press one of the press switches (61) to get the FM receiver to scan for a channel. For best FM reception, hold the open end of the spring wire (9) in the air.

As discussed in the previous project, over-the-air propagation losses are huge even at relatively low frequencies like 88-108MHz. In order to overcome this, radio stations transmit with very high power. Some radio stations may transmit up to 50kW (this is radiated power from the FM tower antenna). Based on the calculation in the last project, this means that the signal strength when it arrives at the car antenna would be 50,000/35,096,763 = 0.0014 or 1.4mW. Fortunately, FM receivers can use filtering and amplification to recover, demodulate and play out the FM signal even at these low powers.

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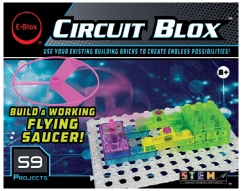
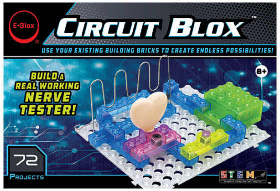
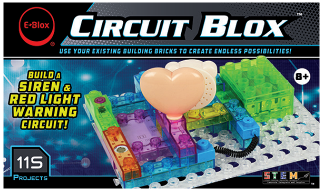


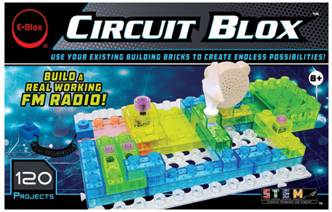
59 Projects
25 pieces, including a motor, fan, fiber optic tree, LEDs, buzzer, switches, and more!



72 Projects
35 pieces, including a maze, hand crank generator, LEDs, buzzer, switches, and more!



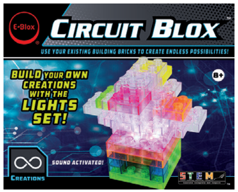
115 Projects
40 pieces, including a motor, fans, LEDs, speaker, sound module, switches, and more!



120 Projects
49 pieces, including a sound module, FM radio module, LEDs, speaker, motor, fans, and more!

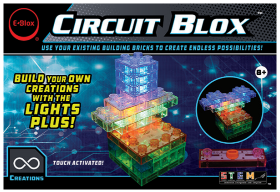
800 Projects
78 pieces, including an inductor coil, magnet spinner, resistors, capacitors, transistors, and more!

Sound activated!



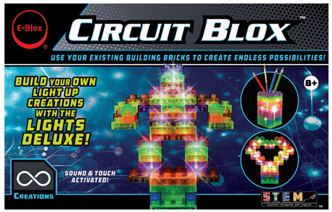
Lights
32 pieces, including 25 transparent spacer blox.

Touch activated!



Lights Plus
19 pieces, including 12 LED blox and USB port.

Sound and Touch activated!



Lights Deluxe
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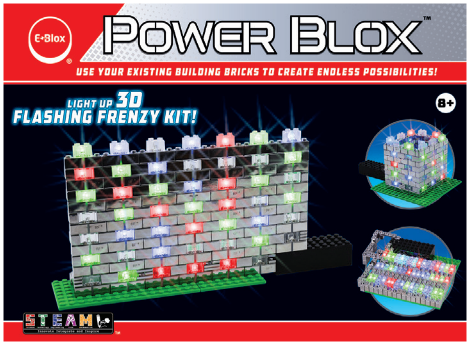
Flashing Frenzy



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Online instructions available for three models.

Compatible with other toy brick sets.

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Ride along with Seymour E. Blox as he travels in an organic submarine named Mimi that travels faster than the speed of sound under water. Help Seymour repair a very famous bridge that is being destroyed by industrial pollution in a large and ancient city.

An exciting adventure story where Seymour E. Blox climbs a mountain on faith alone and discovers a secret cave that holds the answers to many mysteries about the Earth's history, extinct animals, old memories, a new home, and much more.

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