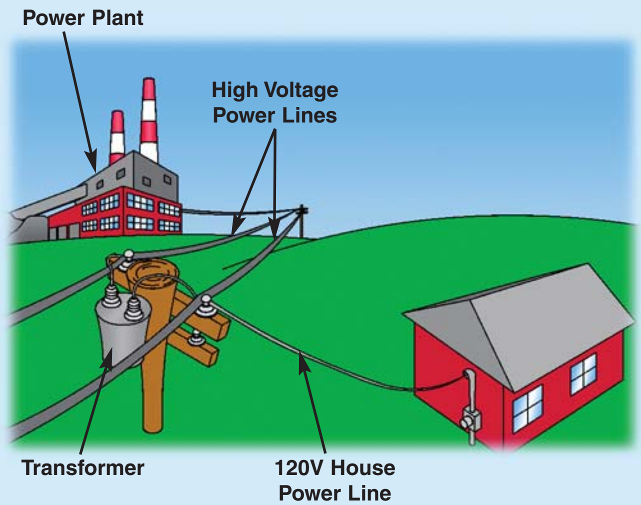
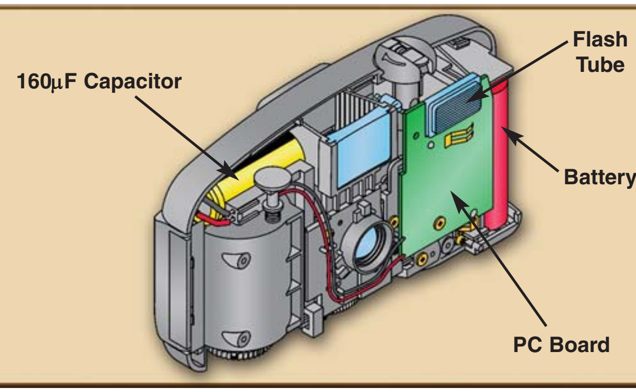
If the second coil in the transformer had twice as many loops of wire as the first, it would have twice the voltage but half the current as the first. The reason is that power is not lost across a transformer, and Power = Voltage x Current. A transformer can use a small voltage to create a very large voltage by using a many-loop coil with a few-loop coil.

Transformers are very important in electronics for two reasons. First, they allow circuits to be isolated from each other, since the connection between them is magnetic and not electrical. Second, they can change the voltage without wasting power (by using coils with more or less loops of wire).

When electric power companies transport electricity across great distances (like between power generating plants and cities), they use very high voltages and low currents since this reduces power loss in the wires. Large transformers convert this to 120V, which is supplied to homes and offices. Many products (like computers) then use small transformers to convert this to smaller or larger voltages as needed. For example, most circuits in computers use 5V.



Flash camera: A flash camera needs to make a very bright flash, but its small battery cannot supply this much power at once. So the camera lets the battery charge up a large capacitor (typically 160μF) to a high voltage using a transformer. It takes a few seconds to charge the capacitor (to about 300V); the flash tube will discharge this in an instant.



8-3 INDUCTANCE & ANTENNAS

Inductance is a measure of one coil's ability to create a current in another. It is expressed in **henrys** (H, named after Joseph Henry who developed electromagnetic induction) or microhenrys (μH, millionths of a henry). The more loops in a coil of wire, the more inductance it has. Placing an iron bar inside a coil of wire magnifies that coil's inductance.

Transformers use electromagnetic fields through iron bars to "bridge" a gap between circuits. If the iron bars through the two coils were close but not connected to each other, their electromagnetic fields would be reduced but would still affect each other.

Coils can be designed with shapes and other characteristics that will maximize their electromagnetic fields for specific frequencies. If the original ("**transmitter**") coil and current through it were large, then the electromagnetic field from it could still be picked up by another ("**receiver**") coil and produce a small current even if the distance was many miles.

This is the concept of **radio**, which uses electromagnetic waves to send information through the air. The coils used for transmitting and receiving these signals are called **antennas**.

Introducing New Parts

Snap Circuits® includes an antenna:

Antenna Coil (A1)


Antenna Coil Symbol

The antenna you will use is a 25μH coil wrapped around an iron bar, which increases the inductance to 300μH. Although it has magnetic effects similar to those in the motor, those effects are tiny and may be ignored except at high frequencies (like in AM radio). At low frequencies the antenna acts like an ordinary wire.

Coils like the antenna are also called inductors. Their magnetic properties enable them to oppose changes in electrical current, and to store electrical energy as magnetism. This allows inductors to be made to **block high frequency signals while passing low frequency signals**. This is **opposite to how capacitors act** on high and low frequency signals, so inductors and capacitors are used together to make complex frequency filters.

An inductor has lower resistance at lower frequencies, but higher resistance at higher frequencies. The resistance of an inductor may be calculated from the frequency and inductor value:

$R_{inductor} = 6.28 \times Frequency \times Inductance$

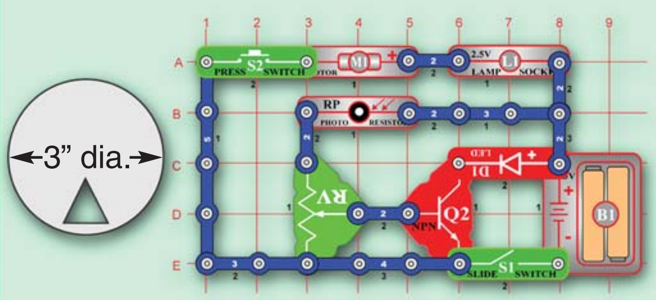
For example, your 300μH antenna will have a resistance of only 1.884Ω at 1000Hz, but a resistance of 1,884Ω at 1000,000Hz (1MHz).

8-4 RADIO

A wide range of schemes are used for encoding the radio signals with the information being sent. These are called modulation. Modulation uses one signal to modify another. You've probably heard of AM and FM radios. These stand for Amplitude Modulation and Frequency Modulation.

Experiments

For a simple demonstration using Snap Circuits®, consider this circuit (which is project 258):



Using the fan outline as a guide cut a 3” circle out of a piece of paper. Then, cut a small triangle in it as shown. Tape the circle onto the fan and then place it onto the motor. Set the adjustable resistor to the center position and turn on the switches. The fan spins and the lamp lights. As the triangle opening moves over the photoresistor, more light strikes it. The brightness of the LED changes, or is modulated.

In AM radio transmitters, one signal (the “message”) is used to modulate the amplitude of another (the “carrier”). In FM radio transmitters, one signal (the “message”) is used to modulate the frequency of another (the “carrier”). The “message” will be talking or music, while the “carrier” will be an oscillator circuit tuned to the desired transmit frequency. Here is an example:


Audio


RF Carrier


Frequency Modulation


Amplitude Modulation

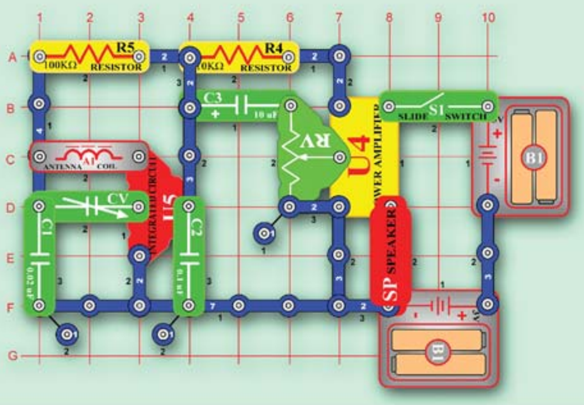
AM radio was developed before FM radio, because the transmitter and receiver circuits are not as complex. FM's greater complexity means it is better protected from interference (such as storms). FM also has wider channel bands (25kHz vs. 7kHz for AM), which gives it better music quality. AM radio uses a carrier frequency range of 500 to 1600kHz while FM radio uses 88 to 108MHz.

There are many different radio signals floating around, but we only want to listen to one. Think of this as being in a large, crowded room and trying to talk to someone on the other side. Connecting the antenna to a capacitor in sort of an antenna-capacitor oscillator solves this. Together, these two components "filter" out a small range of frequency that you listen to.

8-5 Radio Circuits

Experiments

Consider this AM radio receiver circuit (which is project 242 and is pictured on the front cover of your "Experiments 102-305" manual):



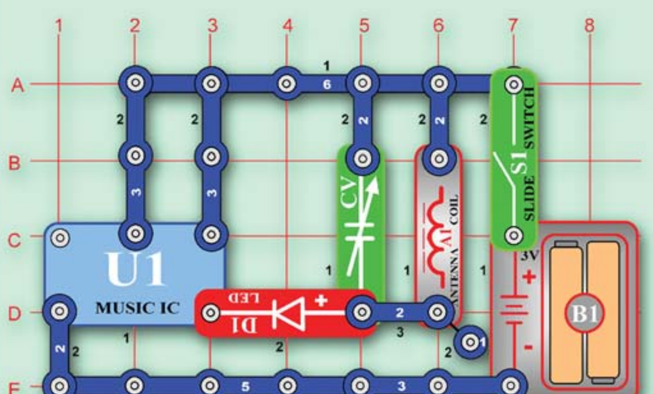
Adjusting the variable capacitor changes the range of frequency that you are listening to. The high frequency IC amplifies and decodes the modulation into the original signal (voice or music). This is amplified by the power amplifier IC. Varying the adjustable resistor makes the sound louder or softer.

This simple radio has the same types of circuits as AM radios sold in stores, but does not have as much filtering and amplification circuitry. Take a look inside an old AM radio in your house; you'll see a lot more components. The tuning dial on all AM and FM radios is a variable capacitor just like yours.

Snap Circuits® project 288 shows another AM receiver circuit, but using a 2-transistor amplifier instead of the power amplifier IC. This circuit has similar performance and appears to be more complex than the circuit with the IC, but there is actually a lot more circuitry hidden in the IC. Snap Circuits® project 289 is similar to project 242 but without loudness control.

Experiments

Consider this AM radio transmitter circuit (which is project 213):



Place the circuit next to an AM radio in your home. Tune the radio so no stations are heard. Turn on the switch. You should hear the song on your radio. Adjust the variable capacitor for the loudest signal.

This circuit uses the antenna to transmit electromagnetic energy to your AM radio. The antenna-capacitor combination tunes the transmit frequency. The music IC provides the amplitude modulation.

Notice that this circuit transmits across a wide part of the AM radio band, not just one station. This circuit has just two components tuning the transmit frequency; a commercial AM radio station will have a complex filtering circuit doing this.

Snap Circuits® projects 122, 145-150, 214, and 255 are variations of this basic AM transmitter circuit, using the alarm IC, space war IC, or the photoresistor. These circuits also show how to use this circuit as an alarm.

Snap Circuits® project 198 (in most manuals) is similar but transmits your voice to a radio. It also shows how variations in air pressure (caused by your talking) can make an electrical signal in a speaker – like a microphone, and opposite to how a speaker is normally used. Replace the speaker with the microphone in this circuit (+ side to Q2) and compare the performance.

Quick Quiz

1. List all the products in your home that use some form of radio or remote control.

Summary

Summary of Chapter 8:

1. An electrical current that is changing is called an alternating current (AC). An electrical signal that is constant and unchanging is called a direct current (DC).
2. The electricity in homes is AC power, with a voltage of 120V and a frequency of 60Hz.
3. Transformers allow one circuit to create a current in another using magnetic fields. This can change the voltage without wasting power.
4. Inductance is a measure of one coil of wire's ability to create a current in another, and is expressed in Henrys. Inductance can be increased by adding more loops of wire or by placing an iron bar inside the coil.
5. Radio uses electromagnetic waves to send information through the air. The coils used for transmitting and receiving these signals are called antennas.
6. Coils are inductors, which have lower resistance at lower frequencies but higher resistance at higher frequencies. Inductors and capacitors are often combined in radios to filter out a range of frequencies.
7. Modulation uses one signal to modify another.
8. In AM radio, a music/voice signal amplitude-modulates the transmit carrier frequency. In FM radio, frequency modulation is used instead.

Quiz

Chapter 8 Practice Problems

1. Why can't DC currents transfer energy across transformers?
   A. DC currents have no magnetic properties.
   B. DC currents don't have enough power to overcome the resistance of transformers.
   C. Transformers block the transfer of energy from both AC and DC currents.
   D. They are not digital circuits.

2. The following are true about transformers except:
   A. They allow circuits to be isolated from each other.
   B. They allow electricity to be efficiently transported over great distances.
   C. They allow a small voltage to create a large voltage.
   D. The coils used can never have the same number of loops.

3. The following are true about radio except:
   A. Frequency modulation circuits are simpler than amplitude modulation circuits.
   B. The FCC regulates radio transmission frequencies.
   C. FM has better music quality than AM.
   D. For DC currents, antennas act like ordinary wires.

4. At low frequencies, the Snap Circuits® antenna acts like a ______________.
   A. 10KΩ resistor
   B. 0.1μF capacitor
   C. 3-snap wire
   D. whistle chip

Answers: 1. A, 2. D, 3. A, 4. C

PART II (Models SC-500R & SC-750R only)

- If you have the **SC-300R** version, you may wish to purchase the **UC-50 Upgrade Kit** to continue to Part II of this manual. The **UC-70 Upgrade Kit** will allow you to continue to Parts II & III of this manual.
- If you have the **SC-500R** version, you may wish to purchase the **UC-80 Upgrade Kit** to continue to Part III of this manual. Upgrade kits can be purchased online: ***www.snapcircuits.net***

CHAPTER 9: METERS, TRANSFORMERS, & FM RADIO

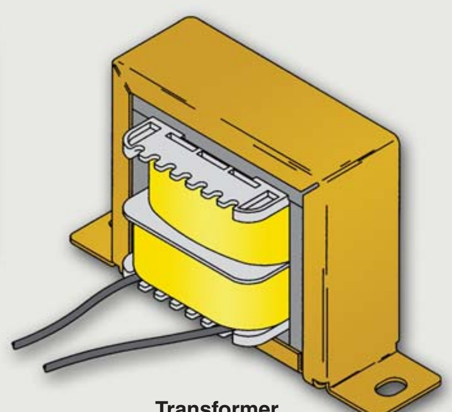
Learn By Doing®

This chapter introduces components that expand on some of the topics in PART I. Meters are used to measure the current and voltage in a circuit, instead of a lamp or LED. Snap Circuits® is used to show how a basic meter can be used. Meters are used in many places in our homes and cars; can you name some of them?

Transformers are studied here, with many Snap Circuits® that will demonstrate their magnetic properties. Transformers can be used to make oscillator circuits that are much more efficient. By building Snap Circuits®, transformers will be easy to understand.

You will also learn more about FM radio, and how the properties of electronic components change at high frequencies.

Meter


Transformer

FM Radio

9-1 Meters

So far you have been using LEDs and lamps to indicate how much current is flowing in a circuit. Although useful, these indicators are not very accurate since the brightness is difficult to quantify. Electronics engineers use meters to accurately measure the current in a circuit.

Introducing New Parts

Snap Circuits® includes a meter:

Meter (M2)

Meter Symbol

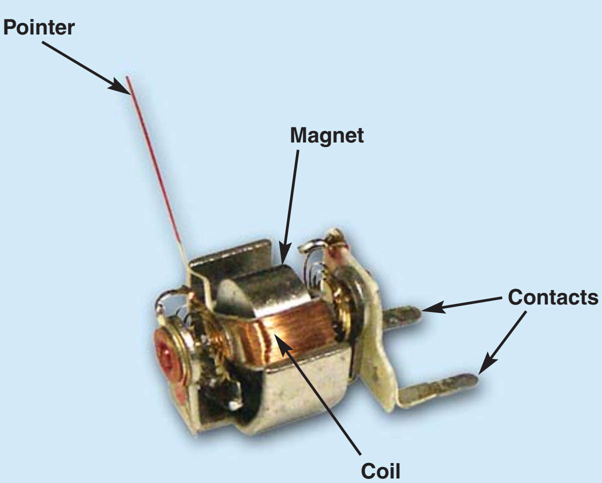
The meter has + and – polarity marking to indicate which direction the current will move the pointer. On most models, it also has a switch to change between low and high current scales (marked as LOW-HIGH or 10mA-1A. **Always use the LOW (or 10mA) setting unless told to use the HIGH (or 1A) setting.**

The meter will measure the current when connected in series in a circuit. By itself, it can measure currents up to 300μA in the LOW setting and up to 1A in the HIGH setting, but higher currents may be measured by connecting a low value resistor in parallel.

The meter will measure voltage when connected in parallel with a circuit. By itself, it can measure voltages up to 0.3V in either switch setting, but higher voltages may be measured by connecting a high value resistor in series with it.

Inside the meter there is a fixed magnet and a moveable coil around it. As current flows through the coil, it creates a magnetic field. The interaction of the two magnetic fields causes the coil (connected to the pointer) to move (deflect).

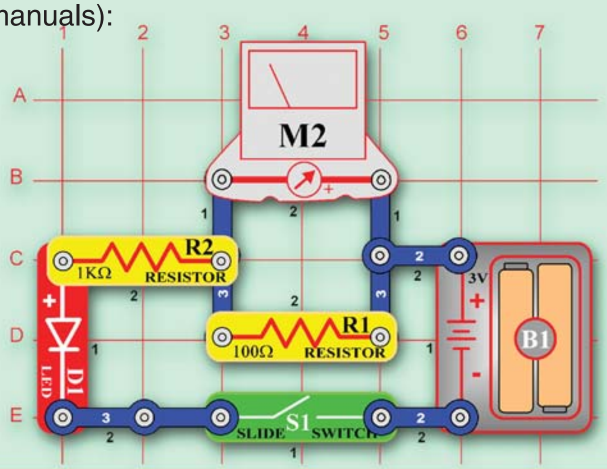
Engineers use multi-purpose meters to measure current, voltage, resistance, and other parameters of a circuit. Although they have complex controlling circuitry, most still need to have the measurement range selected by the user with a dial.



9-2 Meter Circuits

Experiments

Consider this circuit (which is project 323 in most manuals):



If your meter has a switch, then use the LOW (or 10mA) setting for all circuits in this booklet.

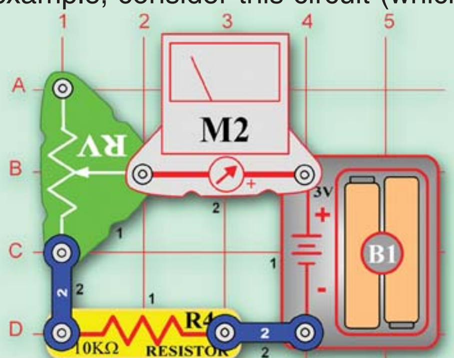
The meter reading should be around 5 for this circuit. If you replace the 100Ω resistor with a 3-snap wire then no current will flow through the meter and it will point at zero; if you replace it with the 5.1KΩ resistor then more current will flow through the meter and it will point past 10.

Quick Quiz

What do you think will happen to the meter reading if you replace the 1KΩ resistor with a lower value? How about a higher value? Try it and find out.

Experiments

As another example, consider this circuit (which is project 325):

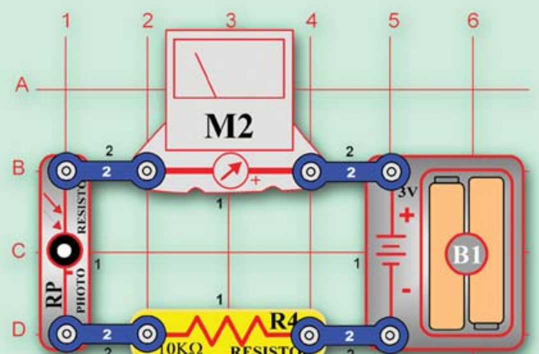


The adjustable resistor value may be adjusted to give meter readings typically between 2 and 10 (actual results may vary). This represents actual currents of 50-300μA.

This range may be changed by replacing the 10KΩ resistor with a higher or lower value part.

Experiments

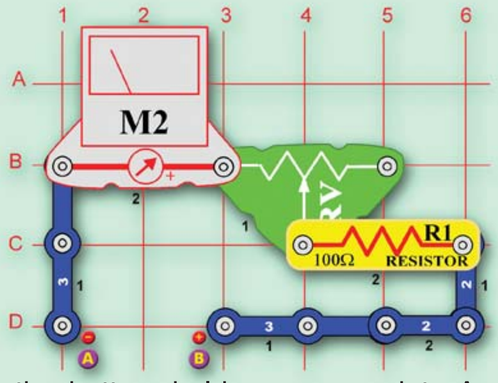
The meter may also be used as a light meter, by using it with the photoresistor in a circuit like this (which is project 326):



As more light shines on the photoresistor, more current flows and the meter gives a higher reading.

Experiments

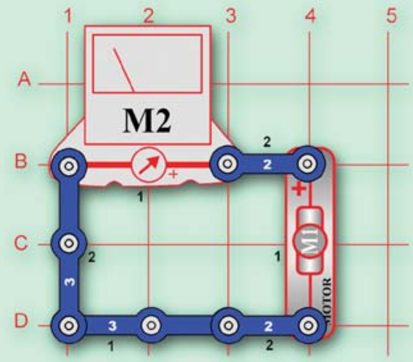
Many meters must be adjusted to a reference before they can make accurate measurements. As an example, consider this simple voltmeter circuit (which is project 324):



Place the battery holder across points A and B and install new batteries, then set the adjustable resistor so that the meter reads 10. The new batteries are used as a reference to set the meter scale. Then other batteries can be measured accurately.

Experiments

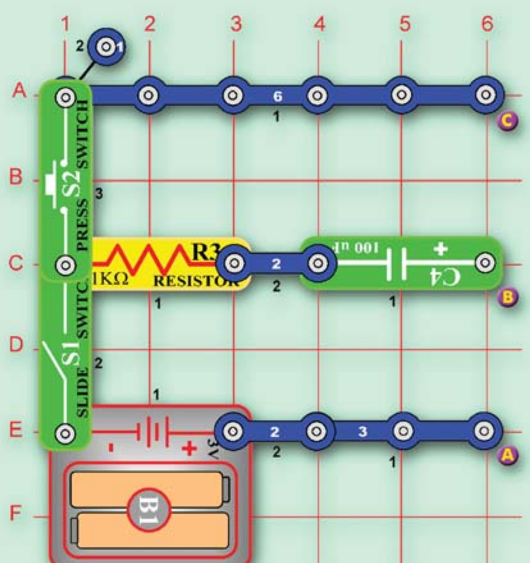
In the preceding examples, if the orientation of the meter is flipped around then it will always read zero or less. This circuit (which is project 327) will show this better:



If you spin the motor clockwise with your fingers, the meter measures how fast you spin it. What do you think the meter reading will be if you spin the motor counter-clockwise?

Experiments

The meter can show how capacitors charge up and discharge much more clearly than the circuits in chapter 4 that used LEDs. Consider this circuit (which is project 506):

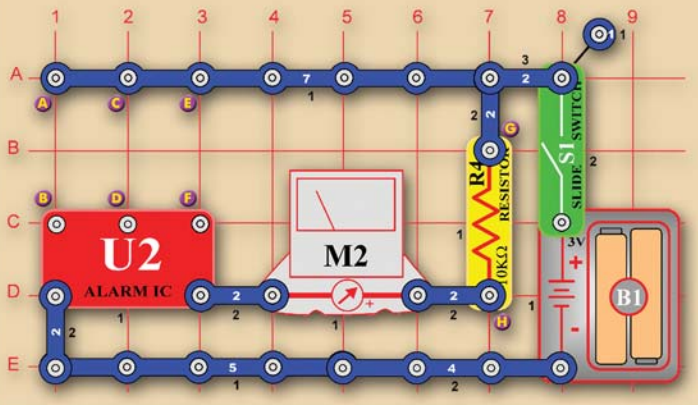


Place the meter across points A and B (+ side to A) and turn on the slide switch (S1); the meter shows a current flowing that slowly drops to zero as the 100μF capacitor charges up.

Then place the meter across points B and C (+ side to B) and press the press switch (S2); the meter shows a current flowing that slowly drops to zero as the 100μF discharges.

Experiments

Now consider this circuit (which is project 508):



Place a 3-snap wire across the points labeled C and D, and another across points E and F. The alarm IC is used to control the meter, and the meter pointer movements represent a machine gun sound. If you place the whistle chip directly on top of the 10KΩ resistor then you will hear the machine gun while the meter pointer moves.

Other Snap Circuits® projects that use the meter: 409, 410, 485, 486, 489, 490, 491, 492, 493, 494, 507, 509, 510, 511

9-3 More About Transformers

In sections 8-2 and 8-3 you learned about transformers and inductance, you may want to review these sections now.

Introducing New Parts

Although the SC-300R did not include a transformer, this SC-500R version does:

Transformer (T1)

Transformer Symbol

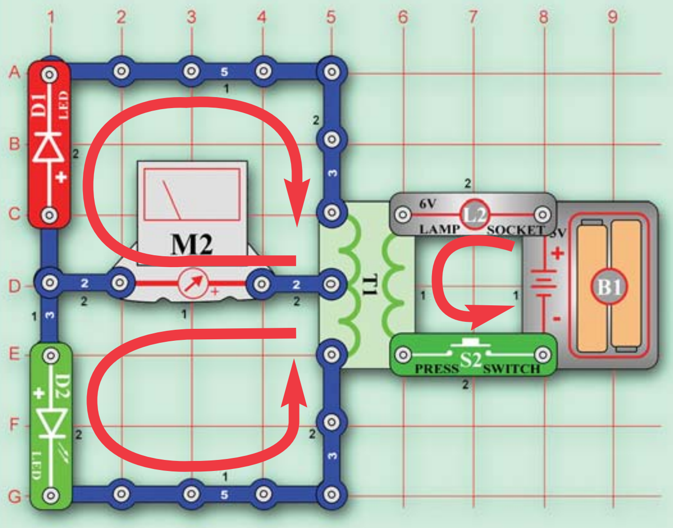
This transformer has a 3.6mH coil and a 750mH coil wrapped around an iron bar. The 750mH coil also has a center tap point, allowing use as two connected smaller coils.

The difference in inductance values between the two coils is that the 750mH coil has many times the loops of wire as the 3.6mH coil. As a result, the 750mH coil will have many times more voltage across it and many times less current through it than the 3.6mH coil. The 750mH coil has a resistance of about 100Ω, and the 3.6mH coil has about 1Ω. In oscillator circuits the transformer will be used with a speaker, which needs a high current at a low voltage.

Transformers can vary in size from less than an inch high (like in Snap Circuits®) to more than 10 feet high (like in electric power plants). The best way to learn about transformer properties is to make circuits that use them.

Experiments

Consider this circuit (which is project 358, or a variation of it):



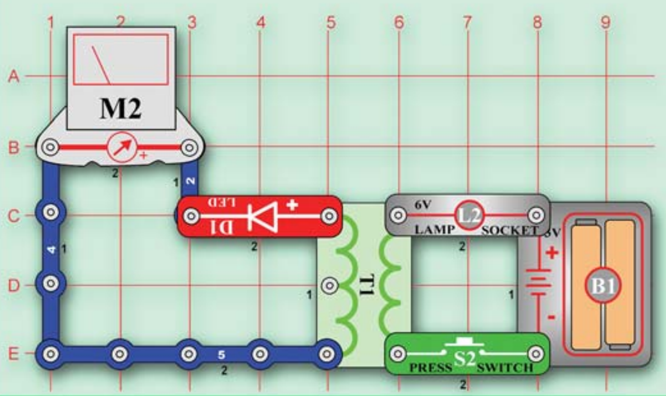
When the switch is pressed, a current flows in the right loop that creates a temporary current in the upper left loop due to magnetic fields in the transformer. When the switch is released, current stops flowing in the right loop and that creates a temporary current in the lower left loop.

Note that no current flows through the left loops while the switch is held down, only when it is pressed or released. This is because **transformers only have magnetic effects for changing (AC) currents; a steady unchanging (DC) current creates no magnetic effects**. For DC, transformers are just two separate unconnected wires with no magnetic properties.

If you press the switch many times quickly you can simulate a constantly changing (AC) signal. This will maintain a current through the meter and make the LEDs blink constantly.

Experiments

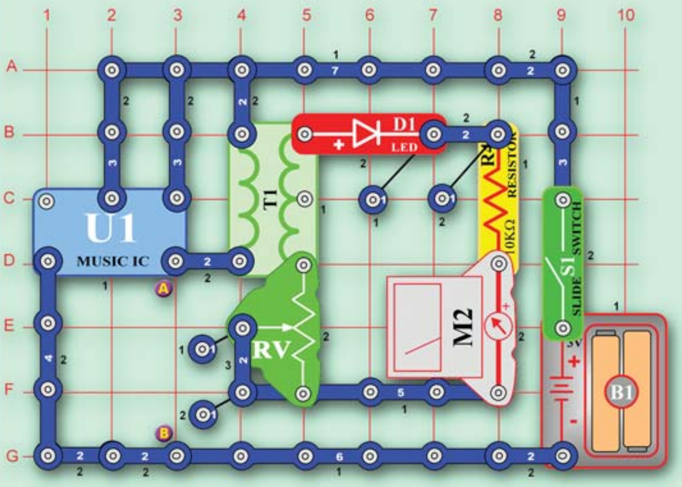
Now consider this circuit (which is project 359, or a variation of it):



A temporary current flows through the LED and meter when you RELEASE the switch. A current would also be created when the switch is pressed, but the LED prevents any current from flowing in that (opposite) direction. If you replace the LED with a 3-snap wire then you will see the meter deflect to the left when the switch is pressed.

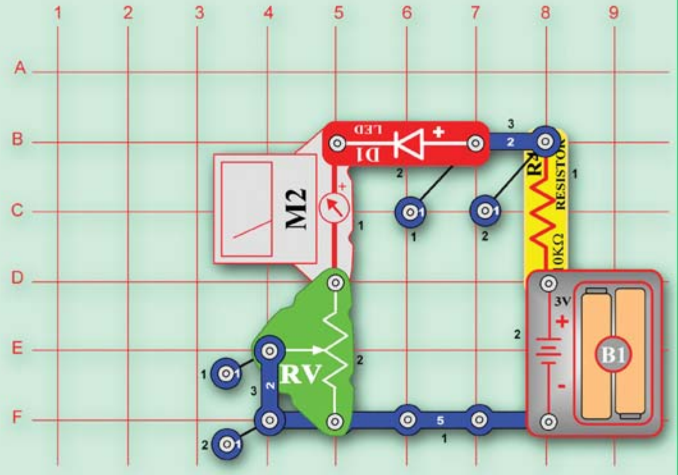
Experiments

Now consider this circuit (which is project 340):



Move the adjustable resistor control lever around, and then set it at mid-range. The music IC makes a high current through the lower inductance of the transformer, which makes enough voltage at the secondary side to make the LED bright despite the high resistance (about 35KΩ) in the circuit.

To demonstrate this, modify the circuit to look like this:



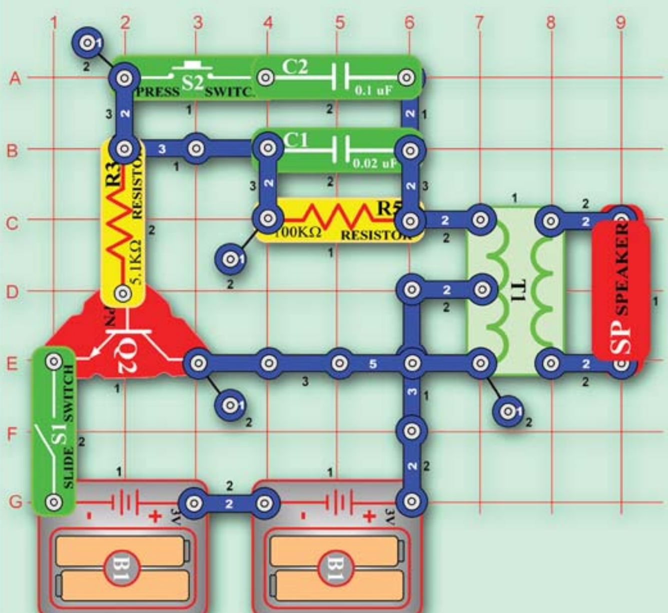
Set the adjustable resistor at mid-range. A small current will flow but the LED will be off, since the voltage is too low to overcome all of the resistance in the circuit.

9-4 Transformers in Oscillators

Transformers can be used in oscillator circuits, and there are many Snap Circuits® that use them this way. You learned about oscillators in section 6-2 and you may want to review that now.

Experiments

Consider this circuit:



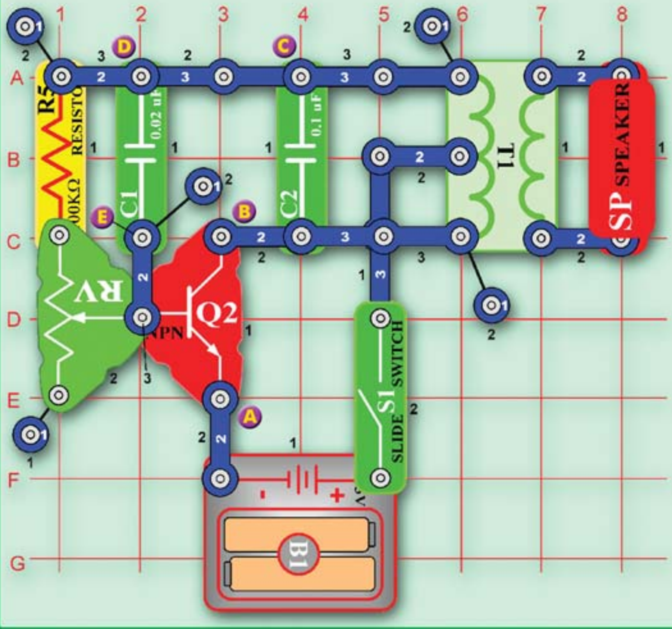
This circuit makes a high-frequency tone. Pressing switch S2 lowers the frequency of the tone by increasing the capacitance in the oscillator. The frequency can also be changed by changing the resistance in the circuit, so what would happen if you replaced the 100KΩ resistor R5 with the 10KΩ resistor R4?

The transformer is used to isolate different parts of the circuit from each other, and to increase the AC current on the lower inductance side. For example, the transformer's 750mH windings (on the left in this circuit) isolate the batteries, the NPN transistor, and the R5/C1/C2 network from each other and from the speaker.

Since the left (750mH) side has more loops of wire than the right (3.6mH) side, there will be a higher current (and lower voltage) to the speaker than on the left side. This makes the sound louder without drawing as much power from the batteries. For example, this circuit draws about 30mW of power from the batteries while the circuit for project 197 (which you studied in section 6-4) draws more than 300mW.

Experiments

Consider this circuit (which is project 477):

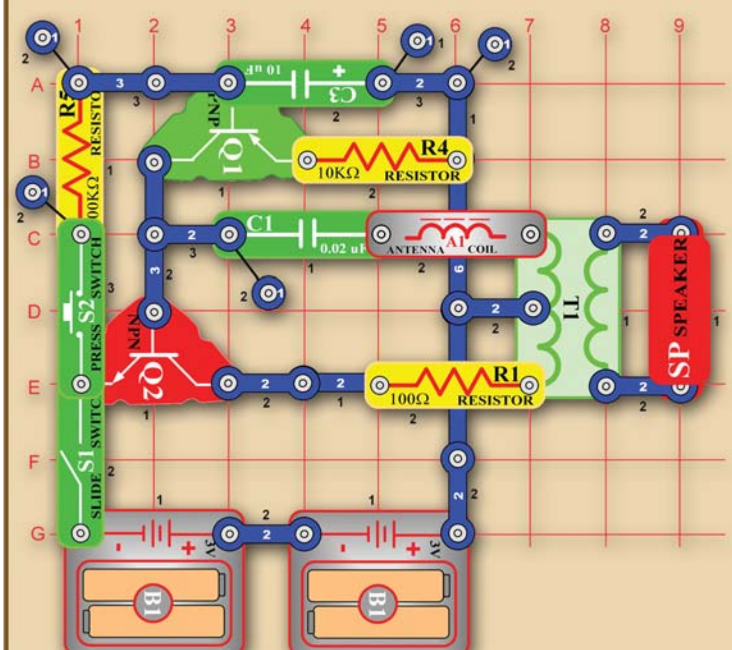


This is another oscillator using the transformer; use the adjustable resistor to change the frequency of the sound.

Many variations of this circuit are possible, as described in projects 478-484. You can place the whistle chip, the 10μF capacitor, or the 100μF capacitor on top of the 0.02μF capacitor. Or replace the 100KΩ resistor with the photoresistor and wave your hand over it. Or place the whistle chip across points A & B, B & C, and D & E, then remove the speaker from the circuit and repeat.

Experiments

Consider this circuit:

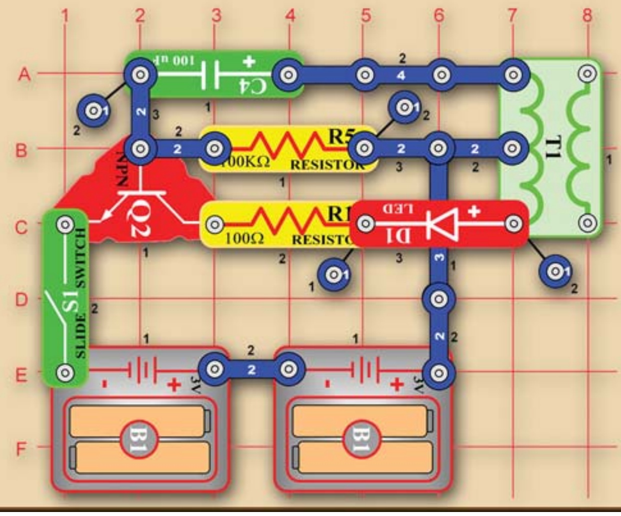


When switch S2 is pressed the 10μF capacitor C3 charges up. After switch S2 is released the siren sound continues as C3 slowly discharges.

You can change the parts to experiment with the properties of this circuit. 0.02μF capacitor C1 and 10KΩ resistor R3 control the frequency of the siren tone. 10μF capacitor C3 controls the start-up and fading time for the siren, so what will happen if you can replace it with the 100μF or 470μF capacitors?

Experiments

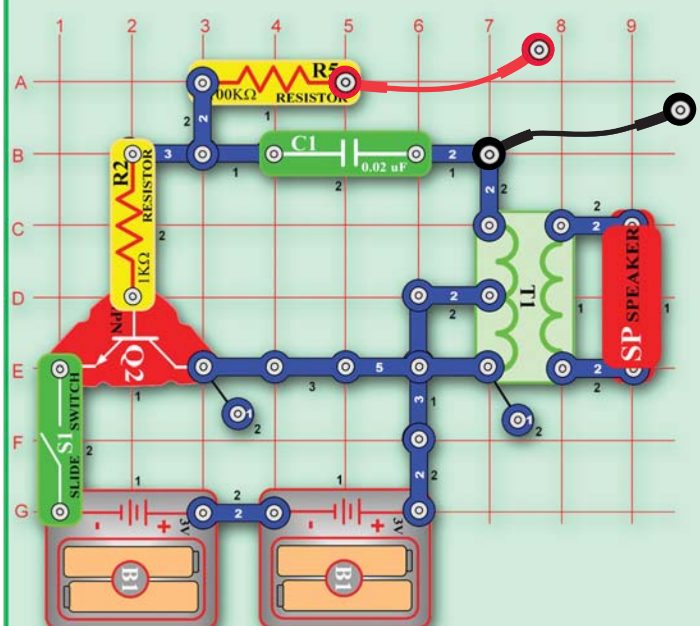
Now consider this circuit:



This circuit will flash the LED about once a second. The 100KΩ resistor and the 100μF capacitor control the flash rate.

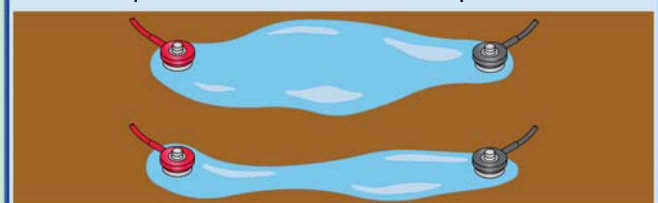
Experiments

In Part I, section 6-4 on page 57, you learned how water or pencil drawings can be used as resistors in an oscillator. With a transformer you can make a circuit with better performance:



Using either the water or pencil methods shown on the right, create shapes that cause oscillation at different frequencies.

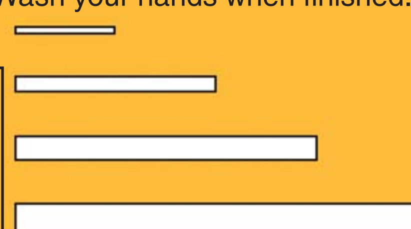
Method A (easy): Spread some water on the table into puddles of different shapes, perhaps like the ones shown below. Touch the jumper wires to points at the ends of the puddles.



Method B (challenging): Use a SHARP pencil (No. 2 lead is best) and draw shapes, the ones shown below are recommended. Draw them on a hard, flat surface. Press hard and fill in several times until you have a thick, even layer of pencil lead. Touch the jumper wires to points at the ends of the drawings. You may get better electrical contact if you wet the metal with a few drops of water. Wash your hands when finished.

Shapes to be drawn

Use a SHARP No. 2 pencil, draw on a hard surface, press hard and fill in several times for best results.

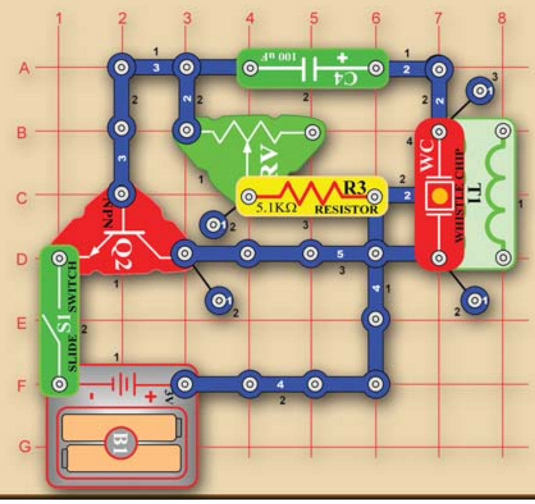


Longer shapes will have more resistance while wider shapes will have less. So these four shapes should produce about the same sound, re-shape your puddles or improve your drawings if they do not.

Touch both jumper wires to the widest part of this shape, and then slide one jumper across the drawing to the other end. The sound should change from high to low frequency.

Experiments

Consider this circuit:



The whistle chip makes a sound like a dripping faucet; use the adjustable resistor to make it drip faster or slower. Although the sound may seem to be nearly continuous, the transistor is only activating for about 1/100 second for each drip.

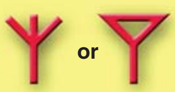
Other Snap Circuits® using the transformer in an oscillator: 347-351, 399-408, 419-424, 447-452, and 458-465.

9-5 More About FM Radio

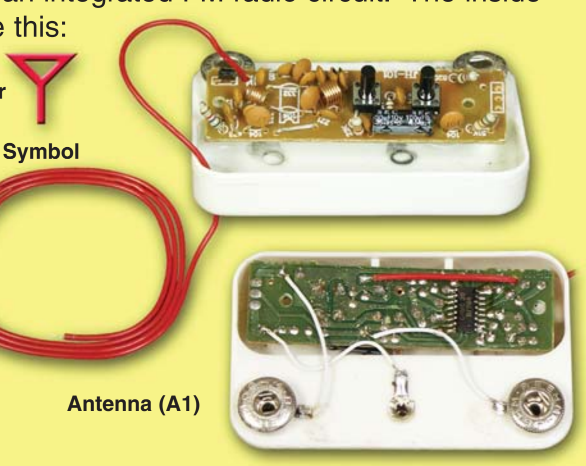
In sections 8-4 and 8-5 you learned about AM (Amplitude Modulation) and FM (Frequency Modulation) radio, and built some AM radio circuits. You may want to review those sections now.

Introducing New Parts

Snap Circuits® includes an FM module, which contains an integrated FM radio circuit. The inside looks like this:

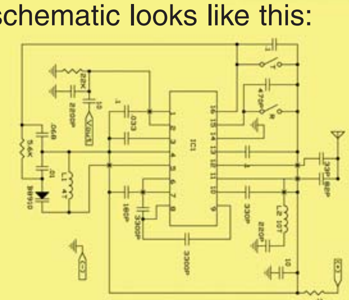


Antenna Symbol

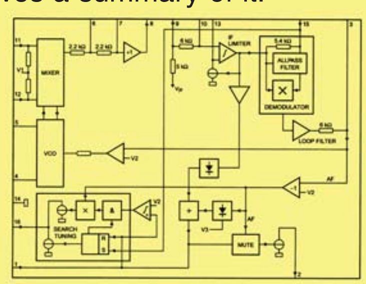


Antenna (A1)

Its actual schematic looks like this:



This circuit is actually much more complex than it appears here, since it is built around an integrated radio circuit. A schematic of the circuitry within this part would be too large to show here, but this block diagram gives a summary of it:



Its Snap Circuits® connections are like this:

(–) OUT (+)

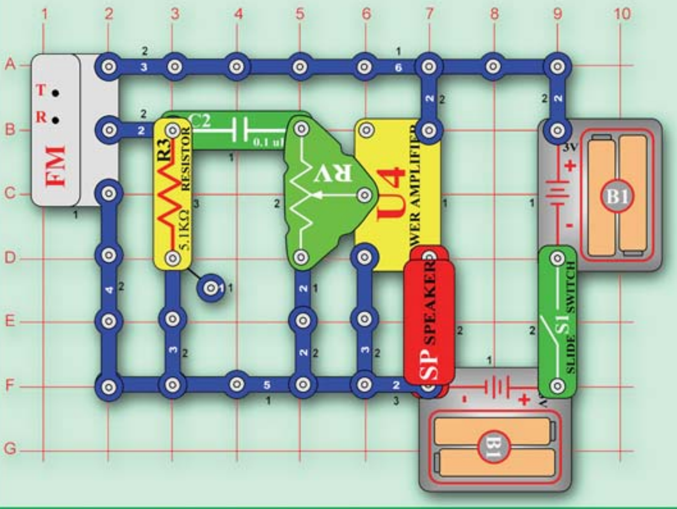
FM Module:

(+) - power from batteries
(–) - power return to batteries
T - tune up
R - reset
OUT - output connection

The antenna (Y) is a loose wire that should always be left unconnected and spread out for best radio reception.

Experiments

Consider this circuit (which is project 307, or a variation of it):



Turn on the switch (S1) and press the R button. The R button resets the frequency to 88MHz (the beginning of the FM band). Now press the T button and the FM module scans for an available radio station.

When a station is found, it locks on to it and you hear it on the speaker. Adjust the volume using the adjustable resistor (RV). Press the T button again for the next radio station. The module will scan up to 108MHz (the end of the FM band), and stop.

Snap Circuits® project 316 is a variant of this circuit without a volume adjustment. Project 306 is a variant of the AM radio circuits discussed in section 8-5.

9-6 When Wires Are Not Wires

In section 8-3 you learned that the AM antenna (Snap Circuits® part A1) has inductance due to its magnetic affects at AM radio frequencies, and that at low frequencies it acts like an ordinary wire. At FM radio frequencies (88-108MHz) a long wire has enough inductance to become an antenna, and one is used like this on the Snap Circuits® FM module.

AM Antenna (A1)

FM Antenna Wire

The entire FM radio circuit comes as a complete module, instead of coming as individual parts that you could build and experiment with. This was necessary because at FM frequencies the snap wires connecting your parts on the base grid are long enough to have enough inductance to change the performance of the circuit. The output signal to the power amplifier IC (U4) is at much lower frequency (audio, 300-3000Hz).

At microwave frequencies (>1000MHz) circuit design becomes very complicated since every component or interconnection has some amount of capacitance and inductance. Components and the spaces between them must be as small as possible for circuits to perform properly.

Summary

Summary of Chapter 9:

1. Meters are used to measure the current or voltage in a circuit.
2. In a transformer, the side with less loops of wire has higher current while the side with more loops of wire has higher voltage.
3. The magnetic effects in transformers only work with AC (changing) currents.
4. At high frequencies wires can act like inductors and change the performance of a circuit, so the spacing between components becomes very important.

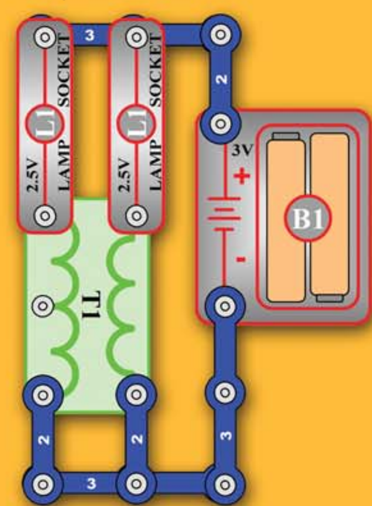
Quiz

Chapter 9 Practice Problems

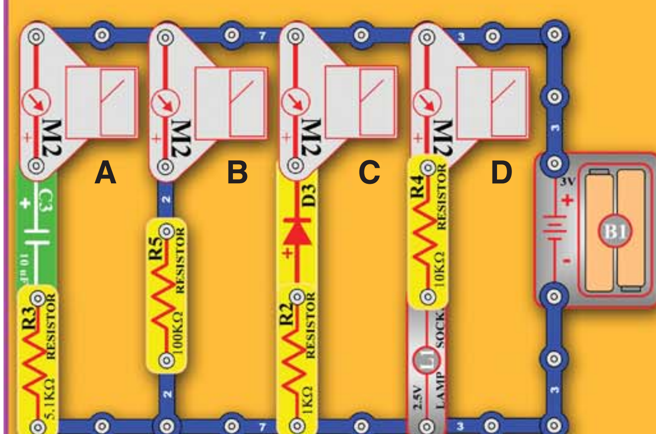
1. The side of a transformer that has more loops of wire will have _____________ than the other side.
   A. more voltage C. less resistance
   B. more current D. higher frequency

2. In which of these frequency ranges does the spacing between components in the circuit matter the most?
   A. Audio range (300-3000 Hz)
   B. AM band (500-1600 kHz)
   C. FM band (88-108 MHz)
   D. Spacing between components is of equal importance in all the above ranges.

3. Which lamp will be brighter?
   A. Left lamp
   B. Right lamp
   C. Both lamps will be equally bright.
   D. Both lamps will be off.



4. Which meter will measure the highest current?
   A. Meter A C. Meter C
   B. Meter B D. Meter D



Answers: 1. A, 2. C, 3. B, 4. D

CHAPTER 10: DIODES & APPLICATIONS

This chapter introduces some other types of diodes and their applications. The LEDs that you learned about in chapter three and have used in many circuits are one type of electronic diode.

Silicon diodes are the most common diode type, and also the easiest to understand. You will see how they can be used to convert AC voltages into DC voltages.

You will also see that LEDs can come in different shapes. By combining several LEDs you can create the numeric displays seen on many of the electronic products in your home, such as microwave ovens.

You will also learn about electronic recording and memory circuits.

10-1 More About Diodes

In section 5-1 you learned about diodes, you may want to review that section now.

Introducing New Parts

Although Part I did not include a diode, Part II does:

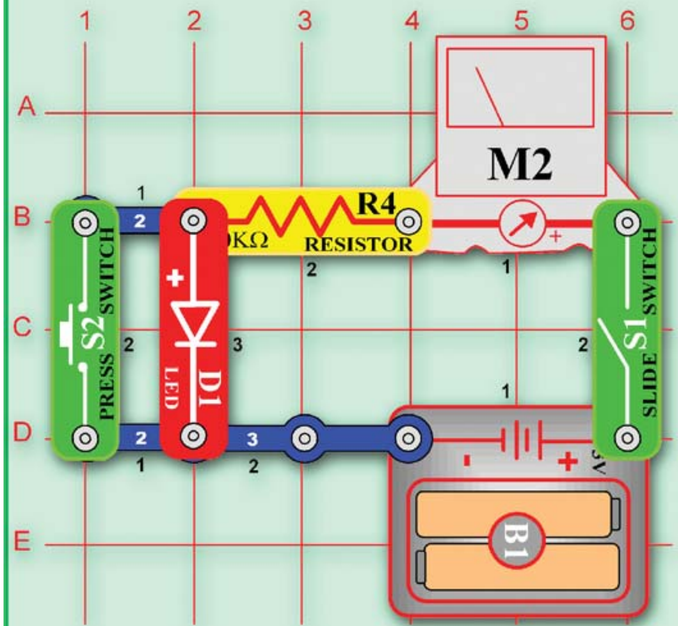
Diode (D3)

Diode Symbol

Diodes are used to block current in one direction. This silicon diode has a turn-on level of about 0.7V. LEDs (light emitting diodes) are made from Gallium Arsenide and have a turn-on level of 1.5V, then emit light as the current through them increases. The easiest way to understand diodes is to use them in a circuit.

Experiments

Consider this circuit (which is project 487):



If your meter has a switch, then use the LOW (or 10mA) setting.

Turn on the slide switch (S1), the LED lights as the meter deflects to the middle of the scale. The voltage from the batteries is divided between turning on the LED and pushing current through the 10KΩ resistor.

Press the press switch (S2) to bypass the LED and use the full battery voltage across the resistor. The meter deflects more to the right, showing that a higher current flows when the batteries don't have to overcome the LED turn-on level.

Replace the LED with the diode (D3). What do you think the meter reading will be? The meter will indicate a higher current with the diode than it did with the LED, because the diode has a lower turn-on level.

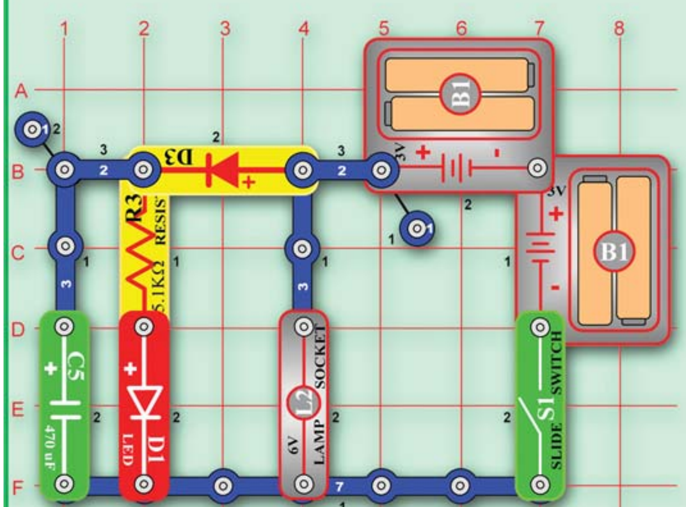
Reverse the orientation of the diode. No current flows through it because diodes block current in the reverse direction. What do you think will happen if you reverse the red LED?

Quick Quiz

How do you think the green LED (D2) will perform in this circuit? Try it and find out.

Experiments

Consider this circuit:

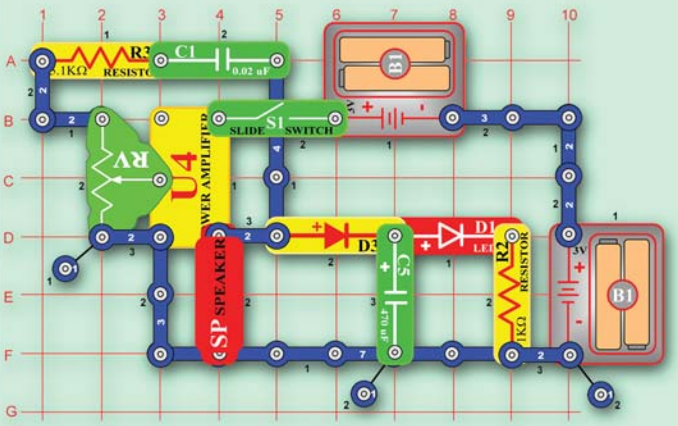


Turn on the switch, the lamp will be bright and the LED will be lit. The diode allows the batteries to charge up capacitor C5 and light the LED.

Turn off the switch, the lamp will go dark immediately but the LED will stay lit for a few seconds as capacitor C5 discharges through it. The diode isolates the capacitor from the lamp; if you replace the diode with a 3-snap wire then the lamp would drain the capacitor almost instantly.

Experiments

Consider this circuit:

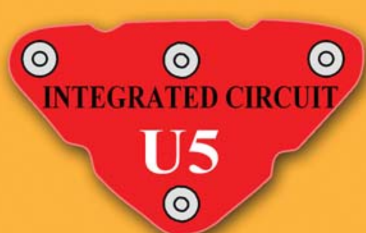


This circuit is based on the Trombone project #238, turn on the switch and set the adjustable resistor for mid-range for the best sound. The LED will also be lit.

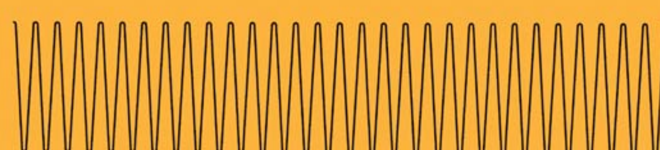
The signal from the power amplifier (U4) to the speaker is a changing (AC) voltage, not the constant (DC) voltage needed to light the LED. The diode and capacitor are a **rectifier**, which converts the AC voltage into a DC voltage.

The diode allows the capacitor to charge up when the power amp voltage is high, but also prevents the capacitor from discharging when the power amp voltage is low. If you replace the diode with a 3-snap or remove the capacitor from the circuit, the LED would not light.

Diode rectifiers like this can also track the peaks of an AC voltage, such as on a high frequency signal that is changing in amplitude. An example of this is AM radio. By tracking the peaks of a received AM signal, the original message (talking or music) may be recovered. The Snap Circuits® high frequency IC (U5) that is used in all your AM receiver circuits contains a diode rectifier sub-circuit.



Audio

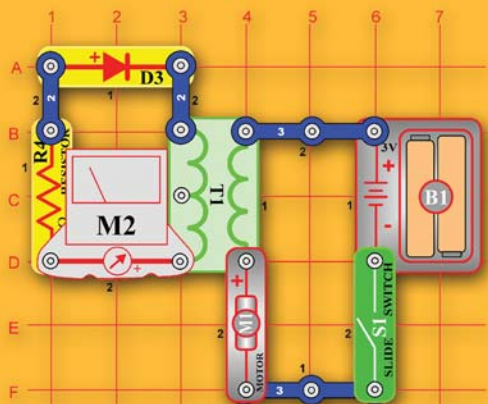


RF Carrier

Amplitude Modulation

Experiments

Now consider this circuit (which is project 360):

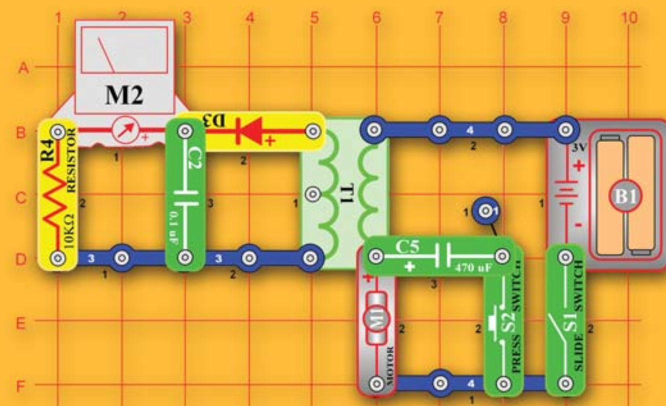


Place the fan on the motor and turn on the switch. The battery provides DC voltage to the motor, and the meter measures the DC current on the other side of the transformer. But transformers only work with AC voltages, so how does this work? And why is the diode needed?

If your meter has a switch, then use the LOW (or 10mA) setting. Motors only work with AC voltages, but this motor is designed so that as the shaft spins it connects/disconnects several sets of electrical contacts. These contacts change the polarity of the DC current in the coil producing the magnetic field, and allow the DC voltage from the battery to act like an AC voltage.

When the shaft switches between contacts an AC ripple is created in the voltage, and it is this ripple that is passed through the transformer. The diode rectifies part of the ripple into a DC current that the meter measures.

If you modify the circuit, it will be easier to see how this works:



Place the fan on the motor and turn on the slide switch, the meter shows a much higher current than before. By adding capacitor C2 next to the diode we made a better rectifier.

Holding down the press switch will place the 470μF capacitor in parallel with the motor. Do you know how that will affect the circuit?

The 470μF capacitor acts as a filter, eliminating most of the AC ripple voltage that the motor had created in the circuit. This does not affect the motor speed but results in a much lower DC current through the meter on the other side of the transformer. **Almost all electronic products use capacitors like this to filter out unwanted AC ripples in their DC voltages.**

10-2 Digital Displays

LEDs are often arranged together in groups to form special patterns, usually to convey information. Examples of this include the displays for digital clocks, microwave ovens, radios, and wristwatches.

Microwave Oven

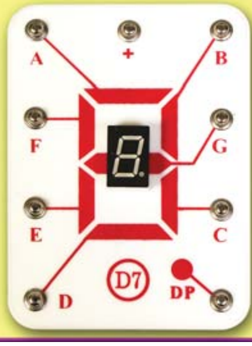
Clock Radio

Copy Machine

Introducing New Parts

Snap Circuits® includes a 7-segment LED Display. Take it out and look at it if the parts are with you.

7-Segment Display (D7)



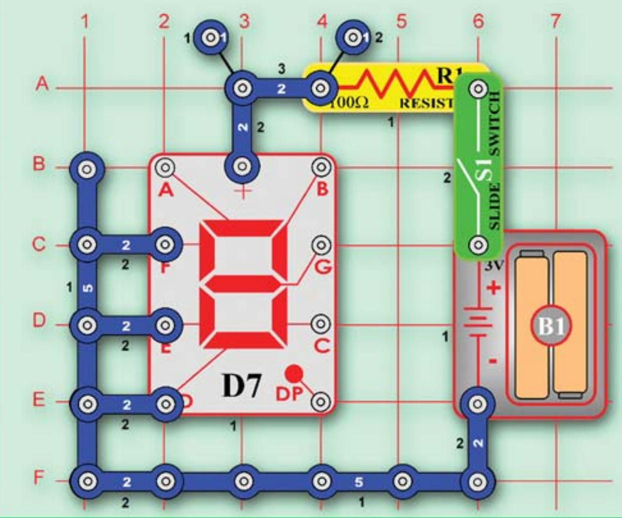
7-Segment Display Symbol

This part consists of eight LEDs (labeled A-G and DP) with their "+" sides connected together, arranged to form the number 8 and a decimal point. By connecting to some of these LEDs but not all, different numbers or letters can be displayed. This will be easy to understand by using the display in a circuit.

Note: The LEDs in this display can be damaged by high currents (just like the red and green LEDs), so always use a resistor or other components to limit the current.

Experiments

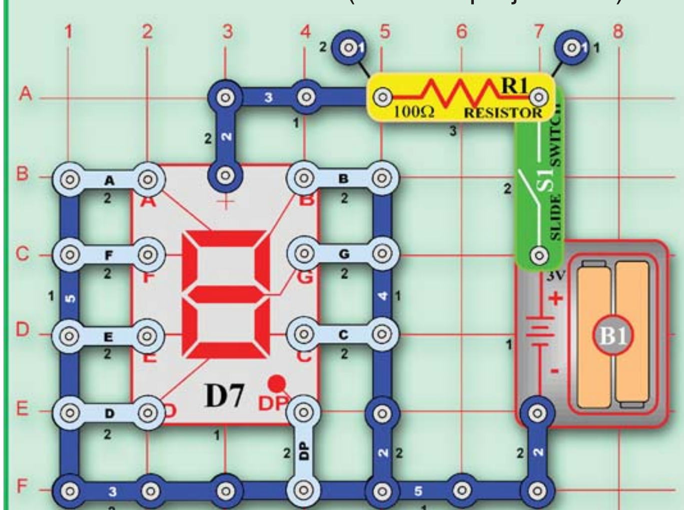
Consider this circuit (which is project 329):



This circuit puts a current through the LEDs in segments D, E, and F, and the letter "L" is displayed.

Experiments

Now consider this circuit (which is project 330):



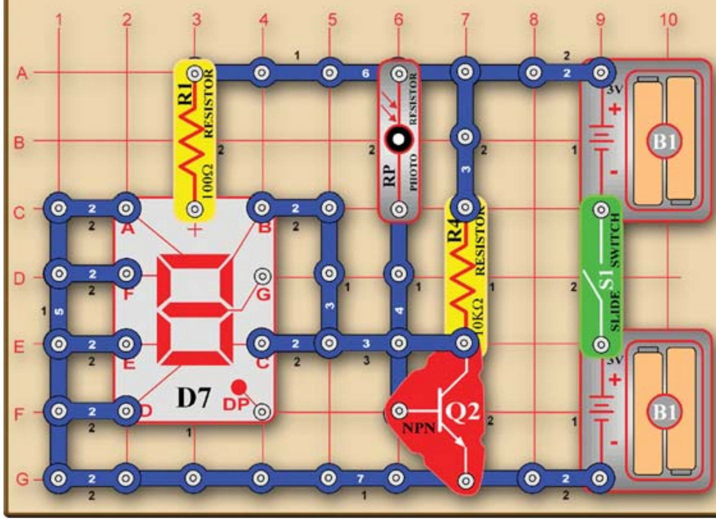
The eight 2-snaps that connect to snaps A-G and DP on the display control which LEDs are lit. Connect them one at a time or in various combinations until you understand how this part works.

Snap Circuits® projects 330-339 show you which connections to make to display the numbers 1-9 and 0. For example, connect the 2-snaps to points B, C, F, and G to display "4".

Snap Circuits® projects 363-376 show you which connections to make to display letters F, H, P, S, U, C, E, b, c, d, e, h, o, and the decimal point. For example, connect the 2-snaps to points B, C, D, E, and F to display "U". Can you think of any other letters that can be displayed?

Experiments

Now consider this circuit (which is project 488):

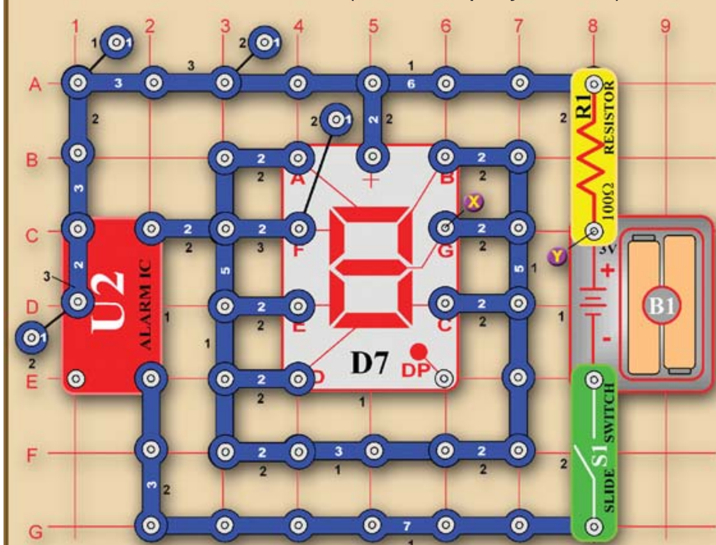


When light shines on the photoresistor RP, the letter “O” is displayed. When you cover the photoresistor, the letter “C” is displayed. The transistor is used to control segments B and C of the display.

You can think of this as a light sensor monitoring whether a door is open or closed. When there is lots of light, the door is open and “O” is displayed. When the room is dark, the door is closed and “C” is displayed.

Experiments

Now consider this circuit (which is project 396):



This circuit uses the alarm IC to flash the number “8” on the display. If you place the speaker across points marked X and Y on the drawing (between display D7 and resistor R1), you will also hear sound whenever the “8” is displayed.

Other Snap Circuits® using the 7-segment LED display: 317, 411-418, 435-443 (and 444-446 in some manuals), 467-476, and 495-505.

10-3 Recording IC

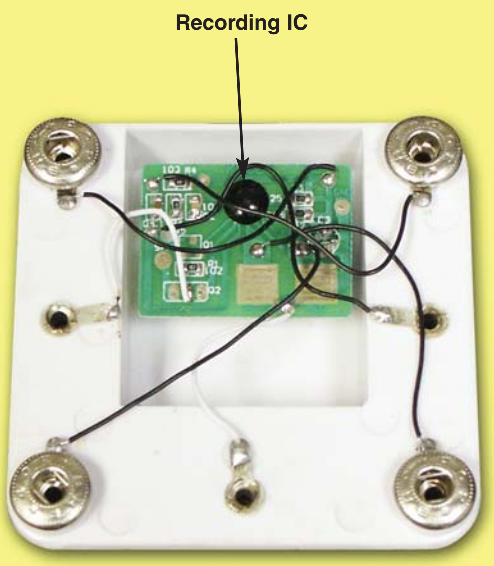
There are several types of electronic memory circuits used to store music or sounds for short durations. These are made up of vast arrays of transistors in integrated circuits. For longer recordings mechanical memories are used, such as videotapes, CDs, or the hard disk drives in computers.

Musical ICs, such as those in Snap Circuits® and many electronic toys, play pre-recorded songs or sounds that have been stored in electronic memory within the ICs. These recordings cannot be changed. The electronic memory in computers can be changed as desired, but is erased when the power is turned off.

Other types of electronic memory can be changed or re-recorded as desired, but is not erased when the power is turned off. These memory circuits are simple to use but expensive, so are usually used only for short recordings. These are used in electronic toys and other products.

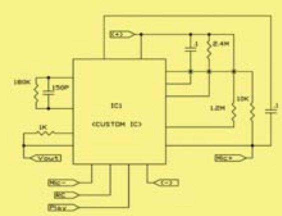
Introducing New Parts

Snap Circuits® includes a Recording Module containing a specialized recording integrated circuit and supporting resistors and capacitors that are always needed with it. The inside looks like this:

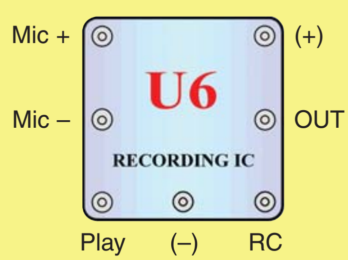


Recording IC (U6)

Note that the parts here are miniaturized and "surface-mounted" to the printed circuit board. The actual recording IC is under the black blob of protective plastic. Its actual schematic looks like this:



Its Snap Circuits® connections are like this:



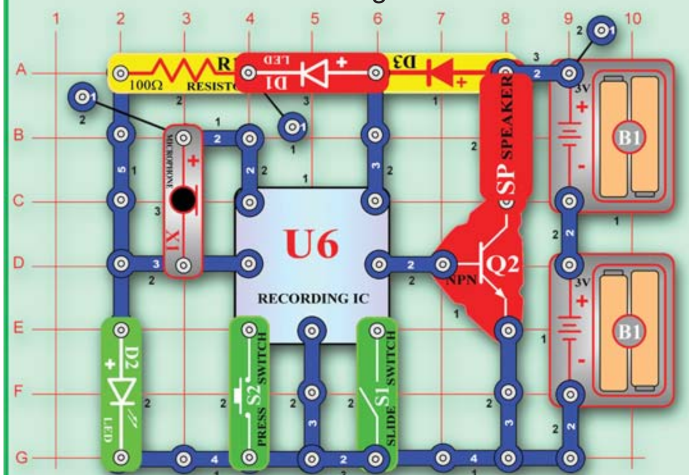
Recording IC Module:

(+) - power from batteries
(–) - power return to batteries
RC - record
Play - play
OUT - output connection
Mic + - microphone input
Mic – - microphone input

The recording IC can record and play back a message up to eight seconds long. There are also three pre-recorded songs.

Experiments

This circuit (which is project 384) will demonstrate the features of the recording IC:



Turn on the slide switch (S1), you hear a beep signaling that you may begin recording. Talk into the microphone (X1) up to 8 seconds, and then turn off the slide switch (it also beeps after the 8 seconds expires).

The green LED is on except when you are recording. The red LED is always on, indicating the batteries are installed.

Press the press switch (S2) for playback. It plays the recording you made followed by one of three songs. If you press the press switch before the song is over, the music will stop. You may press the switch (S2) several times to play all three songs.

Experiments

You can also make recordings electronically without using the microphone. Consider this circuit (which is project 428), which records the sound from the alarm IC into the recording IC:

Turn on the slide switch (S1), the first beep indicates that the IC has begun recording. When you hear two beeps, the recording has stopped. Turn off the slide switch (S1) and press the press switch (S2). You will hear the recording of the alarm IC before each song is played.

Projects 429 and 430 are variations of this that describe how to record different alarm sounds. You can also use the music IC instead of the alarm IC using the same circuit.

Other Snap Circuits® using the recording IC: 308-315, 385, 398, 425-427, and 453.

Summary

Summary of Chapter 10:

1. Diodes are semiconductors that block current in one direction.

2. Diodes can be used in rectifiers to track the peaks of an AC voltage, such as recovering talking or music from an AM radio signal.

3. Capacitors are often used to filter out unwanted AC ripples in DC voltages.

4. LEDs are often arranged in groups to display letters or numbers.

5. There are several common types of electronic memories, which use vast arrays of transistors in integrated circuits to store information.

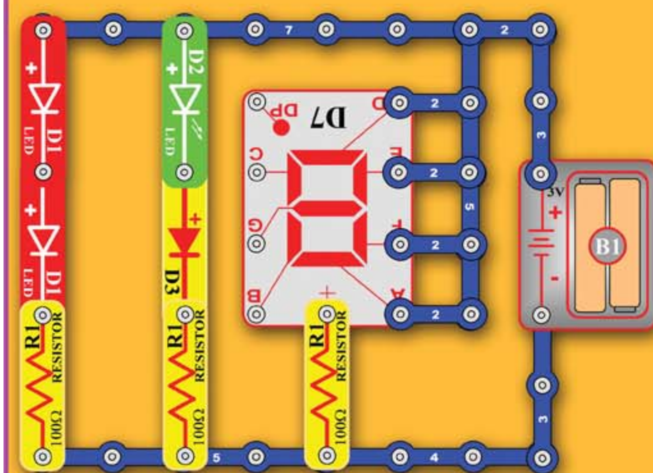
Quiz

Chapter 10 Practice Problems

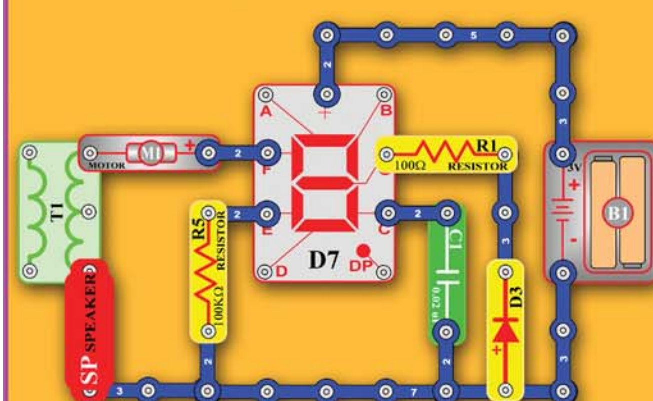
1. What turn-on voltage is needed to make current flow in a standard silicon diode?
   A. About 0.3V   B. About 0.7V   C. About 1.5V
   D. Current flows when any voltage is present; there is no minimum level required.

2. Which of these products can make electronic recordings that last until another recording is made?
   A. Music CD   C. Cordless drill
   B. AM radio   D. VCR tape

3. Which LED will be lit?
   A. Red LEDs
   B. Green LED
   C. 7-segment LED display (any of the segments)
   D. Red and green LEDs



4. Which segment of the LED display will be lit?
   A. Segment F   C. Segment C
   B. Segment E   D. Segment D



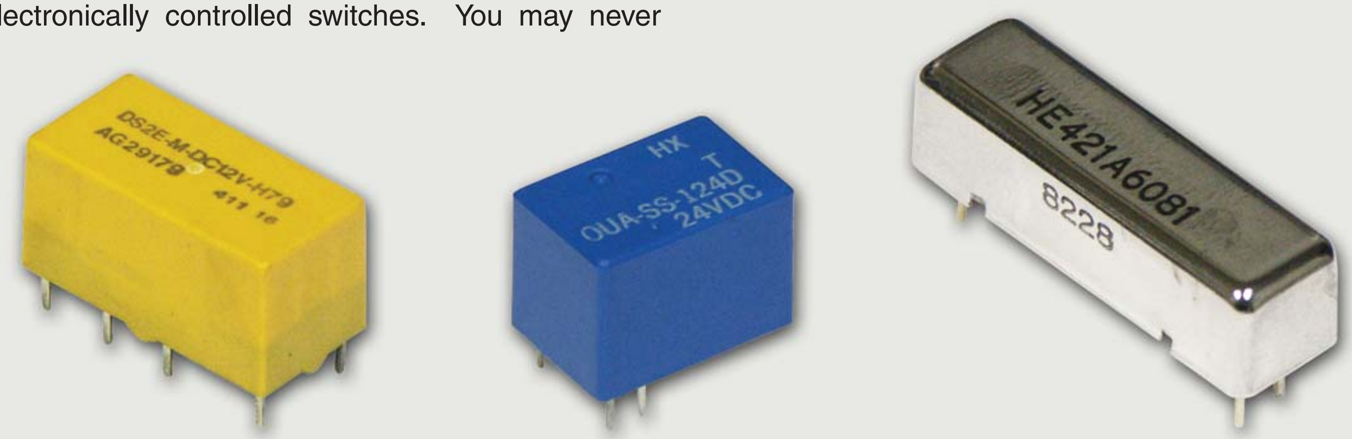
Answers: 1. B, 2. D, 3. B, 4. A

CHAPTER 11: ELECTRONIC SWITCHES

You already know about some of the mechanical switch types used in electronics, such as the slide and press switches in Snap Circuits®. But these are controlled using your finger. You also know how transistors can be used as switches, but they cannot be used in many applications.

In this chapter you will learn about **relays** and **silicon controlled rectifiers**, which are electronically controlled switches. You may never have heard of these components, but they are used in many appliances in your home. They can be used in many fascinating ways, as shown by the range of exciting Snap Circuits® that use them.

You will also learn about two of the basic principles for analyzing circuits: how voltages divide in series circuits and how currents divide in parallel circuits.

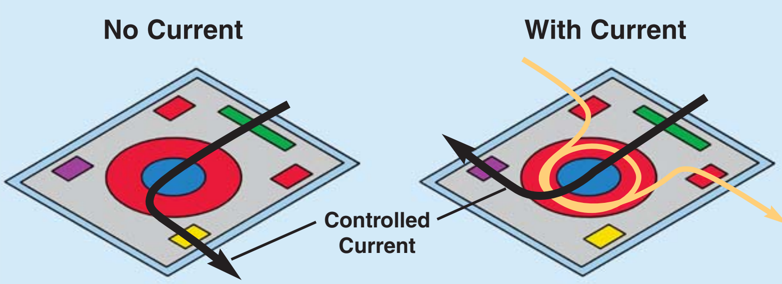


11-1 Relays

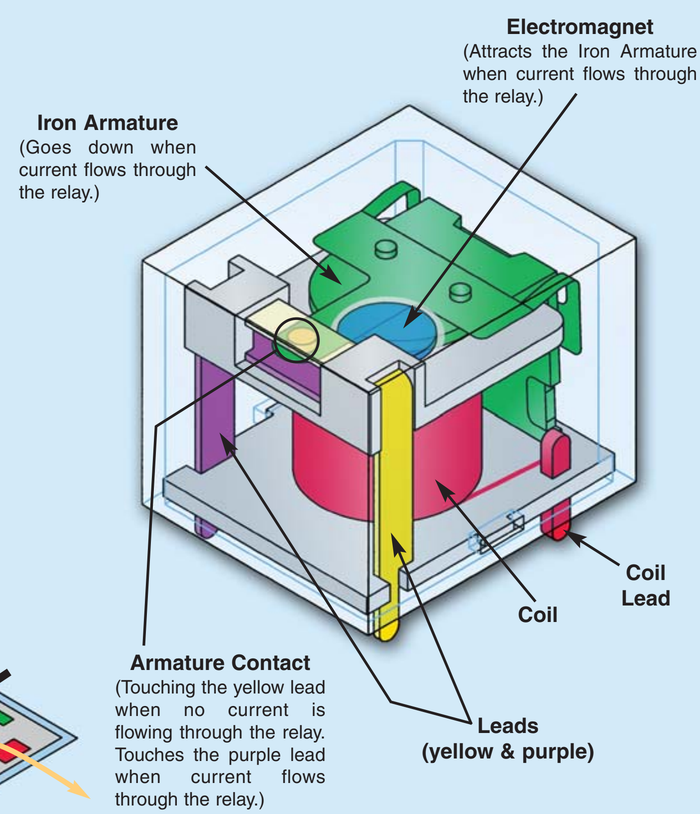
Transistors often act as electronic switches by using a small current to control a much larger current. However there are many electronic switching applications where transistors cannot be used, such as to have a low-voltage circuit control a high-voltage or high-current circuit.

What is needed is a device where the controlling signal and the signal being switched do not affect each other. A relay does this, by using magnetism to open or close a mechanical switch.

A relay contains a coil that produces a magnetic field when a current flows through it, just like in a motor. The magnetic field attracts an iron armature, which closes a set of contacts like a switch.



Top View of the Relay

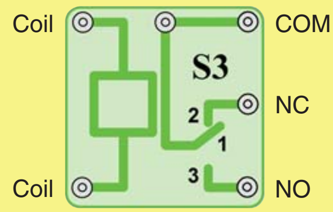


Introducing New Parts

Relays come in many different configurations and sizes depending on the circuit they are used in. Snap Circuits® includes one:

Relay (S3)

The coil in the relay has an inductance of about 60mH, and a DC resistance of about 70Ω.



Relay:

Coil - connection to coil

Coil - connection to coil

NC - normally closed contact

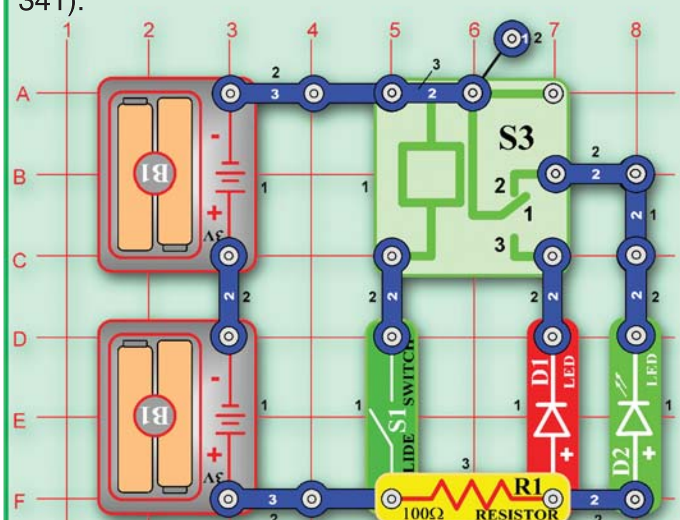
NO - normally open contact

COM - Common

Most industrial machinery and home appliances operate at voltages of 120V or higher. However, the integrated circuits, transistors, and diodes used to control them (either automatically or by interfacing with people) operate at low voltages. These voltages are usually less than 6V and very rarely higher than 50V. Relays allow these low voltage devices to control high voltage machinery and appliances.

Experiments

Relays will be easy to understand using an example. Consider this circuit (which is project 341):

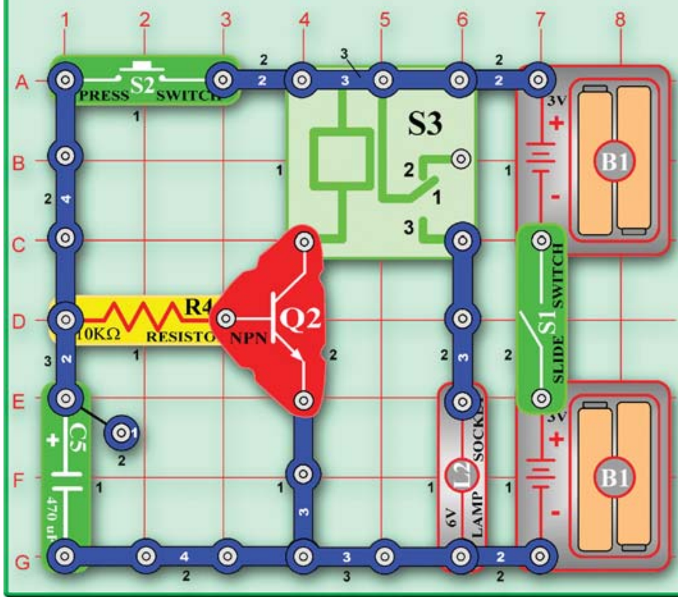


With the slide switch turned off, the green LED should light. Contact #2 is normally closed, connecting the green LED and the resistor across the batteries.

Now turn on the switch so a current flows through the coil. This causes contact #1 on the relay to switch to contact #3, lighting the red LED. Note that when you change the position of the slide switch, you hear a click in the relay as it switches.

Experiments

Now consider this circuit (which is project 342):



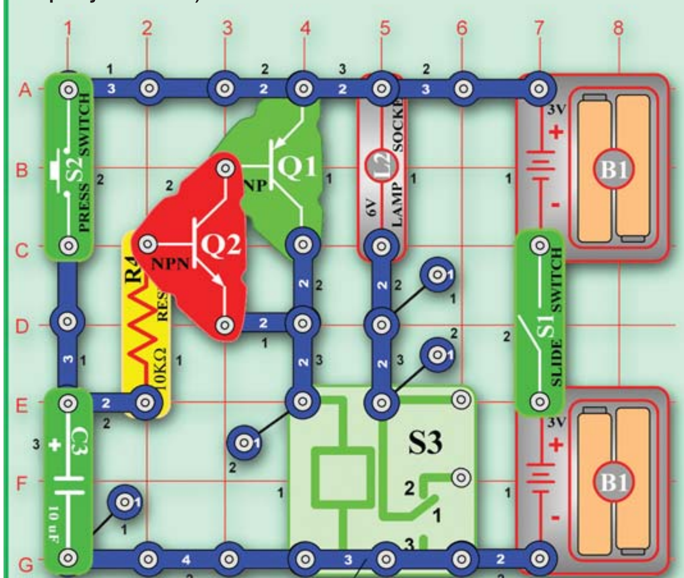
The transistor (Q2) acts as a switch, turning on the relay. As long as there is voltage on the transistor's base (where R4 connects), the lamp will light. Turn on the slide switch (S1) and hold down the press switch (S2). The transistor turns on, capacitor C5 charges up, and the lamp lights up.

When the press switch is released, the capacitor discharges through the base, keeping the transistor on. The transistor will turn off when the capacitor is discharged, about 7 seconds. The relay contacts will switch and the lamp will turn off.

In this circuit the lamp is at full brightness until it turns off. In similar transistor circuits that do not use a relay (such as projects 252 and 291), the lamp dims as the capacitor discharges.

Experiments

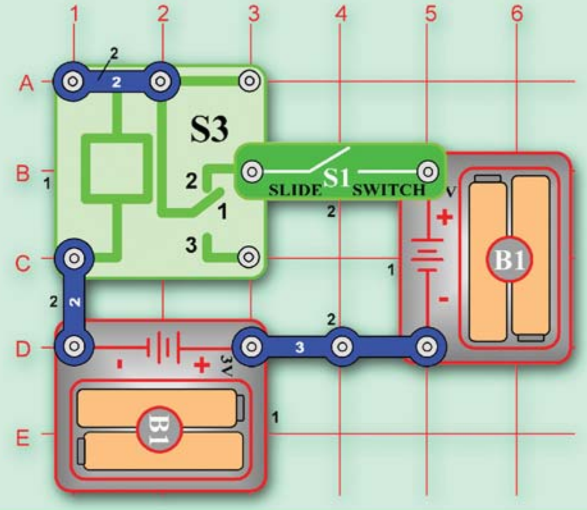
If a second transistor is added to the circuit for project 342 then the lamp will stay on much longer even if a smaller capacitor is used. The new circuit would work the same way, and look like this (which is project 354):



The high current gain of the transistors allows the capacitor to discharge at a slow rate. You can replace capacitor C3 with a larger or smaller capacitor if desired. Compare the lamp shut-off delay of this circuit with the delay in project 291.

Experiments

Now consider this interesting circuit (which is project 353), what do you think it will do?

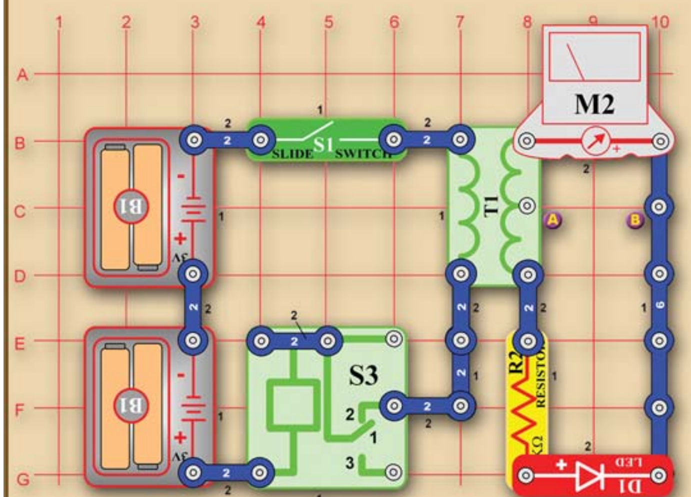


When you turn on the switch (S1), you hear a buzzing sound from the relay. The sound is caused by the relay's contacts opening and closing at a fast rate.

What's happening is this: when the switch is turned on, current flows through the relay's coil, causing contact 1 to disconnect from contact 2 and connect to contact 3. This opens the circuit and stops current from flowing through the coil, which causes contact 1 to move back to contact 2. This closes the circuit and current flows through the coil again, and the cycle repeats continuously.

Experiments

The electrical signal created by the rapid opening and closing of the relay contacts in project 353 is an example of an AC voltage. It can be converted into a DC voltage using a rectifier circuit like this one (which is project 343):



If your meter has a switch, then use the LOW (or 10mA) setting.

The AC voltage across the transformer would create a current in both directions on the transformer's secondary side, however the LED (D1) only allows it to flow in one direction (for one polarity of applied voltage). This makes a DC current, which is indicated by the meter and the LED.

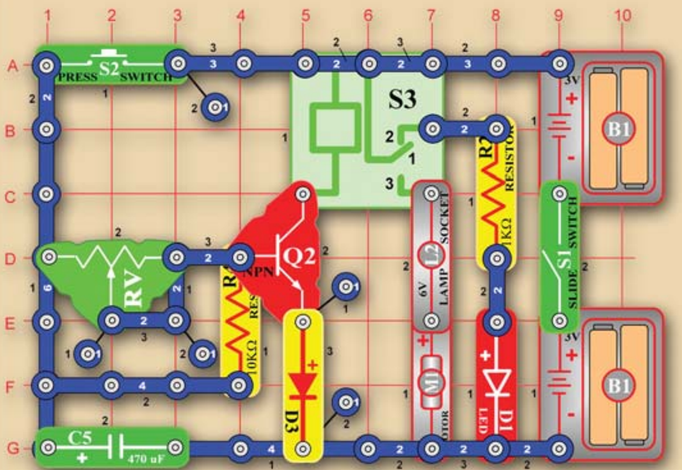
If you reverse the LED then the current will only flow in the reverse direction. The LED would still light but the meter would deflect to the left.

Quick Quiz

1. What will happen if you move the meter to the center position on the transformer (across points A and B)? See project 344 to find out.
2. What if you replace the LED with the diode (D3)? See project 345 for the answer.
3. What if you replace the resistor with a different one? See project 346 to find out.

Experiments

Now consider this circuit (which is project 431):



Turn on the slide switch (S1) and place the fan on the motor, the red LED (D1) lights. Now press and release the press switch (S2), the lamp lights and the motor spins for a while. The adjustable resistor controls the shut-off delay for the lamp and motor. This circuit is similar to project 342.

Other Snap Circuits® using the relay: 352, 355, 356, 357, 361, 362, 432, 433, 434 (fun), 454 (fun), 455, 456, and 457.

11-2 Silicon Controlled Rectifiers

Silicon controlled rectifiers (SCRs) are electronic switches used for voltage control. They are commonly used in the industry to control motors, and often as part of AC/DC voltage rectifier circuits. They are often preferred over relays because they can switch faster.

An SCR is a controlled diode that you can turn on, but once on it stays on. Like transistors and diodes, SCRs are made from semiconductor materials like silicon.

Introducing New Parts

Snap Circuits® includes one SCR, it has three connection points and is packaged like a transistor:

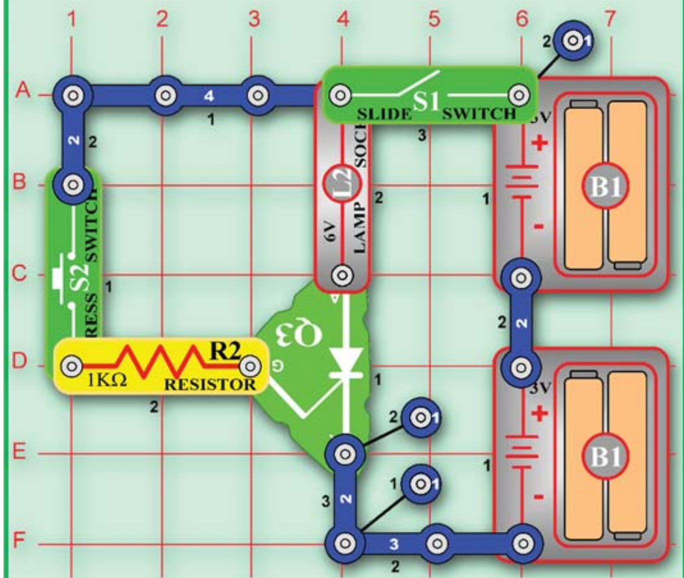
SCR Symbol

An SCR is turned on when voltage is applied between the gate and cathode. Like a diode it allows current to flow in only one direction. SCRs may be damaged by high currents, so current must be limited by other components in the circuit.

SCR:
A - Anode
K - Cathode
G - Gate

Experiments

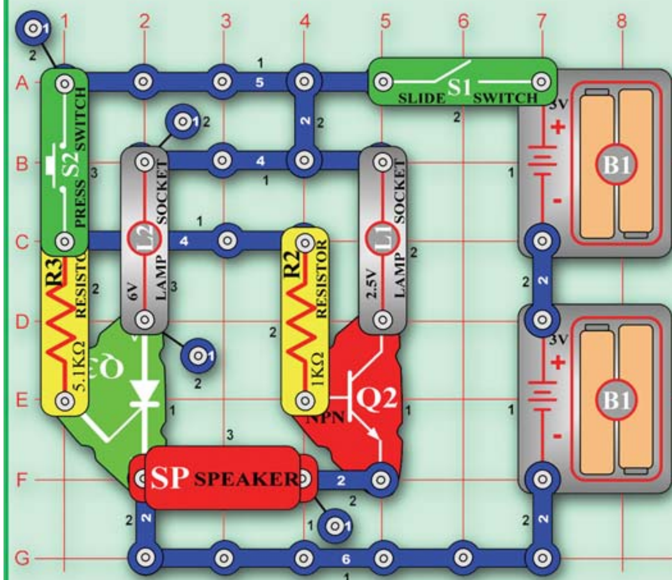
Snap Circuits® will make SCRs easy to understand. Consider this circuit (which is project 328):



Turn on the slide switch; nothing happens. Press and release the press switch, the lamp turns on. It stays on until the slide switch is turned off. Once the SCR has been turned on, it stays on until voltage is removed from its anode.

Experiments

This circuit will show the difference between an SCR and a transistor:



Turn on the slide switch (S1) and push the press switch (S2). Both lamps light while S2 is pressed, but only L2 stays on after S2 is released. The transistor (Q2) requires a continuous voltage to stay on, but the SCR only needs a pulse.

The SCR and NPN transistor are used in almost identical sub-circuits here to compare them. You can exchange the locations of Q2 and Q3; only L1 will stay on after S2 is released.

The speaker (SP) is used here to protect the 2.5V lamp (L1), it may not make any sound.

Experiments

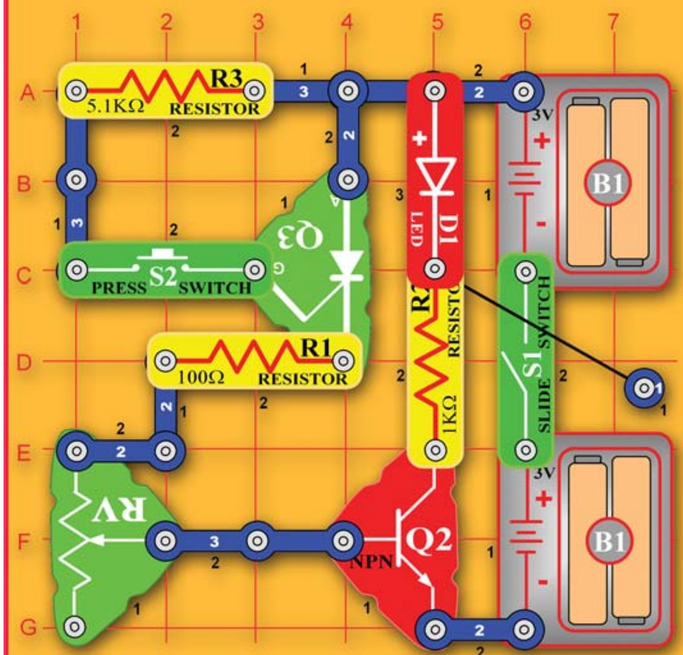
SCRs are often used to control the speed of a motor. The voltage to the gate would be a stream of pulses, and the pulses are made wider to increase the motor speed. Here is an example:

Turn on the switch, the motor spins and the lamp lights. Wave your hand over the photoresistor to control how much light shines on it, this will adjust the speed of the motor. By moving your hand in a repeating motion you should be able spin the motor at a slow and steady speed.

Can you guess what all the parts in this circuit are doing? Your hand motion over the photoresistor represents a control signal to regulate the motor speed. The music and alarm ICs reset the SCR by periodically shutting off the current (allowing the SCR gate control to be used). The lamp measures and limits the current.

Experiments

Now consider this circuit:



In this circuit the press switch controls an SCR, which controls a transistor, which controls an LED. The adjustable resistor controls the current through the SCR, set its control lever to the top (toward the press switch).

Turn on the slide switch; nothing happens. Press and release the press switch; the SCR, transistor, and LED all turn on and stay on. Now move the adjustable resistor control down until the LED turns off. Press and release the press switch again, this time the LED comes on but goes off after you release the switch. Can you guess why?

When voltage is removed from the gate of an activated SCR, the SCR doesn't always stay on. If the current through an SCR (anode-to-cathode) is above a threshold level (about 1mA for the SCR in snap circuits) then the SCR stays on. If the current is below the threshold then it will shut off. In this circuit you can set the adjustable resistor so that the SCR (and the LED it controls) just barely stays on or shuts off.

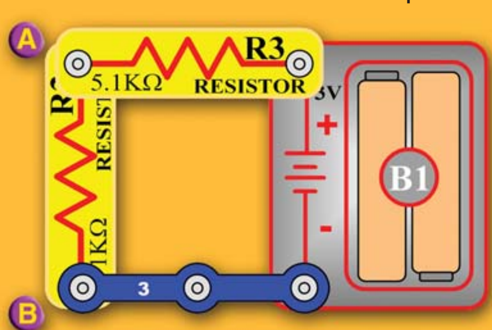
Snap Circuits® provides many other examples of using the SCR: 318, 319, 320, 321, 322, 377, 378, 379, 380, 381, 382, 383, 386, 387, and 388-395.

11-3 Voltage Dividers & Current Dividers

The current is the same through all the resistances in a series circuit. Ohm's Law (see section 3-3) says that Voltage equals Current times Resistance, so the highest resistances in a series circuit will have the largest voltage drop across them. Equal resistances will have the same voltage drop. In other words:

$$\text{Voltage}_{\text{(across one resistor)}} = \frac{\text{Resistance}_{\text{(of that resistor)}}}{\text{Resistance}_{\text{(total of resistors in the circuit)}}} \times \text{Voltage}_{\text{(total applied to the series circuit)}}$$

Consider this mini-circuit as an example:



The voltage at point A (across the 1KΩ resistor) may be determined from the formula on the left, as:

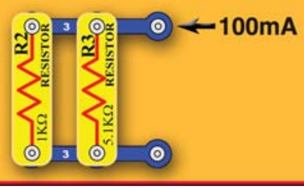
$$\text{Voltage}_{\text{(across R2 1K}\Omega\text{ resistor)}} = \frac{1\text{K}\Omega}{1\text{K}\Omega + 5.1\text{K}\Omega} \times 3\text{V} = 0.5\text{V}$$

This simple circuit is an example of a voltage divider; it has only resistors and so won't do anything by itself. But it could be used to provide a 0.5V reference, by connecting another circuit across points A and B. If the added circuit had very high resistance (across points A and B), then it would cause little change in your 0.5V reference voltage.

The voltage is the same across all the resistances in a parallel circuit. Ohm's Law says that Voltage equals Current times Resistance, so the lowest resistances in a parallel circuit will have the most current through them. Equal resistances will have the same current. In other words:

$$\text{Current}_{\text{(through one branch)}} = \frac{\text{Resistance}_{\text{(total in all OTHER parallel branches)}}}{\text{Resistance}_{\text{(total of resistors in all branches)}}} \times \text{Current}_{\text{(total applied to the parallel circuit)}}$$

Consider this mini-circuit as an example:



The current through the 1KΩ resistor may be determined from the formula on the left, as:

$$\text{Current}_{\text{(through R2 1K}\Omega\text{ resistor)}} = \frac{5.1K\Omega}{1K\Omega + 5.1K\Omega} \times 100mA = 84mA$$

If a small resistance were added in series with the 1KΩ resistor (such as the 8Ω speaker), the current through it would still be about 84mA.

Summary

Summary of Chapter 11:

1. A relay uses magnetism to open or close a mechanical switch, isolating the controlling signal from the signal being switched.
2. Silicon controlled rectifiers (SCRs) are controlled diodes, but once on they stay on until the current falls below a threshold level.
3. The current is the same through all the resistances in a series circuit, so the highest resistance will have the largest voltage drop.
4. The voltage is the same across all the resistances in a parallel circuit, so the lowest resistance will have the most current.

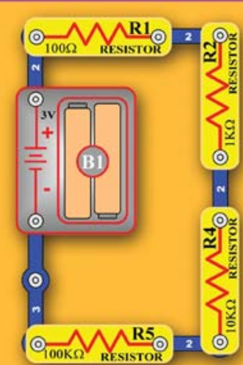
Quiz

Chapter 11 Practice Problems

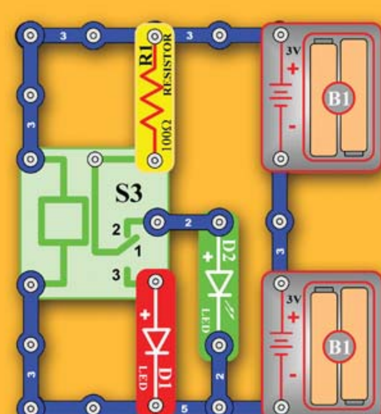
1. Which of these is a good way to use a relay?
   A. To turn on a light bulb after a switch is turned on.
   B. To replace a transistor in a low-voltage circuit.
   C. When using a remote control receiver circuit (which is powered by a 6V battery) to turn on a television (which is powered by the electricity in a home).
   D. When you want to use a large current to control a small current.

2. Why are SCRs sometimes preferred over relays?
   A. They can switch faster.
   B. They are larger.
   C. They give better isolation between the controlling and controlled signals.
   D. None of the above.

3. Which resistor will have the biggest voltage drop across it?
   A. 100Ω
   B. 1KΩ
   C. 10KΩ
   D. 100KΩ



4. Which LED will be on?
   A. Red LED
   B. Green LED
   C. Both LEDs will be on.
   D. Both LEDs will be off.



Answers: 1. C, 2. A, 3. D, 4. A

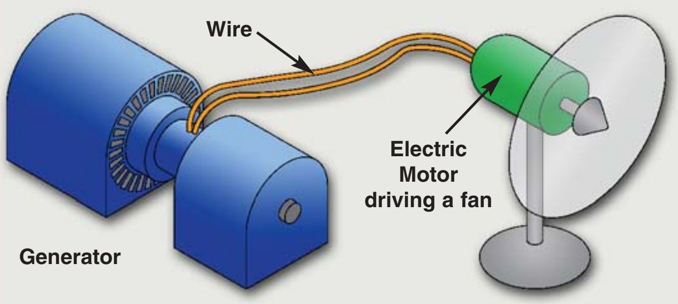
PART III (Model SC-750R only)

• If you have the **SC-500R** version, you may wish to purchase the **UC-80 Upgrade Kit** to continue to Part III of this manual. Upgrade kits can be purchased online: ***www.snapcircuits.net***

CHAPTER 12: ELECTROMAGNETISM

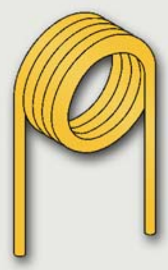
Learn By Doing®

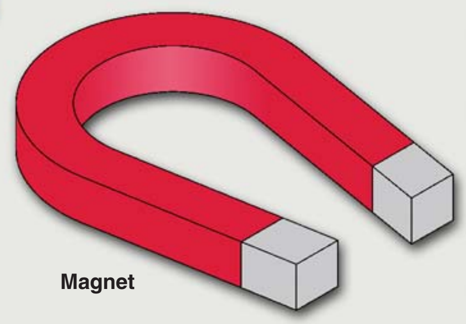
Magnetism is about as important to electricity as butter is to bread. Steam-driven generators produce electricity using magnetism, and electric motors use magnetism to move things. Wires carry the electricity from where it is made to where it is used.



Computer programs are stored on magnetic disks, which store electrical data as magnetic patterns.

In this chapter you will learn about magnetism and how it relates to electricity. Snap Circuits® will show you how electricity can make a magnet. And you will see how electricity can control a magnetic field better than a magnet can.

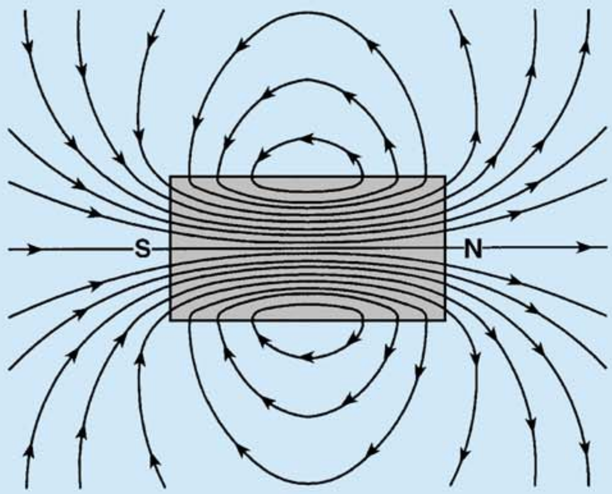




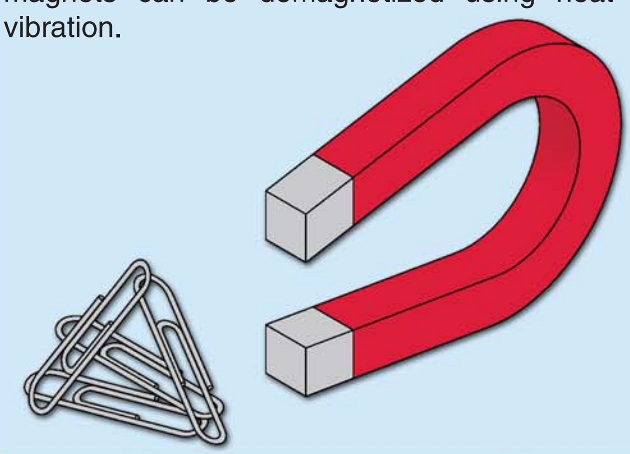
12-1 Magnetism

All materials have tiny particles with electric charges, but these are so well balanced that you do not notice them unless an outside voltage disturbs them. The same tiny particles also have magnetic charges, which are usually so well balanced that you do not notice them unless a magnetic field disturbs them.

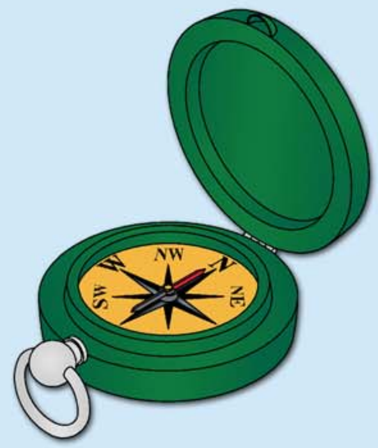
Magnets are materials that concentrate their magnetic charges at opposite ends. One side attracts while the other repels, but the overall material is neutral. Most magnets are made of iron. The name "magnet" comes from magnetite, an iron ore that magnetism was first seen in.



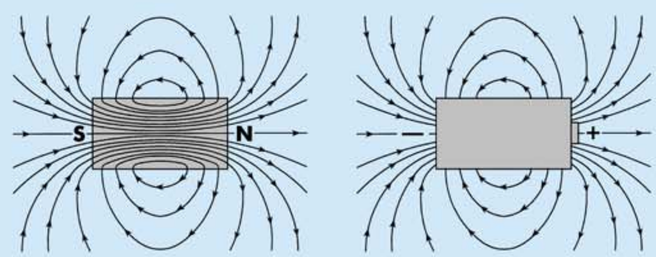
Magnets can magnetize other materials (usually iron), dividing their magnetic charges to opposite ends. This causes the magnetic attraction/ repulsion that you see. Magnetization can be temporary or long-lasting, depending on the materials and magnetic force used. For example, paperclips attracted to a magnet sometimes stick together after the magnet is removed. Most magnets can be demagnetized using heat or vibration.



The earth we live on is a giant magnet, due to its iron core. A compass needle always points north because it is attracted to the earth's magnetic field. The opposite ends of a magnet are often labeled north and south, representing the north and south poles of the earth. For centuries ships have used suspended magnets for navigation.

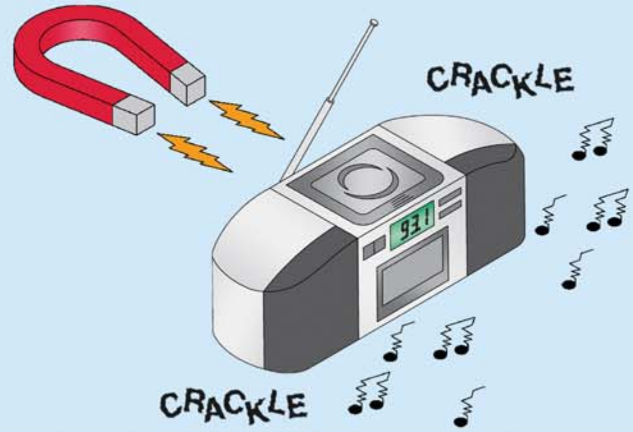


A magnet has a magnetic field, and a battery has an electric field. The north and south poles of a magnet are comparable to the positive and negative terminals of a battery.



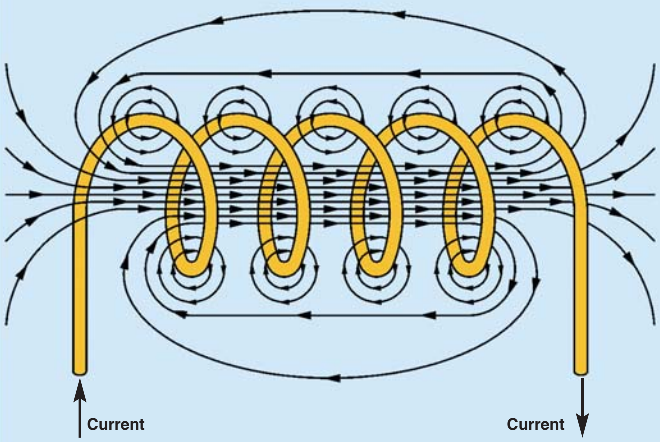
Magnet - magnetic field **Battery - electric field**

Electric and magnetic fields affect each other. If you place a magnet next to a radio your reception can be disturbed.

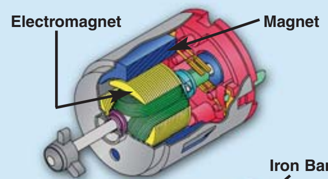


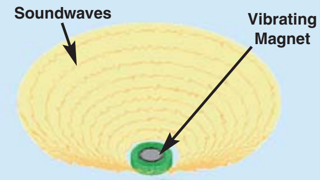
12-2 An Electronic Magnet

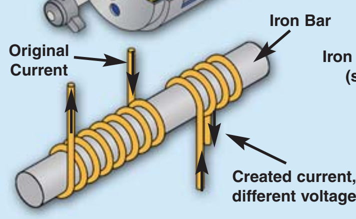
In the preceding chapters you learned how electricity uses magnetism to get things done. Remember that an electric current flowing in a wire has a tiny magnetic field. By looping a long wire into a coil the tiny magnetic field is concentrated into a large one.

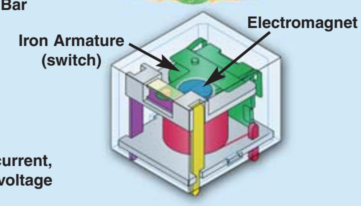


A motor uses a magnetic field to spin a shaft. A transformer creates a current in another circuit using magnetic fields through an iron bar. A speaker uses magnetic fields to create mechanical vibrations, which become sound waves. A relay uses magnetic fields to flip a switch.









All of these create the magnetic field with a current through a coil of wire. But none of these are powerful enough to create a magnetic field like the magnets you have around your house. You need a component that is designed to act like a magnet.

Introducing New Parts

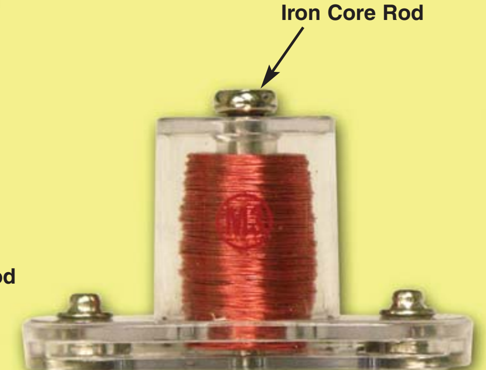
Snap Circuits® includes an electromagnet. If you have the parts with you, then take a look at it; it's just a big coil of wire.

Electromagnet Symbol

Electromagnet (M3)

Placing an iron rod inside the electromagnet concentrates the magnetic effects. Snap Circuits® includes the Iron Core Rod, which fits neatly inside the electromagnet:

Iron Core Rod



In Section 8-3 you learned that inductance describes one coil's ability to affect another using magnetic fields. This also describes a coil's ability to act as an electronic magnet. The inductance of your electromagnet is about 8mH by itself, or about 30mH with the iron core rod inside.

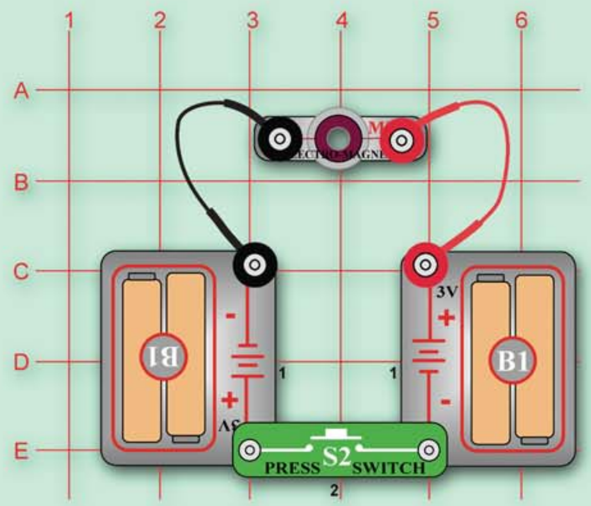
By comparison, the antenna's inductance is only about 0.3mH.

The resistance of the electromagnet is about 25Ω for constant voltages, but this increases for changing voltages.

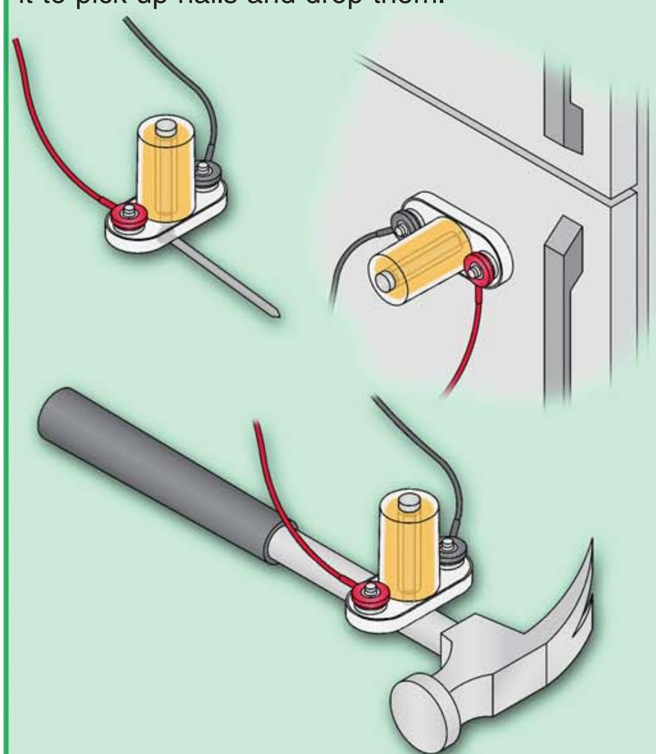
12-3 Magnetic Fields

Experiments

You can use Snap Circuits® to see how electricity makes magnetism. Place the iron core rod inside the electromagnet, hold it next to something iron like a pair of scissors, a hammer, or refrigerator. You won't notice any attraction.

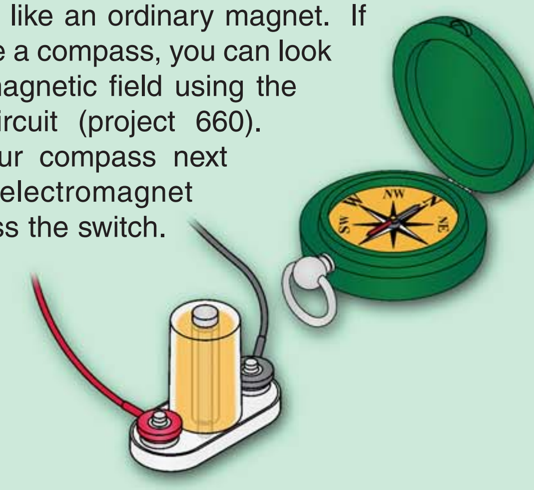


With the wires attached and the iron core rod inside, place the electromagnet next to the same iron objects and press the switch. The electric current through the coil turns the iron core rod into a magnet. It sticks to a refrigerator or hammer but lets go when you release the switch. You can use it to pick up nails and drop them.

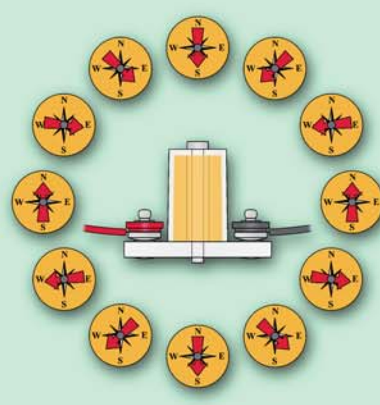


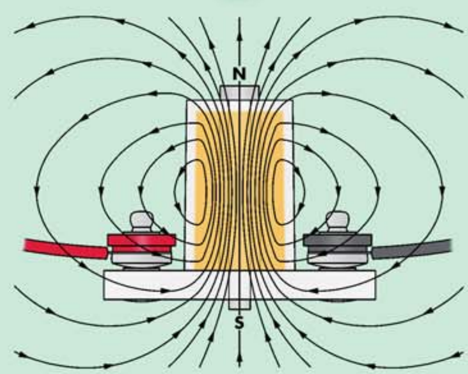
The electromagnet has more power when the batteries are new, so replace them for best results. Don't press the switch continuously, or you will quickly drain your batteries.

An electronic magnet has a magnetic field just like an ordinary magnet. If you have a compass, you can look at the magnetic field using the same circuit (project 660). Hold your compass next to the electromagnet and press the switch.



Move the compass all around the electromagnet and watch where the compass points.



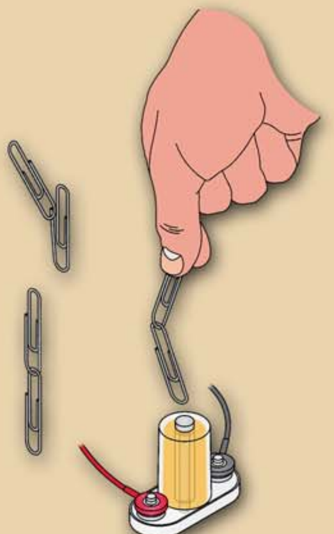


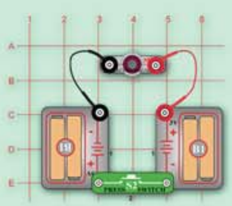
The iron core rod concentrates the magnetic effects. Remove the rod and hold the compass next to the electromagnet again. The attraction is now very weak.

Experiments

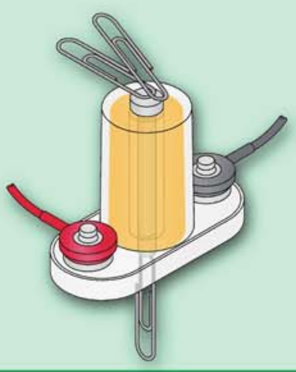
If you don't have a compass, you can make one using metal paperclips. Slide two paperclips together, using their loops.

Hold the paperclips just above the electromagnet, without them touching the iron core rod. Press the switch and watch how the lower paperclip is attracted to the rod. It will point toward it like a compass.

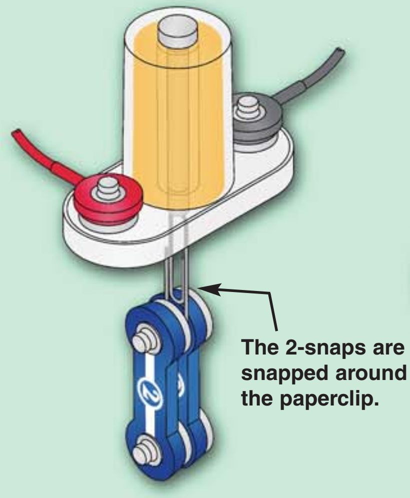


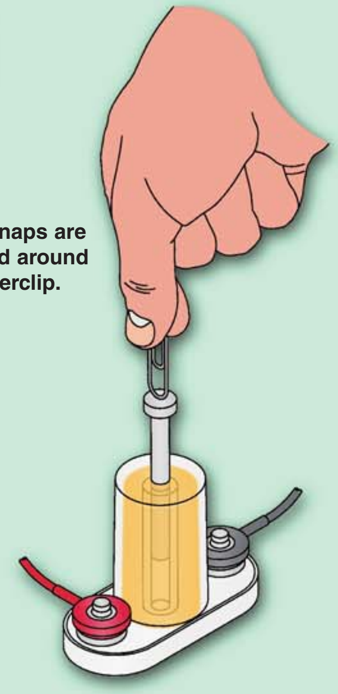


Snap Circuits® includes some paperclips, use the electromagnet to pick up some. Release the switch to drop them.

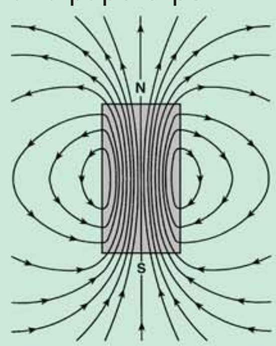


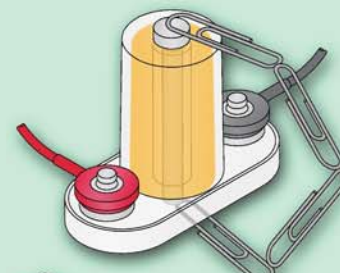
Use the paperclips to pick up things.

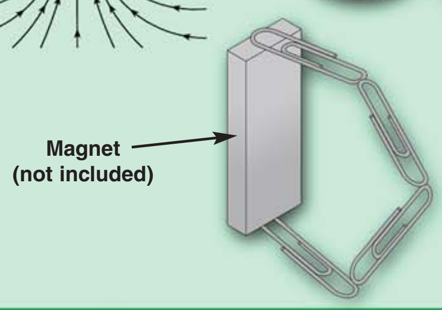




The magnetic field created by a magnet occurs in a loop. You can see this using the electromagnet and paperclips:



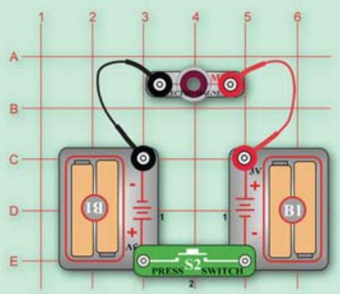




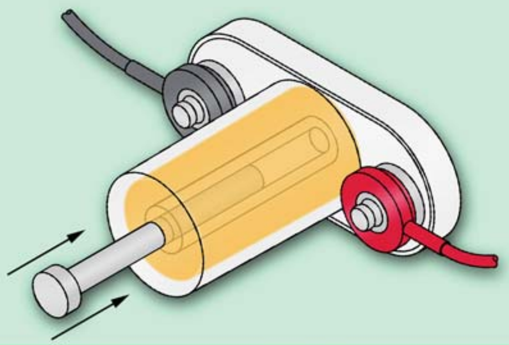
Materials made of iron concentrate their magnetic effects at both ends. The center of the material is magnetically neutral because the attraction from each end is the same.

The magnetic field created by the electromagnet works the same way. It is strongest at both ends but neutral in the center. But the electromagnet is hollow - so iron at one end will be sucked into the middle.

Experiments

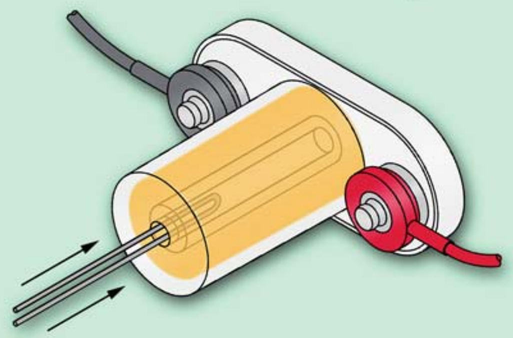


Use the same simple circuit but lay the electromagnet on its side with the iron core rod sticking out about halfway. Press the switch to see the rod get sucked into the center.



A lighter iron object will move better. Straighten out a paperclip, and bend it in half.

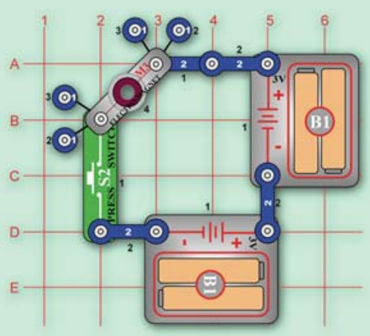
Place it on one side of the electromagnet and press the switch to see it sucked inside. Hold the switch and gently pull it out to see how much suction the electromagnet has.



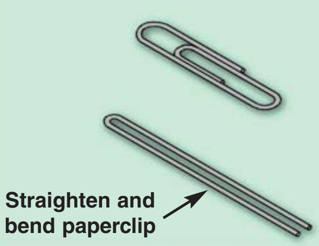
Try sucking in other thin iron objects, like nails.

Experiments

This circuit will use electromagnetism to defy gravity. Mount the electromagnet on the base grid using this circuit (which is project 664).

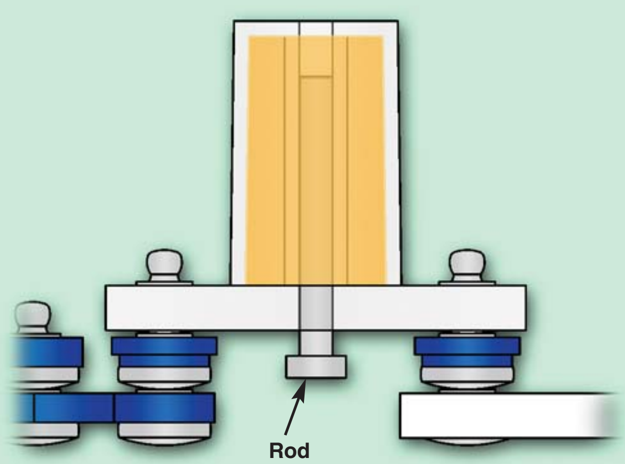


Bend a paperclip as shown, and drop it into the electromagnet. Press the switch to suspend the paperclip in mid-air.



Add two more 1-snaps under the electromagnet to make it higher, and try it again.

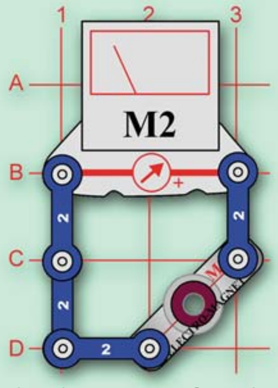
You can also make your electromagnet tower shorter (one 1-snap on each side) and place the iron core rod under it. Then you can suspend the rod in mid-air.



All of the preceding circuits used electricity to create magnetism. But most electricity is made using magnetism, by steam-driven generators in power plants operated by your electric company. These spin a magnet to create a current in a wire.

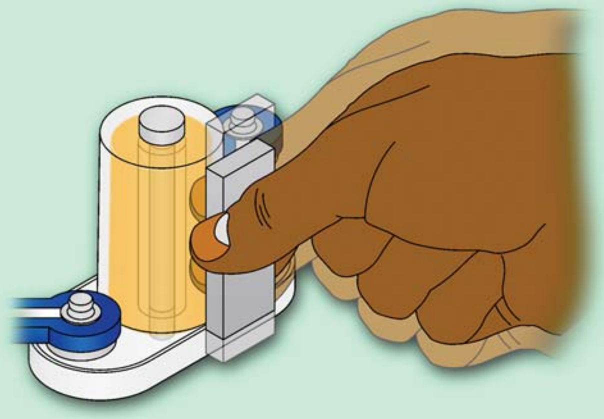
Experiments

If you have a magnet available (Snap Circuits® does not include one), consider this mini-circuit:



Set the meter (M2) to the LOW (or 10mA) setting and place the iron core rod in the electromagnet. This circuit has no batteries and won't do anything by itself.

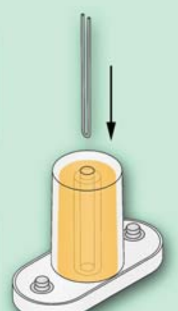
Move your magnet up and down next to the electromagnet. The meter deflects to show that you created an electrical current in the circuit.



12-4 Electromagnetic Oscillators

Experiments

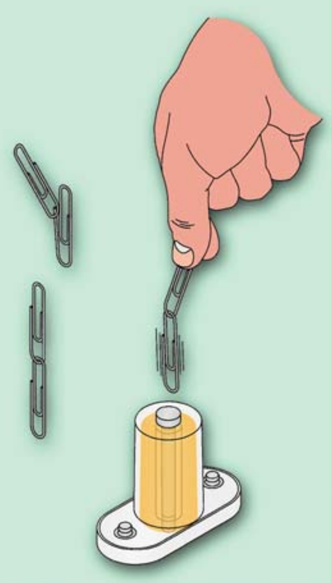
Snap Circuits® will now give you a more dramatic demonstration of how electricity can control magnetic fields in ways ordinary magnets can't. Consider this circuit (which is project 669 or a variation of it):



Straighten and bend a paperclip as shown, and drop it into the electromagnet. Set the adjustable resistor (RV) control lever to the right, and the paperclip gets sucked into the electromagnet. Set the lever to the left and it falls. Now slowly slide the lever until you find a spot where the paperclip is bouncing up and down!

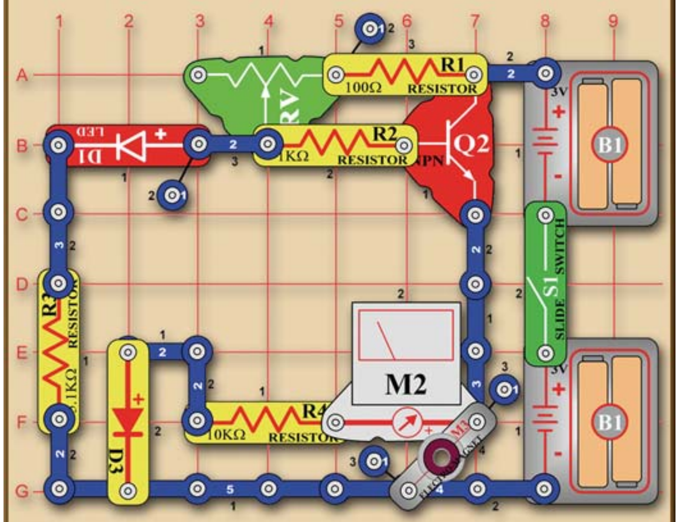
The transistors make an oscillator that turns the electromagnet current on and off. If the oscillator frequency is just right, the paperclip bounces up and down.

For another demonstration, replace the bent paperclip with the iron core rod. Slide two paperclips together using their loops and dangle one above the rod without touching it. Slide the adjustable resistor control lever around to see the lower paperclip vibrate as the magnetic field changes.



Experiments

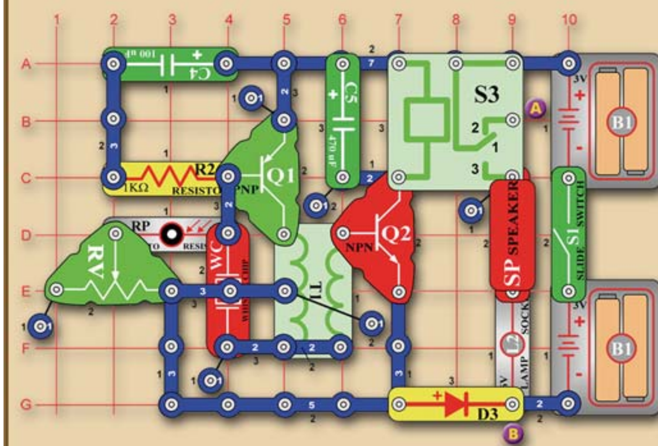
Consider this circuit (which is project 666):



Set the meter to the LOW (or 10mA) scale and drop a bent paperclip into the electromagnet. Move the adjustable resistor control lever to adjust the height of the paperclip above the table. The meter shows how the current changes as you adjust the paperclip height.

Experiments

Consider this circuit (which is project 683):



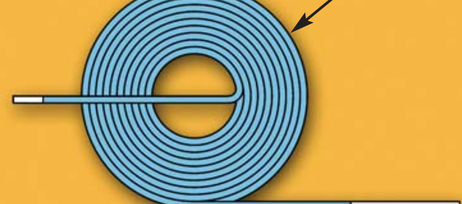
Connect the electromagnet to points A & B using the jumper wires. Hold the electromagnet one inch above the table and drop a bent paperclip into it. Slide the adjustable resistor control lever around and watch the paperclip vibrate. Covering the photoresistor (RP) stops the vibration. You can control the height and frequency of the vibration.

Replace the bent paperclip with the iron core rod. Slide two paperclips together using their loops and dangle one above the rod without touching it. Slide the adjustable resistor control lever around to see the lower paperclip vibrate as the magnetic field changes.

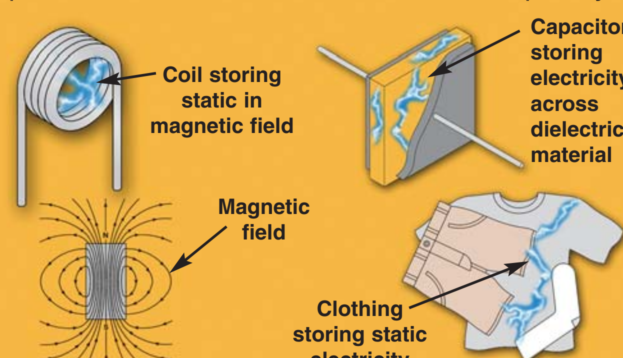
Other paperclip vibration circuits: 667, 668, and 670-682.

12-5 The Anti-Capacitor

Coils of wire like those in the electromagnet, antenna, transformer, relay, and motor can store electricity in a magnetic field. Electricity is needed to set up the magnetic field, and is released into the circuit when the magnetic field collapses. A coil of electricity is like a long garden hose – the water doesn't start or stop immediately when you turn the water on or off.

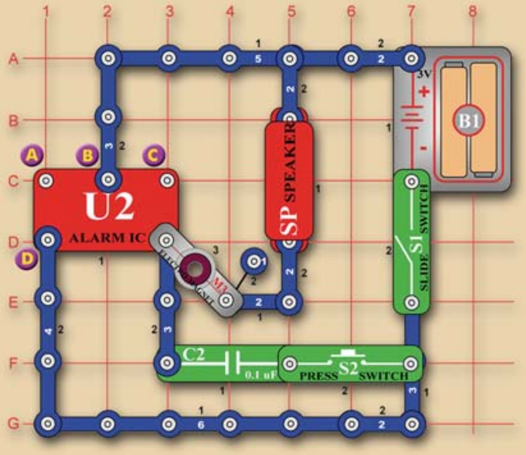


Coils store energy in a magnetic field while capacitors store energy as an electric charge across a material (an electric field). Coils and capacitors have opposite effects on a circuit, but it depends on their construction and the frequency.



Experiments

Consider this circuit (which is project 535 in most manuals):



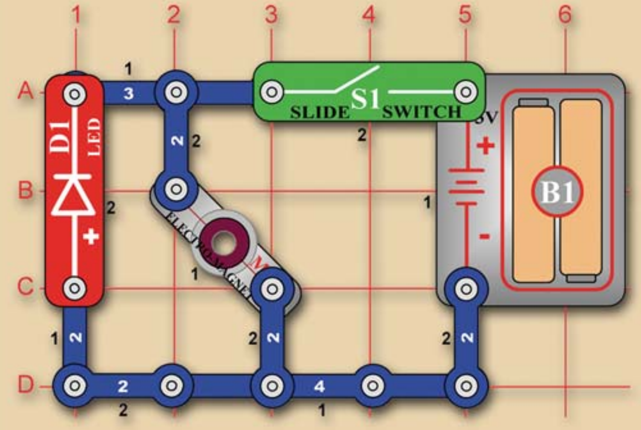
Turn on the slide switch (S1) and the familiar siren sound is badly distorted. The distortion occurs because the electromagnet opposes some of the siren frequencies more than others. You can test it with and without the iron core rod.

Now push the press switch (S2) and the siren sounds more normal. The 0.1μF capacitor counteracts the electromagnet effects.

Now use a jumper wire to connect points A & B, and test the effects using a different alarm sound. Then move the jumper wire to points B & C, then A & D.

Experiments

Consider this circuit (which is project 531 in most manuals):



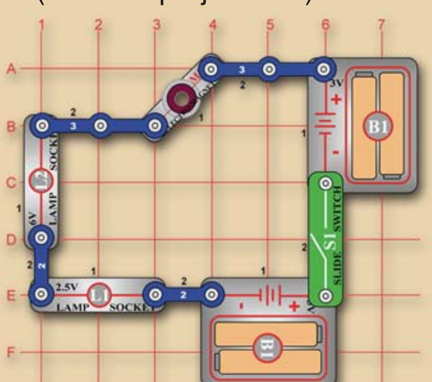
Place the iron core rod in the electromagnet and turn the switch on and off. When the switch is turned off the energy from the electromagnet's magnetic field discharges through the LED.

If you remove the iron core rod then the LED will not flash as brightly, because less energy is stored in the magnetic field.

Snap Circuits® projects 530, 532, 533, and 534 are similar circuits showing that the antenna, transformer, and relay store energy in magnetic fields. Project 529 shows the fan blade storing energy as mechanical motion.

Experiments

The electromagnet is a long wire wrapped in a coil. For constant or slowly changing voltages, its magnetic properties can be ignored and the resistance of the wire is about 25 ohms. Consider this circuit (which is project 658):



The iron core rod isn't needed, because the voltage changes slowly. Notice how lamp L2 takes longer to get bright while lamp L1 gets bright initially but becomes less bright as L2 turns on. Why?

Incandescent lamps like these are made with a high-resistance filament that gets hot enough to glow. The current is higher when a lamp is cold than when the filament has heated up (and has more resistance). This is why bulbs only burn out when you first turn on the light.

Lamps L1 and L2 have low resistance at first because the filaments are cold. The resistance increases as the filaments heat up, and L1's filament heats up faster than L2's.

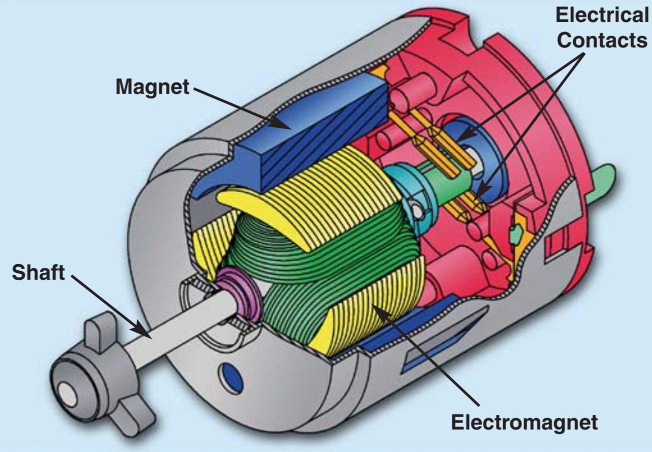
The resistance of the electromagnet lowers the current, so the filaments don't heat up as fast. Compare this circuit to project 152, which will turn on the lamps faster.

Snap Circuits® projects 656 and 657 are variations of project 658.

12-6 More About Motors

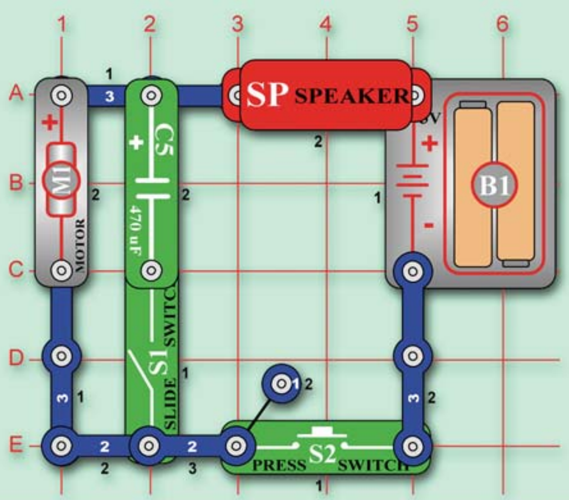
The motor shaft has a coil of wire wrapped around metal plates, just like the electromagnet (M3) with the iron core rod. Current flows in the coil through electrical contacts. The motor shell has a magnet on it. When current flows through the motor coil it repels from the magnet and spins the shaft.

Every half rotation, the electrical contacts are switched to reverse the magnetic field that the magnets are aligning to. This makes the shaft spin continuously, and the switching creates an electrical disturbance.



Experiments

Consider this circuit (which is a variation of project 536):



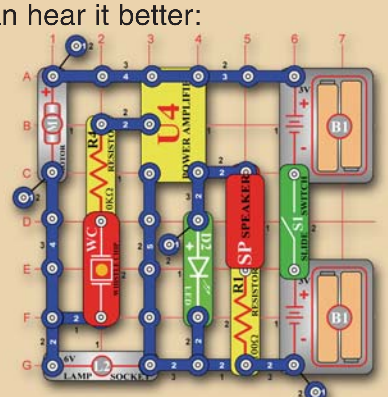
Place the fan on the motor. Push the press switch (S2) and listen carefully to the sound from the speaker. The sound is from the disturbance created when the contacts switch in the motor.

Now turn on the slide switch (S1) to connect the 470µF capacitor across the motor. Listen carefully to the speaker - you don't hear anything from it. The capacitor stores the energy from the disturbance and releases it slowly. In this way the capacitor filters out the disturbance but doesn't affect the speed of the motor.

You can also listen to the sound with the fan off the motor. If you replace the motor with the 2.5V lamp you will not hear anything, because nothing is switching in the lamp.

Experiments

This circuit (which is project 617 or variation of it) amplifies the electrical disturbance from the motor so you can hear it better:



Turn on the switch and listen to the sound. Project 618 is a variation of this circuit using the SCR.

Summary

Summary of Chapter 12:

1. Magnets are materials that concentrate their magnetic fields at opposite ends.

2. A compass needle points north because it is attracted to the earth's magnetic field.

3. An electric current flowing in a coil of wire has a magnetic field.

4. Placing an iron rod inside a coil of wire increases the magnetic effects from a current flowing through the wire.

5. Electricity can use magnetism to move things, and can control magnetic fields in ways ordinary magnets can't.

Quiz

Chapter 12 Practice Problems

1. Which of these would be attracted to an electronic magnet?
   A. A plastic paperclip
   B. A wooden toothpick
   C. An iron screw
   D. A resistor

2. How can you increase the magnetic field from the electromagnet?
   A. Increase the current through the electromagnet.
   B. Remove the iron core rod from the electromagnet.
   C. Place a resistor in series with the electromagnet.
   D. Decrease the current through the electromagnet.

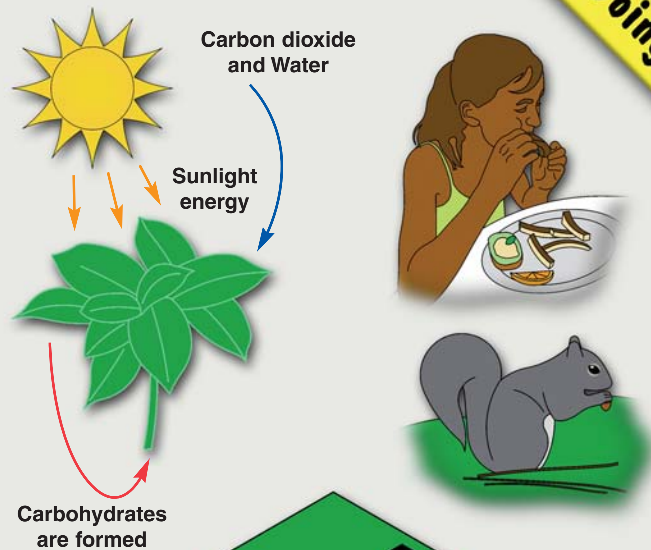
3. Which of these is an advantage of using an electromagnet instead of an ordinary magnet?
   A. An electromagnet can attract materials that aren't attracted to ordinary magnets.
   B. An electromagnet can be used as a compass.
   C. You can turn the magnetic field on and off quickly by controlling the current through an electromagnet.
   D. None of the above.

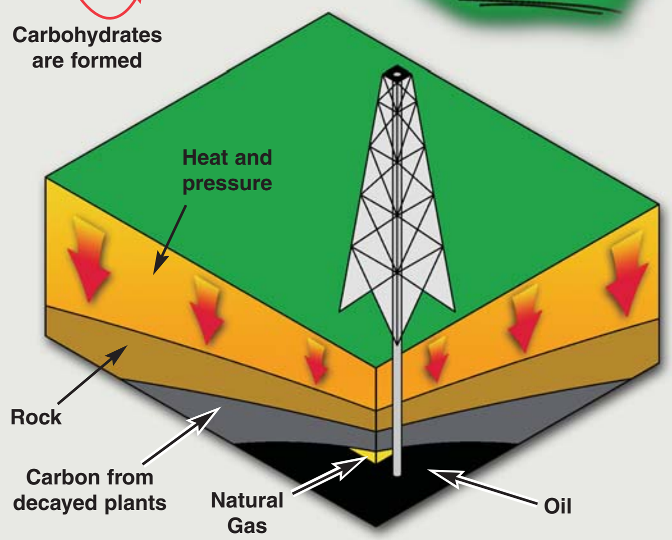
4. Which has the most inductance?
   A. The 470μF capacitor
   B. The electromagnet with the iron core rod inside.
   C. The antenna
   D. The 6V lamp

Answers: 1. C, 2. A, 3. C, 4. B

CHAPTER 13: SUN POWER

The sun produces heat and light on an immense scale, by transforming Hydrogen gas into Helium gas. This "transformation" is a thermonuclear reaction, similar to the explosion of a Hydrogen bomb. The earth is protected from most of this heat and radiation by being so far away, and by its atmosphere. But even here the sun still has power, since it can make the street hot to walk on and give you sunburn on a hot day.



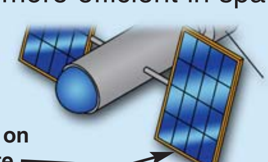


Nearly all of the energy in any form on the surface of the earth originally came from the sun. Plants get energy for growth from the sun using a process called photosynthesis. People and animals get energy for growth by eating plants (and other animals). Fossil fuels such as oil and coal that power most of our society are the decayed remains of plants from long ago. These fuels exist in large but limited quantity, and are rapidly being consumed.

In this chapter you will learn how solar cells work. With Snap Circuits® you will understand many of the uses and limitations of solar power.

13-1 Born in the Space Program

The solar panel is a photovoltaic cell, with photo meaning light and voltaic meaning that it produces electricity. Photovoltaic cells were first developed for the space program, to recharge batteries and power various systems in spacecraft and satellites. Although they were expensive, they saved money because heavier batteries or other fuel sources did not have to be launched into earth's orbit on very expensive rockets. The sun's brightness is reduced when it passes through the earth's atmosphere, so solar cells are more efficient in space.



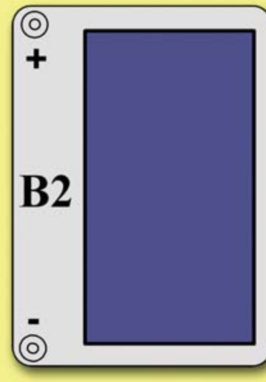
Solar Cell on a Satellite

Solar cells are used to power most satellites because they are lightweight and never wear out (sending a serviceman to do maintenance on a satellite is extremely expensive). Over the years manufacturing processes for photovoltaic cells have improved and reduced costs, and now they are used in many common products on earth such as calculators. It is likely that a large portion of America's electricity will be produced from solar cells by the end of this century.

Introducing New Parts

Snap Circuits® includes a solar cell, which is a flat panel mounted on a white platform. A solar cell creates a voltage like a battery and is controlled by light like a photoresistor. A common schematic symbol for it is a combination of the battery and photoresistor symbols.

Solar Cell Symbol

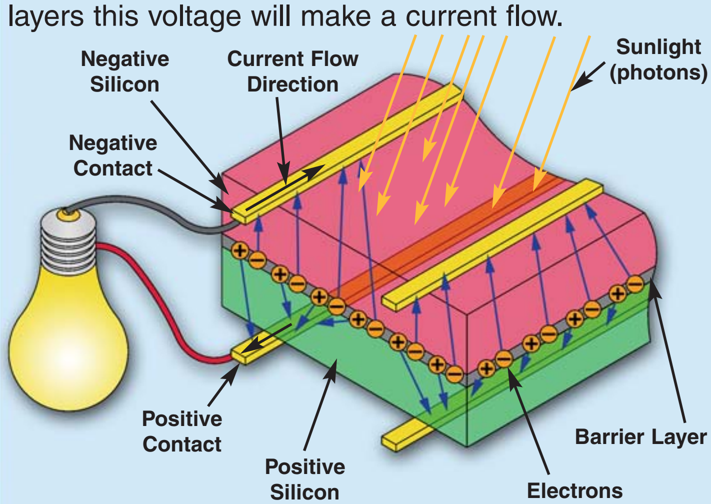


Solar Cell (B2)

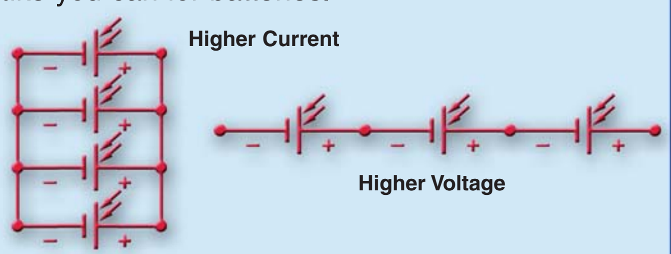
13-2 How Your Solar Cell Works

Your solar panel is made from silicon, like the transistors and microprocessors used throughout the electronics industry. Silicon is easy to find, since ordinary sand contains mostly silicon.

The silicon is refined into two layers of very pure crystal, but tiny amounts of different minerals (such as Boron and Phosphorus) are added to give one side a positive electrical charge and the other side a negative charge. These opposite charges cancel each other out, producing a neutral cell. When sunlight shines on the silicon crystal, charged particles in the light unbalance the cell and create an electrical charge across it (voltage). By connecting wires to the positive and negative layers this voltage will make a current flow.



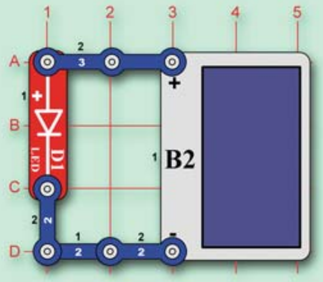
Your solar panel produces a voltage of about 3V, which is determined by the characteristics of the silicon material. The current produced is determined by the size of the crystal cell, and the brightness and type of light that shines on it (typically 20mA in bright sunlight). Although the current available from solar cells like yours is relatively low (for example, a 1.5V "AA" battery can supply 300mA), you could get higher currents by increasing the size of the solar cell or by placing several cells in parallel. You could increase the voltage by placing several solar cells in series just like you can for batteries.



Silicon crystals can convert as much as 15% of the energy in sunlight into electricity, but different types of light are not nearly as effective. Bright sunlight is best, and will enable the cell to supply the most current. "Yellow light" incandescent light bulbs (used in house lamps) will work with most circuits but "white light" fluorescent light bulbs (used in the overhead lights in offices, stores, and schools) may not work at all.

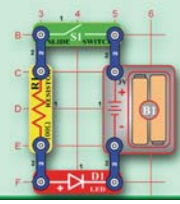
Experiments

The best way to understand the solar cell is to use it. Consider this circuit (which is similar to project 549):

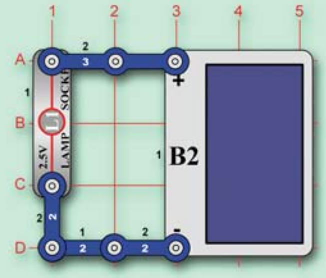


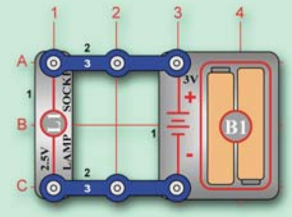
Place this circuit near different types of lights and see how brightly the LED (D1) shines. Compare how it works with bright sunlight, incandescent light bulbs, and fluorescent lights if these are available.

Note that this LED circuit does not have a resistor to limit the current, like project 7 does.



The reason there is no resistor is that the solar cell cannot produce enough current to damage the LED, but the batteries can. To demonstrate this, compare these two circuits:

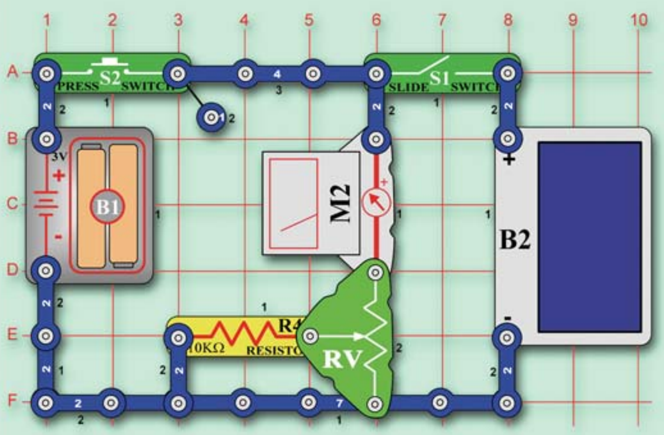




Even if you place the solar cell circuit in bright sunlight it will not light the lamp. The difference in performance between the solar cell and batteries will be easier to see with a meter.

Experiments

Consider this circuit (which is project 555 or a variation of it):



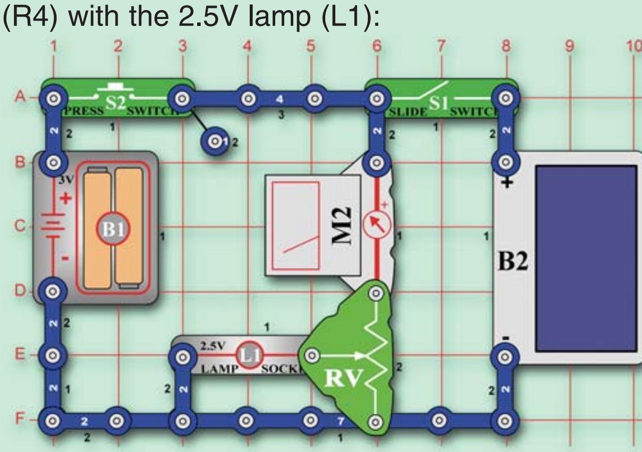
Set the meter (M2) to the LOW (or 10mA) setting. Press the press switch (S2) and set the adjustable resistor (RV) so that the meter reads “5”, then release it. Turn on the slide switch (S1) and vary the brightness of light on the solar cell. Try different light sources and partially covering the solar cell.

The meter measures the current through the adjustable resistor, so if the current increases then the voltage must have increased. Since the voltage from the batteries is 3V, if the meter reading is higher than “5” then the solar cell voltage is greater than 3V.

The current also changes if you change the circuit resistance, so you can also change the meter reading by changing the adjustable resistor setting.

If you have rechargeable batteries and your solar cell voltage is higher, then turning on both switches at the same time will use the solar cell to recharge your batteries.

Modify the circuit by replacing the 10kΩ resistor (R4) with the 2.5V lamp (L1):

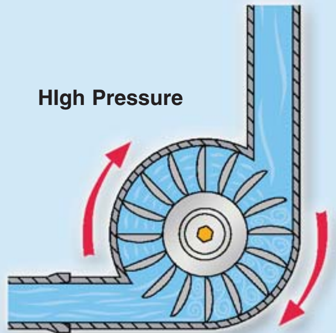


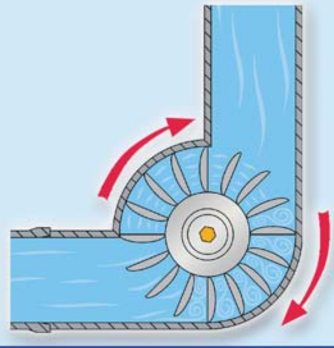
Set the meter to the HIGH (or 1A) setting and set the adjustable resistor to the top setting (so there is 0Ω between the meter and lamp). Press and release the press switch (S2). The lamp turns on and the meter deflects, showing that a current flows.

Now turn on the slide switch (S1) and shine a bright light on the solar cell. Nothing happens, because the solar cell cannot produce enough current to light the bulb or deflect the meter on the high scale.

When a power source cannot supply enough current, the voltage drops. For example, when power plants cannot supply enough current to a city during high demand, the voltage drops below the normal 120V. Compare this to how a small pump can pump water through a small pipe at high pressure, or through a large pipe at low pressure.

Although the limited current from your solar cell may seem like a big disadvantage of solar power, large arrays of solar cells in series and in parallel can be combined to supply high currents at high voltages. These could power satellites in space or homes/buildings in remote areas.

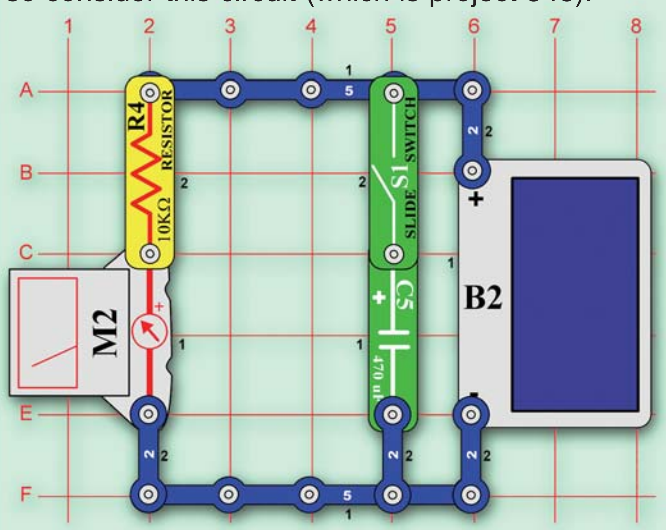




13-3 More Solar Cell Circuits

Experiments

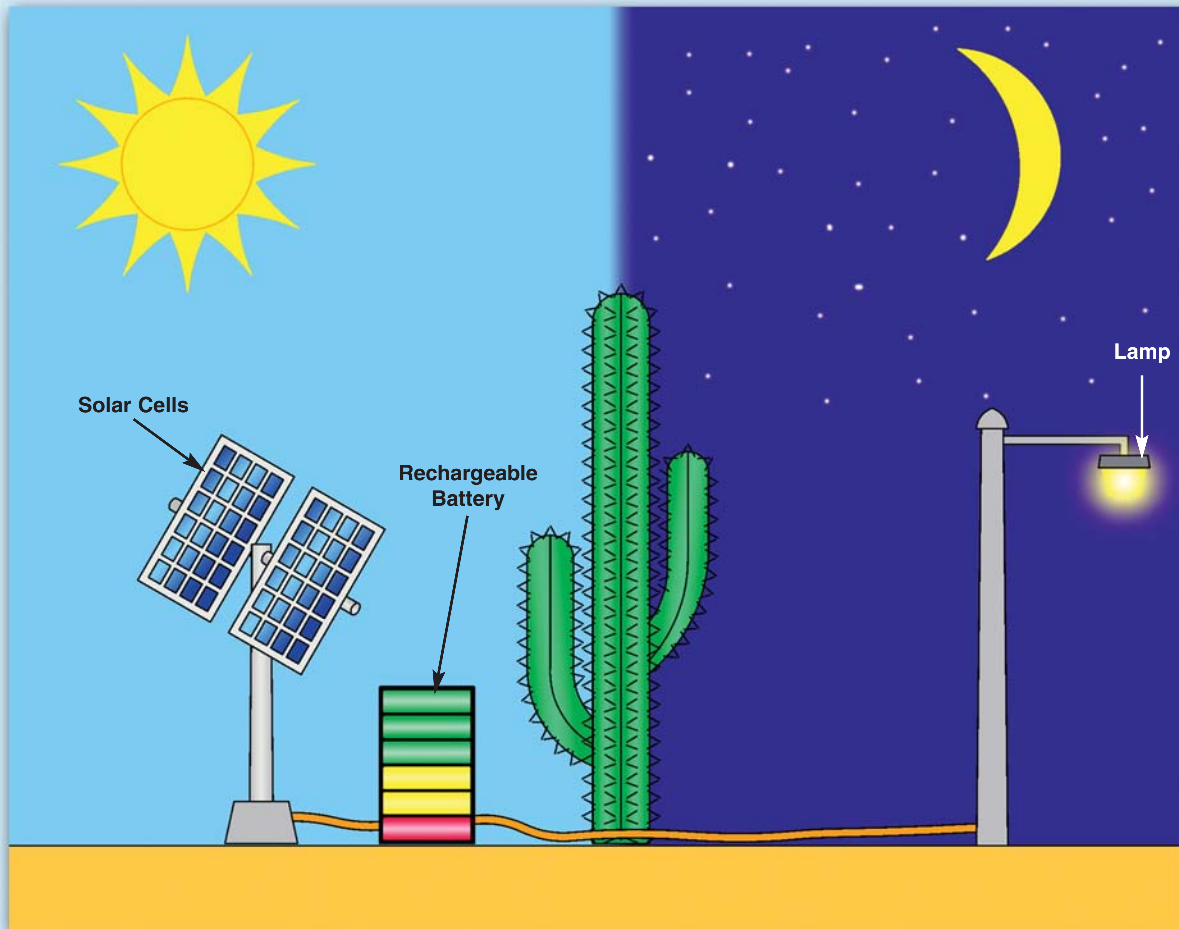
Rechargeable batteries allow the electricity-producing chemical reaction to be reversed. Since the sun isn't always shining, solar cells are often used along with rechargeable batteries. A capacitor can be used like a rechargeable battery, so consider this circuit (which is project 548):



Use the LOW (or 10mA) scale on the meter and turn off the slide switch. Vary the current measured on the meter by moving your hand over the solar cell to block the light.

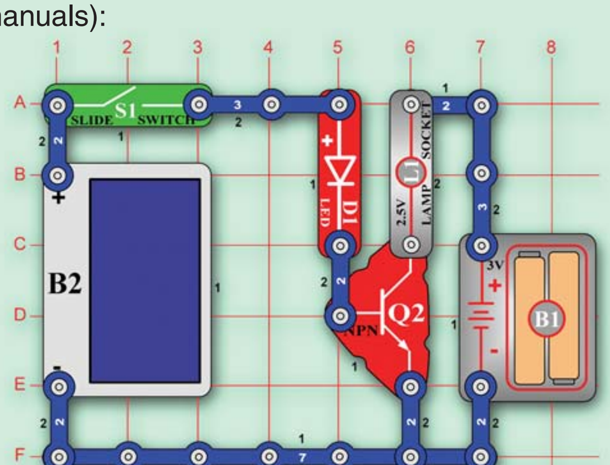
Now turn the switch on and watch the meter as you wave your hand over the solar cell. Now the meter current drops slowly when the light is blocked because the 470μF capacitor (C5) is acting like a rechargeable battery. When the light shines the solar cell powers the circuit and charges the capacitor. When the light is blocked (perhaps due to clouds) the capacitor powers the circuit as it discharges.

Solar cells operate best when bright sunlight is available at all times. Unfortunately, most areas of the United States only get about 4-5 hours of direct sunlight per day on average. The electricity needs of people vary throughout the day, whether or not the sun is shining. Because of this, most solar cell arrays are used to charge rechargeable batteries. The batteries provide for people's electricity needs throughout the day, and are recharged whenever the sun shines. Solar power is often used in remote desert areas, because it is too expensive to build electricity distribution networks to them.



Experiments

The solar cell cannot produce enough current to power a lamp, but it can be used to control one. Consider this circuit (which is project 550 in most manuals):

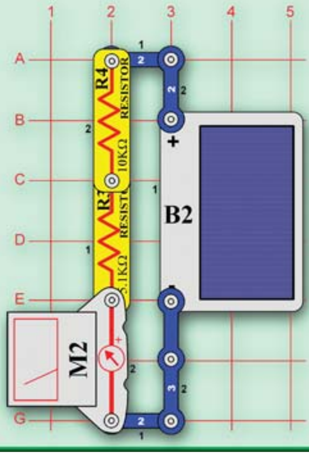


If sunlight shines on the solar cell then it will turn on the red LED and the NPN transistor, which turns on battery power to the 2.5V lamp.

You could replace the lamp with the motor and fan in this circuit. Then you can control the motor speed by partially blocking the light to the solar cell with your hand.

Experiments

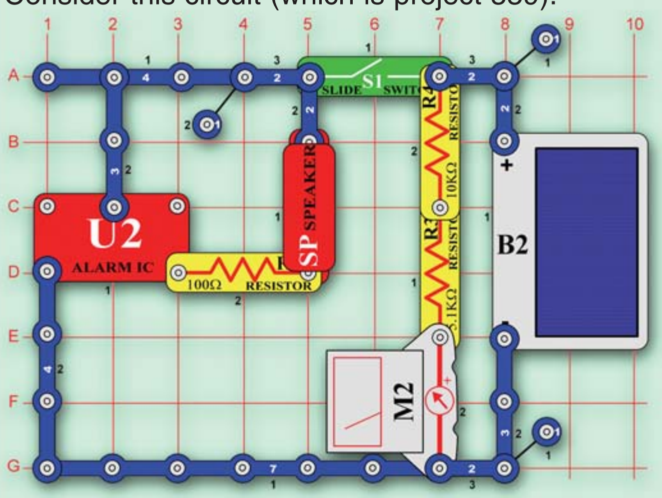
Many of your Snap Circuits® projects will not work properly if your batteries are very weak. And most projects that use the solar cell will not work if there isn't enough light on the solar cell. You need a light meter:



This mini-circuit measures the light on the solar cell, to see if it can produce enough voltage and current to power a circuit. It will be used in some of the next circuits. Always use the LOW (or 10mA) meter setting.

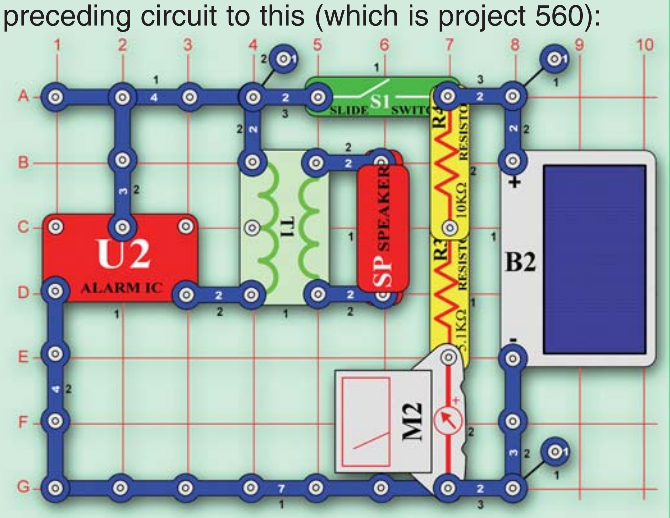
Experiments

Consider this circuit (which is project 559):



This circuit uses the solar cell to make a siren sound. With the slide switch off and the meter on the LOW (or 10mA) setting, make sure you have a bright light on the solar cell so the meter reads 10 or higher. The speaker needs a high current to make sound, so you will need bright sunlight or an incandescent lamp.

The speaker needs high current but only low voltage, while the solar cell produces a high voltage but low current. This is an ideal situation for a transformer, which changes the voltage/current level of a circuit using magnetism. Change the preceding circuit to this (which is project 560):

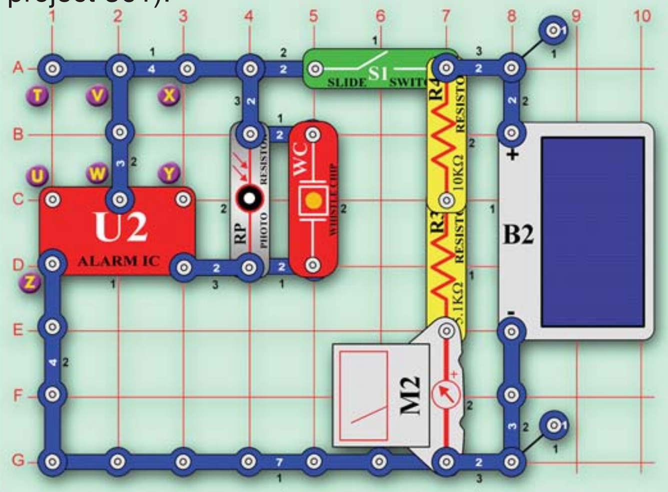


This transformer circuit is louder and only needs a meter reading of 8 or higher with the switch off.

If you flip the transformer around then its effects are reversed and there will be little or no sound.

Experiments

Now change the preceding circuit to use the whistle chip (WC) instead of the speaker (as in project 561):



This circuit is not as loud but only needs a meter reading of 6 or more with the switch off. The whistle chip needs less current than the speaker, but its sound is not as clear.

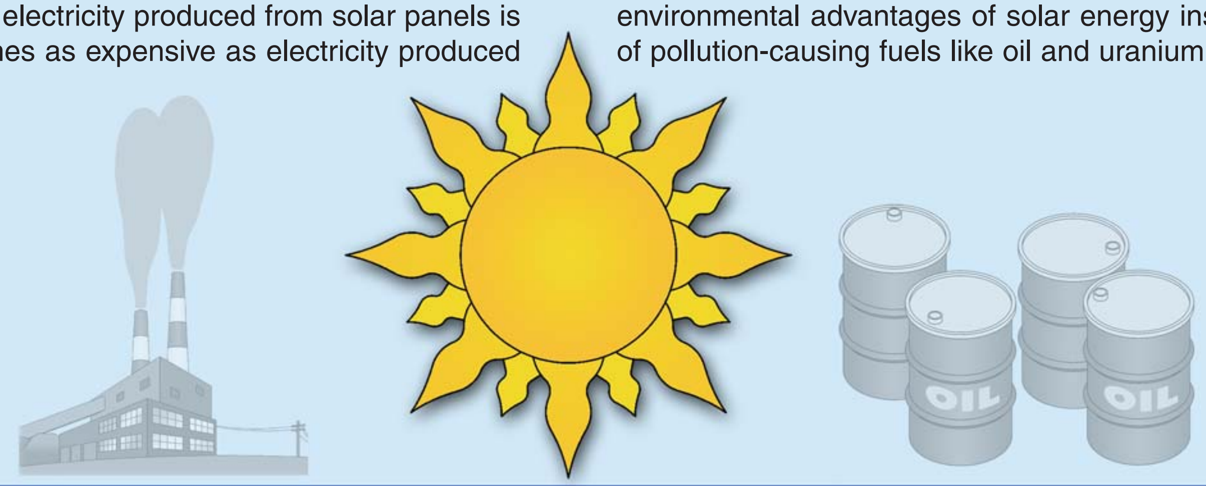
Other solar cell projects: 528, 551-554, 556-558, 562-564 (music circuits), 566-567 (flashing lights), 568 (AM radio transmitter), 569-573 and 575-576 (oscillator circuits), 574 (lamp with SCR), and 577 (space sounds with SCR). Also, solar projects 526 and 542 will be discussed in section 14-2.

13-4 Our Solar Future

Although the solar cell may not run all of your circuits as well as the batteries can, it demonstrates the importance of solar energy for our society. With energy costs and pollution rising, the limitless supply of pollution-free solar energy will have an ever-increasing role in meeting our world's energy needs. Since the sun will always be bright, solar energy will always be available. Solar panels are quiet, clean, and will last for years since they don't have any moving parts that could wear out.

Right now electricity produced from solar panels is several times as expensive as electricity produced by normal energy sources. But that is changing as technological and manufacturing improvements make solar panels less expensive and more efficient. Scientists are constantly experimenting with new ways to capture the energy radiated from our sun. More and more products are being developed that use solar panels as their power source.

Solar power will have an important role in meeting America's electricity needs of the 21st century. It is important to educate everyone about the environmental advantages of solar energy instead of pollution-causing fuels like oil and uranium.



Summary

Summary of Chapter 13:

1. Most of the energy on the earth's surface originally came from the sun.

2. The voltage produced by a solar cell depends on the material used, and the current produced depends on the size of the cell and the brightness of the light.

3. Large arrays of solar cells may be combined to supply high currents at high voltages.

4. Solar cells are often used with rechargeable batteries, because the sun isn't always shining when you need electricity.

5. Solar energy is pollution-free.

Quiz

Chapter 13 Practice Problems

1. Which of these light sources will produce the most electricity from a solar cell?
   A. An incandescent light bulb
   B. Bright sunlight
   C. A fluorescent light bulb
   D. Dim sunlight, like on a cloudy day

2. Approximately how much of the energy in sunlight can solar cells convert into electricity?
   A. 95% C. 2%
   B. 15% D. Less than 0.1%

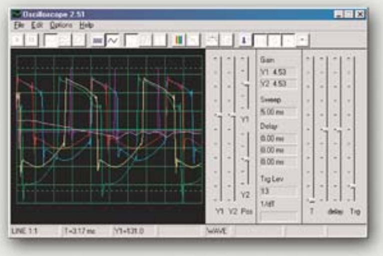
3. What happens when a solar cell cannot supply enough current to a circuit?
   A. The solar cell melts.
   B. The voltage from the solar cell increases.
   C. The voltage from the solar cell drops.
   D. None of the above.

4. Which of these statements is WRONG?
   A. Solar cells are noisy.
   B. Solar cells have no moving parts that could wear out.
   C. The cost of solar cells is decreasing.
   D. Solar cells are often used on spacecraft.

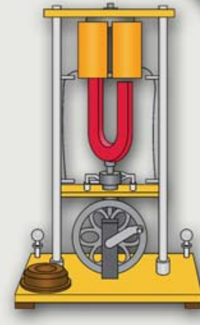
Answers: 1. B, 2. B, 3. C, 4. A

CHAPTER 14: MORE CIRCUITS & NEW WAYS TO LOOK AT THEM

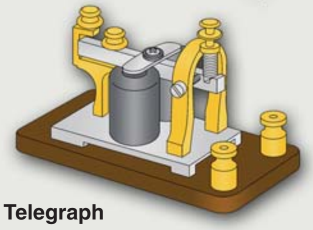
This chapter will show you a number of diverse applications, while reinforcing what you already learned. You will also see what electrical signals look like to engineers, and learn about the tools engineers use to study them.



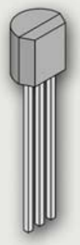
Light Bulb



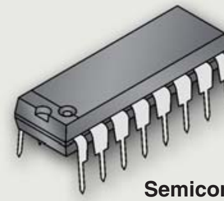
Generator



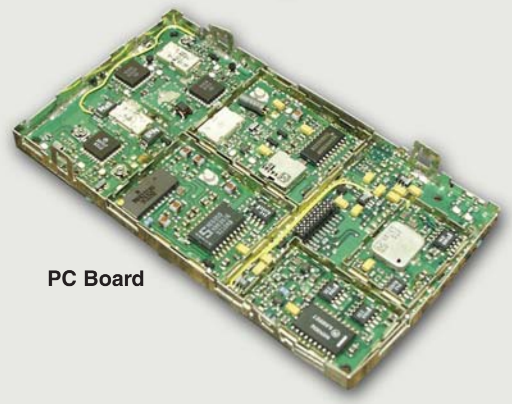
Telegraph



Transistor



Semiconductor



PC Board

Electricity is used in so many different ways that it's impossible to imagine them all. The scientists who discovered electricity in the 18th century could not have dreamed of the things that we do with it today. The 19th century saw the development of motors, generators, light bulbs, and the telegraph. Engineers of the 20th century developed printed circuit boards, transistors, integrated circuits, solar cells, and radio. What will be invented this century?

Right now engineers are designing new circuits and imagining the applications of the future. Maybe some day you will be one of them.

14-1 Vibration Switch

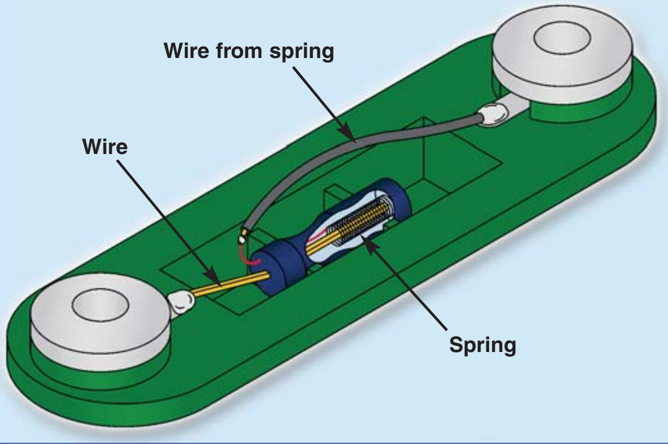
Introducing New Parts

Snap Circuits® includes a vibration switch (S4):

Vibration Switch (S4)

Vibration Switch Symbol

One side of the vibration switch connects to a spring, the other side connects to a wire through the spring. When the switch is shaken, the spring bounces to open or close the circuit.

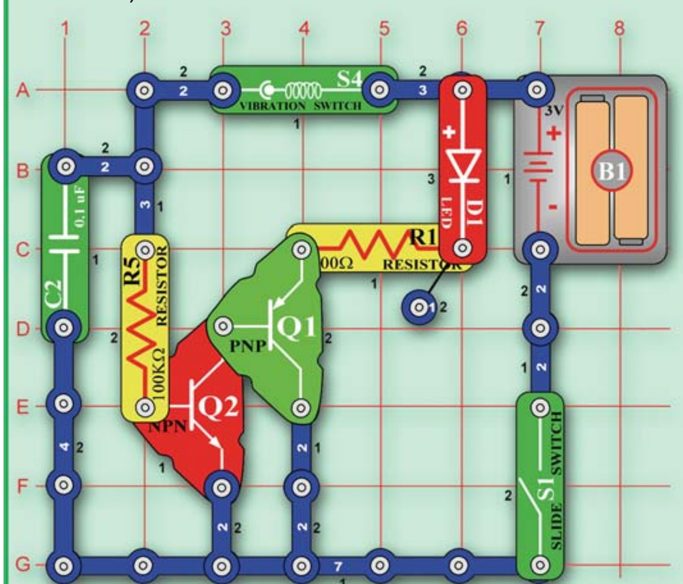


A vibration switch is used to activate a circuit when something happens. They are often used in toys to make sounds when you pick them up.

The vibration switch is sensitive and should only be used with small currents.

Experiments

Consider this circuit (which is project 684 in most manuals):



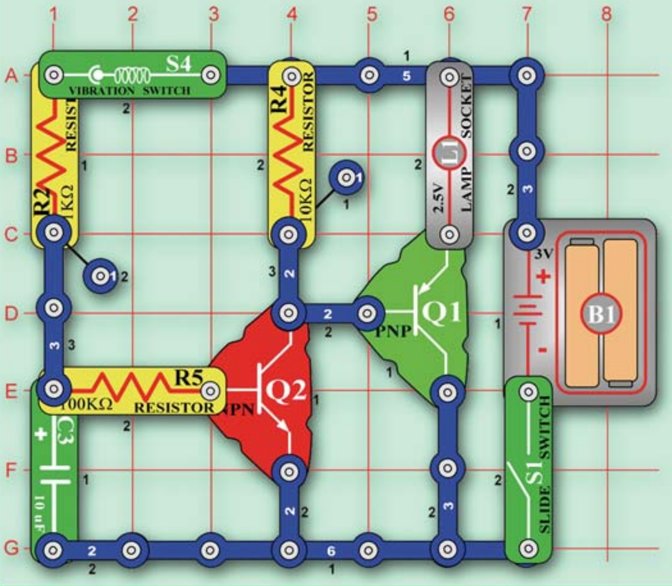
Turn on the slide switch (S1). Tap the vibration switch or bang on the table, the LED (D1) will light briefly. The vibration switch uses the transistors to control a large current.

When shaken, the vibration switch opens and closes many times. The 0.1μF capacitor (C2) stores up electricity from the batteries while the switch is closed, and releases it to keep the transistors on when the switch is open. This way it takes a bigger shock to turn on the LED but it stays on longer. Remove C2 from the circuit to see the difference it makes.

Remove the vibration switch and re-connect it to the same circuit location using the red and black jumper wires. Shake it to turn on the LED. Shake it in different directions to see which it is most sensitive to.

Experiments

Consider this circuit (which is project 692 in most manuals):

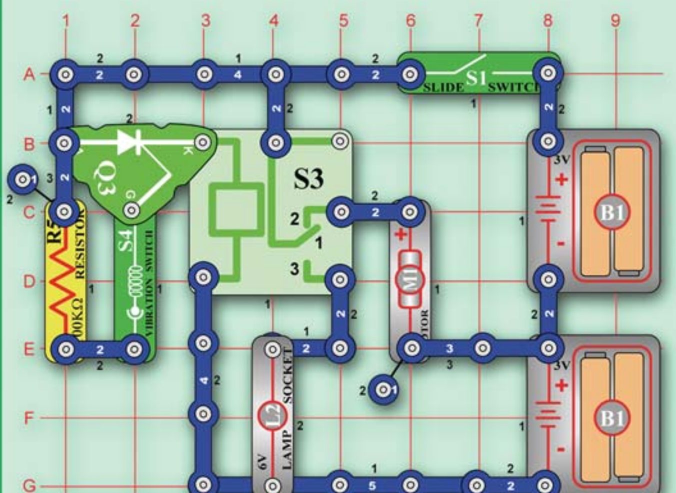


Turn on the slide switch (S1). Tap the vibration switch or bang on the table continuously. The lamp (L1) will light. This circuit uses the larger 10μF capacitor (C3) and the lamp. It needs a longer vibration to activate, but the lamp is brighter.

If you replace the 100KΩ resistor with the 5.1KΩ, the lamp will turn on faster but also turn off faster.

Experiments

Consider this circuit (which is project 689 in most manuals):



Turn on the slide switch (S1), and the motor spins the fan. Tap on the vibration switch or bang on the table. The vibration switch activates the SCR, which turns on the relay. The relay turns off the motor and turns on the lamp.

The vibration switch triggers the SCR, which controls the motor and lamp using the relay. A circuit like this could be used to monitor a motor. If the motor gets out of control and vibrates a lot, the SCR could turn it off and flash an alert.

The SCR is used here instead of a transistor, because it stays on after being triggered.

Other vibration switch circuits: 685-688 and 690-691.

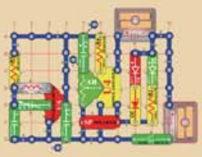
14-2 Other Applications

Experiments

Projects 513 and 520 are low-frequency transistor oscillator circuits (see section 9-4).

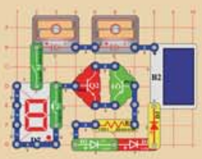
Project 526 shows that electronics uses many forms of output to interface with people. This circuit has six different outputs: motion (motor and meter), sound (speaker), and light (LED, lamp, and display).

Projects 527 and 623 are other AM radio circuits (see section 8-5).

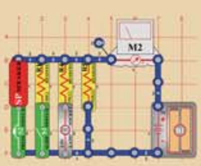


Projects 537-538 explain why the motor draws less current as it speeds up.

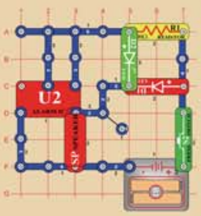
Project 542 shows how it takes a lot of voltage to turn on many diodes connected in series. By combining the diode effects from six parts, a turn-on voltage of more than 6V is needed. It is produced using both 3V battery sets and the solar cell.



Projects 543-547 and 659 compare the current used by the motor, lamps, speaker, electro-magnet, and resistors. You will see how much resistors limit circuit current. Both meter settings are used.



Projects 578-581 have laser sounds and flashing lights.



Project 583 uses the space war IC to control the meter using the power amplifier IC.

Projects 584-587 demonstrate transformer properties. Remember that the connection across the transformer is magnetic, not electric.

Projects 589-591 make an oscillator with the relay. The relay is connected to turn itself on and off repeatedly. This makes a changing voltage which crosses the transformer using magnetism, and lights the LEDs.

Projects 588, 592, and 593 make an oscillator with the relay. The relay is connected to turn itself on and off repeatedly.

Projects 594 and 601-604 have the alarm IC controlling motion (motor and meter), sound (whistle chip), and light (LEDs, through the transformer).

Projects 595-600 have alarm sounds, buzzing sounds, and flashing lights.

Projects 605-613 use the alarm IC to make the 7-segment display flash different numbers or letters. Projects 614-616 are other variations controlled by light or touch.

Projects 619-621 show the difference between the SCR and NPN transistor by using them in almost identical sub-circuits.

Project 622 can make current flow in different directions.

Experiments

Project 624 is another recording IC circuit (see section 10-3).

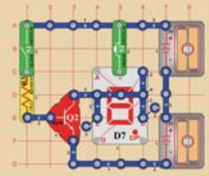
Projects 625-627 flash the LEDs by making an oscillator with the power amplifying IC.

Projects 628, 630, and 631 are transistor oscillators that spin the motor in small bursts.

Projects 629, 633-636, and 652 are transistor oscillators that make some sound effects with the music ICs and relay.

Projects 637-640 and 646-649 are transistor oscillator circuits that make cute sounds or flash lights.

Projects 641-645 review and expand on the introduction to logic in section 3-8. AND, NAND, OR, NOR, and exclusive OR gates are demonstrated, and logic charts are introduced.



Projects 650, 651, and 655 flash the display and LEDs, controlled by the alarm IC. Some also have music and the fan spinning.

Projects 632, 653, and 654 play music, spin the motor, and flash lights, controlled by the music IC.

Introducing New Parts

Snap Circuits® includes a two-spring socket (?1):

The two-spring socket is provided to make it easy to connect your own electronic parts to Snap Circuits®. See page 3 of the Projects 512-692 experiment manual for more information about it.

14-3 The Snap Circuits® Computer Interface

Electronics engineers use specialized test equipment to "see" electrical signals. They use an oscilloscope to look at the waveform of the signal and use a spectrum analyzer to look at its frequency content. This equipment is specialized and usually very expensive.

Engineers use them to make performance measurements on a signal, and to view the relationship between signals in a circuit. It's important to find out what's happening within a circuit, because it's hard to fix something without looking inside it.

Snap Circuits® includes software that simulates this equipment using your computer (PC only). The CI-73 computer interface is described in the Projects PC1-PC73 experiment manual; this section is only an introduction to it. The computer interface is only for advanced students.

The software program is called Winscope and comes on a CD. A PC-interface cable is included. It is connected from the output of Snap Circuits® to the microphone input port on your computer.

Pages 1-5 in the Projects PC1-PC73 experiment manual show how to set up Winscope and explain its limitations. Projects PC1-PC3 explain how to use Winscope and its features.

How does the computer view the electrical signal? It measures the microphone input and records a series of numbers as described in section 3-9 (Digital Electronics). The result is displayed as a graph in oscilloscope mode. The accuracy of the data it takes depends on the resolution of the measurement and how frequently it takes a measurement. If you try to measure a signal that is changing too fast, you will only see an erratic series of straight lines. For spectrum analyzer mode, the computer does a mathematical transformation (called an FFT) on the data to look at frequency spectrum.

All of the features shown in Winscope (such as adjusting the gain or time scale, storage mode, and triggering) are available in most oscilloscopes and spectrum analyzers used by engineers.

Winscope works best for repeating signals with a frequency of 20 - 5,000Hz. This is due to the microphone input design (which is for audio signals in this range) and the measurement speed of the software. You can connect Winscope anywhere in a circuit but projects PC1-PC73 all connect it to view the output. The output is most interesting, and lets you compare what you see in the signal to what you hear/see from the circuit. Most signals studied are repetitive, since these are easier to view.

Here are some highlights from projects PC1-PC73:

Project PC1: Shows that a tone consists of one strong frequency and many multiples of it at lower amplitudes. It also shows that adding capacitance to an oscillator (lowering the tone of the sound) widens the spacing in oscilloscope mode and lowers the frequency spacing in FFT mode.

Projects PC4-PC7: Shows how the alarm IC makes different siren sounds by changing characteristics of the signal.

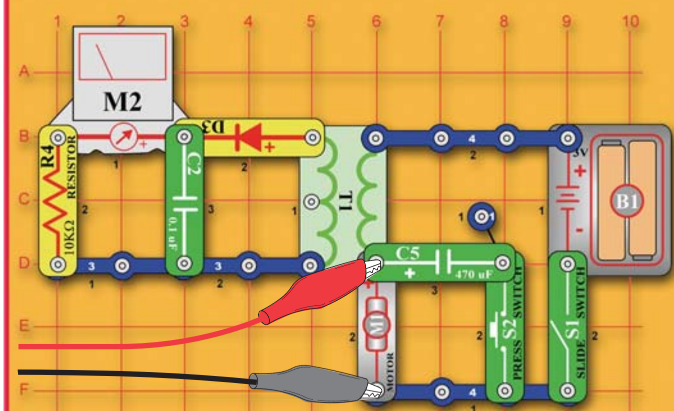
Project PC10: This is an example of modulation (see section 8-4) and filtering.

Project PC12: View the voice signal from a radio.

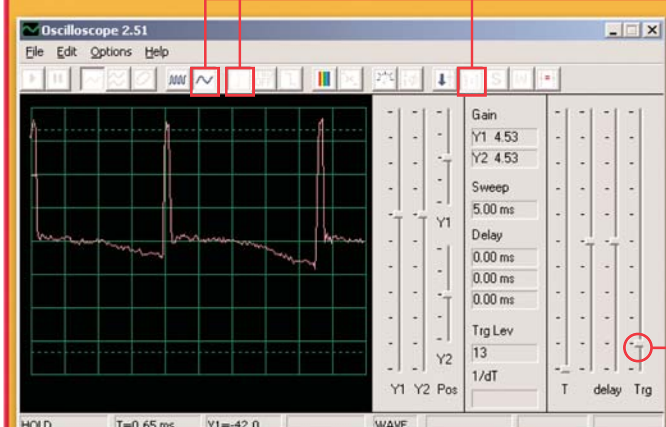
Project PC14: Shows what your voice looks like, and some sound patterns you can make.

Experiments

Use Winscope to take a closer look at this circuit (project 523, which you studied in section 10-1):

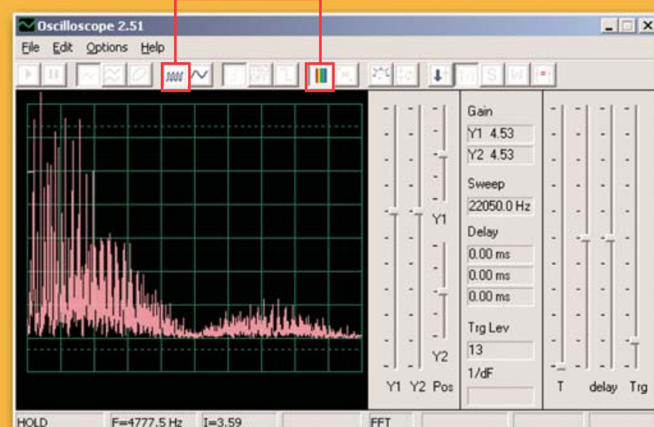


Place the fan on the motor and turn on the slide switch (S1). As the motor spins it connects/disconnects sets of electrical contacts that keep the magnetic field from a coil spinning the shaft. This creates an electrical disturbance which crosses the transformer and moves the meter. Use the Winscope settings shown here to view the disturbance.

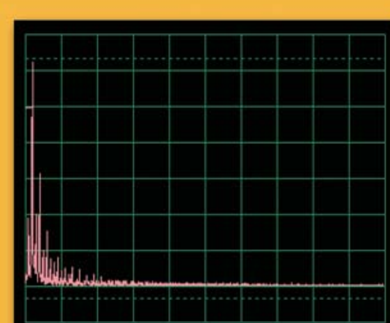


Push the press switch (S2) to connect the 470µF capacitor across the motor. This filters out most of the disturbance, as you can see with Winscope (use the same settings).

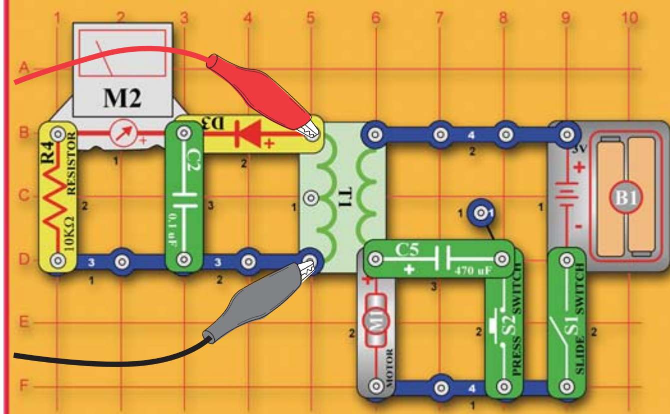
Now change Winscope to FFT mode and change the horizontal scale to compare the frequency spectrum. Press the switch to add the capacitor. This filters out most of the high frequency energy from the disturbance.



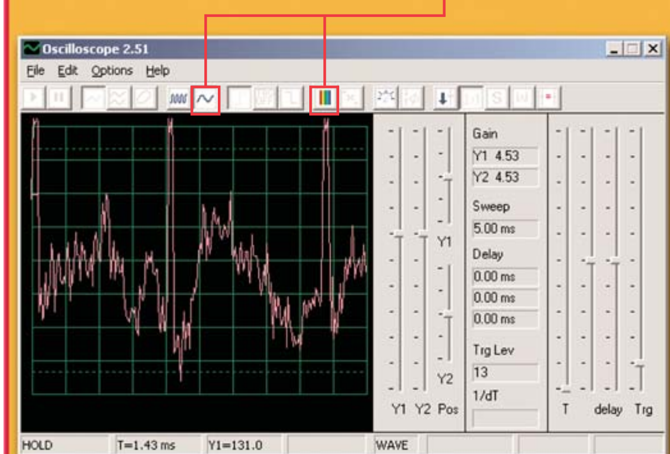
Press switch pressed, same Winscope settings.

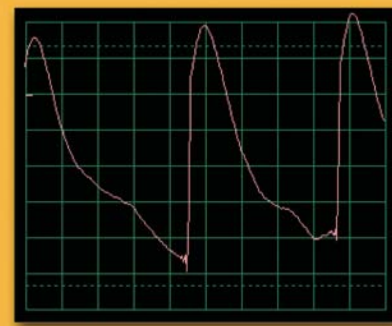


Now connect the PC-interface cable on the other side of the transformer to view the signal there.



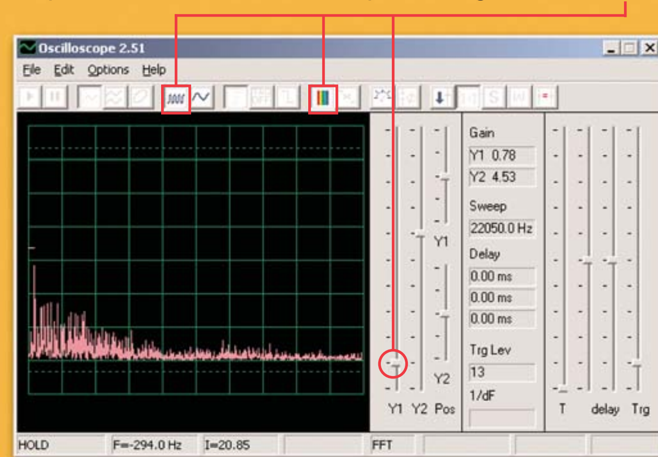
The transformer output has lots of jitter, representing energy at high frequencies. Pressing the switch adds the 470μF capacitor to filter out the high frequency energy and the signal looks smooth. The basic waveshape of the disturbance is the same; this is the energy that crossed the transformer using magnetism.

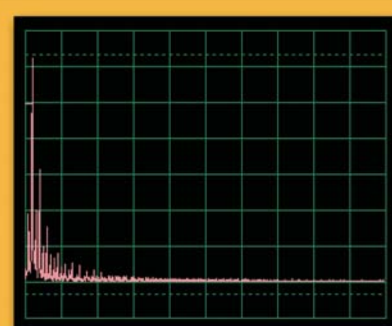




Press switch pressed, same Winscope settings.

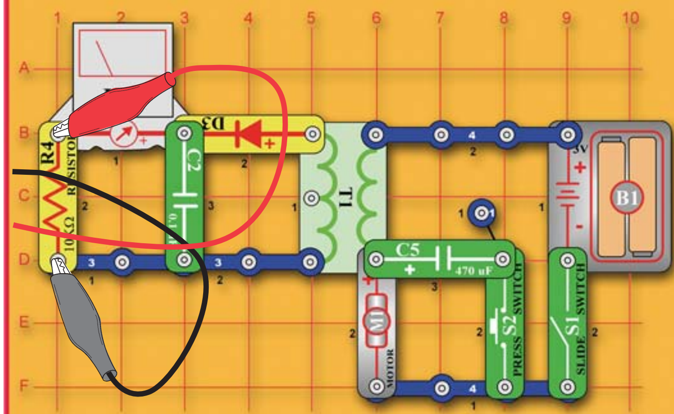
Now compare the frequency spectrum. Adding the capacitor concentrates most of the energy into a few frequencies. Use the Winscope settings shown here.



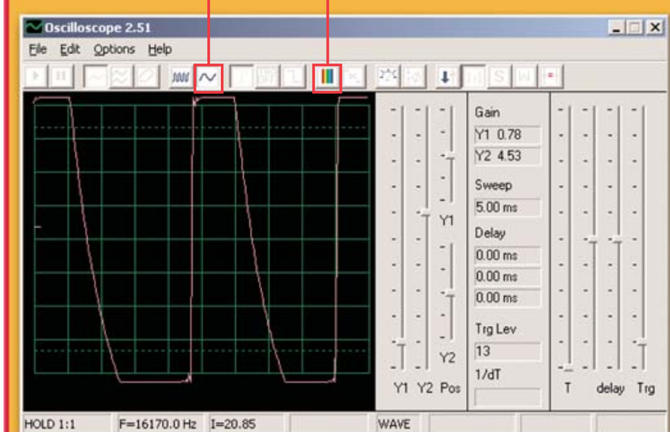


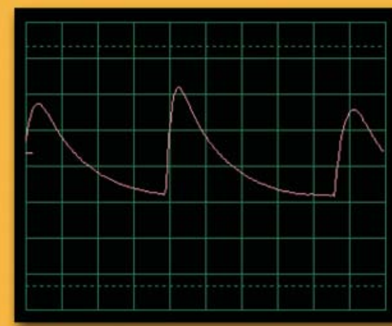
Press switch pressed, same Winscope settings.

Now connect the PC-interface cable across the 10KΩ resistor to view the signal there.



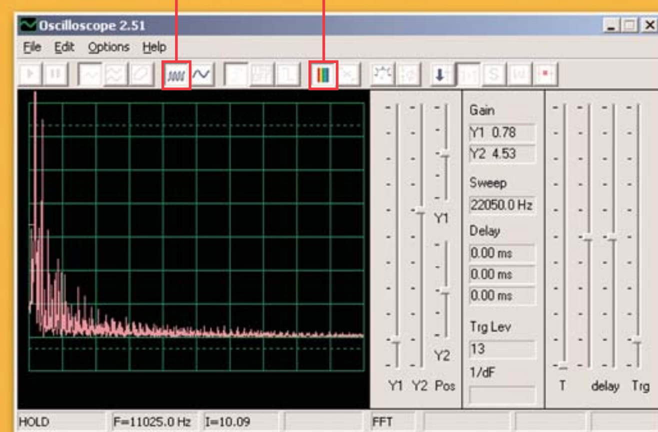
The diode (D3) and 0.1µF capacitor (C2) convert the changing signal from the transformer into a more stable signal that can be measured by the meter. Compare the signal here to how it looked at the motor and transformer.

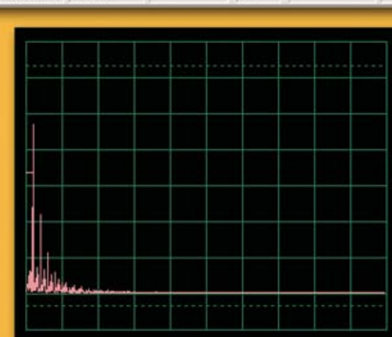




Press switch pressed, same Winscope settings.

Now compare the frequency spectrum.





Press switch pressed, same Winscope settings.

Summary

Summary of Chapter 14:

1. A vibration switch can be made to activate a circuit when it is moved.

2. Engineers use oscilloscopes to look at the waveform of electric signals, and spectrum analyzers to look at the frequency content.

3. A computer measures electric signals and records them as a series of numbers. The accuracy depends on the resolution of the measurement and how often it measures.

Quiz

Chapter 14 Practice Problems

1. Which of these would be a good application for a vibration switch?
   A. As an on/off switch for an oven.
   B. To activate an earthquake detector.
   C. To turn on a furnace when the house is cold.
   D. To turn on an alarm clock.

2. Oscilloscopes and spectrum analyzers __________.
   A. Can be found in most homes.
   B. Are never used by electronics engineers.
   C. Are used to make performance measurements on electronic signals.
   D. Are not very expensive.

3. Why do projects PC1-PC73 all connect Winscope to the circuit output?
   A. This allows you to compare what you see in the signal to what you hear or see from the circuit.
   B. It is the only place in the circuit that you can connect to.
   C. The signal would be too high in frequency to view anywhere else in the circuit.
   D. It doesn't matter because the signal looks the same everywhere in the circuit.

4. Which of these is an advantage of using Snap Circuits® to learn electronics?
   A. Snap Circuits® uses low voltages, which are safe.
   B. Snap Circuits® makes it easy to connect electronics parts into circuits, since no soldering is needed.
   C. Snap Circuits® is fun.
   D. All of the above.

Answers: 1. B, 2. C, 3. A, 4. D

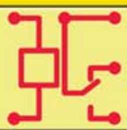
SUMMARY OF COMPONENTS

Schematic Symbol	Part	Function	Quantity
	Wire	Connection of other components.	Various
	Battery	Produce electrical voltage using a chemical reaction.	2
	Switch	Connects or disconnects parts in a circuit.	2
	Lamp	Make light from electricity.	2
–	Printed Circuit Board	Used for mounting and connection of components.	0
–	Solder	Special metal that is melted to make solid electrical connections.	none
	Motor	Make mechanical motion from electricity.	1
–	Fuse	Used to shut off a circuit when excessive current is drawn.	0
	Resistor	Limits and controls the flow of electricity in a circuit.	5
	Adjustable Resistor	Resistor with adjustable value.	1
	Photo Resistor	Light-sensitive resistor.	1
	Capacitor	Stores electical energy. Passes AC currents, but blocks DC currents.	5
	Adjustable Capacitor	Capacitor with adjustable value.	1

SUMMARY OF COMPONENTS (continued)

Schematic Symbol	Part	Function	Quantity
	LED	A one-way, low-current lamp.	2
	PNP Transistor	Uses a small current to control a large current.	1
	NPN Transistor	Uses a small current to control a large current.	1
	Microphone	Sound-sensitive resistor.	1
	Speaker	Make sound from electricity.	1
	Whistle Chip	A capacitor that can also make sound.	1
–	Music IC	Module to make musical sounds.	1
–	Alarm IC	Module to make alarm sounds.	1
–	Space War IC	Module to make space war sounds.	1
–	Power Amplifier IC	Amplifier module.	1
–	High Frequency IC	Specialized amplifier for radio circuits.	1
	Inductor	Opposes changes in current. Passes DC currents, but blocks AC currents.	0
	Antenna	Inductor that concentrates radio signals for reception.	1

SUMMARY OF COMPONENTS (continued)

Schematic Symbol	Part	Function	Quantity
	Meter	To measure how much current is flowing in a circuit.	1 SC-500R & SC-750R only
	Transformer	Inductor used to change the AC voltage without wasting power.	1 SC-500R & SC-750R only
	FM Module	Module containing an FM receiver and amplifier circuit.	1 SC-500R & SC-750R only
	Diode	Block current flow in one direction.	1 SC-500R & SC-750R only
	7-Segment	A group of seven LEDs that can display one letter or number.	1 SC-500R & SC-750R only
	Recording IC	Module to record and play music or talking.	1 SC-500R & SC-750R only
	Relay	An electronic component that uses magnetism to open or close a mechanical switch.	1 SC-500R & SC-750R only
	SCR	A controlled diode used as an electronic switch.	1 SC-500R & SC-750R only
	Solar Cell	Uses light to produce a voltage that can power a circuit.	1 SC-750R only
	Electromagnet	Inductor that acts like a magnet when a current flows through it.	1 SC-750R only
	Vibration Switch	Connect or disconnect power to a circuit when shaken.	1 SC-750R only
	Two-spring Socket	Easy connection of other electrical components to Snap Circuits®.	1 SC-750R only
	Computer Interface	View the electrical signals in a circuit.	1 SC-750R only

Additional / replacement parts may be ordered at www.snapcircuits.net or by calling Elenco® at 847-541-3800.

DEFINITION OF TERMS (also see Summary of Components pages 132-134)

AC	Common abbreviation for alternating current.
Alternating Current	A current that is constantly changing.
AM	Amplitude modulation. The amplitude of the radio signal is varied depending on the information being sent.
Ampere (A)	The unit of measure for electric current.
Amplify	To make larger.
Amplitude	Strength or level of something.
Analogy	A similarity in some ways.
Anode	The side of a diode that current flows into.
Antenna	Inductors used for sending or receiving radio signals.
Audio	Electrical energy representing voice or music that can be heard by human ears.
Base	One of the connection points on a transistor.
Battery	A device which uses a chemical reaction to create an electric charge across a material.
Blackout	When part of a city is cut off from the power plants supplying it with electricity.
Capacitance	The ability to store electric charge.
Capacitor	An electrical component that can store electrical pressure (voltage) for periods of time.
Cathode	The side of a diode that current flows out of.
Circuit	An arrangement of electrical components to do something.
Clockwise	In the direction in which the hands of a clock rotate.
Coil	A wire that is wound in a spiral.
Collector	One of the connection points on a transistor.
Color Code	A method for marking resistors using colored bands.
Conductor	A material that has low electrical resistance.
Counter-Clockwise	Opposite the direction in which the hands of a clock rotate.
Current	A measure of how fast electricity is flowing in a wire or how fast water is flowing in a pipe.
DC	Common abbreviation for direct current.
Diaphragm	A flexible wall.
Digital Circuit	A wide range of circuits in which all inputs and outputs have only two states, such as high/low.
Digital Electronics	Using a series of numbers to represent an electrical signal.
Diode	An electronic device that allows current to flow in only one direction.
Direct Current	A current that is constant and not changing.
Disc Capacitor	A type of capacitor that has low capacitance and is used mostly in high frequency circuits.
Electric Charge	An electrical attraction/ repulsion between materials.
Electrical Power	A measure of how much energy is moving in a wire.
Electricity	An attraction and repulsion between sub-atomic particles within a material.
Electrolytic Capacitor	A type of capacitor that has high capacitance and is used mostly in low frequency circuits. It has polarity markings.
Electromagnetic	Involving both electrical and magnetic effects.
Electronics	The science of electricity and its applications.
Emitter	One of the connection points on a transistor.
Farad, (F)	The unit of measure for capacitance.
Feedback	To adjust the input to something based on what its output is doing.
Filament	A high-resistance wire used in incandescent light bulbs.

DEFINITION OF TERMS (also see Summary of Components pages 132-134)

Fluorescent Lamp	A lamp that creates light using a glowing gas.
FM	Frequency modulation. The frequency of the radio signal is varied depending on the information being sent.
Frequency	The rate at which something repeats.
Friction	The rubbing of one object against another. It generates heat.
Fuse	A device used to shut off a circuit when excessive current is drawn.
Gallium Arsenide	A chemical element that is used as a semiconductor.
Generator	A device which uses steam or water pressure to move a magnet near a wire, creating an electric current in the wire.
Ground	A common term for the 0V or "–" side of a battery or generator.
Henry (H)	The unit of measure for Inductance.
Incandescent Lamp	A lamp that creates light using a material that is heated until it glows.
Inductance	The ability of a wire to create an induced voltage when the current varies, due to magnetic effects.
Inductor	A component that opposes changes in electrical current.
Insulator	A material that has high electrical resistance.
Integrated Circuit	A type of circuit in which transistors, diodes, resistors, and capacitors are all constructed on a semiconductor base.
Kilo- (K)	A prefix used in the metric system. It means a thousand of something.
LED	Common abbreviation for light emitting diode.
Light Emitting Diode	A diode made from gallium arsenide that has a turn-on energy so high that light is generated when current flows through it.
Lightning	A discharge of static electricity between a cloud and the ground.
Lightning Rod	A metal rod between the roof and ground, used to protect houses from lightning.
Magnetic Field	The region of magnetic attraction or repulsion around a magnet or an AC current. This is usually associated with an inductor or transformer.
Magnetism	A force of attraction between certain metals. Electric currents also have magnetic properties.
Meg- (M)	A prefix used in the metric system. It means a million of something.
Micro- (μ)	A prefix used in the metric system. It means a millionth (0.000,001) of something.
Microphone	A device which converts sound waves into electrical energy.
Milli (m)	A prefix used in the metric system. It means a thousandth (0.001) of something.
Modulation	Methods used for encoding signals with information.
Motor	A device which converts electricity into mechanical motion.
NPN	A type of transistor construction.
Ohm's Law	The relationship between voltage, current, and resistance.
Ohm, (Ω)	The unit of measure for resistance.
Oscillator	A circuit that uses feedback to generate an AC output.
PNP	A type of transistor construction.
Parallel Circuit	When several electrical components are connected between the same points in the circuit.

DEFINITION OF TERMS (also see Summary of Components pages 132-134)

Pitch	The musical term for frequency.
Polarity	Markings indicating which direction a device is positioned in, usually (+) and (–).
Printed Circuit Board	A board used for mounting electrical components. Components are connected using metal traces "printed" on the board instead of wires.
Receiver	The device which is receiving a message (usually with radio).
Resistance	The electrical friction between an electric current and the material it is flowing through.
Resistor	Components used to control the flow of electricity in a circuit.
Schematic	A drawing of an electrical circuit that uses symbols for all the components.
Semiconductor	A material that has more resistance than conductors but less than insulators. It is used to construct diodes, transistors, and integrated circuits.
Series Circuit	When electrical components are connected one after the other.
Short Circuit	When wires from different parts of a circuit (or different circuits) connect accidentally.
Silicon	The chemical element most commonly used as a semiconductor.
Solder	A tin-lead metal that becomes a liquid when heated to above 500°F. It makes a strong mounting that can withstand shocks.
Speaker	A device which converts electrical energy into sound.
Static Electricity	A naturally occurring build-up of electrical charge between materials, usually at high voltage.
Switch	A device to connect ("closed" or "on") or disconnect ("open" or "off") wires in an electric circuit.
Transformer	A device which uses coils to change the AC voltage and current (increasing one while decreasing the other).
Transistor	An electronic device that uses a small amount of current to control a large amount of current.
Transmitter	The device which is sending a message (usually with radio).
Tungsten	A highly resistive material used in light bulbs.
Tuning Capacitor	A capacitor whose value is varied by rotating conductive plates over a dielectric.
Voltage	A measure of how strong an electric charge difference between materials is.
Volts (V)	The unit of measure for voltage.
Watt (W)	The unit measure for electrical power.

FOR FURTHER READING (all of these are available through Elenco® Electronics, Inc.)

Basic Electricity, 736 pages, ISBN 0-7906-1041-8, Sams 61041

Basic Electricity & DC Circuits, 928 pages, ISBN 0-7906-1072-8, Sams 61072

Basic Solid-State Electronics, 944 pages, ISBN 0-7906-1042-6, Sams 61042

Beginning Electronics Through Projects, 236 pages, ISBN 0-7506-9898-5, Sams 67102

Modern Electronics Soldering Techniques, 304 pages, ISBN 0-7906-1199-6, Sams 61199

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