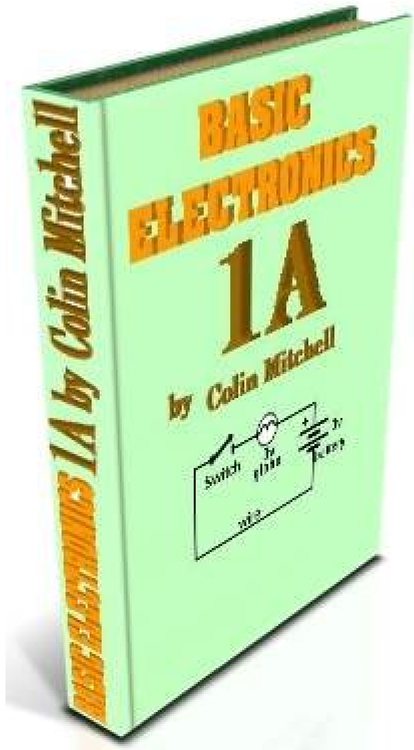


For any enquiries email Colin Mitchell

BASIC ELECTRONICS

INDEX

BEFORE WE START

Too many text books start with the physics of the atom and have equations and mathematics to show how smart the author is.
Don't worry, we wont have any physics or equations.
The reason . . .
This is not a physics course. It is a practical electronics course to teach the basics as quickly as possible. There are no equations because most transistor circuits cannot be worked out mathematically as the gain of a transistor changes according to the current-flow and these gain-values are never provided. So the mathematics is worthless.
To get an answer, all you have to do its build the circuit and measure the values with a multimeter.
Also lots of discussions in text books will never be used in your next 40 years of electronics, so this course doesn't have any unnecessary material and is much-more concentrated than anything you have read before.
Every frame contains important points.
Don't skip anything . . .

Learn electronics from the beginning . . .

START HERE:

WIRE **Fig 1** The wire in a circuit diagram	All electrical and electronic circuits need wire to connect the components.

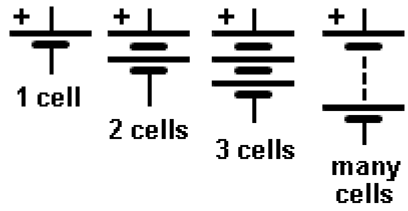


Fig 2 A single Cell and many Cells

Next we need a **battery**. A battery consists of two or more cells. The positive terminal of a battery is the long line in the diagram and you must add the voltage (of the cell or battery) to the symbol as a single cells can be 1.2v, 1.5v, 2.2v or up to 3.6v. The symbol does not let you know the voltage. The positive is always at the top.

Fig 3: A Globe

Next we need a globe. A globe has two connections (a fine wire inside a glass bulb glows when the globe is connected to a battery).

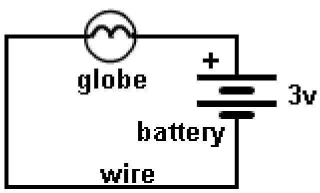


Fig 4: A Circuit

With a globe, battery and wire we have produced a **CIRCUIT**. A **CIRCUIT** is a complete path and we say the "electricity" the **CURRENT** emerges from the positive of the battery, moves through the globe and returns to the battery via the wire.
If the globe is a "3v GLOBE" it will glow when connected to a 3v battery.
The globe can be connected either way around.
The circuit we have shown is called a **SCHEMATIC** and consists of symbols: a globe symbol and a battery symbol.
The line connecting the two components is called WIRE.

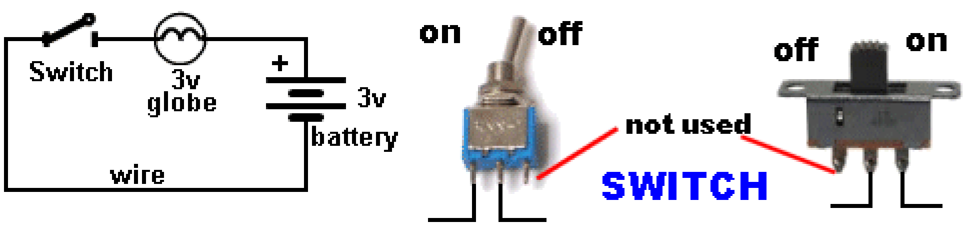


Fig 5: Adding a SWITCH

To turn the globe ON and OFF we need a SWITCH.
The switch may be a push button, a slide switch or a toggle switch (a "click" action). You could twist the wires together and untwist them. The result is the same. We say the circuit is "broken" or "open" via the switch and the lamp does not glow. Closing the switch turns ON the globe.

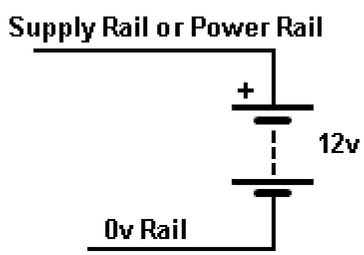


Fig 6: Naming the RAILS

The top rail of the **CIRCUIT DIAGRAM** is called the **SUPPLY RAIL** or **POWER RAIL**.
The lower rail is called the **0v Rail** or **EARTH RAIL**.

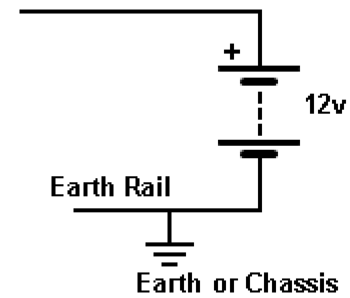


Fig 7: The **EARTH RAIL**

The lower rail is also called the **Chassis**.
This comes from the "old days" when electronics constructors build radios on a metal chassis (metal box) and it was connected via wire to a pipe in the ground to help the radio pick up distant radio stations.
The term also comes from car and truck wiring where one side of each globe is connected to the frame or chassis so that only one wire is needed to each globe and the return "path" is via the chassis.

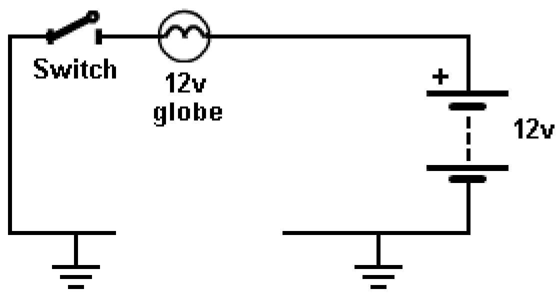


Fig 8: EARTH Return

The circuit shows a 12v globe connected to a 12v battery and the circuit appears to be "broken" (not continuous).
But the **current returns** via the earth connection.
We talk about the **CURRENT RETURNING**. We don't say: the voltage returning.
The voltage of the globe must be the same as the battery voltage, otherwise it will not glow fully or it will **burn out** if it is say a 6v globe.

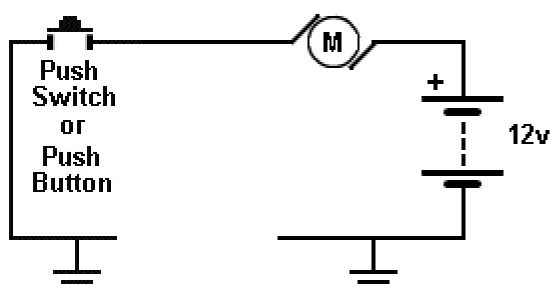


Fig 9: Connecting a Motor

The circuit shows a 12v **Motor**.
It is turned ON when the push-switch is pressed.

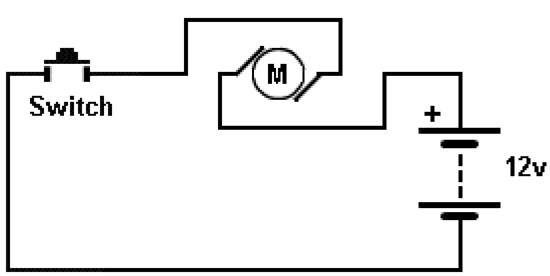


Fig 10: Reversing a Motor

If the wires are connected to the motor "around the other way," the motor will reverse direction.

All the above circuits are called **ELECTRICAL CIRCUITS** because they contain electrical

components (such as a motor, globe, relay, switch).
When the circuit contains an **ELECTRONIC** component such as a diode, transistor, LED, it is called an **ELECTRONIC CIRCUIT** or **ELECTRONIC SCHEMATIC**.

VOLTAGE AND CURRENT

What is voltage and what is current?
Here is a very simple description.

VOLTAGE

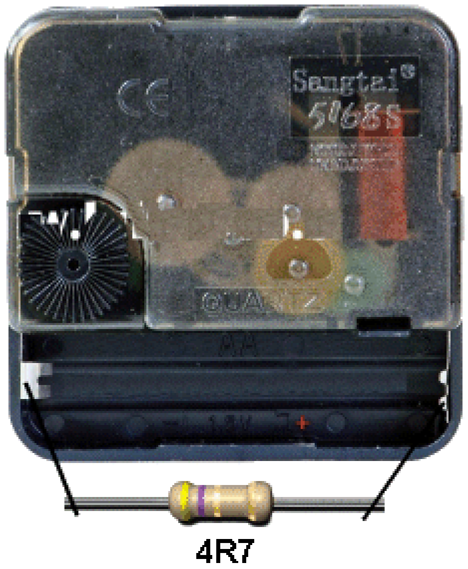
Voltage is a value produced by an electrical component called a battery or cell.
A single cell produces one and a half volts. (1.5v) and although this is not a high voltage, when cells are connected together we get higher voltages.
If 6 cells are connected in series we get 9v.
Here is a 9v battery:

Touch the two terminals with your tongue. You get a tingle. This is a 9v tingle. Now you have "felt" electricity. This is a 9v tingle.

CURRENT

You cannot feel current with your tongue so we have to carry out another experiment:

Place a 22 ohm or 47 ohm resistor across the terminals of the battery and hold your fingers on the resistor. It will get hot. This is the result of current flowing through the resistor and heating it up. The current will be about half an amp and the voltage is 9v, so the wattage will be about 2 to 4 watts.
Feel the heat produced.
Other devices require less current to operate.
The globe used in the experiments requires about 300mA. (1,000mA = 1 amp)
The 3v motor used in the experiments requires about 250mA
The LEDs used in the experiments require about 20mA.



WATTAGE and CAPACITY

A 9v battery has 6 very small cells and they will not last very long.
A "AAA" cell is larger and a "D" cell is much larger.

A large cell is said to have a **LARGE CAPACITY.** This means it will deliver a larger current for a longer period of time.
The **WATTAGE** of a cell is the multiplication of the voltage x current. The answer is milliwatts or watts.
The **CAPACITY** of a cell is the wattage x hours. The answer is milliwatt-hours or watt-hours. This is also called watt-hours.
You can determine the capacity of a cell (such as a rechargeable cell) by connecting it to a clock-mechanism that has a 4R7 connected across the terminals. The resistor will take a considerable current and deplete the cell in a few hours. The clock will let you know exactly how long the cell delivered the current. You can then compare other cells.

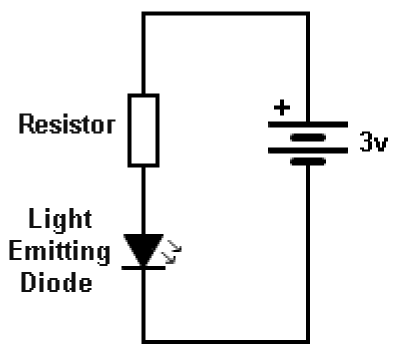


Fig 11. The **LED**

This simple **ELECTRONIC CIRCUIT** contains a **LIGHT EMITTING DIODE (LED), RESISTOR** and battery.

The circuit is classified as electronic because the LED is not an electrical item (such as a globe) but more-complex, as it produces light when current flows through a crystal and the crystal produces the colour.

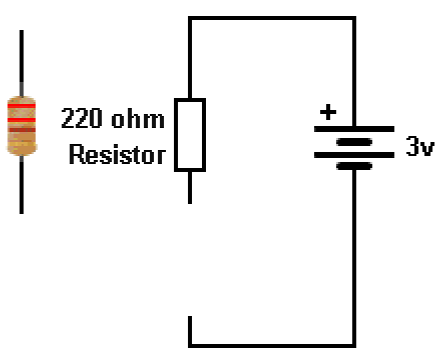


Fig 12. The **Resistor**

A **RESISTOR** must be included in the circuit to prevent the LED being damaged.
The resistor in this circuit must be 220 ohms.
This is shown by the colours on the resistor. The colours for 220 ohms: **red - red - brown**. The 4th band is gold - indicating a tolerance of 5%.
A resistor has **RESISTANCE**.
It reduces the current from the battery to a required amount to prevent the LED glowing too bright.
A resistor is just like putting your foot on a hose. The water trickles out the end. The resistor "resists" the high current-flow that the battery is able to deliver.

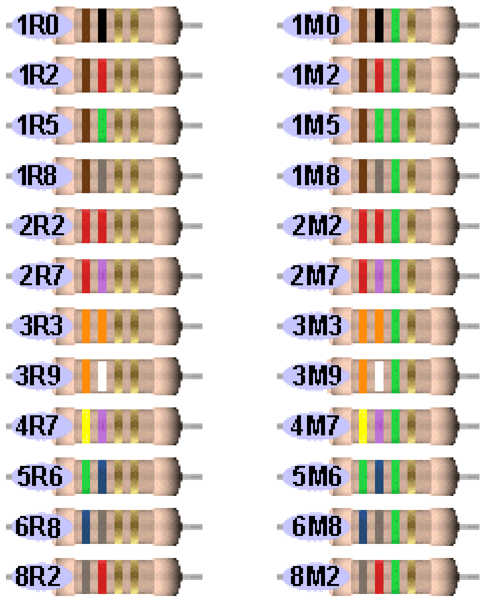


Fig 12a. The **Resistor Colours**

There are hundreds of different resistors because the resistance-values need to cover the range one ohm to 10 million ohms.
There are also small, medium and large resistors.
The resistors on the left are just a few in the range. (See the full range below). They show colour bands for 1 ohm to 8.2 ohms and 1 million ohms to 8.2 million ohms. All the other values are shown below.
An electronics engineer does not have the room to store 10 million different resistors so they make each resistor 5% or 10% higher than the previous.
This reduces the number to about 100 to 200.
The first 3 bands indicate the value of the resistor and the 4th band indicates either 5% or 10% tolerance.
All modern resistors are 5% or 2% or 1%. The "old" 10% resistors are no longer made.

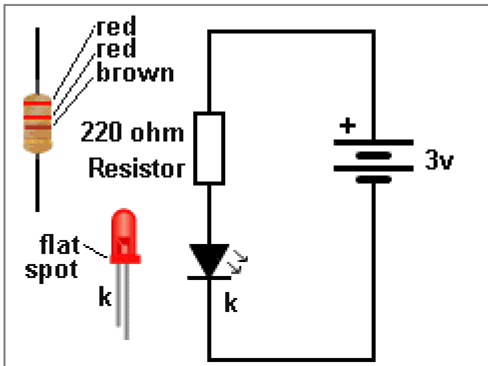


Fig 13. The **Resistor and LED**

The **LIGHT EMITTING DIODE** is called an electronic component (mainly because it is more complex than a globe and it produces light by a more-complex means than heating a wire).
A **LED** must be connected around the correct way. It will not illuminate if connected around the wrong way.
All **LEDs** have one lead longer than the other. The SHORT lead is called the **CATHODE** (k).
All LEDs have a flat on one side and this is the **CATHODE** lead.
The arrows on the diagram indicate light is "given off" (emitted - produced).

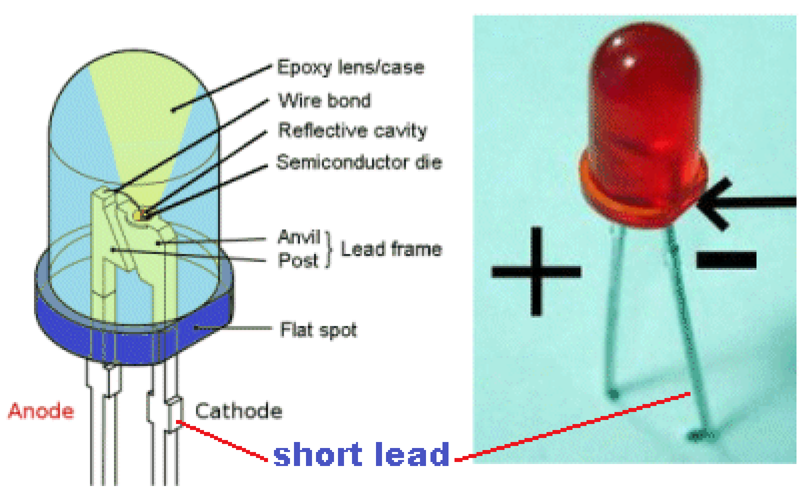


Fig 14. The **LED - showing the flat spot**

A close-up of a red LED. The cathode lead is the short lead and next to a flat side on the LED.
DO NOT show "+" or "-" on a diagram. Only show the letter "k" to indicate cathode.
The symbols "+" and "-" are used when a component produces a voltage or is connected directly to "+" and "-" A LED is connected via a resistor.

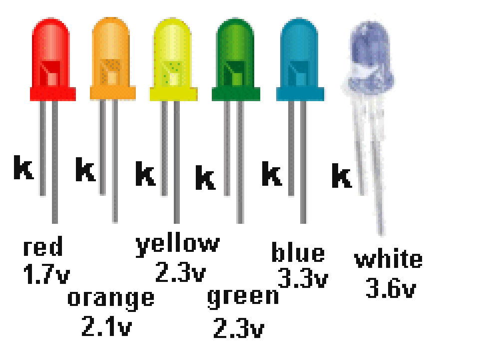


Fig 15. LED VOLTAGES

When a LED is connected to a circuit, (and the correct-value resistor is included), a voltage will be develop across the LED called the **CHARACTERISTIC VOLTAGE DROP**.
This voltage is due to the colour of the LED and the crystal inside the LED that produces the colour.
The diagram on the left shows the approximate voltage developed for each LED.
The voltage **does not change** for small, medium, surface-mount, or large LEDs.

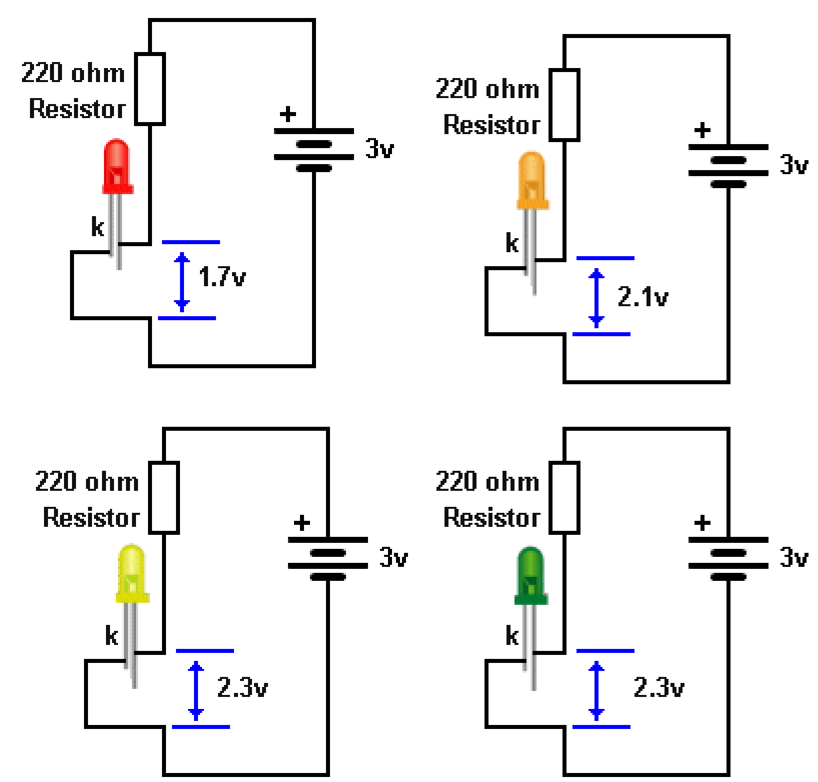


Fig 16. LED VOLTAGES

When a LED is connected to 3v battery, the following **CHARACTERISTIC VOLTAGE DROPs** will develop across each LED.
You will notice we **have not changed** the value of the resistor. It is 220R.
The LED creates the voltage and if the value of resistance is decreased, the LED will illuminate BRIGHTER.
If the LED illuminates too bright it will be DAMAGED.

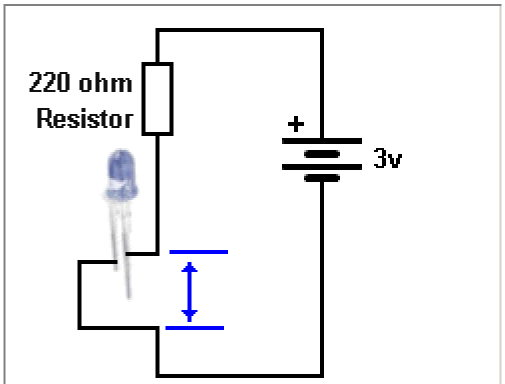


Fig 17. WHITE LED VOLTAGE

If we connect a WHITE LED to 3v supply, it will not illuminate because it needs a supply higher than 3.6v.

The resistor in series with the LED is called a **CURRENT LIMITING RESISTOR**.

In this circuit **no current flows** because the supply is not high enough.

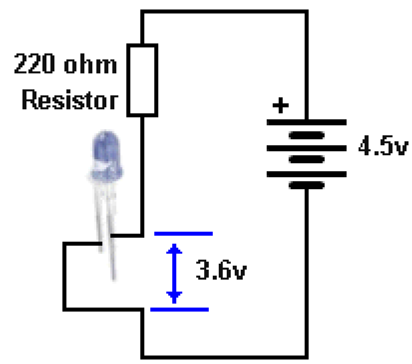


Fig 18. WHITE LED VOLTAGE

When the supply is increased to 4.5v, the 220R resistor will allow a current to flow through the white LED and it will develop a CHARACTERISTIC VOLTAGE DROP of 3.6v across it.

The supply (the voltage of the battery) must be higher than the CHARACTERISTIC VOLTAGE DROP of the LED so the resistor will allow the correct amount of current to flow.
The ideal current for a LED is 20mA, however some LEDs will work when 1mA flows, so you have to know what you are doing.

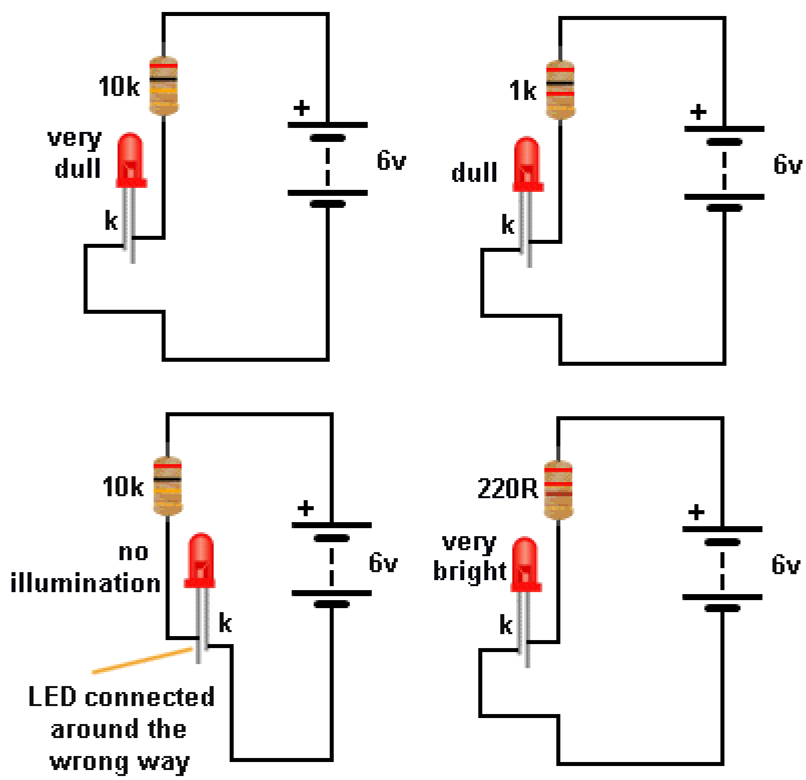


Fig 19. Testing A LED
Now connect either the 1k, 470R or 220R and determine the brightness you need.
As the brightness increases, the current will be higher.
You can use 3v supply for all LEDs except blue and white.

HOW TO TEST A LED
Some clear LEDs produce red or orange and some LEDs do not have the cathode lead clearly identified.
Here's how to find the colour, cathode lead and the current.
You need a 6v battery, 10k resistor, 1k resistor, 470R resistor and 220R resistor.
Connect the 6v battery and 10k resistor to the LED and it will only illuminate when the cathode is connected to the negative of the battery. This is the short lead.

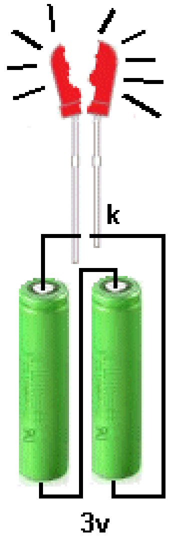


Fig 20. Damage a LED

Do not connect a 3v battery directly across a LED. It will be DAMAGED. You MUST include a resistor.

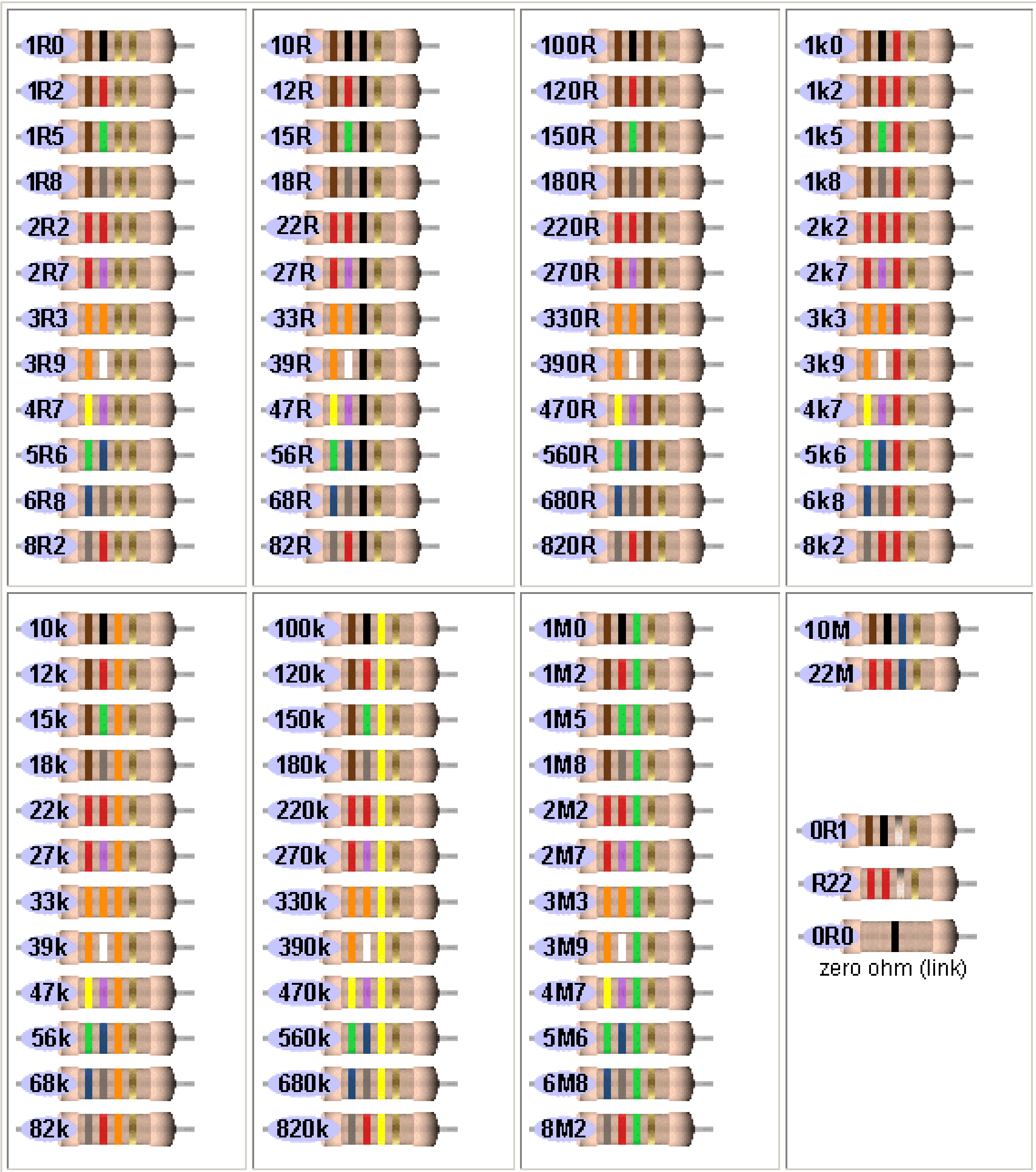


Fig 21. All the resistor values

Here are all the colours and values for the resistors you will using in this course. Just match-up the colours on your resistor with the resistors above and you will find the value.

Resistor values are always OHM values. One ohm is a small value. It might be the resistance of a length of wire 3 metres long.
When a switch is open the resistance is infinite - millions and millions of ohms.
The resistance of your body from one hand to the other will be about 70,000 ohms.
The resistance between two wires dipped in water will be about 1,000 to 100,000 ohms (depending on the dissolved-salts in the water - pure water has a very high resistance)
The resistance of the filament of a 3v globe will be about 30 ohms.
The resistance of the winding of a 3v motor will be about 3 ohms.
Resistors are made with values from less than one ohm to more than 10 million ohms by adding carbon to the mixture inside the resistor (and cutting a track around the outside of the resistor) then connecting a lead to each end. Adding more carbon reduces the value of resistance. Carbon has a low resistance.
Resistance-values are measured with the RESISTANCE settings on a MULTIMETER.
This is called the "Ohms Range." Sometimes with the symbol: Ω
A Multimeter will have 2, 3 4 or more scales to cover the range one ohm to 10 million ohms.
Low value resistors (from 1 ohm to 999 ohms) are written as 1R, 220R, 470R, 999R. with the letter "R" indicating Resistance (ohms). You can also use the symbol "omega" (Ω)
For values above 1,000 ohms to 99,999 ohms, they are written as: 1k, 2k2, 4k7, 10k, 100k, 220k, 470k, with the letter "k" indicating "kilo" (thousand).
1M = 1,000,000 - one million ohms   1M2, 2M2, 4M7, 10M.
The letters "R, k and M" are placed so they take the place of the decimal point. This prevents any mistake, as a decimal point can be missing in a poor photocopy.

MULTIMETERS

There are two types of **MULTIMETER**. The top two are called **DIGITAL MULTIMETERS** (DMM) and show numbers on a display.
The lower two meters are called **ANALOGUE MULTIMETERS** and have a pointer and scale.
All meters come with a set of red and black leads.
The **red lead** is always connected to the positive of the battery or the positive on a project and the **black lead** is connected to the negative or earth or chassis.
When making a resistance measurement, the leads can be around either way.
Resistance measurements are always made with the power removed from a circuit. Any voltage on a circuit will upset the resistance reading.

 **Fig 22. Resistance Measurement with Analogue Multimeter**	The resistance of a resistor is measured by placing the leads of the multimeter on the ends of a resistor and turning the dial on the analogue multimeter to the resistance scale to make the pointer move to about the centre of the scale. The resistance scale is marked with a high value on the left and 0 ohm on the right. This is opposite to all the other scales. You must get the pointer to move to the middle of the scale as it is not accurate at left-end. Analogue multimeters are only suitable for reading values from 1 ohm to 100,000 ohms. The scale is too hard to read above 100k. To find the value of a resistor, you can compare the colours with the table above.

 **Fig 23. Resistance Measurement with** **a DMM**	A digital multimeter produces a more-accurate reading of resistance. It is accurate from 1 ohm to 10M ohms. Select the scale that provides a reading.

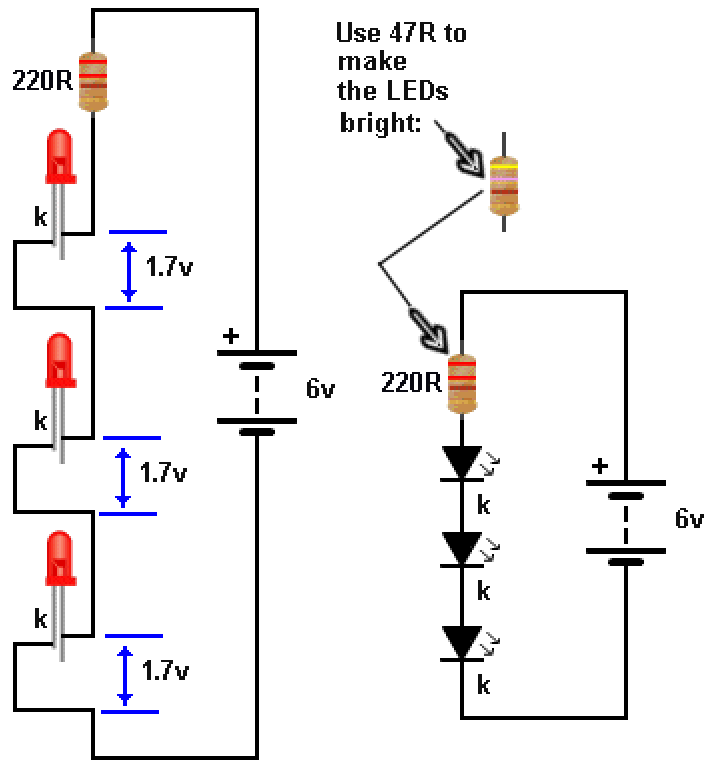


Fig 24. Connecting **LEDs in series**
LEDs can be placed in series provided the total **CHARACTERISTIC VOLTAGE DROP** across the LEDs is LESS than the supply voltage.
In this case the voltage across the LEDs is 1.7v + 1.7v + 1.7v = 5.1v
The supply is 6v and this allows 0.9v for the CURRENT LIMITING RESISTOR.
The LEDs will not be very bright with 220R.
Change the resistor to 47R
If you connect 4 LEDs in series, the total **CHARACTERISTIC VOLTAGE DROP** will be 6.8v and no LEDs will illuminate because the total is higher than the 6v supply.

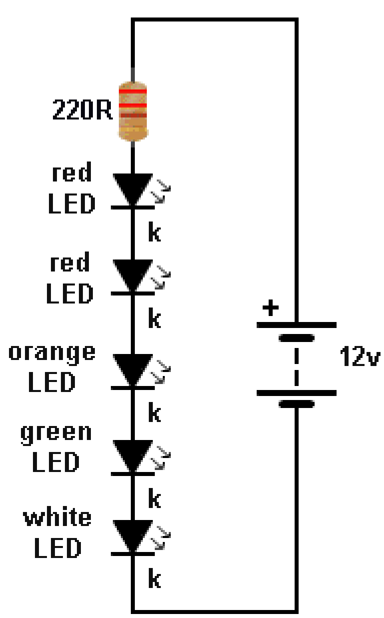


Fig 25. Connecting LEDs in series

Different-colour LEDs can be connected in series. Add up the total Characteristic Voltage for the 5 LEDs and see if it is less than 12v.

The 220R resistor will have to be reduced to 47R to make the LEDs bright.

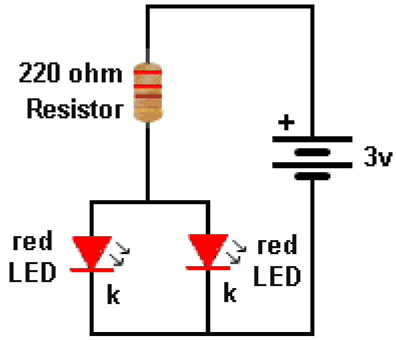


Fig 26. Connecting LEDs in parallel

LEDs can be connected in parallel if they are the same colour.
In the diagram a red LED drops a CHARACTERISTIC VOLTAGE of 1.7v and if they are from the same manufacturer or the same batch, they will work ok.
Although we say the characteristic voltage for a red LED is 1.7v, this can change slightly from different manufacturers and one LED may glow brightly while the other is dull.
You have to build the circuit and see the result.

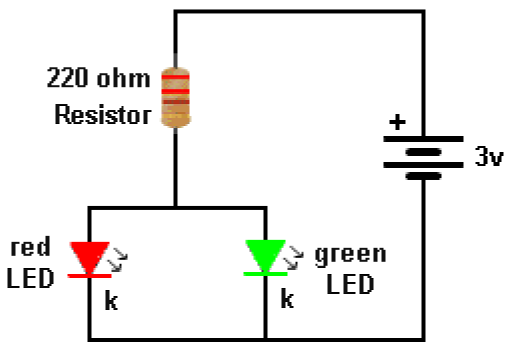


Fig 27. Connecting LEDs in parallel

Different colour LEDs cannot be connected in parallel. The voltage across a red LED is 1.7v. This becomes the "Supply Voltage" for the green LED and it is too low. The green LED needs a supply of 2.1v to 2.3v.
Only the red LED will illuminate.

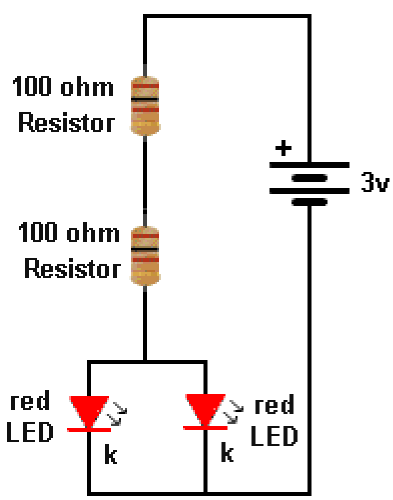


Fig 28. Connecting Resistors in Series

Suppose you don't have a 220 ohm resistor.
You can make a 220 ohm resistor with two resistors in series. The total resistance will be 200 ohms, but resistors are not accurate and the result will be very close to 220R.
Electronic circuits are not very critical. You will not be able to see the difference in brightness between 200 ohms and 220 ohms.

When resistors are connected in series, the total resistance is found by adding the resistance of each resistor.

$$R_{total} = R_1 + R_2 + R_3 + ...$$

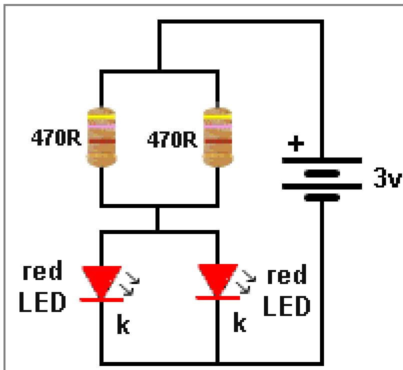


Fig 29. Connecting Resistors in Parallel

You can create a 220 ohm resistor by connecting two resistors in Parallel.
When two equal-value resistors are connected in Parallel, the total resistance across the combination is HALF.
470R in parallel with 470R produces 235R.
This is very close to 220R.
We are not going into the formula as it is very complex.
Three equal-value resistors in parallel produce a total of **one-third.**
Simply get two resistors and connect them in parallel and measure them with a multimeter.

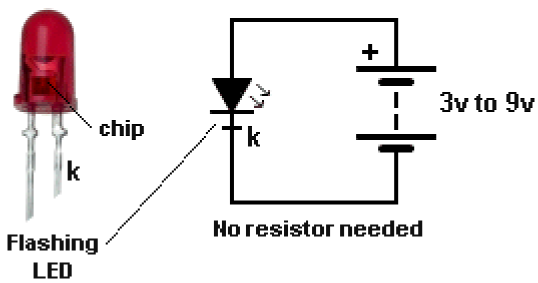


Fig 30. Flashing LED

There are some special LEDs that can be connected to 3v to 9v and they flash or produce a range of colours.
These LEDs have a chip and resistor inside the body of the LED to produce the effect and allow the LED to operate on a voltage without the need for a current limiting resistor.

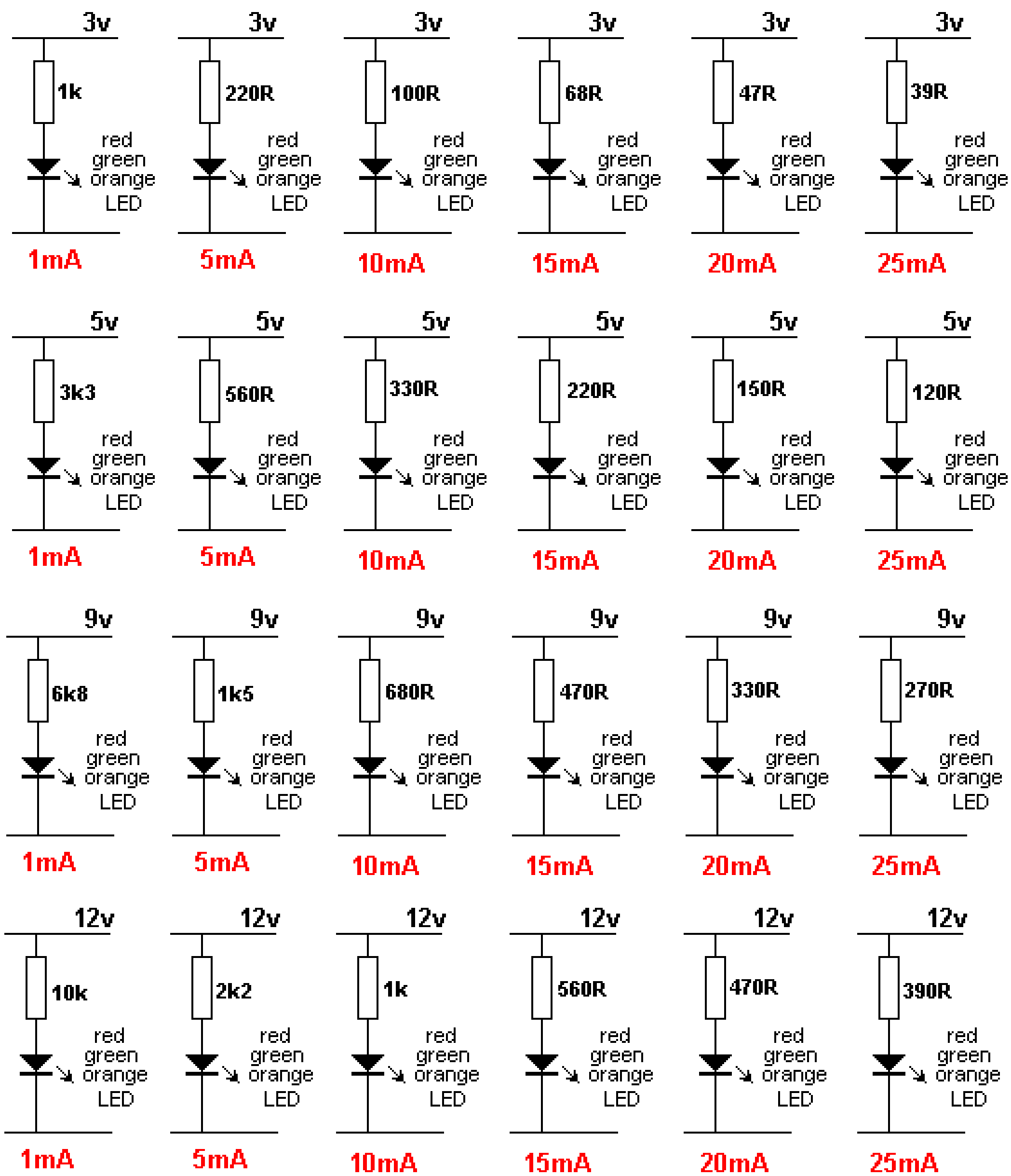


Fig 31. These diagrams show the resistor needed to produce 1mA to 25mA current through a single LED on 3v, 5v, 9v and 12v supply.

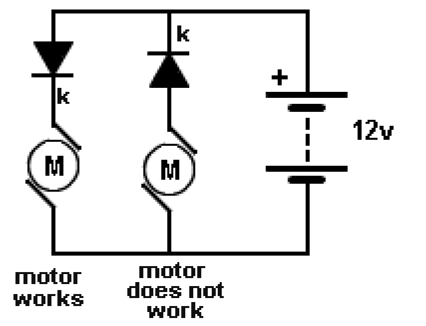
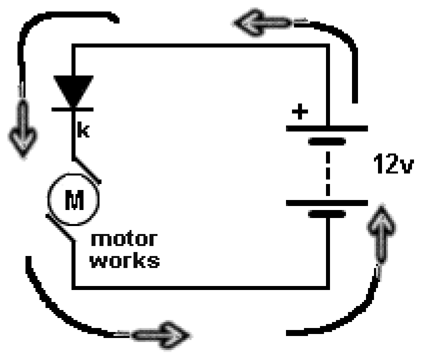
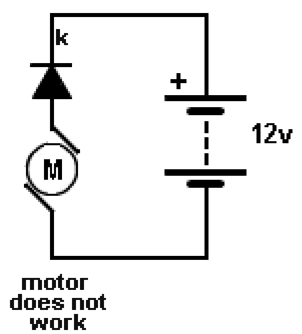


Fig 32. The DIODE

THE DIODE
The next simple electronic component is the **DIODE.**
It only works when connected correctly.
A DIODE allows current to flow through it when it is connected as shown in the diagram.
A Diode is similar to a one-way water valve.
When the diode is "facing down," the motor spins.
When it is "facing up" the motor does not spin.



The diagram shows the "current path" around the circuit. The current is measured in AMPS and we discuss current as CONVENTIONAL CURRENT. This is the way current was thought to flow when electricity was born and they said it flows out the POSITIVE TERMINAL of the battery, around the circuit and into the NEGATIVE TERMINAL.
The arrow on the diode shows the current will flow through the diode and allow the motor to spin.
The diode is said to be **FORWARD BIASED**.



There is no flow of current because the diode prevents any current-flow when connected as shown.
The motor DOES NOT WORK.
The diode is said to be **REVERSE BIASED**.

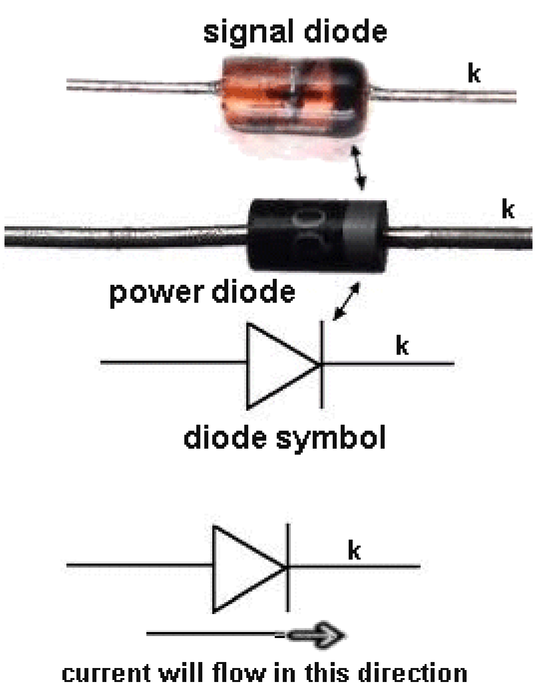
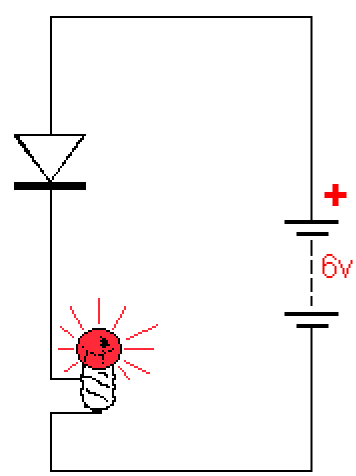


Fig 33. A Signal diode and a Power diode

There are hundreds of different types of diodes.
Power diodes, signal diodes, low voltage diodes, high voltage diodes, high-speed diodes and many other types.
They all do one thing.
They pass current in one direction and if turned around, they **do not pass** any current.



How a diode works

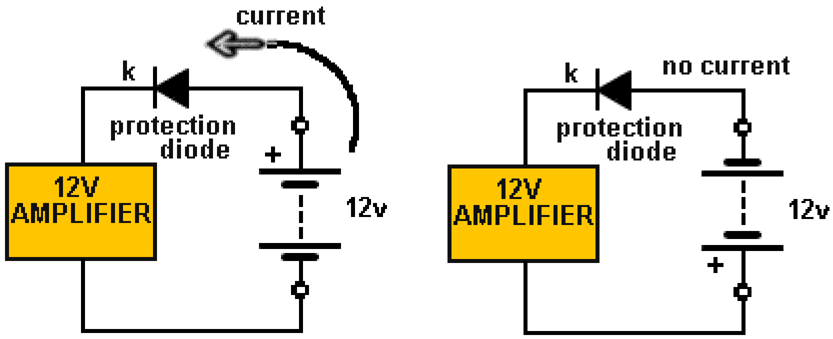


Fig 34. A Protection diode

Diodes perform many function in electrical and electronic circuits. Here is an application as a **PROTECTION DIODE.**
It protects the amplifier. If the 12v battery is connected around the wrong way, no current will flow.

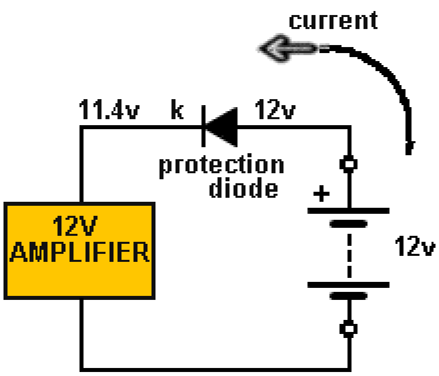


Fig 35. Diode "Voltage Drop"

When a diode is placed in a circuit (and current is flowing), a small voltage develops across the diode.
This voltage is approximately 0.6v.
This is due to a junction inside the diode where two different materials are joined.
Normally, this voltage is not important because it is only small, but sometimes you need to take it into account.
For the circuit above, the amplifier only gets 11.4v

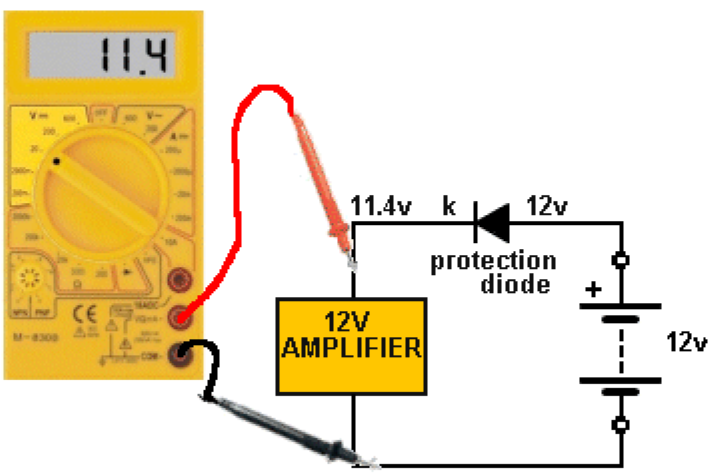


Fig 36. Measuring Voltage with a Digital Multimeter

Voltage is measured with a **VOLTMETER**.
Multimeters have 2 or 3 voltage ranges so you can measure low voltage (0v to 20v),
medium voltages (0v to 200v and high voltages (0v to 500v).
A voltmeter is placed across the component being tested, as shown in the diagram.
The Digital Multimeter is detecting 11.4v across the amplifier.

.

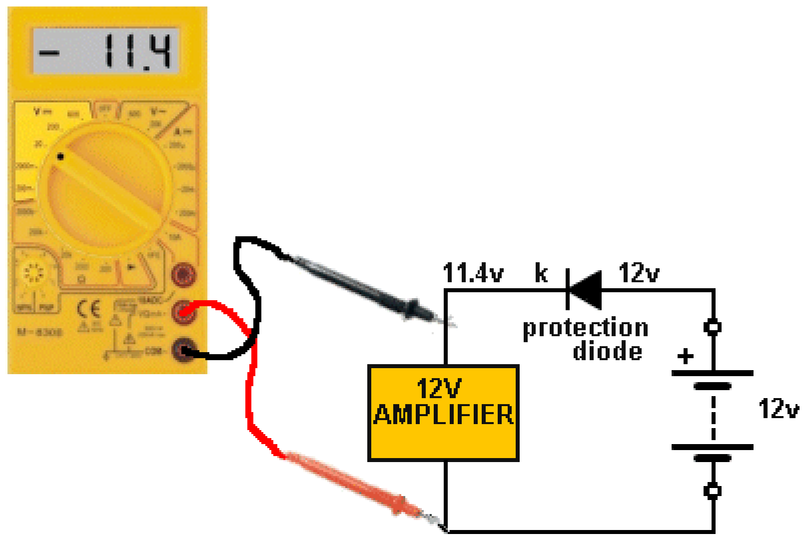


Fig 37. Measuring Voltage with a Digital Multimeter

If you place the probes of a digital multimeter around the wrong way on a component, the display will show a "-" The meter will not be damaged.

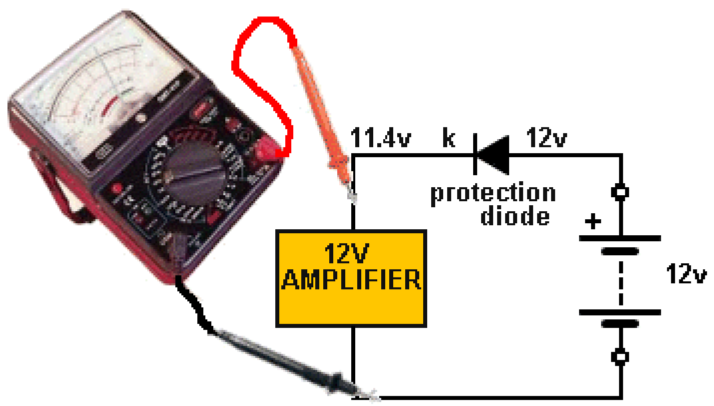


Fig 38. Measuring Voltage with an Analogue Multimeter

An analogue Multimeter must be connected around the correct way to make the pointer move "up scale." Select the range that will allow the pointer to show somewhere in the middle of the scale.

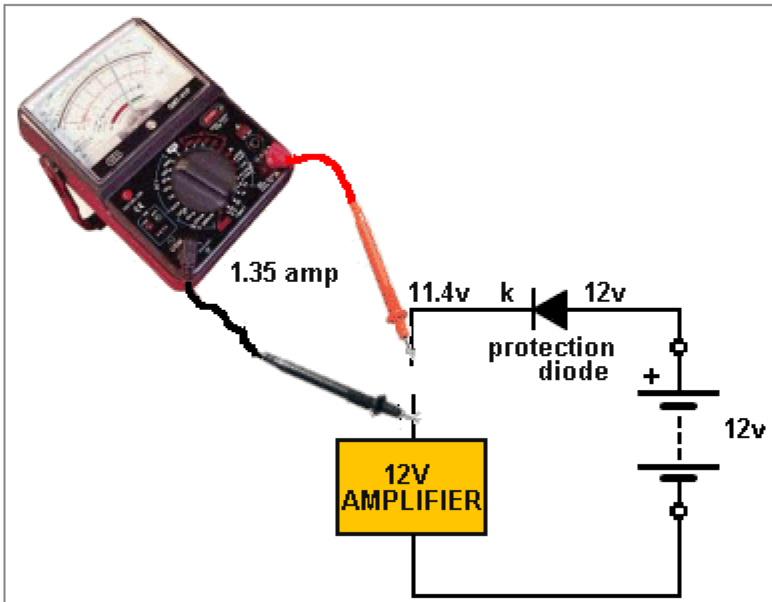


Fig 39. Measuring Current with an Analogue Multimeter

Current is measured by "breaking into the circuit" and inserting the leads so the positive probe is closest to the positive of the battery.
If you connect the leads around the other way, the needle will not move but it will hit the "end stop" and you may have to "bump" the meter to get the pointer to move from its jammed position.

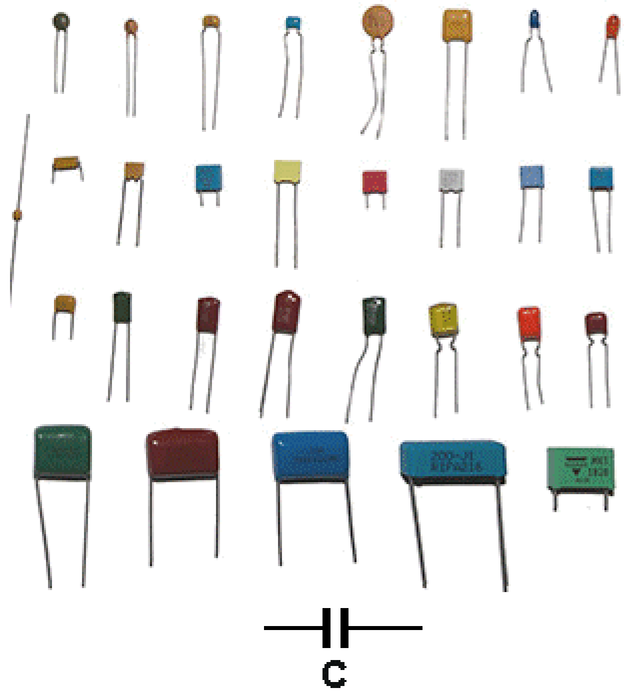


Fig 40. Capacitors and symbol

The next component we cover is the **CAPACITOR**.
There are thousands of different types of capacitor.
Each value of capacitor can have a low voltage rating, medium voltage or high voltage.
Capacitors can be very small in size and shape or very stable with temperature-rise or simply very cheap to make.
A capacitor consists of two thin sheets of metal such as aluminium with a thin sheet of plastic between.
The sheets may be rolled up in a cylinder or laid on top of each other.
The fact is this: the top sheet of metal does not touch the bottom sheet. This is shown in the symbol.
The resistance between the two terminals is INFINITE.
The 6th capacitor in the top row is called a **MONOBLOCK**.

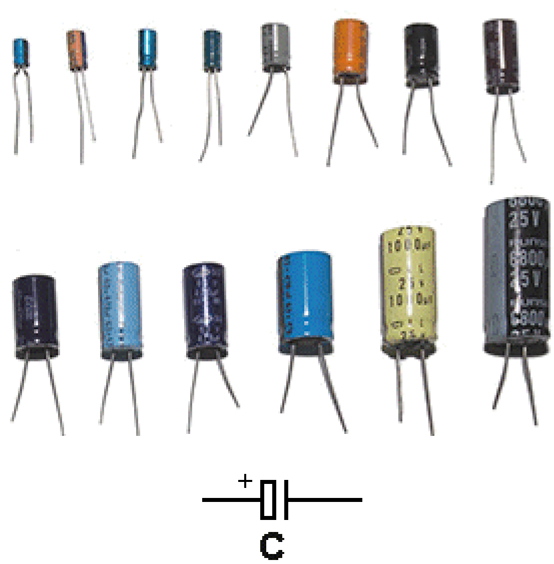


Fig 41. Electrolytic Capacitor

A capacitor gets bigger as its value increases.
It also gets bigger when the voltage-rating increases.
The basic unit of capacitance is the FARAD. A one-farad capacitor would be the size of a house. To make the capacitor smaller the sheets are etched to increase the surface-area and different insulating materials are used between the sheets.
The result is a capacitor called an **ELECTROLYTIC**. It is a bit like a rechargeable battery. It stores a lot of energy in a small space.
The negative lead is shorter and has a black stripe on the side of the electrolytic.

One FARAD is too big to handle. We use smaller values.
The middle of the range is one microfarad. This is written as 1u. (sometimes you see uF)
This is one-millionth of a FARAD.
The smallest value of capacitance is one picofarad. This is one millionth of a microfarad.
It is written as 1p.
Capacitors are broadly separated into two groups. 1p to 1u and 1u to 100,000u
Capacitors 1p to 1u are ceramic, polyester, air, styroseal, monoblock and other names.
Capacitors 1u to 100,000u are electrolytic or tantalum. A tantalum is the same as an electrolytic - for testing purposes - it is a more-compact electrolytic.

1 microfarad is one millionth of 1 farad.
1 microfarad is divided into smaller parts called nanofarad.
1,000 nanofarad = 1 microfarad
Nanofarad is divided into small parts called picofarad
1,000 picofarad = 1 nanofarad.

Recapping:

1p = 1 picofarad. 1,000p = 1n (1 nanofarad) 1,000,000p = 1u
1,000n = 1u (1 microfarad)
1,000u = 1millifarad
1,000,000u = 1 FARAD.

Examples:
All ceramic capacitors are marked in "p" (puff")
A ceramic with 22 is 22p = 22 picofarad
A ceramic with 47 is 47p = 47 picofarad
A ceramic with 470 is 470p = 470 picofarad
A ceramic with 471 is 470p = 470 picofarad
A ceramic with 101 is 100p (it can also be 100)
A ceramic with 102 is 1,000p = 1n
A ceramic with 223 is 22,000p = 22n
A ceramic with 104 is 100,000p = 100n = 0.1u A common 100n is called a **MONOBLOCK**.
A ceramic with 105 is 1u

TYPES OF CAPACITOR
For testing purposes, there are two types of capacitor.
Capacitors from 1p to 100n are non-polar and can be inserted into a circuit around either way.
Capacitors from 1u to 100,000u are electrolytics (or tantalum) and are polarised. They must be fitted so the positive lead goes to the supply voltage and the negative lead goes to ground (or earth).

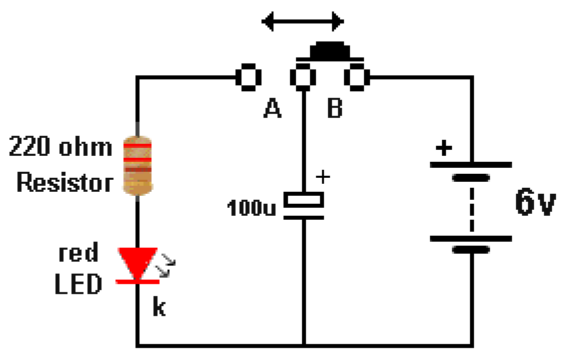


Fig 42. Charging a Capacitor

Here is an experiment to show how much (little) energy is stored in a 100u electrolytic.
When the slide-switch is in position "B", the 100u is charged by the 6v battery.
When the slide switch is moved to position "A" the electrolytic supplies energy to illuminate the red LED via the 220R resistor. It will illuminate for a short period of time.
By moving the switch back and forth, you can keep the LED illuminated.

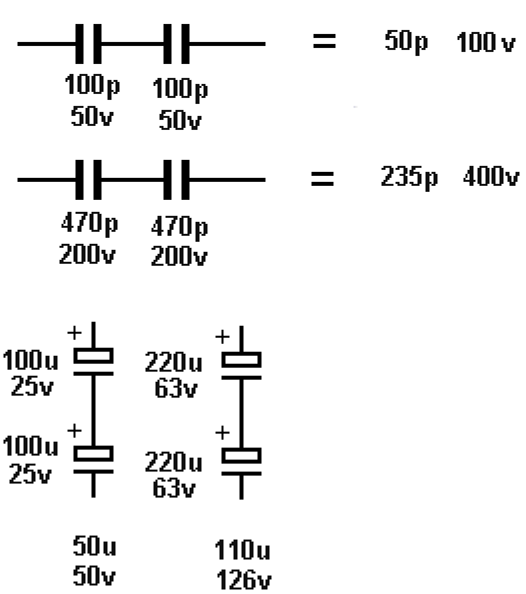
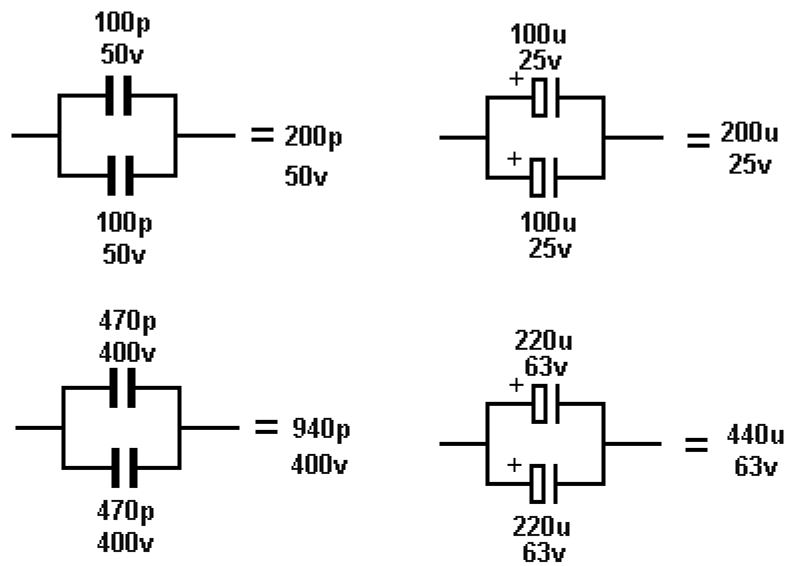


Fig 43. Capacitors in Series

Capacitors can be connected in **Series or Parallel** to obtain a value of capacitance you may not have available.
They are also connected in series to increase the effective **VOLTAGE RATING**.
However when two equal-value capacitors are connected in series, the final value is HALF, and thus you need two with double the final-value to get a value with an increased voltage-rating.
When two equal-value capacitors are connected in series, the result is HALF.
(This is the opposite to connecting resistors)



$$C_{total} = C_1 + C_2 + C_3 + \cdots$$

Fig 44. Capacitors in Parallel

Capacitors can be connected in **Parallel** to obtain a value of capacitance you may not have available. (This does not change the **VOLTAGE RATING**.)
When two equal-value capacitors are connected in parallel, the result is DOUBLE. (This is the opposite to connecting resistors).
If one electrolytic is 25v and the other 63v, the answer is the LOWER VOLTAGE = 25v.

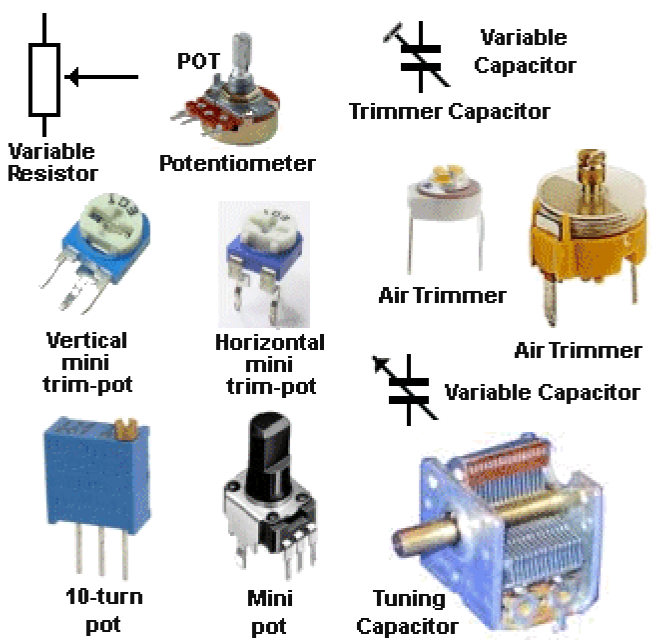


Fig 45. Variable Capacitors and Resistors

The value of a capacitor or resistor may need to be increased or decreased in a circuit to tune in radio stations or increase and decrease the volume of a speaker.
The symbol for these components have an arrow to show they can be adjusted.
The resistance of a potentiometer can be from 1 ohm to 2M
They come in many different shapes and sizes to suit the PC board or front-panel layout.
The "T" represents a trimmer capacitor and this can be from 1p to about 120p.
A variable capacitor will be from about 10p to 415p.

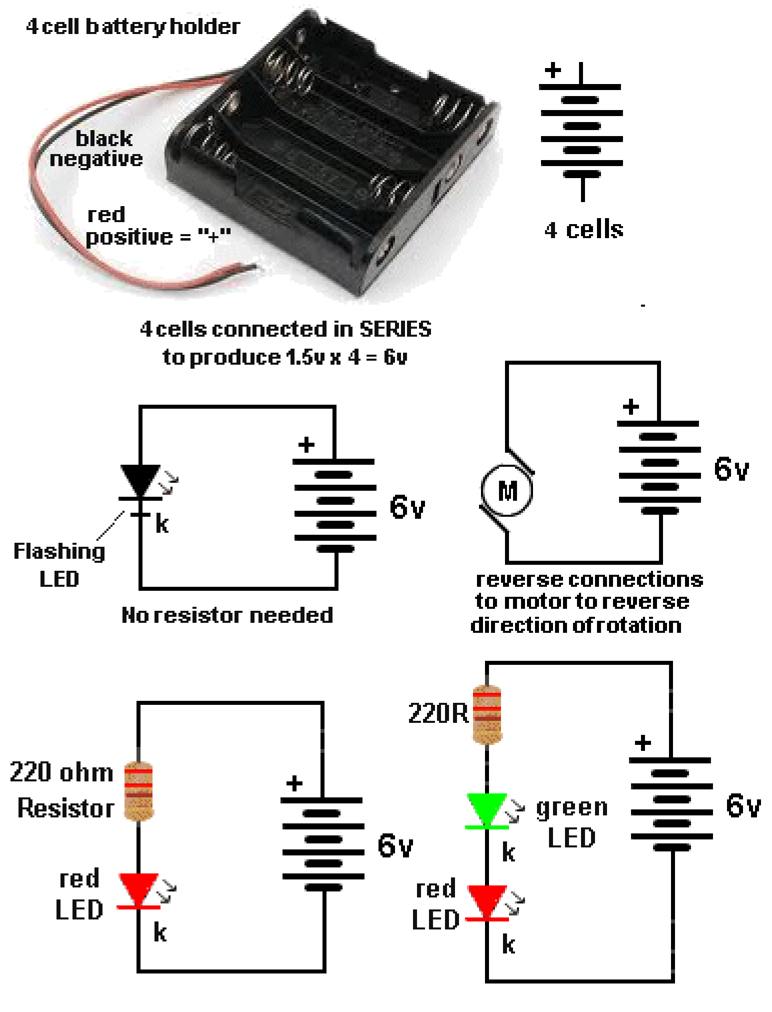


Fig 46. Simple Circuits

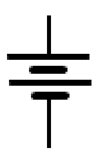
Simple CIRCUITS
We have covered enough symbols and components to create a number of simple circuits.
These circuits will show how to connect a motor, a LED, (how to make it bright or dull) and how to connect 4 cells to make a battery.

Note: The flashing LED does not need a resistor because a resistor and chip are inside the LED, to make it flash and control the current.

Connect all the components around the correct way and then connect them around the wrong way to see what happens.
Connect the flashing LED in series with a red LED and see what happens.

QUESTIONS

1. Explain why the Flashing LED circuit has no external resistor.
2. How many 1.5v cells are needed to produce a 6v battery
3. Explain what happens when you reverse the leads to a motor.
4. Identify the positive terminal:

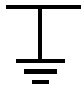


5. Can 3 green LEDs be connected in series to a 6v supply?
6. A variable resistor is also called: ____________________
7. The combined resistance of two 1k resistors in series is: ______________
8. The combined resistance of two 1k resistors in parallel is: ______________
9. Name the short lead on a LED
10. Name the type of multimeter with a pointer and scale: ____________________
11. The total capacitance of two 100u electrolytics in series is: _____________
12. The total capacitance of two 100u electrolytics in series is: _____________
13. Write these values in words:

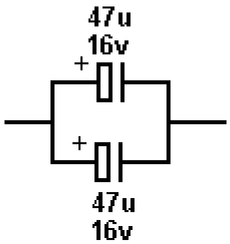
22R __________
4k7 __________
1n ____________
100u ____________

14. How many 1.5v cells in a 9v battery?
15. The red probe is: ________________ (positive/negative)
16. Conventional current flows from: __________ (positive to negative / negative to positive)

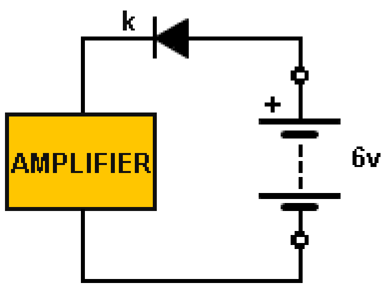
17. Make a 470u electrolytic with two electrolytics:
18. What is the voltage drop across a diode?
19. Name the component that only allows current to flow in one direction: ____________
20. Name this symbol:



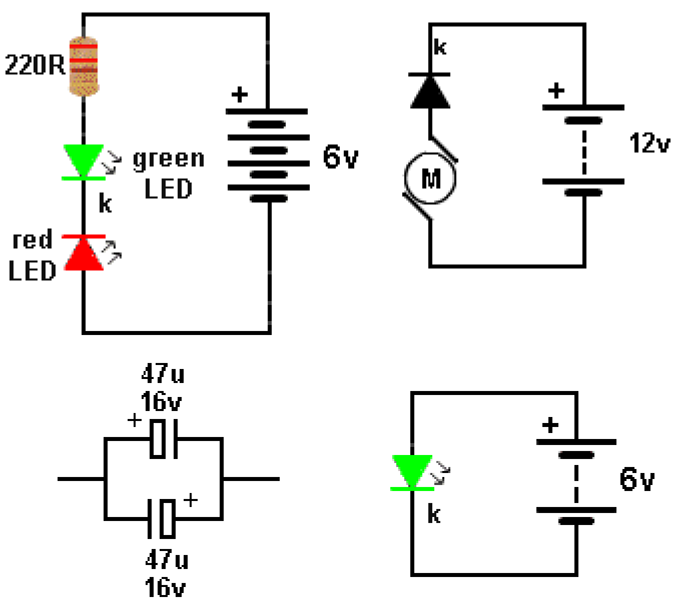
21. When resistors are connected in series, the resistance of the combination: _________ (increases / decreases)
22. When two capacitors are connected in parallel, the voltage-rating of the combination: _______________ (increases / equal to the capacitor with the lowest voltage-rating)
23. Draw two 2k2 resistors in parallel.
24. Which is larger: 470R or 22k
25. What is the value of this combination:



26. What is the name of the resistor in series with a LED: ____________________
27. What is the voltage across the amplifier: _________



28. Identify the fault with these circuits:



Name these components:

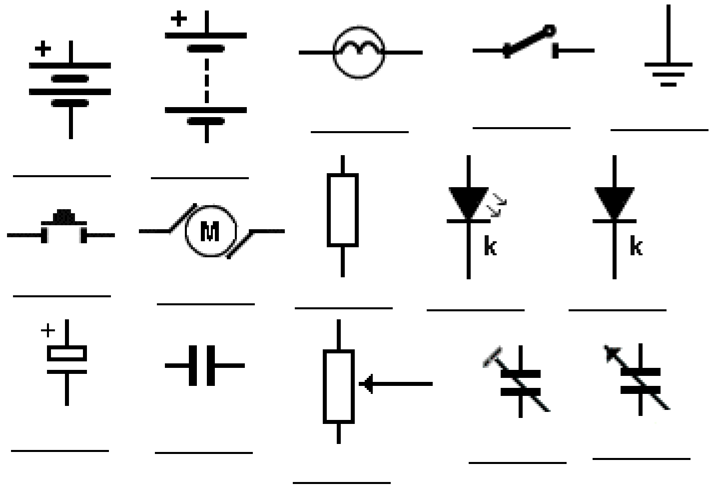


Fig 47. Passive Components

Passive Components

All the components shown on the left are called PASSIVE COMPONENTS. This means they do not amplify.
Write the name beside each symbol.

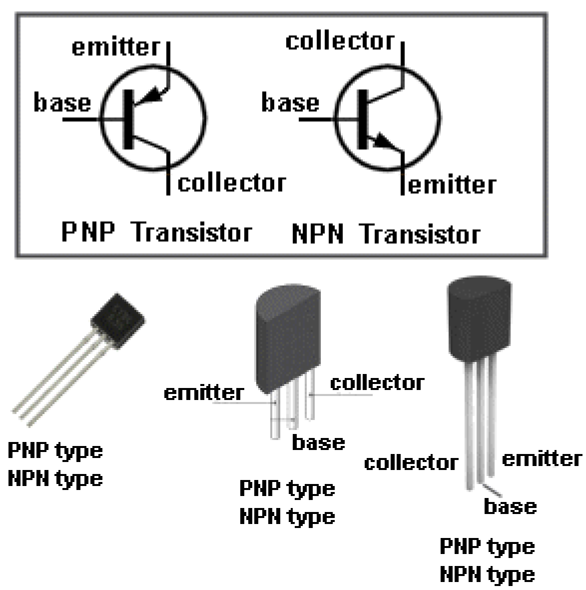


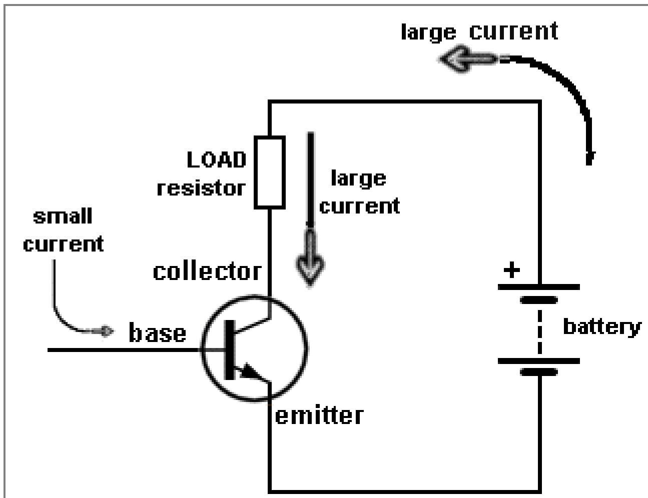
Fig 48. The TRANSISTOR

The TRANSISTOR

A TRANSISTOR is an ACTIVE device. It AMPLIFIES.
There are many types of transistor (over 20,000 different types) from hundreds of manufacturers and they have many different names.
We are going to study the simplest. It has the technical name **BIPOLAR JUNCTION TRANSISTOR (BJT)** but we are going to call it a **TRANSISTOR**.
There are two types in this group: **PNP** and **NPN**.

The type we will study is also called a **SMALL-SIGNAL TRANSISTOR.**

You cannot tell an **NPN** transistor from **PNP** by looking at it. You must test it in a circuit.
In **Fig 65** you will make a **Transistor Tester** project, but first some basic facts:



The first type of transistor we are going to study is the **NPN**.
A transistor has three leads:
BASE, COLLECTOR and **EMITTER**
Basically, a small current enters the base and a large current flows through the collector-emitter leads as shown in the diagram.
The resistor in the collector lead is called the LOAD Resistor.
Sometimes the load is a speaker.

Fig 49. The NPN TRANSISTOR in a Circuit

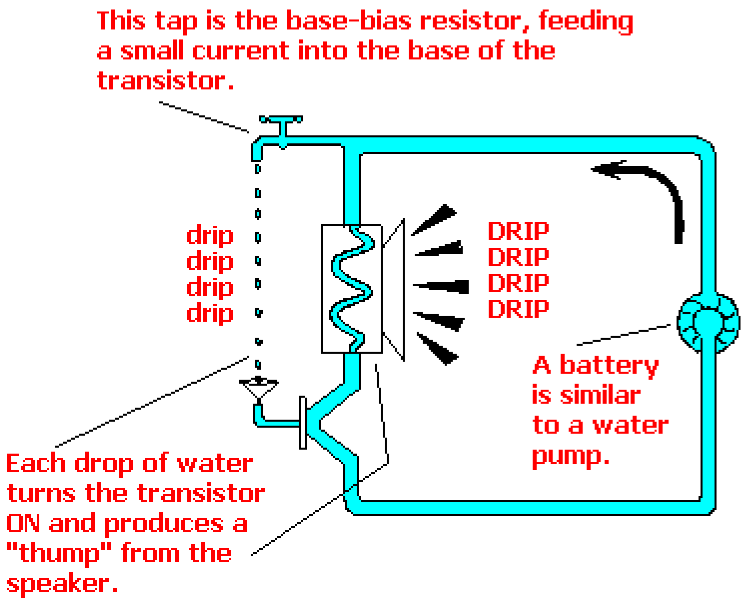
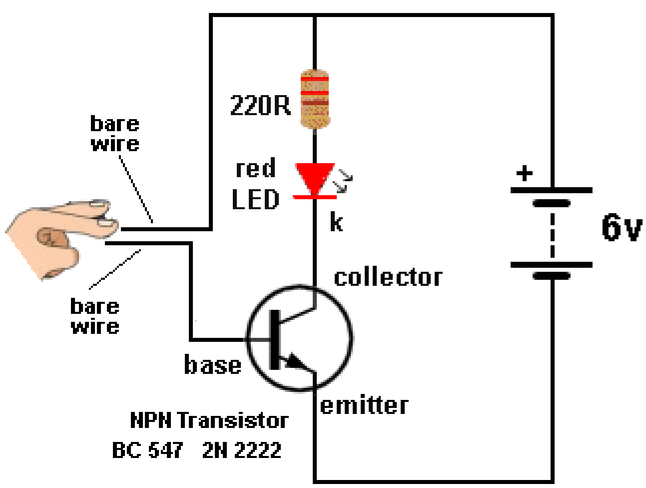


Fig 50. The Water TRANSISTOR

The transistor is similar to the diagram opposite. A small drop of water entering the base is amplified to produce a loud DRIP from the speaker.



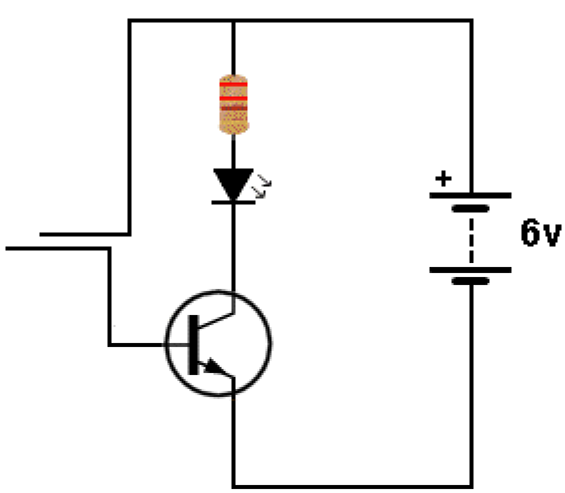


Fig 51. One Transistor Circuit

In this experiment we will construct a ONE TRANSISTOR circuit similar to the WATER TRANSISTOR above and observe the results.
Make sure the two leads DO NOT TOUCH. If they touch, the transistor will be DESTROYED.

The transistor is amplifying the current through your finger via the two leads and it will be very dim.

ANIMATION

The lower diagram shows the transistor turning ON when a finger is pressed against the two wires.
The finger produces a resistance that turns the transistor ON and this turns the transistor into a smaller and smaller resistor.
That's how more and more current flows through the LED and it gets brighter and brighter.

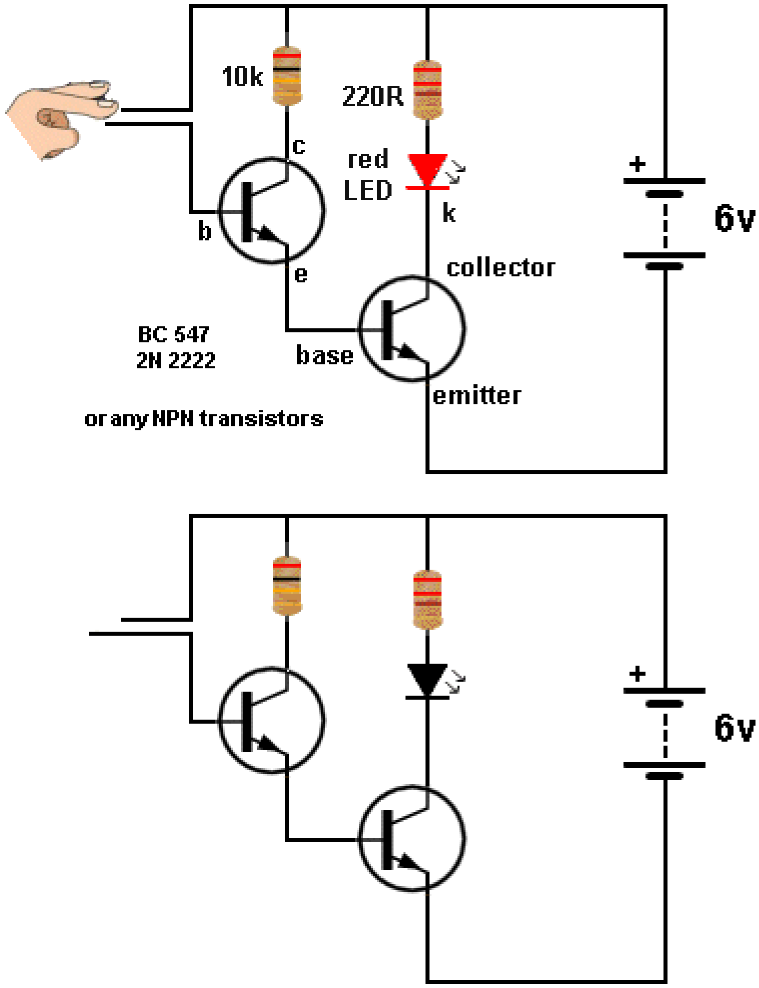


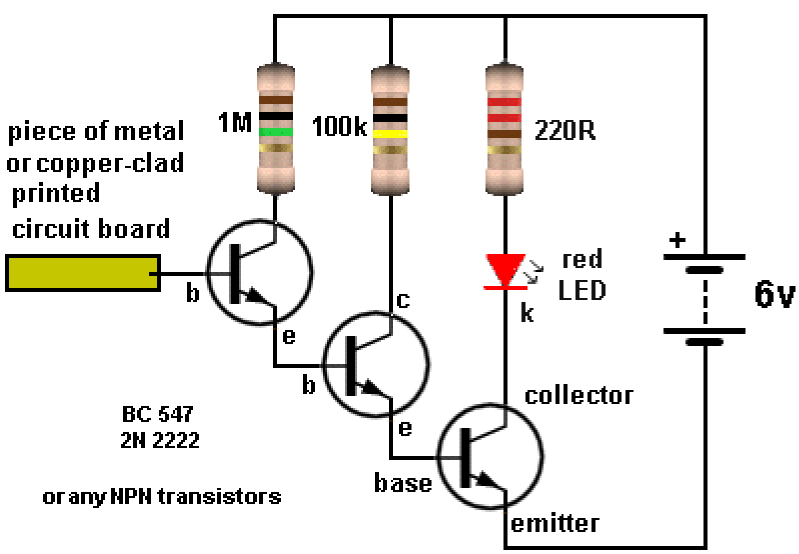
Fig 52. Two Transistor Circuit

By adding another transistor we amplify the current through the finger about 200 times and now the LED will glow bright.

Make sure the bare wires do not touch each other as this will destroy BOTH transistors.

ANIMATION

The lower diagram shows both transistors turning **ON** when a finger is pressed against the two wires.
They both becomes smaller and smaller resistors.
The first transistor allows more current to flow into the base of the second transistor and this is how the second transistor turns on more and more. This allows more current to flow through the LED and it gets brighter and brighter.



This circuit has enormous gain.
Each transistor has a gain or more than 200 and the final gain will be more than:
200 x 200 x 200 = 8,000,000

8 MILLION!

The circuit is very sensitive to static voltages in the air or electrical waves such as the waveform produced by the electrical wiring in a house.
Move the project around a room and detect all the electrical signals.

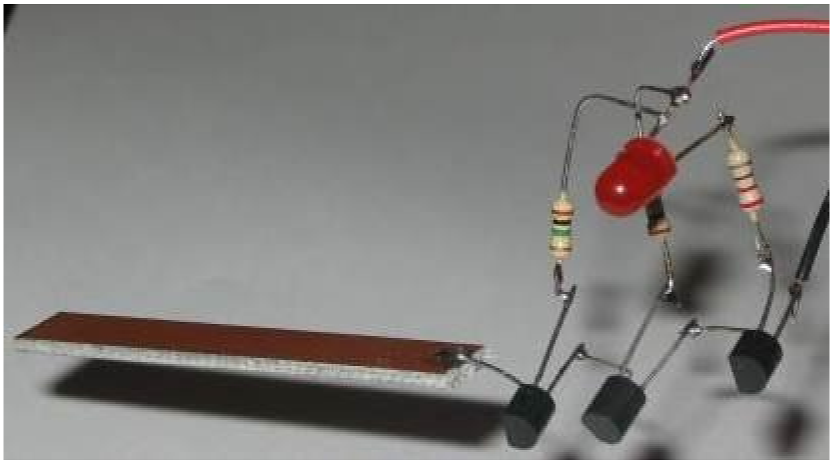


Fig 53. Three Transistors

You can see the effect of one transistor. It does not do much.
The two transistor circuit allows the resistance of your finger to deliver current into the base of the first transistor and this transistor delivers more current into the base of the second transistor. The result is more collector-emitter current and the LED illuminates.
The three transistor circuit produce an ENORMOUS effect.
It will pick up STATIC ELECTRICITY and all forms of electro-magnetic energy (radiation) and illuminate the LED.

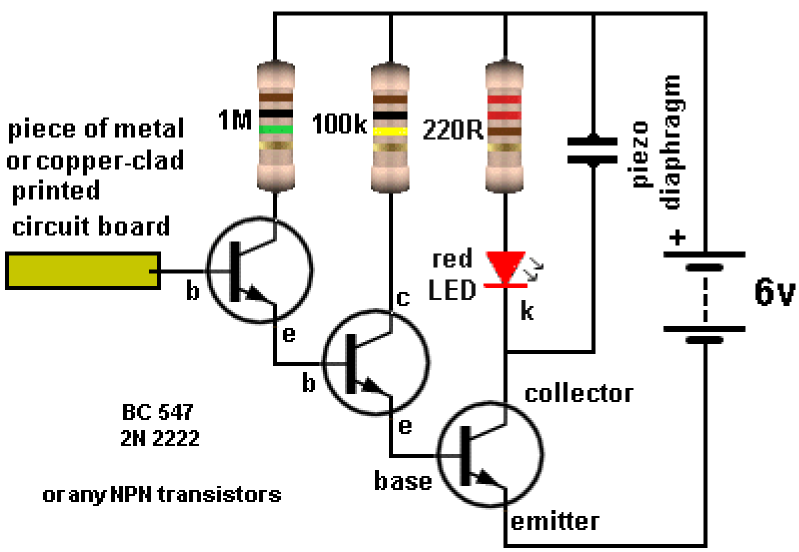


Fig 54. Adding a PIEZO

By adding a piezo diaphragm to the output you will be able to hear the hum of the mains.
This is the frequency of the supply into your house. It will be either 50 cycles per second or 60 cycles per second.
The term: "cycles per second" is given the name HERTZ after **Heinrich Rudolf Hertz**, who was the first to prove the existence of electromagnetic waves.

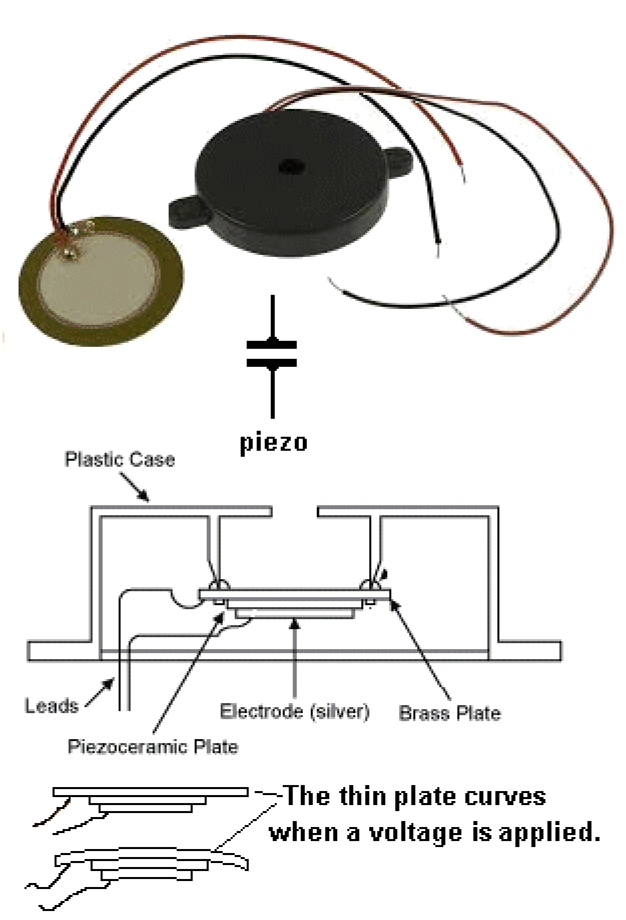
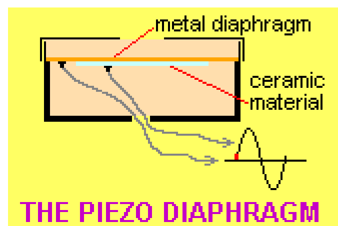


Fig 55. The Piezo

The Piezo diaphragm is held around the outer edge inside a plastic case and when a voltage is applied to the two leads, the thin plate curves very slightly.
When the voltage is removed, the plate returns to its flat shape.
If the voltage is reversed, the plate curves in the opposite direction.

The curving is due to a thin layer of ceramic material under the plate and then a film of metal is deposited onto the ceramic so a lead can be soldered.

There is infinite resistance between the two leads as the ceramic material is an INSULATOR.
The capacitance between the two leads is approx 22n.
The Piezo is a passive device. It needs a pulse or frequency for it to produce an output.



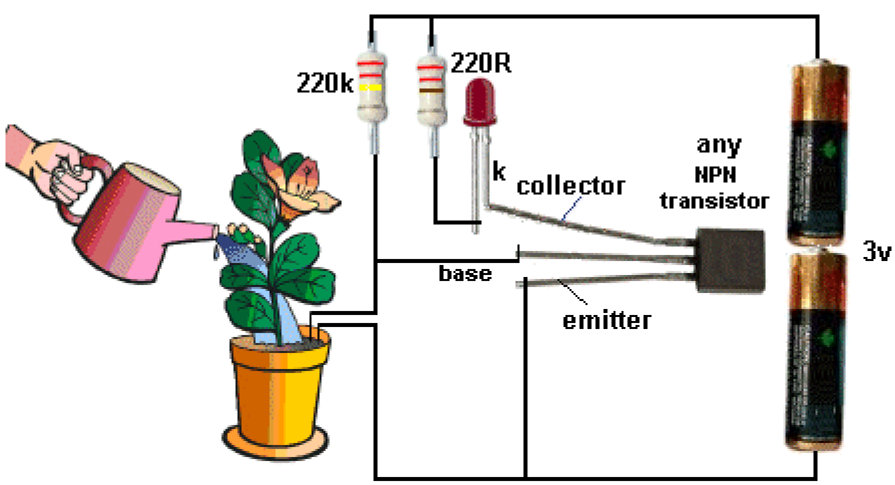


Fig 56. Plant Needs Water

The **ONE TRANSISTOR CIRCUIT** above can be turned into a detector to show when a plant needs water.
Place the two probes into the soil and water the plant. The LED will turn off.
As the water evaporates the LED will turn **ON** to let you know the plant needs watering.

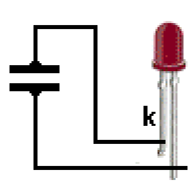


Fig 57. Tap the Piezo

This experiment produces a pulse from the piezo when it is tapped and the LED illuminates briefly.

The LED can be connected either way around.

This proves the diaphragm flexes when a voltage is applied and also in the reverse situation. A voltage is produces when the diaphragm is tapped.

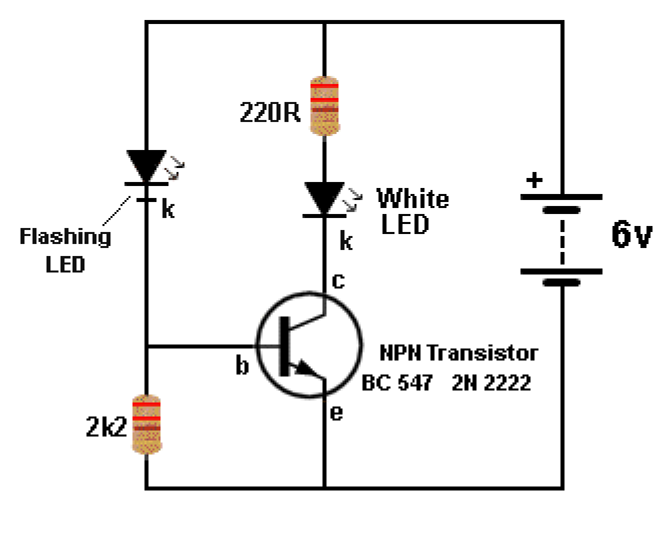


Fig 58. Flashing LED and White LED

A flashing LED is not very bright. It can be connected to a transistor and the transistor will drive a very bright white LED.
The transistor is an amplifier.
It is amplifying the current flowing through the flashing LED and supplying a higher current for the white LED.

We cannot discuss any further details of the circuit at the moment because the actual operation of the circuit is quite complex.

At the moment we just need to experiment with simple transistor circuits.

Fig 59. Soldering Iron

We now come to the point of HELPING YOU WITH CONSTRUCTION.
We have already shown you 6 different circuits and there are many ways to build them.
You can:
1. Solder them.
2. Build them on an Experimenter Board
3. Connect the components with clips or twist the leads together.
It does not matter how you build the circuits.
The fact is this: YOU MUST START BUILDING.
The best soldering iron for a beginner is a CONSTANT TEMPERATURE soldering iron.
It has a dial that can be turned to set the desired temperature.
An ordinary soldering iron GETS TOO HOT. It is not suitable for soldering electronic circuits.
This is something that no-one has mentioned before. An ordinary soldering iron will melt the solder TOO QUICKLY and burn the resin inside the solder and make soldering very difficult for a beginner.
Soldering must be done slowly so the resin in the middle of the solder gets hot and cleans the leads of the components so the solder will "stick."
That's why you must apply the solder to the leads you are soldering and allow the resin to "attack" the leads and clean them.
The cheapest TEMPERATURE CONTROLLED soldering Iron is available on eBay for les than $10.00 (post FREE).
You will also need a small roll of solder (0.9mm) and a soldering Iron stand.
Email Colin Mitchell for links to eBay. (talking@tpg.com.au)
A whole book could be written on the ART OF SOLDERING.
Look on the web for articles and videos on SOLDERING.

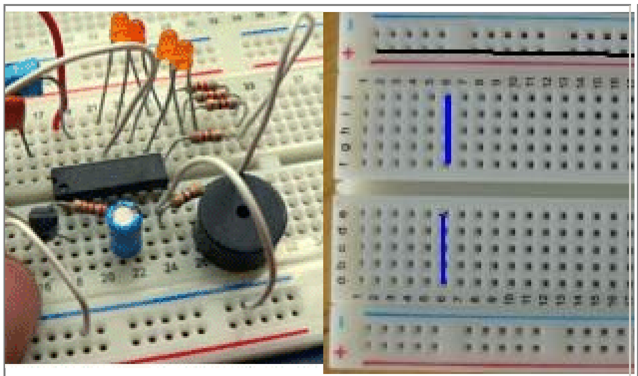


Photo shows a number of components fitted to the breadboard.

Fig 60. BREADBOARD and Components

The term BREADBOARD refers to any piece of wood or plastic containing pins or pegs or clips or holes where you can build a circuit.
The components can be soldered, twisted clipped or fitted into holes.
Breadboard also means the circuit can be easily pulled apart.
Some breadboards do not have two rows for the positive and negative rails. Connections under the board for the positive rail is shown with a black line in the photo. Connections on the main section of the board are shown with blue lines. Your breadboard MUST look exactly like the photo opposite.
Other breadboards are quite useless.
The breadboard in the photo can be purchased on eBay for less than $5.00 (post FREE).

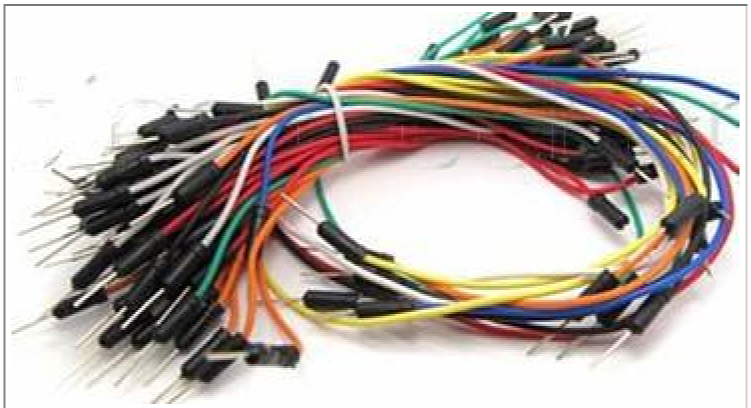


Fig 61. Jumpers

The components on the BREADBOARD are fitted down the holes and metal strips under the board join each column of 5 holes. If you want to join one hole with another, you can use 0.5mm tinned copper wire or JUMPERS. See photo opposite. Jumpers can be purchased on eBay for less than $3.00 posted.

Email Colin Mitchell for links to eBay. (talking@tpg.com.au)

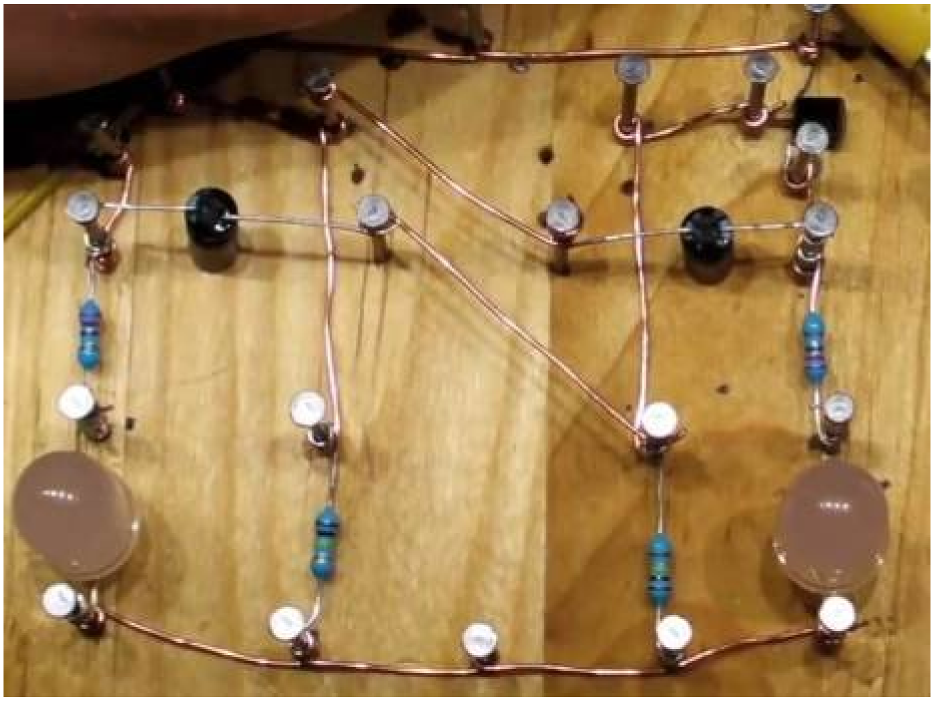
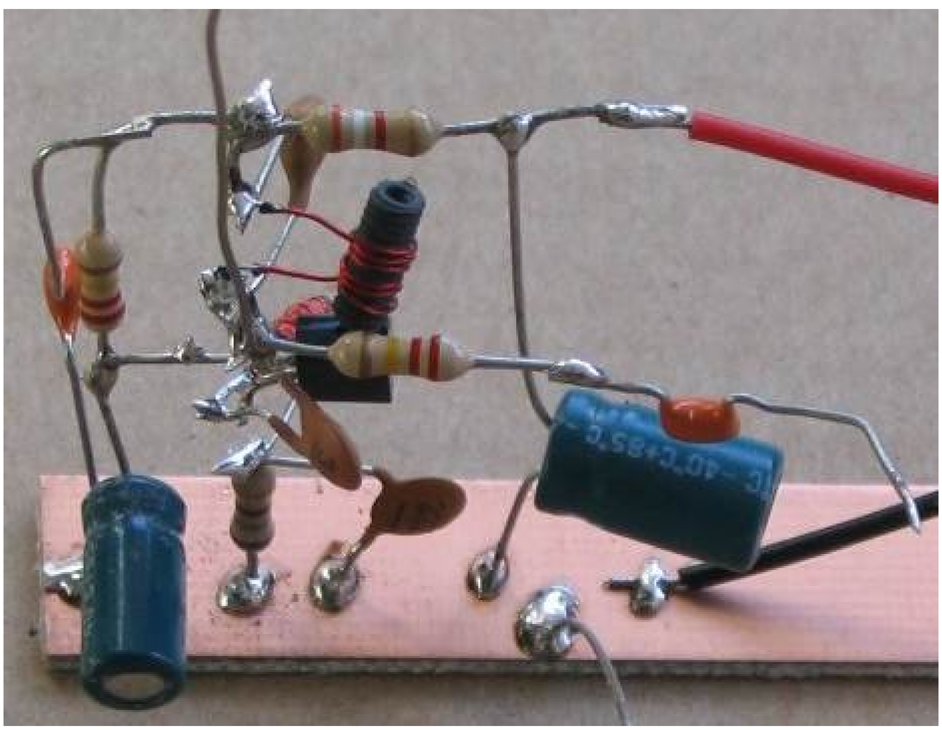


Fig 62. Breadboard with Nails

If you don't have a soldering iron or experimental breadboard, you can make your own board with nails. See the photo above. It is a multivibrator circuit and we will be presenting this circuit in a moment. The components can be twisted around the nails and bare wire used to join some of the nails to complete the circuit.

Another method of connecting the components is called BIRD-NESTING. This involves soldering the components "in the air" as shown in the 27MHz transmitter circuit below:



Another way to connect the component(if you don't have a soldering iron), is to wind 6 turns of bare wire around each connection and leaving all the components "in the air." The bare wire can be obtained from hook-up flex. This is plastic coated "wire" containing up to 15 fine strands of wire. Use a single strand for the connections. None of the components will touch each other BY MISTAKE and the circuit will work perfectly. Bird-nesting is a good way to build a quick circuit and test its performance. It might look messy but you can easily change any component.

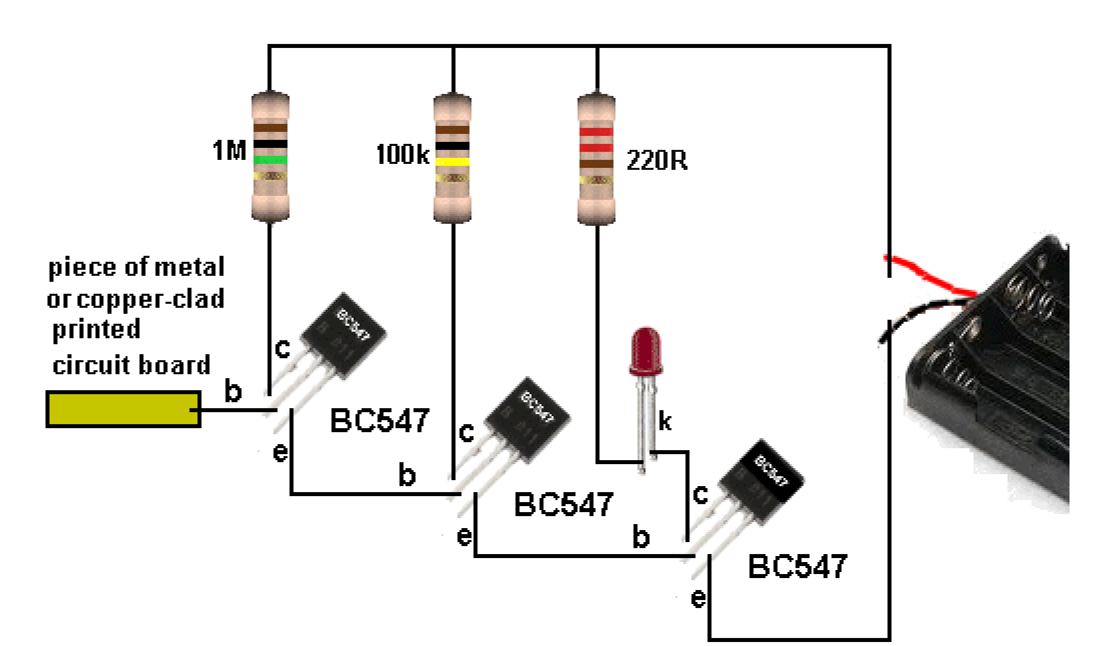


Fig 63. Wiring the 3-Transistor Circuit using BC547 Transistors
The diagram shows how to connect 3 x BC 547 transistors.
The leads of a transistor can be collector-base-emitter OR
emitter-base-collector and that's why we have provided 2 different wiring diagrams.

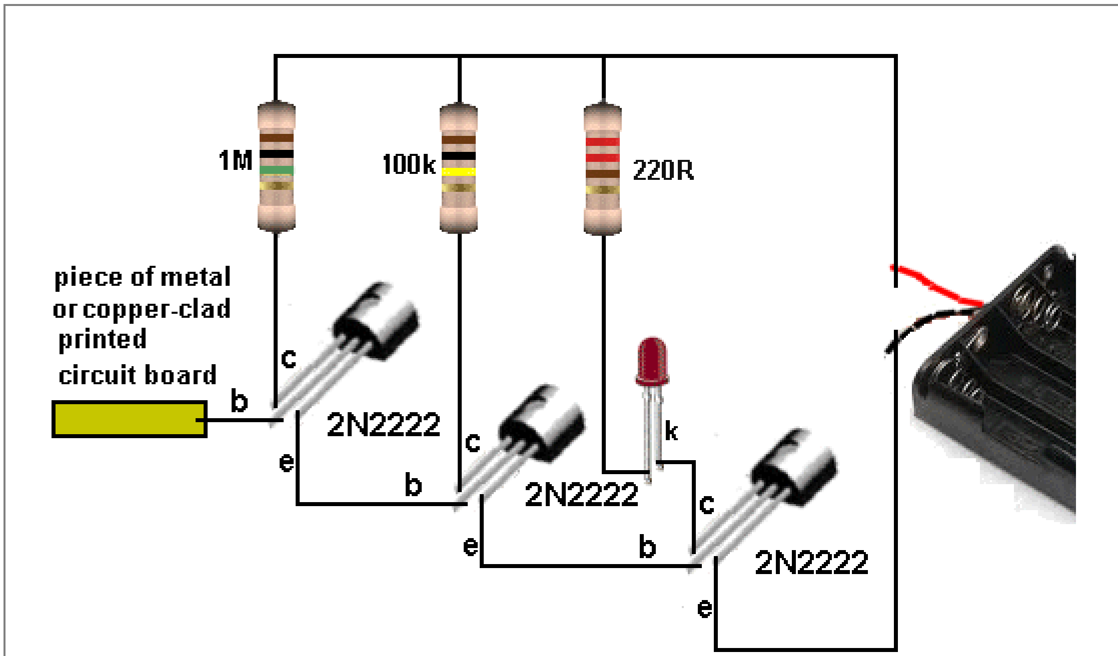
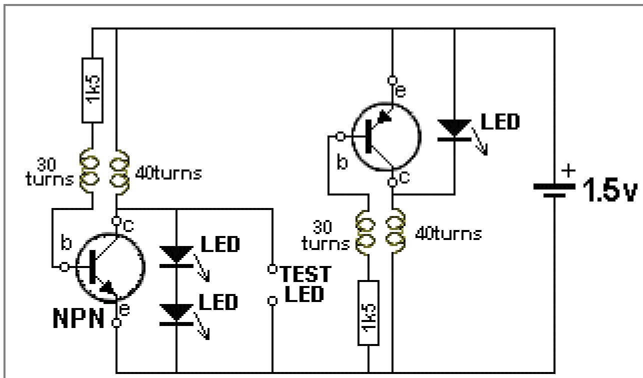


Fig 64. Wiring the 3-Transistor Circuit using 2N2222 Transistors
The diagram shows how to connect 3 x 2N2222 transistors.



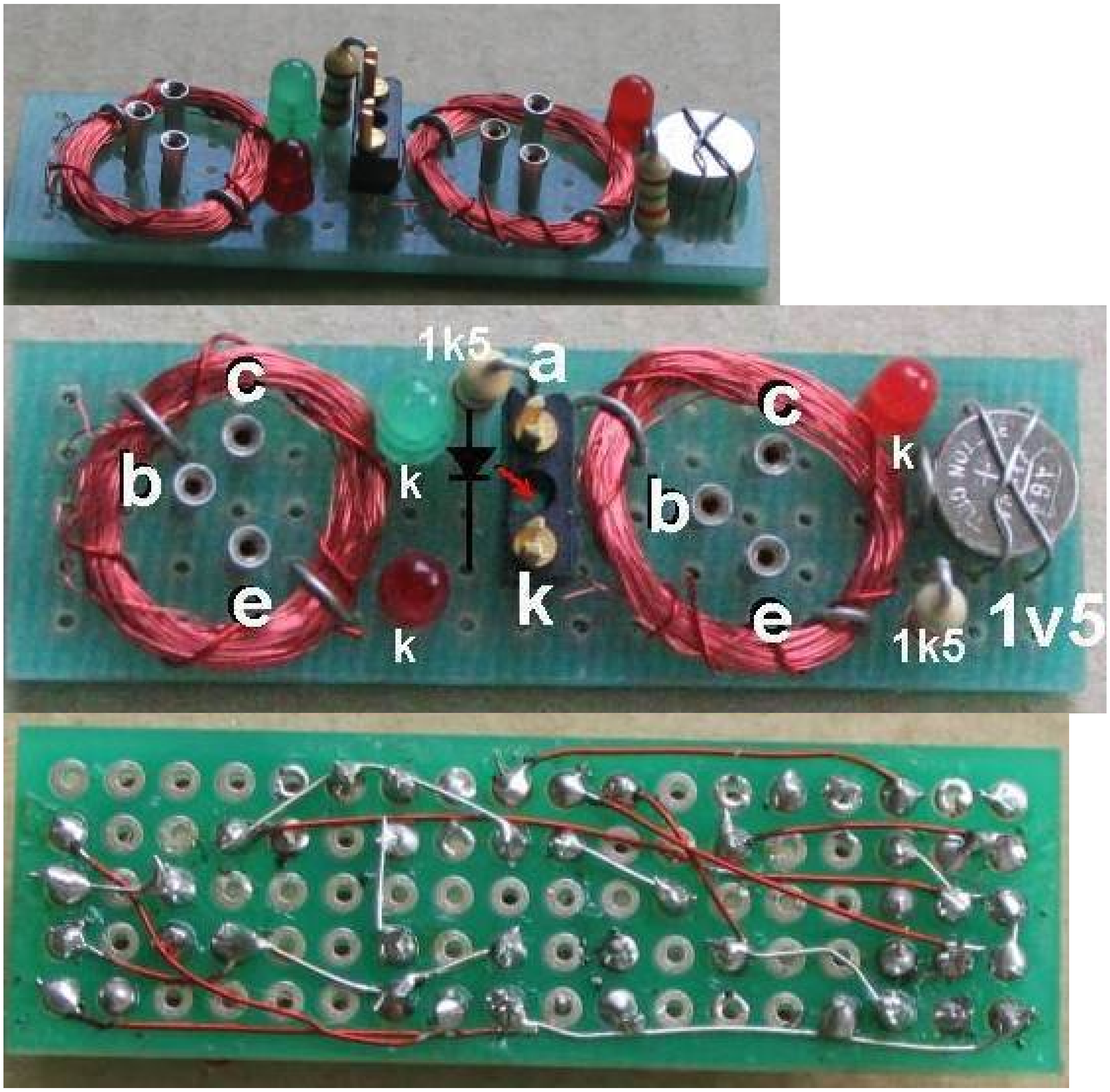


Fig 65. Transistor Tester

This handy transistor and LED tester can be built to test LEDs and both PNP and NPN transistors.
The project consists of two identical circuits, one for NPN and one for PNP.
You can build just the NPN section and then build the PNP section later.

LED VOLTAGE

We have shown a LED needs at least 1.7v supply for it to operate.
This circuit works on 1.5v and thus the action of the transistor and coil (called a Transformer) MUST be increasing the voltage for the LED to illuminate.
This circuit works on two "actions."
1. Transistor ACTION - this is the action of a transistor providing gain to make the circuit oscillate.
2. Transformer ACTION - this is the action of a coil of wire producing a voltage higher than the supply voltage when it is turned off.

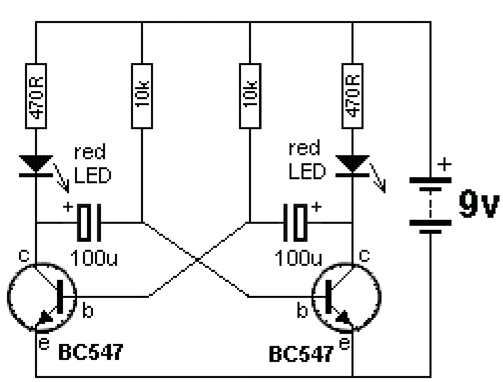
This circuit is very technical and very complex.
We will be explaining it in a very simple way because this is a **Basic Electronics Course**.

THE TRANSFORMER - the two coils of wire on the left and the two coils of wire on the right.
When the voltage (actually the current) is switched off, the 40 turn coil in either of the circuits in this project; the voltage across the coil rises to more than the 1.5v supply and is in the opposite direction to the voltage of the supply.
The circuit looks to be very simple but it uses an air-cored transformer to produce the voltage needed to illuminate the LED indicators and the circuit only works when the transistor is connected correctly. There are two separate circuits, one for NPN transistors and one for PNP transistors. We will cover the NPN section:
The circuit turns ON when the NPN transistor is fitted and the current through the 30 turn coil

and 1k5 resistor turns ON the transistor and produces expanding flux in the 40 turn coil. This flux cuts the turns of the 30 turn coil and produces a voltage in the coil that adds to the supply voltage and increases the current into the base. This turns the NPN transistor ON more. This action continues until the transistor is fully turned ON. At this point the current in the 40 turn coil is a maximum but it is not expanding flux and the 30 turn coil ceases to see the extra voltage. Thus the current into the base reduces and this turns the transistor OFF slightly. The flux produced by the 40 turn coil now becomes collapsing (or reducing) flux and it produces a voltage in the opposite direction to greatly reduce the current into the base. In a very short period of time the transistor becomes TURNED OFF and it is effectively removed from the circuit. The flux in the 40 turn coil collapses quickly and it produces a voltage in the 40 turn coil that is higher than the supply voltage and is in the opposite direction. This means the voltage produced by the 40 turns ADDS to the supply voltage and is delivered to the LEDs to illuminate them.
The NPN circuit has two LEDs in series so that a LED of any colour (including white) can be connected to the TEST LED terminals and it will illuminate. You can use any colour LED for any of the LEDs, however it is best to use either green or yellow or white for the single LED.
The two "coils" are wound on a 10mm dia pen with 0.1mm wire (very fine wire). The loops of tinned copper wire holding the coils on the board are connected to separate lands under the board and MUST NOT produce a complete loop as this will create a “Shorted Turn” and the circuit WILL NOT WORK.
If the LEDs do not illuminate, simply reverse the wires to the 30 turn coil.
The circuit does not need an ON/OFF switch because the LEDs require a voltage of over 2v to illuminate (the orange LED) and the supply is only 1.5v. A red LED needs about 1.5v to 1.7v to operate but when it is in series with a green LED, this voltage is over 3.5v.
All the components fit on a small matrix board 5 holes x 18 holes. A kit of parts for the project is available for $4.00 plus $3.00 postage and ordering details can be obtained by emailing Colin Mitchell. (talking@tpg.com.au)
Build the circuit and test your transistors and LEDs.
We will be covering more on the action of a transistor and the action of a transformer in the discussion below, but it is important to build the circuit and see it working.
It is your first piece of **TEST EQUIPMENT**.

Questions

1. Identify the letters "c" "b" and "e"
2. What type of transistor is tested in the first set of hollow pins?
3. Put a PNP transistor into the first set of hollow pins and try all positions. Does the red and green LEDs illuminate?
4. When both the red and green LEDs illuminate, what is the approximate voltage across the pair?
5. When you fit a red LED to the test-socket, what is the approximate voltage across it?
6. When you fit a red LED to the test-socket, why does the red LED and green LED on the PC board turn off?
7. Why doesn't the project need an on/off switch?
8. The two coils for the circuit on the left is called a TRANSFORMER. Do the connections of the windings have to be connected to the circuit around a particular way?



ROBOT MAN

This multivibrator circuit will flash the Robot Man's eyes as shown in the photo. The kit of components is available from Talking Electronics for $8.50 plus postage. Send an email to find out the cost of postage: talking@tpg.com.au
The photo shows the LEDs flashing.
The circuit is called an **ASTABLE MULTIVIBRATOR** and this means it is not stable but keeps switching from one transistor to the other.
It is also called a **FLIP FLOP** circuit.

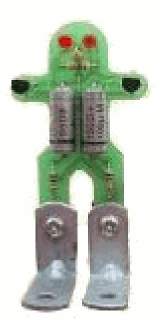


Fig 66. **ROBOT MAN**
The ASTABLE MULTIVIBRATOR or "free-running" multivibrator.

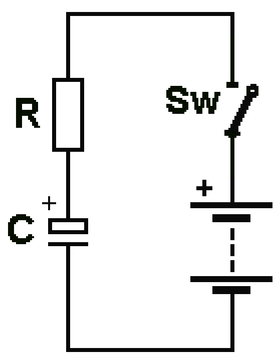


Fig 67. The TIME DELAY

The **TIME DELAY** circuit consists of a Resistor **R** and Capacitor **C** in **SERIES**.
When the switch is closed, the electrolytic (called the CAPACITOR) charges slowly because the resistor only allows a small amount of current to flow.
It's just like charging your mobile phone. The battery takes time to charge because there is a resistor in the circuit to limit the current. If we remove the resistor in the mobile phone, the battery will get too hot when it is being charged but in the **TIME DELAY** circuit, we want the capacitor to charge slowly, because we want a **TIME DELAY.** .

Fig 68. The charging of a capacitor is the same as building a brick wall.

CHARGING A CAPACITOR

The capacitor in **Fig 67** charges via the resistor **R**.
But the voltage on the capacitor does not rise at a constant rate.
It starts off charging very quickly and as the voltage across it get higher, the voltage increases at a slower and slower rate.
In the photo I am building a brick wall.
I am working at a constant rate.
When I started building the brick wall, I laid 5 rows of bricks (5 courses) in the first hour.
As the wall increased in height, I had to climb the ladder and I could only lay 3 courses an hour and finally the wall was so high I could only lay 1 course per hour.
This is exactly the same as a capacitor charging.
When the capacitor is uncharged, the supply voltage allows a high current to pass through the resistor **R** and the energy quickly fills the capacitor. This results in a rapidly increasing voltage on the capacitor. But as the voltage on the capacitor increases, the difference in voltage between that on the capacitor and the supply is very small and only a small current will pass through the resistor. This means the voltage on the capacitor increases at a slower rate.

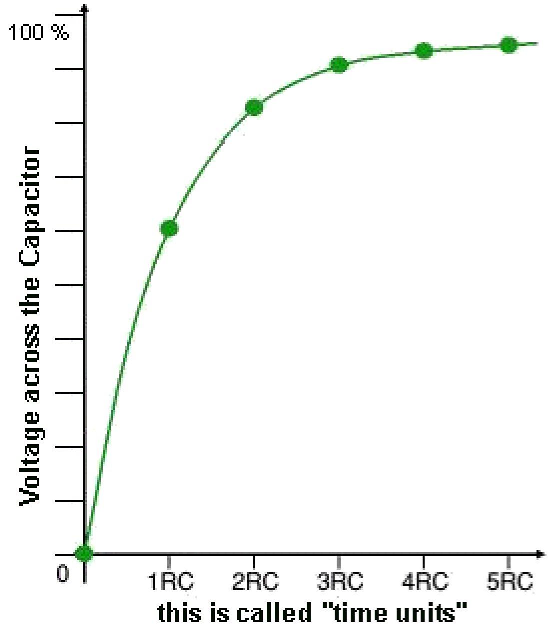


Fig 69. Time Units

It really does not matter how fast or slow or uneven a capacitor charges because most circuits detect a voltage on a capacitor and the time taken to reach this voltage is called the **TIME DELAY**.
But to prevent you thinking the capacitor charges "smoothly" we have to explain what actually happens.
The graph on the left shows the capacitor charging. You can see it charges quickly at the beginning and then charges slowly and then very slowly.
You can see the first part of the graph is fairly "straight" (constant charging) - NOT "straight up and down" but a straight line - and this applies to a voltage of about 63%. The time taken to reach this voltage is called **ONE TIME UNIT** - also called **ONE TIME CONSTANT**. The graph continues for another 4 "time units" (time-constants) and the final voltage is very nearly 100%. (It never reaches 100%.)

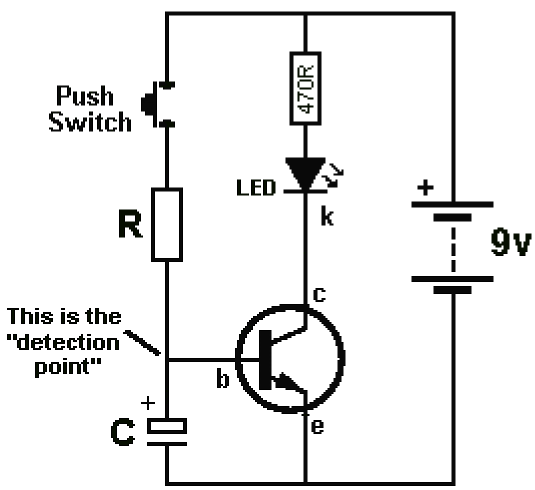


Fig 70. Time Delay Circuit

A **TIME DELAY** circuit needs three things:
1. A Resistor (R)
2. A Capacitor (C)
3. A "Detection Point."

When the switch is pressed, capacitor (**C**) takes time to charge via resistor (**R**) and after a short period of time the voltage at the **DETECTION POINT** is 0.6v and the transistor is TURNED ON. The LED illuminates.

Build the circuit with 100u and 100k and see how long it takes before the LED illuminates.

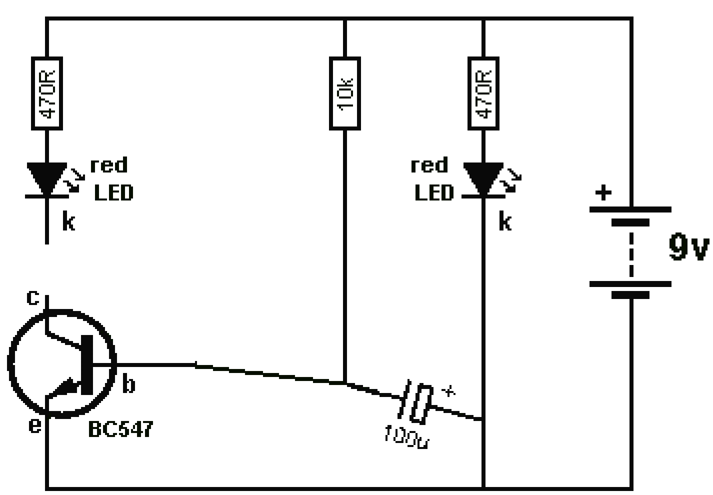


Fig 71. The "TIME DELAY" in the ROBOT MAN Project

In the **ROBOT MAN** project you can see the "**TIME DELAY**" circuit made up of the 100u, 10k resistor and the base of the transistor.

This is one of the most important **BUILDING BLOCKS** in electronics.
It is the basis of all oscillators and will be discussed below, after we explain a few more details.

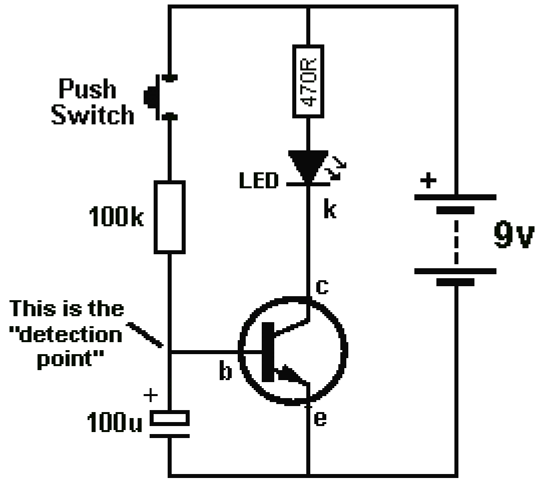


Fig 72. Turning A Transistor ON

We will use the **TIME DELAY** circuit to turn the transistor **ON**.
Make sure the 100u is uncharged by touching both leads (both ends of the capacitor) at the same time with a JUMPER - this is a piece of wire shown in Fig 61.
Push the switch and noting happens. After a short period of time the LED starts to glow and then comes on fully.
This shows two things:
1. The transistor is not turned ON when the base voltage is zero.
2. The base voltage must be 0.6v for the transistor to start to turn ON and when the voltage is 0.65v the transistor is turned **ON FULLY.**

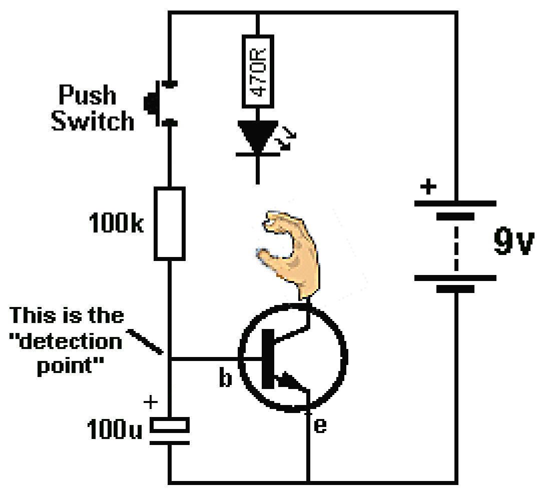


Fig 73. How the LED turns ON

Here is an explanation of how the LED turns ON.
When the circuit is first assembled and the switch is not pressed, the transistor is not turned on and it is just like the diagram opposite. The LED is not connected to the transistor.

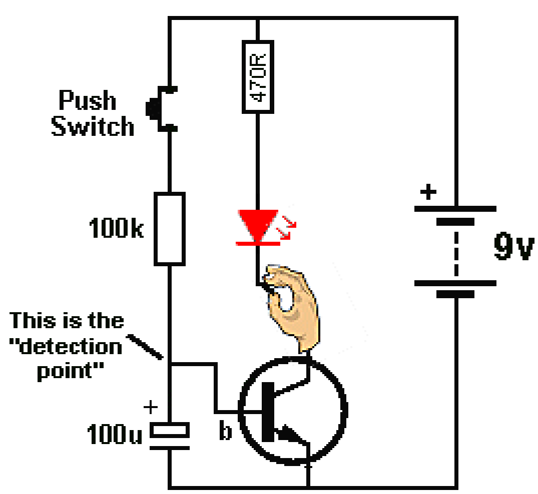


Fig 74. The LED turned ON

When the switch is pushed, the transistor turns **ON** (after a few seconds) and it pulls the lower lead of the LED down towards the 0v rail and this action turns the LED **ON**.

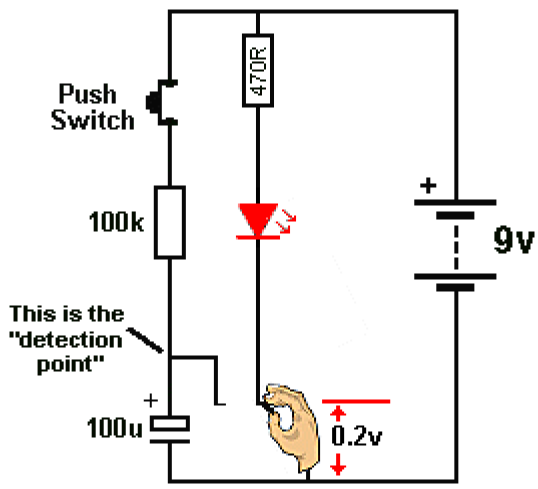


Fig 75. The LED fully turned ON

When the LED is **fully turned ON**, the lower lead of the LED is almost directly connected to the 0v rail.
In other words:
When the transistor is **FULLY TURNED ON**, the lower lead of the LED is almost directly connected to the 0v rail.
The voltage between the lead of the LED and 0v rail is 0.2v. This is the characteristic voltage across the collector-emitter terminals of a transistor when it is TURNED ON.

In the three diagrams above you can see the LED is changed from an **OFF** condition to an **ON** condition by the action of the transistor.
The transistor is acting **LIKE A SWITCH.**
This action is one of the most important actions in electronics.
It is called: **"The Transistor as a SWITCH"**
It is the basis to ALL Digital Circuits.
It is the basis because of these two facts:
1. When the transistor is **OFF**, the circuit is taking **no current** and no power is being lost or wasted.
2. When the transistor is **ON**, the LED is almost at 0v and no resistor is in the lower lead to waste any power.
Thus we can turn things **ON** and **OFF** without wasting and power.
This is the basis to **DIGITAL ELECTRONICS**.

DIGITAL ELECTRONICS revolves around circuits that are either **FULLY ON** or **FULLY OFF**. This means they take almost no power and we can combines lots of circuits and still take almost no power.
This means they do not get hot and it also means they will last a long time.
You may not think turning a transistor **ON** and **OFF** will achieve any worthwhile outcome but a circuit can be designed to use two transistors (similar to the **ROBOT MAN** above). The circuit does not Flip-Flop but requires a switch and when the switch is pressed, the circuit changes state. The two transistors are connected together and it takes two presses of the switch to make the output of the second transistor change state ONCE.
The circuit is a divider. It is called a: **divide-by-two** and is the basis of all counting in a computer.
By adding more "**divide-by-two"** circuits we can get "**divide by 4**, **divide by 8**" etc. Two transistors don't do much but when you combine millions of transistors we have a **COMPUTER.**

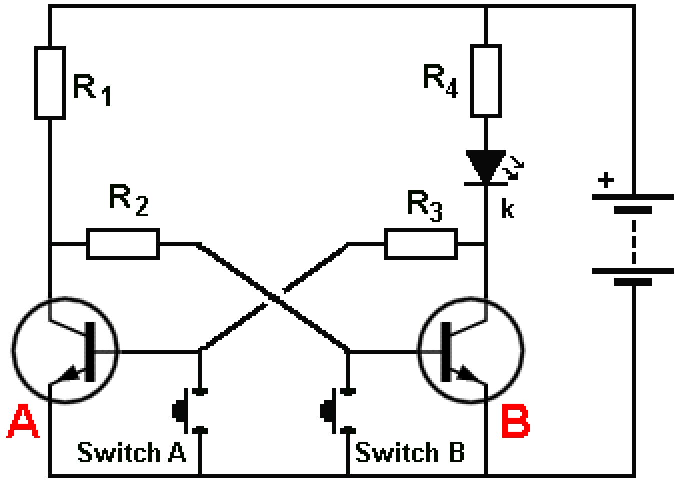


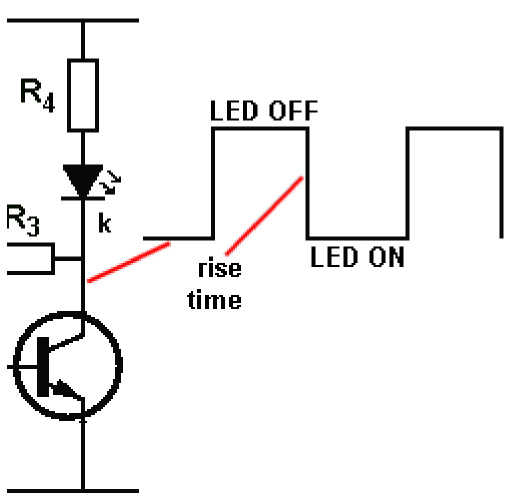
Fig 76. The "MEMORY CELL"

When Switch **A** is pressed, the voltage on the base is removed and transistor **A** turns OFF.
Transistor **B** turns ON via resistors R_1 and R_2 and the LED is turned **ON**.
When the switch is released, the voltage on the collector of transistor **B** is less than 0.6v and the two transistors remain in this state.
Pressing switch **B** turns the LED **OFF.** (transistor **A** turns ON via R_3, R_4 and the LED - very little current flows through the LED and you can hardly see it glowing). The voltage on the collector of transistor **A** is less than 0.6v and the two transistors remain in this state.

Two transistors can do one more thing. They can "**REMEMBER**."
Here is a manual circuit.
Pressing Switch **A** turns the LED **ON** and pressing switch **B** turns the LED **OFF**.
The circuit "remembers" or remains in each state called a stable state.
The technical name for this circuit is:
BISTABLE MULTIVIBRATOR or **BISTABLE SWITCH** or **BISTABLE LATCH**.

This is the basis to all the memory in a computer.

In electronics, we talk about the **DIGITAL TRANSISTOR** and **ANALOGUE TRANSISTOR**.



This is just an ordinary transistor (called a Bipolar Junction Transistor) in a **DIGITAL CIRCUIT** or **ANALOGUE CIRCUIT**.
We are now discussing the **DIGITAL CIRCUIT** - The Multivibrator - Astable Multivibrator and Bistable Multivibrator (Memory Circuit).
The **DIGITAL CIRCUIT** has **2 STATES**.
The **ON STATE** and the **OFF STATE**.
It is conducting in the ON STATE and the LED is illuminated.
In the OFF STATE, the LED is not illuminated.
In the ON STATE the transistor is said to be **CONDUCTING** or **BOTTOMED**.
In the OFF STATE the transistor is said to be "**CUT OFF** or "**OFF**."
These two states are reliable and guaranteed.
They are not "half on" or "quarter on" or "75% off."
These states are easy to transmit "down a wire." The ON STATE is transmitted as "1" (voltage present) and the OFF STATE is transmitted as "0" (voltage not present).
These are the two **DIGITAL STATES**.

The **ROBOT MAN** is a **DIGITAL CIRCUIT**.
Each LED is ON or OFF.
The waveform on the output of each transistor is called a **DIGITAL SIGNAL**.

The waveform is said to be **DIGITAL** or **SQUARE WAVE**.
The top line of the graph represents the LED OFF.
The bottom line of the graph represents the LED ON. The LED is ON when the collector voltage is LOW because we are pulling the lead of the LED to the 0v rail as shown above.
The circuit changes from one state to the other very quickly and this is called the **RISE TIME**.

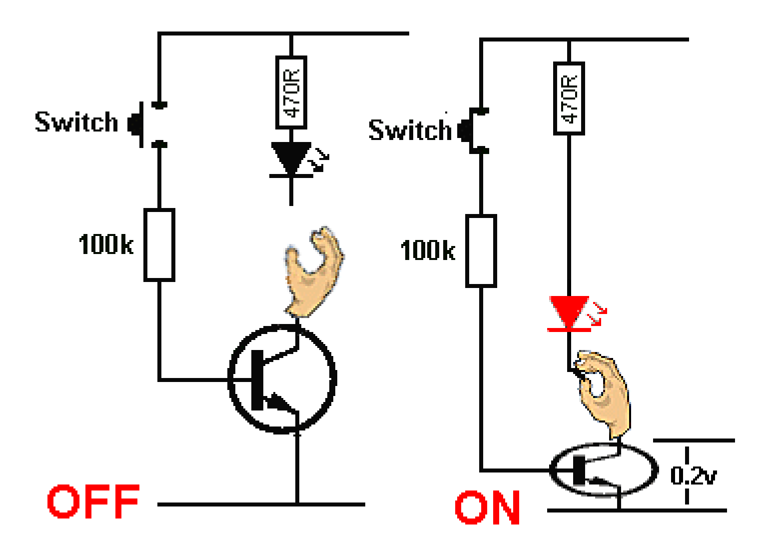


Fig 77. The two Digital States

Going over the two **DIGITAL STATES** for a transistor.

In the first diagram the switch is not pressed and the base does not see a voltage to turn the transistor on. The transistor is "**OFF**" (not conducting) and it is not "grabbing" the LED. The LED is not illuminated.

In the second diagram the base of the transistor sees a voltage via the switch and it is TURNED on. The LED is illuminated.

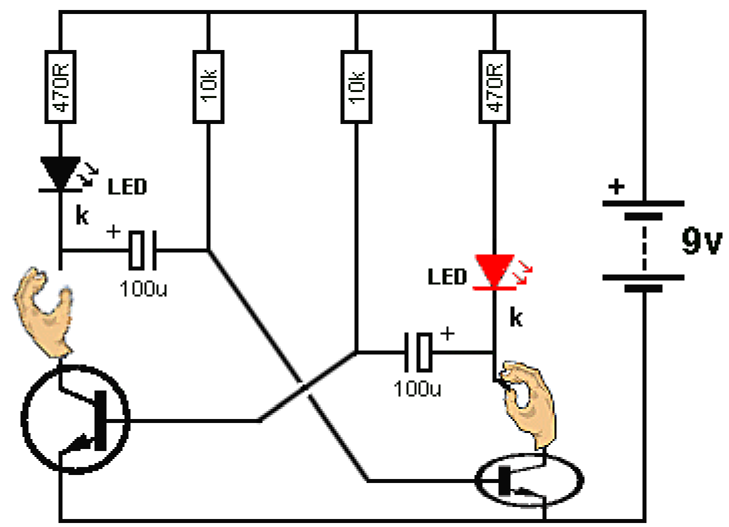


Fig 78. ROBOT MAN Animation

This animation shows how a transistor grabs a LED and pulls it towards the 0v rail to turn it ON.

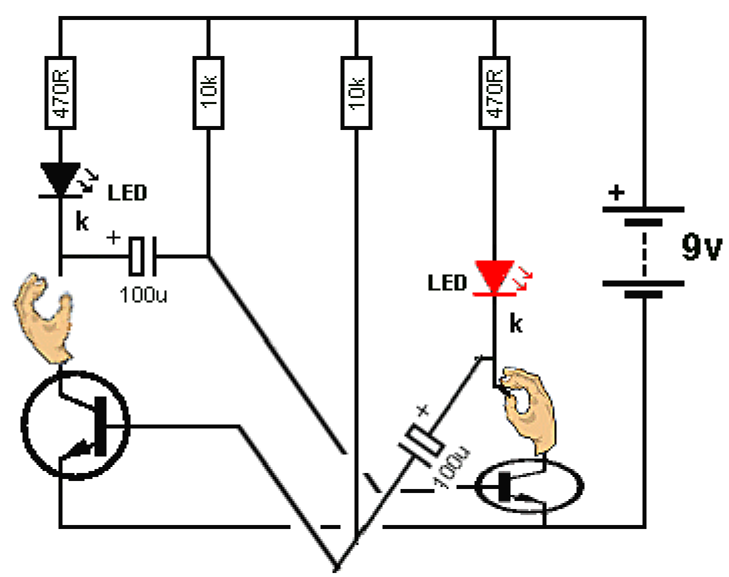


Fig 79. TIME DELAY Animation

The animation in **Fig 78** shows the two transistors turning the LEDs **ON** and **OFF** in a **FLIP FLOP** circuit.
We know the 10k and 100u components form a **TIME DELAY** to create the time for each LED to be illuminated. The timing for one LED plus the other LED creates a **CYCLE** and this is the **FREQUENCY OF OPERATION** for the circuit. It is measured in cycles per second - Hertz - Hz.
We will now go into more detail of how the **TIMING COMPONENTS** create the **TIME DELAY** for each LED.
The circuit is more-complex than you think.
The 100u is already charged from a previous cycle and we show how it gets discharged via the 10k and charged in the opposite direction by the 10k to create a **TIME DELAY**.

GATES

Animations of **GATES** and more details of their operation is covered in **DIGITAL ELECTRONICS** chapter.

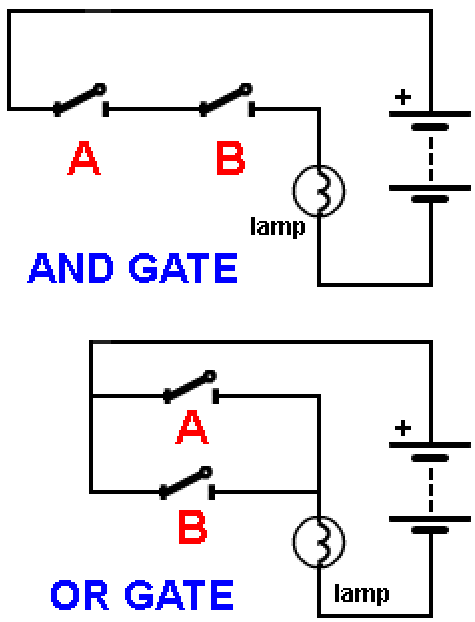


Fig 80. The "AND" GATE and "OR" GATE with switches

The next **BUILDING BLOCK** we will cover is called the **GATE**.
In its simplest form it is an electrical circuit consisting of switches.
Its just two or more switches connected in series or parallel.
We give each circuit a name so we can talk about it and explain its action with a single word.
Later we will cover the electronic version and show how diodes and a transistor are needed to perform a **GATING FUNCTION.**
The type of GATE we are talking about is a **LOGIC GATE**.
The circuit performs an operation called a **LOGICAL OPERATION** on an input or a number of inputs and creates a single output - called a **LOGICAL OUTPUT**.
LOGICAL means "understandable" or "correct" and in this case it means DIGITAL - the signal will rise to full rail voltage or fall to zero voltage. The output will not be half rail or quarter-rail voltage.
The diagram show an **"AND" GATE** and **"OR" GATE** with switches.
For the **AND GATE** close switch A **AND** switch B for the lamp to illuminate.
For the **OR GATE** close switch A **OR** switch B for the lamp to illuminate.

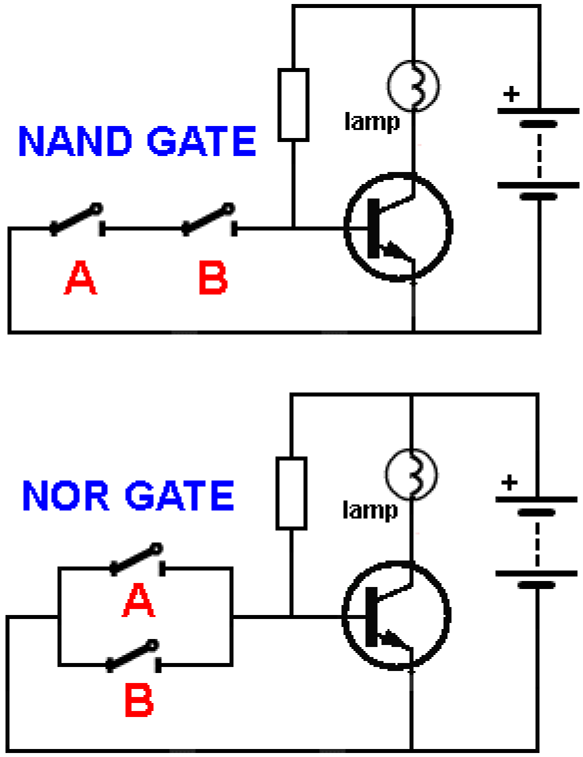


Fig 81. The "NAND" GATE and "NOR" GATE with switches and a transistor

INVERSION

Inversion produces the opposite effect to the results above.
Suppose we want to turn OFF a lamp when one or two switches are pressed.
We need a transistor.
The technical word for Inversion is **NOT**.
It is simplified to the letter "**N**."

For the **NAND GATE** close switch A **PLUS** switch B for the lamp to turn OFF.
For the **NOR GATE** close switch A **OR** switch B for the lamp to turn OFF.

These gates are only **demonstration-gates** to show how one or two switches will turn a lamp OFF.

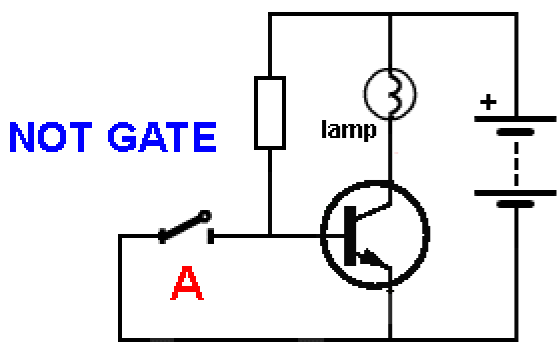


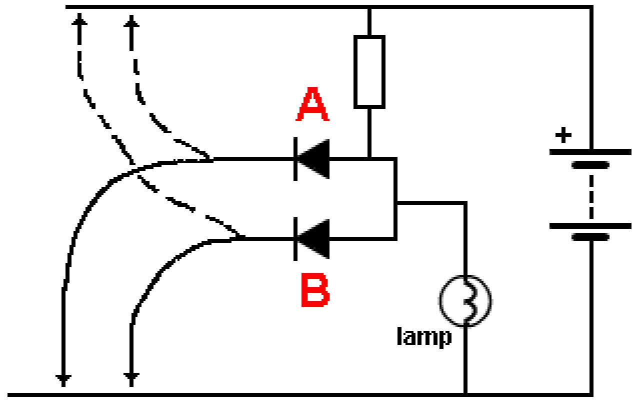
Fig 82. The "NOT" GATE

NOT GATE

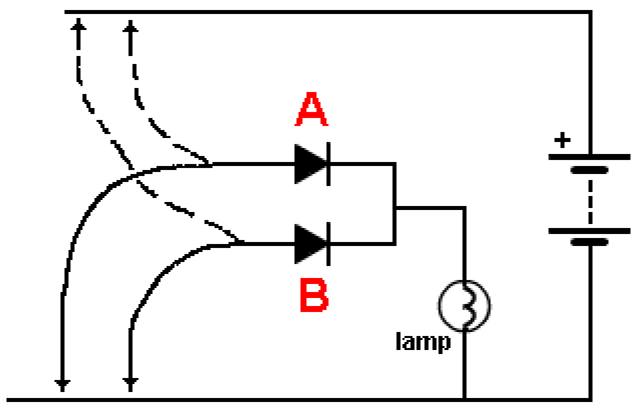
A single switch and transistor produces a **NOT GATE.**
This is simply an **INVERSION**.

The resistor turns the transistor **ON** and the lamp illuminates. The switch removes the voltage on the base and the transistor turns **OFF**.
This is only a demonstration circuit to show how a switch can turn a lamp OFF.

The 5 gates above form the basis to turning a circuit **ON** and **OFF**. We will discuss these gates later in the digital section.



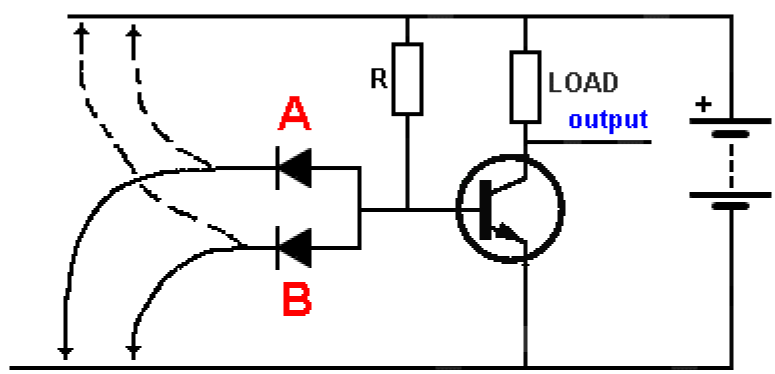
AND GATE with DIODES



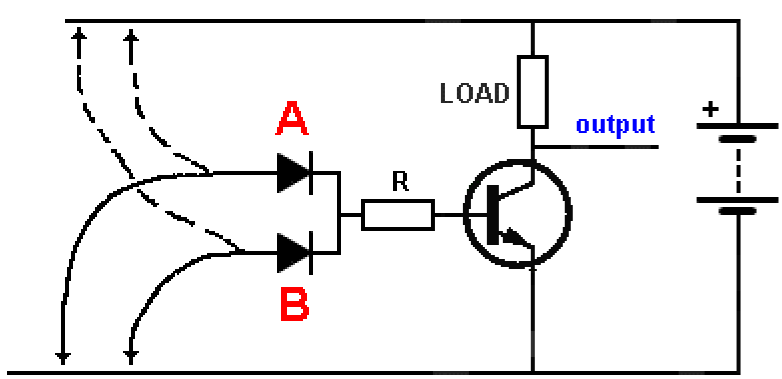
OR GATE with DIODES

Fig 83. "AND and "OR" gate with diodes

The next building block is the **GATING DIODE**.
We have shown a diode allows current to flow when the diode is correctly placed in a circuit and blocks current when it is reversed.
The 5 gates above are electrical circuits but an electronic circuit works in a slightly different way.
The electronic circuit will be covered later in the DIGITAL section.
For the moment we will explain how a diode can be used to create a **GATE**.
In other words it creates a ONE-WAY PATH to allows signals to pass from one stage to another and prevents signals passing in the opposite direction.
In the AND GATE circuit, both inputs are LOW and current flows through the resistor (it will get HOT). When one input is taken HIGH, current still flows through the other diode and the lamp does not illuminate.
When BOTH inputs are HIGH, current flows through the resistor to illuminate the lamp. No current flows through the diodes.
In the OR GATE, when one input is taken HIGH, current flows through the diode to illuminate the lamp.
This can be done with EITHER input.



NAND GATE with DIODES and Transistor



NOR GATE with DIODES and Transistor

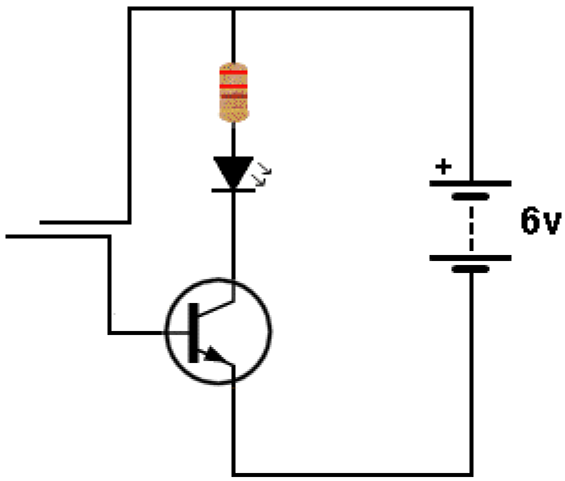
A **NAND** and **NOR** gate can be made with diodes and a transistor.
This time we the output is either HIGH or LOW.
We are gradually producing circuits that are electronic, rather than electrical circuits.
In the **NAND GATE** circuit, taking one of the inputs HIGH will still allow the other input to prevent the transistor turning ON.
When BOTH inputs are HIGH, the transistor turns on via resistor R and the output is LOW.

In the **NOR GATE** circuit, taking one of the inputs HIGH will turn the transistor ON and the output will be LOW.

Fig 84. "NAND" and "NOR" gate with diodes and a transistor.

HOW A TRANSISTOR TURNS ON

When a transistor turns **ON**, it is just like a resistor having a **smaller and smaller** value of resistance. But the way it works in a circuit and the "effect" on other components can be different. Here are animations to show how a transistor can be turned **ON**:

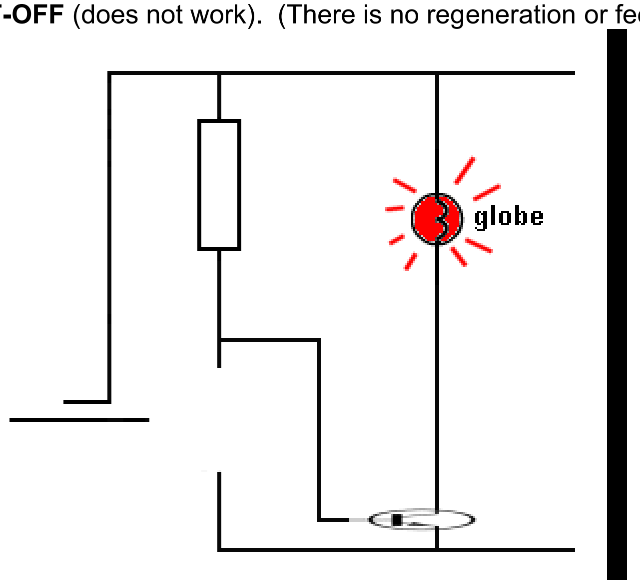


SIMPLE AMPLIFICATION

The finger is just like a resistor. As you press harder, the resistance gets smaller and the transistor turns **ON** more.
This is because more current flows from the positive rail and into the base of the transistor. The transistor amplifies this current and allows more current to flow in the collector-emitter circuit. The LED is in the collector-emitter circuit and it gets more current. This makes it glow brighter.

CUT-OFF and SATURATION

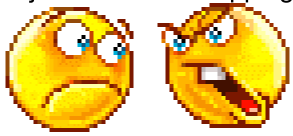
In this animation we see the first transistor turning OFF the second transistor. This action will be covered in more detail in the TRANSISTOR chapter.
At the moment, we just need to see is it possible to turn **ON** a transistor via a finger and this transistor will turn **OFF** the second transistor because it "robs" (takes away) the 0.6v (the base voltage) needed to start to turn **ON** a transistor.
The second transistor is receiving two different signals. The first signal consists of a voltage above 0.6v and current from the LOAD resistor to turn it **ON** (it is **SATURATED**). After the finger is applied, the second signal consists of a voltage less than 0.6v and the transistor is **CUT-OFF** (does not work). (There is no regeneration or feedback in this circuit.)



REGENERATION due to FEEDBACK

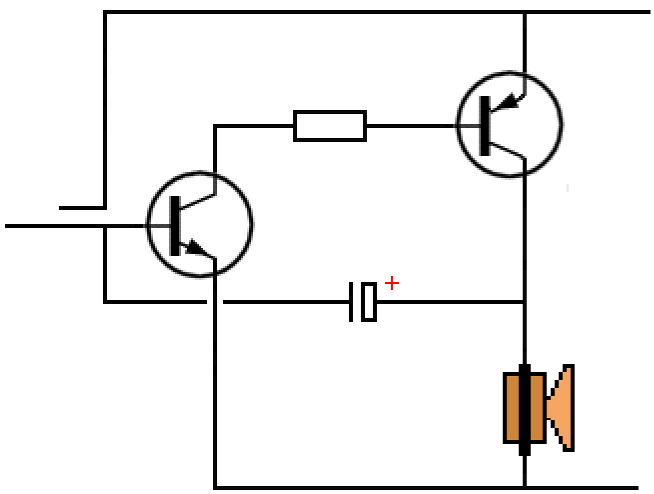
When two transistors are connected so one transistor turns **ON** the second transistor and the second transistor **FEEDS-BACK** to the first transistor to turn it **ON MORE**, the action is called **REGENERATION**.

It is just like "face-slapping." It starts with a slight slap, and it gets stronger and



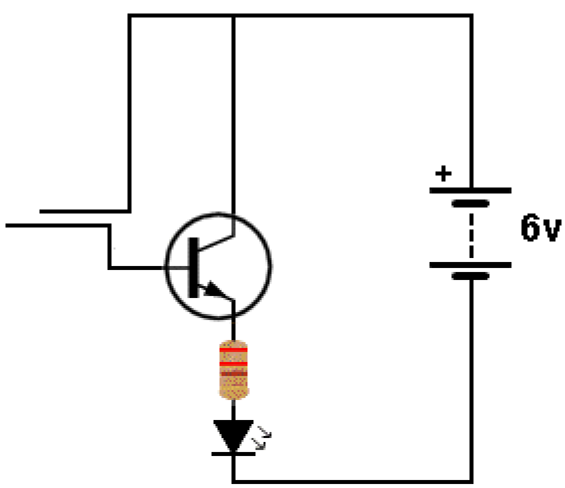
stronger until both transistors are **FULLY TURNED ON**.
Regeneration can apply to a single transistor where a percentage of the output is fed back to the input to increase the amplitude of the signal or it can apply to two transistors where the feedback is provided by a capacitor (electrolytic).
Regeneration is a feature called **POSITIVE FEEDBACK** and the circuit turns itself **ON** more and more. Generally it only requires a very small signal to start the action.

This animation shows how a finger starts to turn **ON** the first transistor. The first transistor turns **ON** the second transistor and the output of the second transistor is FED BACK to the first transistor to turn it **ON** more.
You can see the finger is removed very quickly and the action continues due to **FEEDBACK**.
The circuit is a **HIGH GAIN DC AMPLIFIER** with **POSITIVE FEEDBACK**.
At the moment we are only interested in seeing how the circuit keeps turning itself **ON** more and more . . .



TURNING ON an EMITTER-FOLLOWER

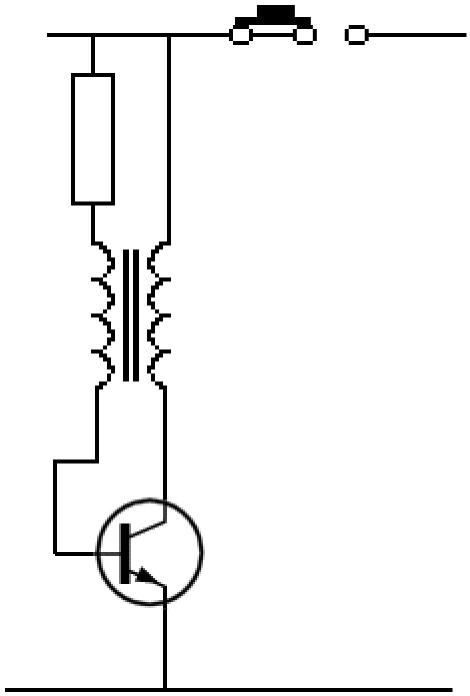
When a LED is in the emitter lead of a transistor, it will be illuminated when a finger touches the wires shown in the following animation:



FEEDBACK via a TRANSFORMER

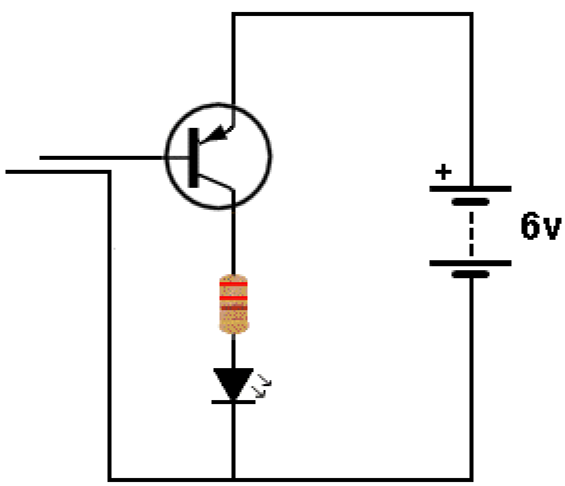
A transistor can be turned on via a positive **FEEDBACK** winding of a transformer. This is a winding that supplies voltage (and current) to turn the transistor **ON** harder.

The transformer turns the transistor **ON** fully then IMMEDIATELY stops turning it on.
This is one of the amazing features of a transformer when connected as shown in the diagram and you will learn more about this in the course.
At the moment, we are only describing the **TURN ON** of the transistor and the fact that as soon as it is fully turned ON, the transformer stops turning the transistor ON. This is because the expanding flux suddenly stops when the transistor is fully turned **ON** and the feedback winding ceases to supply energy to the base.



PNP TRANSISTOR

A PNP transistor is a mirror-image of an NPN transistor and is turned **ON** by a finger as shown in this animation:



These animations are designed to help you "SEE" a circuit working. They represent a visual indication of how an **electronics engineer** sees a circuit in operation. **He sees every part of a circuit working and moving and when a fault develops, he can SEE WHY!**

These animations only show half a cycle.
The other half-cycle turns the transistor OFF (in the **Regeneration** and **Feedback via a Transformer** animations). Turning the circuit **OFF** is complex and will be covered in a future chapter.