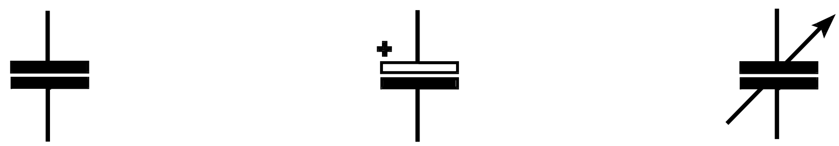
ACTIVITY 39. PROPERTIES OF A CAPACITOR

The three most common types of capacitor are:

NON-ELECTROLYTIC **ELECTROLYTIC** **VARIABLE**



Note that the capacitor supplied with the kit is an electrolytic with a value of 2000μF.

Electrolytics have a specific polarity, like a battery, and must be connected exactly as they are shown.

A capacitor is basically a device which permits a flow of electrons (current) into it, but not through it. The ability to do this is called *capacitance*. The larger the capacitance, the more electrons will be allowed to flow into the capacitor.

Capacitance is measured in *farads* (symbol F). Because a farad is a very large unit, smaller sub-units are normally used. These are *microfarads* (1/1,000,000F--symbol μF), *nanofarads* (1,000,000,000F--symbol nF), and *picofarads*
(1/ 1,000,000,000,000F--symbol pF).

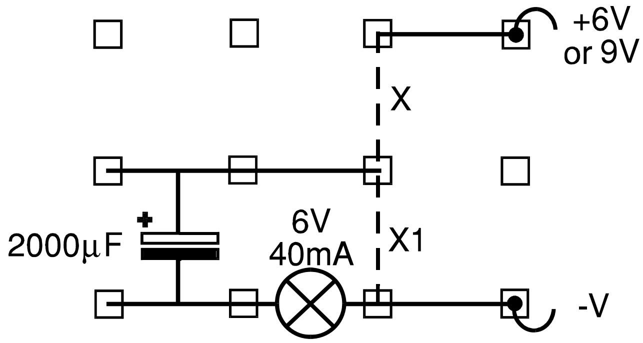
When the maximum number of electrons permitted by its capacitance have flowed into the capacitor, it is considered to be charged. At this point, the voltage across the capacitor is equal to its supply voltage.

Inspect the capacitor under its carrier. Examine the labeling on it carefully. Notice especially the voltage rating. This is the *working voltage* of the capacitor, and must not be exceeded under any circumstances.

Like resistors, capacitors are normally available only in preferred values.

Set up the circuit shown on the following page.

Insert a link at X. The lamp will light for a moment as current flows through it into the capacitor. The current stops flowing once the capacitor is fully charged. The capacitor is now holding a store of electrons, and because of this it has an e.m.f.



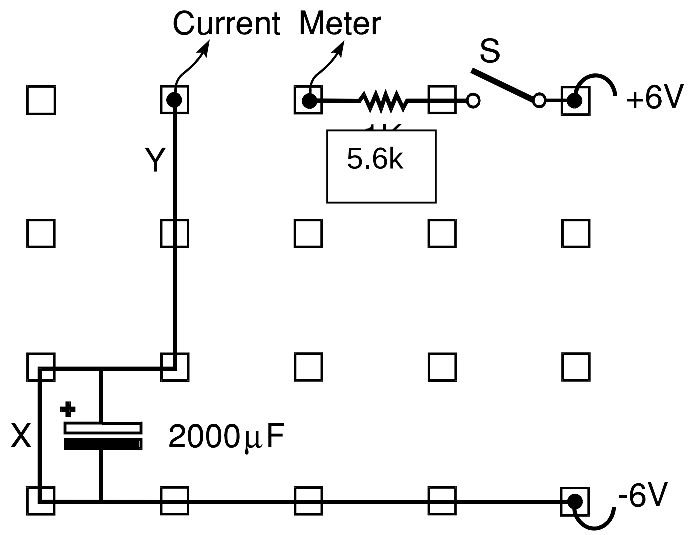
Move the link from X to X1. The e.m.f. resulting from the charge on the capacitor will drive the stored electrons through the lamp again, lighting it for a moment. The capacitor is now considered to be discharged. You can notice the effect even more clearly if a 9 volt supply is used.

The e.m.f. in the capacitor resulting from the charge is equal to the e.m.f. which is used to charge it, which is the supply voltage. The e.m.f. quickly decreases once the capacitor begin to discharge.

A large capacitor can store its charge for a long time.

ACTIVITY 40. CAPACITORS IN SERIES

Set up the circuit shown.



Remove the link at X. Press switch S and watch the meter reading.

Count the number of seconds which elapse before the current falls to zero: ....S.

The capacitor is now fully charged.

Release switch S and short circuit the capacitor by replacing link X for a moment.

Remove link Y and replace it with a second 2000μF capacitor (borrowed from another kit). The two capacitors are now in series. Press switch S again.

Count the number of seconds taken by the capacitors in series to charge: ....S.

Compare the two times. A shorter time must of course indicate a smaller charge and therefore a smaller total capacitance.

Q.40.1. What can you say about the total capacitance of capacitors in series compared with the value of the smallest capacitor used?

....
....

Refer to Activity 19 to see how this differs from resistors in series.

ACTIVITY 41. CAPACITORS IN PARALLEL

Set up the circuit shown in Activity 40 using a single capacitor.

Remove the link at X. Press switch S and watch the meter reading.

Count the number of seconds which elapse before the current falls to zero: ....S.

The capacitor is now fully charged.

Release switch S and short circuit the capacitor by replacing link X for a moment.

Connect a second (borrowed) 2000μF capacitor to the right of the first one so that the two capacitors are in parallel. Make sure that you observe the polarity of the capacitor.

Short circuit the capacitors by momentarily replacing the link X. Then once again press switch S.

Count the seconds to estimate the charging time: ....S.

Q.41.1. What is the total capacitance of capacitors in parallel equal to?

....

Refer to Activity 20 to see how this differs from resistors in parallel.

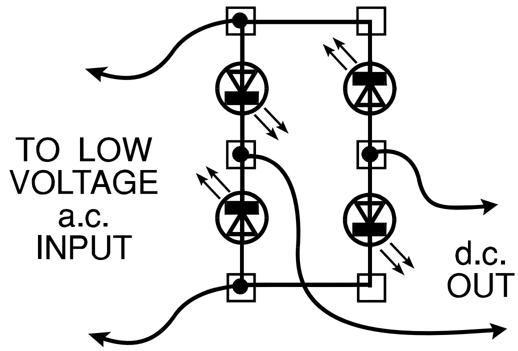
To find how long a capacitor can hold its charge, charge the capacitor with the current meter in series.

When it is fully charged, disconnect the supply. This time **do not** short circuit the capacitor. Leave the supply disconnected for a short time, then reconnect it. Watch the current meter reading.

Repeat this procedure a number of times, leaving the supply disconnected for a longer period each time.

ACTIVITY 42. BRIDGE RECTIFIER WITH CURRENT FLOW INDICATED

Set up the circuit shown. You will need to borrow three LEDs from other kits.



Connect the circuit to low voltage a.c. , and check that rectification is taking place by measuring the d.c. output .

Watch the LEDs. They appear to be permanently lighted, but actually they are going on and off so fast that you cannot notice the change.

Disconnect the a.c. source, and replace it with the normal d.c. supply.

Reverse the polarity of the supply by swapping the position of the leads. By doing this, you are simulating the action of one cycle of an a.c. supply. Watch the LEDs.

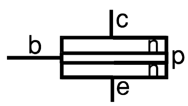
Repeat the process until you are sure that you completely understand the action of the bridge rectifier circuit.

ACTIVITY 43. THE TRANSISTOR

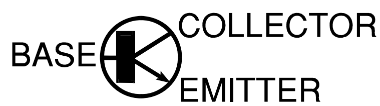
The same two types of specially prepared semiconductor material are needed in a *transistor* as they are in a diode (as was discussed in Activity 35): n-type and p-type.

A transistor is basically a sandwich of both types of material, and may take one of two forms, *n-p-n* or *p-n-p*.

A silicon n-p-n transistor of the type supplied in the kit is formed by silicon that is changed from n-type to p-type and back again to n-type. The p-type region in the middle is called the *base* and is very thin. The other two n-type regions are called the *emitter* and the *collector*.



STRUCTURE



SYMBOL

Perhaps the simplest way to understand how a transistor works is to consider its name, which is derived from 'current transfer resistor'. When a small potential is applied to the base, a small electric current flows from the emitter to the base. As soon as this occurs, a much larger current is transferred to the emitter-collector circuit. The transistor is acting as a current amplifier.

A minimum base-emitter voltage of approximately 0.6V is needed to switch the transistor 'on' and allow collector current to flow.

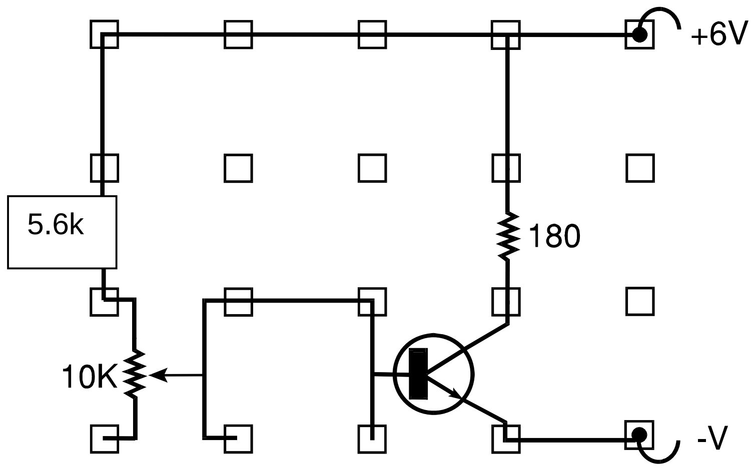
Do not forget that conventional current flow in a transistor is from collector to emitter as indicated by the arrow on the diagram above.

The important concept to understand is that the base acts as the controller of collector current. The base must be forward biased with respect to the emitter in order for the transistor to conduct. The larger the base potential, the greater the collector current. However, be aware that too large a base potential causes a large base current to flow, which can damage the transistor. For this reason, the correct component values shown in the circuit schematics must be used.

Do not worry if everything above is not clear to you. The last paragraph contains the most important concept, and you should re-read this until you understand it.

ACTIVITY 44. CURRENT GAIN OF A TRANSISTOR

Set up the circuit shown.



Rotate the potentiometer control knob fully counterclockwise. The total combined base resistor value is now 15.6kΩ.

Measure the collector current: ....mA.

Rotate the potentiometer control knob fully clockwise. The base resistor value is now 5.6kΩ.

Measure the collector current: ....mA.

Now transfer the milliammeter to the base circuit.

Measure the base current with a base resistor value of 15.6kΩ: ....mA.

Measure the base current again with a base resistor value of 5.6kΩ: ....mA.

Calculate the change in the collector current: ....mA.

Calculate the change in the base current: ....mA.

Divide the change in the collector current by the change in the base current: ....

This is the *small signal current gain* of the transistor, which is usually given the symbol h_{fe}.

The *current gain* can also be found by simply dividing collector current by base current, which is usually given the symbol h_{FE}. For most practical purposes h_{fe} and h_{FE} can be considered to be the same.

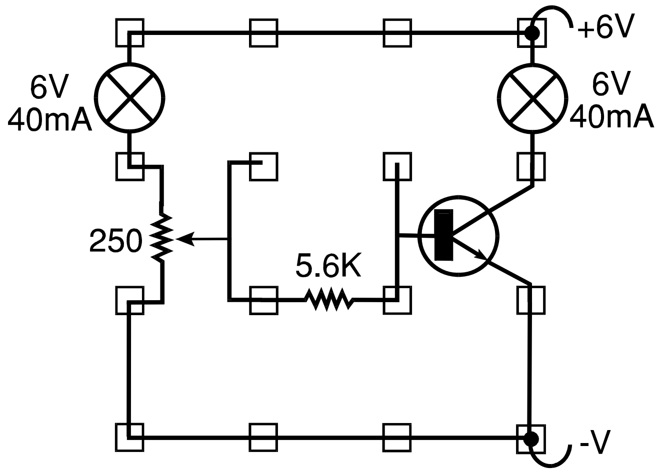
Calculate the h_{FE} of your transistor: ....

Different transistors have different h_{FE}s.

The base resistor is often called the base bias resistor.

ACTIVITY 45. THE TRANSISTOR AS AN A.C. AMPLIFIER

Set up the circuit shown.



Rotate the potentiometer control knob back and forth rapidly to simulate an a.c. signal and observe both lamps.

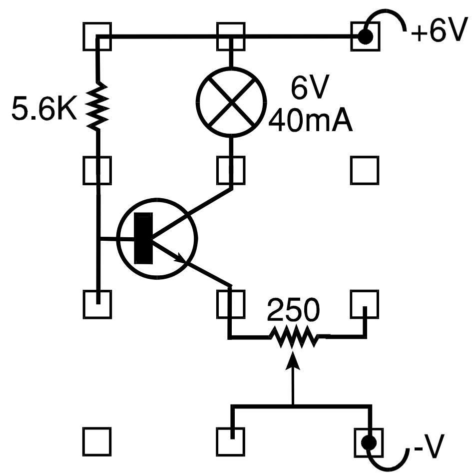
Notice that the very small base current indicated by the left lamp is hardly changing at all, yet the right hand lamp is showing a very large variation in collector current.

Q.45.1. What do very small current changes in the base circuit of a transistor cause in the collector circuit?

....

ACTIVITY 46. EFFECT OF EMITTER RESISTANCE

Set up the circuit shown.



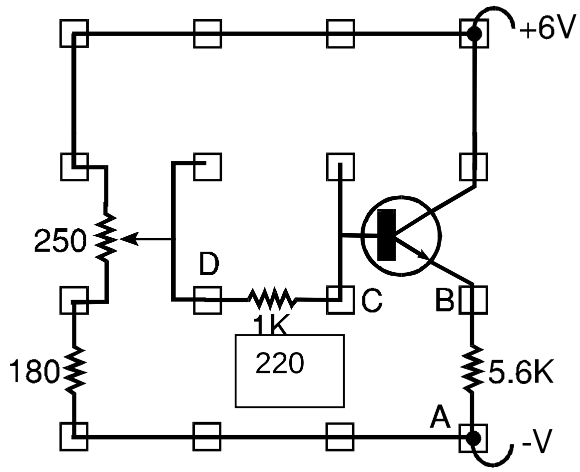
Rotate the control knob and observe the effect on the collector current.

Emitter resistors are often included to improve stability in a transistor circuit. An increase in temperature causes transistor current to increase.

Because of the increased p.d. across the emitter resistor, the base/emitter potential drops and the collector tends to fall towards its original value.

ACTIVITY 47. THE EMITTER FOLLOWER

Set up the circuit shown. Note that in this circuit the collector is connected to the positive rail.



If possible, use a digital multimeter for the following measurements:

Measure the emitter voltage between A and B: ....V.

Measure the base voltage between A and C: ....V.

If you are not using a digital multimeter, measure the input voltage at D instead of the base voltage at C.

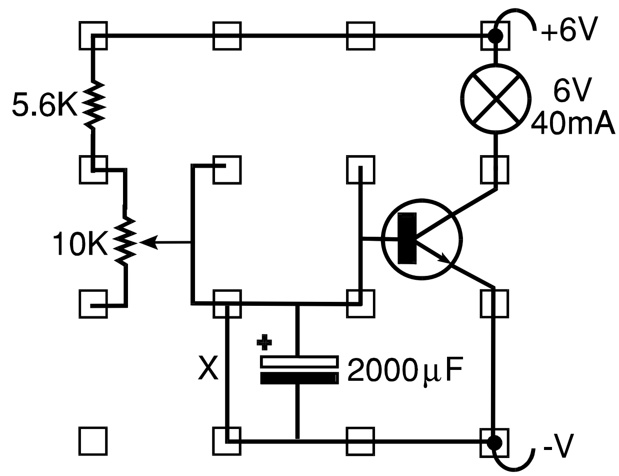
Change the setting of the variable resistor to various different settings and repeat your measurements. Note that the voltage changes at the emitter closely <u>follow</u> those at the base (or input).

Resistance to alternating current is called impedance. All electronic devices offer a certain amount of impedance to alternating current, and this is a very important factor in electronics. When power is being transferred from one device to another, it can be proved that maximum power is transferred when their impedances are equal. When this occurs they are said to be *matched*.

One of the main advantages of the emitter follower circuit is its low output impedance, which enables it to be used to match a device with a high impedance output to a device with a low impedance input.

ACTIVITY 48. TIME DELAY CIRCUIT

Set up the circuit shown.



When your circuit is assembled, make sure link X is connected as shown across the 2000µF capacitor before switching on the power supply.

Why is this necessary?

………………………..

When you have switched on, rotate the potentiometer control fully clockwise, then remove link X.

Count the seconds until the lamp lights: ....S.

Repeat the count a number of times with different potentiometer settings.

Place a second capacitor in parallel with the first one and repeat the count: ....S.

To help you to understand the operation of this circuit, remember that as the capacitor is charging, the base potential slowly rises to 0.7 volts, the 'switch-on' base voltage of the transistor.

If you have a digital multimeter, you can use it to observe the rise of the base potential as the capacitor charges.

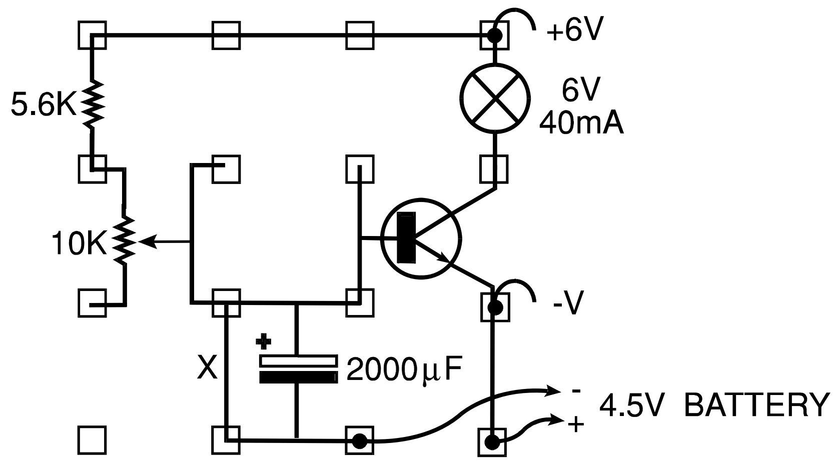
Q.48.1. What is the relationship between the value of resistance, the value of capacitance and the time delay in this circuit?

....

....

ACTIVITY 49. LONG DELAY CIRCUIT

Set up the circuit shown.



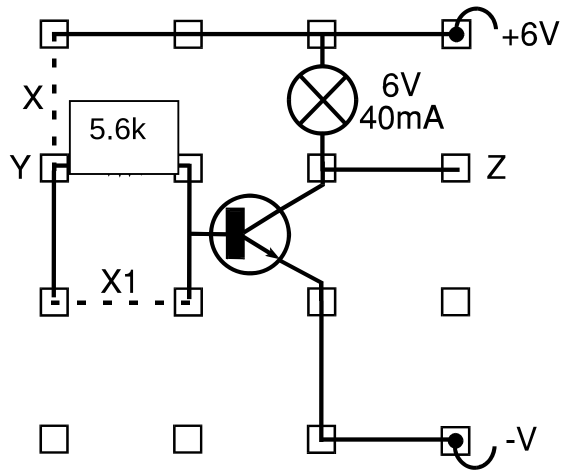
Adding a 4.5V battery to the circuit can considerably increase the delay time. With the battery added to the circuit, the capacitor has to receive a much larger charge before the base potential reaches a value at which collector current flows.

Repeat the procedure in Activity 48, noting that once again the value of the capacitor and the resistor determines the length of the delay.

Do not use an extra battery with an output larger than 4.5 volts, as the maximum reverse base/emitter voltage for the transistor in the kit is 5V. Be sure to connect the battery exactly as shown.

ACTIVITY 50. THE TRANSISTOR AS A SWITCH

Set up the circuit shown.



This is one of the most important activities in this course, as many electronic devices and systems use the transistor in this way.

After you have assembled the circuit without a link at X, connect the power supply and measure the voltage at point Y (the input voltage) and at point Z (the output voltage).

Voltage at Y: ....V Voltage at Z: V

Insert a link at X to switch the transistor on. Measure the input and output voltages again.

Voltage at Y: ....V Voltage at Z: V

Q.50.1. Compare the two sets of voltages, what do you notice?

....

Add a 220Ω resistor in position X1 and watch the lamp. There is clearly no increase in collector current, even though you have definitely increased the base current. When this happens the transistor is said to be *saturated*, and in this condition it is operating like a pair of closed switch contacts.

Q.50.2. If the input voltage of a transistor switch is first high and then goes low, what happens to the output voltage?

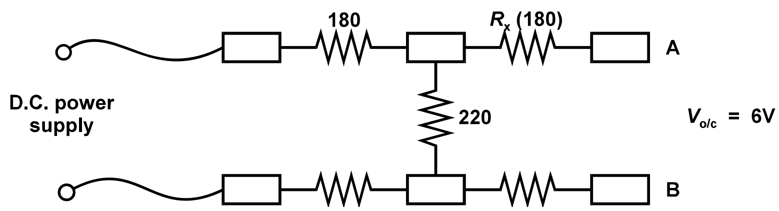
....

This *inverting* property of a transistor switch is very important.

In this activity, you are obviously operating the transistor switch manually by inserting a link. As you may already know, this can also be done in many different ways without requiring any physical movement.

ACTIVITY 51 THEVENINS THEOREM

Thevenin's Theorem states that :- Any complex circuit between two terminals can be replaced with a single equivalent series circuit consisting of a Thevenin Voltage V_{TH} in series with a Thevenin resistance R_{TH} connected between the same two terminals.



Connect the circuit as in the diagram above.

With the power supply unit switched on, but the unit disconnected from the mains, measure the resistance across the terminals AB of the circuit above, using the "ohms" range of a multimeter.

Plug the power supply in to the mains, and set the voltage of the supply to 6 volts d.c., to produce the OPEN CIRCUIT VOLTAGE at the terminals AB.

Connect a resistor having the same value as the measured value as in 2) above, across the terminals AB. You can use a variable resistor, but be careful not to inadvertently move the setting

Measure the voltage across the load resistor, using the d.c. voltmeter, connected across AB . Record this value.

Calculations.

Using Thevenin's Theorem, calculate the value of R in for the terminals AB of the network. Record this value in the table.

Determine the theoretical value of the OPEN CIRCUIT VOLTAGE at the terminals.
Determine the voltage across a matched load at the terminals AB.
Record these values in the table.

RESULTS TABLE

Measured value of R in	

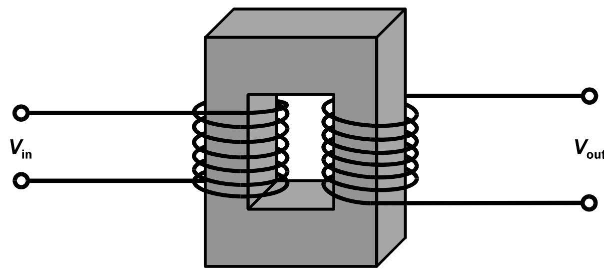
Calculated value of R in	
Measured value of V o/c	
Calculated value of V o/c	
Measured value of load voltage	
Calculated value of load voltage	

Conclusions

Compare the theoretical values for the Thevenin network with the values obtained from the measurements. Do they confirm Thevenins Theorem?

ACTIVITY 52 THE TRANSFORMER

A transformer consists of two separate coils of insulated wire, wound around a common magnetisable core, usually made of laminated iron. There is no electrical connection between the coils, usually referred to as the Primary winding, and the Secondary winding. The purpose of a transformer is to allow us to convert an alternating current (a.c.) supply of a given voltage into an a.c. supply of a different voltage (either higher, or lower voltage). If the voltage is being increased, it is referred to as a "step up" transformer, and if the voltage is being reduced, it is referred to as a "step down" transformer.

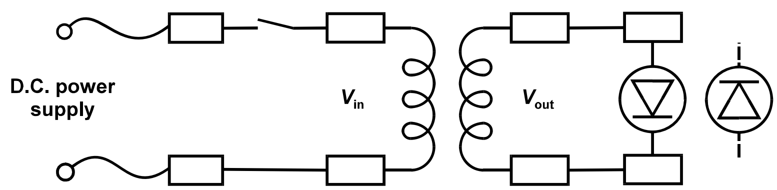


A typical application for large transformers is in electricity distribution. At the Hydro-electric, Nuclear, or conventional "fossil fuel" power stations, electricity is generated by rotating machines producing several thousand volts, and very high currents. Individual machines can produce hundreds of Megawatts of power. But this power then has to be distributed over long distances, and the most efficient way to do this is at very high voltages (lower currents), so the Power Station uses "step-up" transformers to produce hundreds of kilovolts to feed the overhead distribution lines. However, at the consumer end, it would not be safe for us to receive these very high voltages, so for both industrial and domestic purposes, we have local "substations" which are really just a collection of transformers which take these very high voltages, and transform them down to a voltage which is safe to bring into our homes.

There are no moving parts in a transformer, and therefore they are very robust, reliable, and long lasting. The ratio of the two voltages can be varied very simply, because it follows exactly the number of complete turns that we have in each of the two coils. For example, if we apply 10 volts to a transformer which has 100 turns of wire in the Primary coil, and 200 turns in the Secondary coil, we will get 20 volts out from the secondary winding. A transformer like this would be called a 2:1 step up transformer. The transformer in your kit is just such a transformer. It has a "turns ratio" of 2:1, and can be used either to step up, or to step down, a low voltage a.c. supply, depending on how it is connected. If we wanted to step up the voltage by a factor of 10, we simply make a transformer with 10 times as many coils of wire in the secondary winding as in the primary winding.
Transformers, depending on their size, and design, can be made to suit every application, from very small powers (milliwatts) in, for example audio applications, to very large powers (Megawatts) in Power Generator stations.

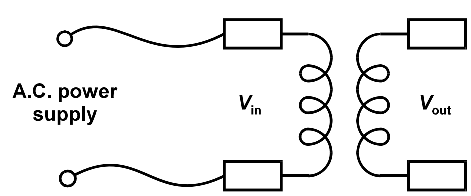
In transformer applications we normally refer to this "power" capacity not in watts, but in "VA", (the a.c. product of VOLTS times AMPS. This is very nearly the same as power in a d.c. circuit.

So how does a transformer work? Transformers are only used with a.c. supplies, but to get an idea about how they function, we will connect one very briefly to a d.c. supply, as in the circuit below. On the output side of the transformer, we have a Light emitting diode. This gives an indication of when current is flowing in the secondary circuit of the transformer. The switch in the primary circuit allows us to momentarily apply a d.c voltage, and then release it.



Closely observe the LED whilst making, holding, and the breaking the switch. Now reverse the polarity of the LED, and observe again. You should see that the LED lights only when the primary circuit is switched on or off - it does not light when there is a steady flow of d.c. current in the primary circuit.

This experiment illustrates that energy is transferred from the primary, to the secondary ONLY when the magnetising force (applied potential, or voltage) is CHANGING. So transformers cannot change d.c. voltages, because these are constant. However, an a.c. voltage is continuously changing, building up to a peak, collapsing, reversing, and then building up again. This process happens 60 times each second with Canadian and USA mains supplies. If you have a double beam oscilloscope, you will now be able to see what happens when a low voltage a.c. supply is connected to the primary circuit. Change your circuit to the one below.

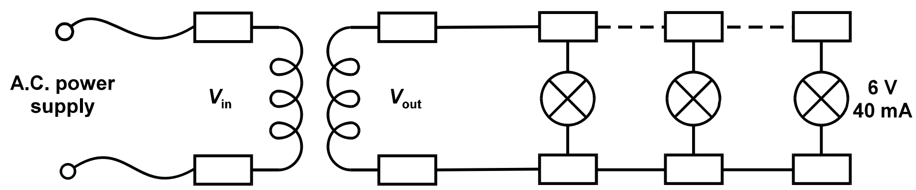


You should now be able to observe the following.
Firstly, the secondary voltage is about 1/2 the primary voltage. If you reverse the transformer, and apply the low voltage a.c. to the secondary winding, the voltage output from the primary is twice the voltage applied. The transformer can step up voltages, or step down voltages. Now you should observe the time relationship between the applied (primary) voltage sine wave, and the secondary sine wave. You will notice that they are not in synchronization with

each other. In fact the peak of the secondary voltage waveform coincides with the "zero" voltage of the primary waveform, and vice-versa. This extends the knowledge that we gained from applying d.c. momentarily. We can now see that the secondary voltage is greatest when the **rate of change** of the primary voltage is greatest (as it passes through zero volts) and is smallest when the **rate of change** of the primary voltage is at zero (i.e. as it goes over the peak).

In all of the following experiments always check, before connecting any bulbs to the circuits, that the transformer output is less than 6 volts. If necessary, adjust the voltage supplied to the transformer to ensure that the output is 6 volts or less.

As with all other devices, transformers can never be made to be perfect, and therefore they are not 100% efficient. Set up the following circuit.



We are now applying a "load" to the secondary circuit, in this case a light bulb. The transformer is being made to do some work, converting one voltage to another. We will measure the voltage and current into the transformer (Power in), and measure the voltage and current out of the transformer (Power out). This is slightly simplistic, because there is also involved in the transformation, a shift in the "phase angle" between voltage and current (known as Power Factor) which your teacher may wish to cover from text books, but this does not have to be understood at this level.

Using the formula Efficiency (%) = 100 x Power Out / Power In

Where Power (for simplicity) = Volts x Amps

Will give you an indication of how efficient your transformer is. You may like to try this experiment with different "loads" - you can use up to three of the 6v, 40mA bulbs in parallel to produce greater loads. Does the efficiency vary with different loads?

What happens to the "missing" energy? - we have put a certain amount into the primary, but we do not get as much out. Where has it gone? Remember, part of this transformation process involves continually magnetising, and then demagnetizing, the iron core of the transformer. Also, because both the primary, and secondary windings are made from copper, and have some resistance to the currents flowing, heat is being dissipated in the windings. In fact the same is happening in the iron core because of eddy currents in the iron which are being produced by the continual building up and collapse of the magnetic field. The result of these factors is that the transformer eventually gets warm, and this is where the "missing" energy has gone - into heat. If you are observant, you will have noticed large transformers at electricity "substations", or mounted on poles in the countryside, and you may have seen that these often have multiple pipes on the outside of the transformer, leading from top to bottom. These large transformers are "oil cooled" and the purpose of these pipes is to take the hot oil from the top of the transformer, and return it to the bottom through exposed pipes where the oil gets cooled by the surrounding air. This forms a natural, cooling mechanism for the whole transformer, to prevent it from overheating.

A further piece of information can be gleaned from the previous experiment. The current in the primary has also been transformed in the same ratio as the voltage BUT - in the opposite fashion. i.e. If we step up the voltage by 2:1 , the current is stepped down by 1:2. This helps with our understanding of Power distribution over long distances by overhead lines. If we are able to reduce the transmitted current by stepping up the transmitted voltage, we can reduce the size of conductor required, saving lots of copper (and money). The POWER transmitted stays the same (Volts x Amps). But surely the insulation against these high voltages must cost more , and this will offset the saving? No, in the case of overhead power lines, safety is assured because they are well out of reach, and remember - air is a very good insulator, so as long as the power lines are kept well separated from each other, the insulation (air) is free.

Voltage regulation.

If you did not try the efficiency experiment, with different loads, you should do so now. Measure voltage in, current in, voltage out and current out for a variety of loads (one, two, and three 6v 40mA bulbs) The precise results of this experiment will depend on the nature of the a.c. supply equipment that you are using to feed the transformer. If you have a variable voltage supply, you should make slight adjustments (if necessary) to the input voltage, to make sure that it is identical for all three load cases. You can now draw a graph of output voltage against output current, and you will see that as the current drawn from the transformer increases, so the voltage falls. How much it falls is entirely dependant on the design of the transformer. Your Locktronics transformer has been specifically designed to be inefficient so as to illustrate easily these features, so the efficiency figures, and the "regulation" value are not typical of values that would apply to industrial transformers, where the design is specifically intended to improve efficiency, and improve regulation.

ANSWERS

Assignment 1: ATOM, ORBITING, ATOM, NUCLEUS, NEGATIVE
Assignment 3: Bulbs are 6V rated, voltage and current rating
Assignment 4: electrons flow from negative to positive
Assignment 5: metals, increases, more, seven
Assignment 6: make, break
Sparking plugs
Assignment 8: Fan settings, cooker switch, radio stations, heater switch
Assignment 9: Double pole, single throw
Assignment 13: sum, equal or the same
Assignment 16: same
Assignment 17: sum
Assignment 18: The higher the resistance, the lower the current
Assignment 19: sum
Assignment 20: sum, half
Assignment 29: greater voltage over 180 ohm, 120 ohm
Assignment 40: half
Assignment 41:: sum
Assignment 45: large
Assignment 48: A fully charged capacitor could damage a transistor
Larger, larger, longer delay
Assignment 50: Inversion, goes high

NOTES