ELECTRONIC COMPONENTS AND CIRCUITS

CP2813

Inspiring The Next Generation Of Engineers

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Contents

Introduction

The course aims to prepare you for Topic 4 of Unit 202 - “Electrical Science” part of the City and Guilds Level 2 “Technical Certificate in Electrical Installations” (8202-20).

As you work through the course, the layouts show you how to build the systems and each task details how to test them.

There are a variety of different tasks, identified by a series of icons.

For your records:
- It is important that you keep accurate records of what you do.
- A Student Handbook is available to assist with these records.
- In addition, take whatever notes you feel are necessary to help with this.

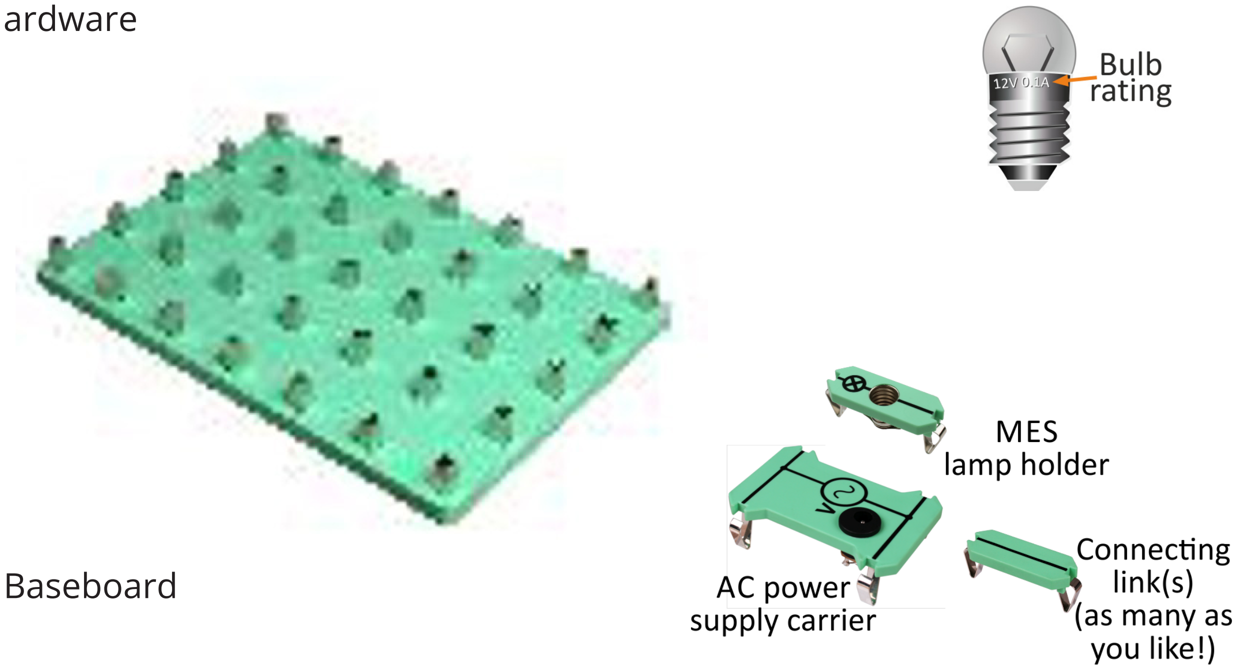
Circuit Training

This activity is **optional.**

- If you recently followed the ‘Electrical Installation 1’ course , it is probably unnecessary.
- If you are new to Locktronics, it is a useful way to introduce the kit.

Build a circuit that makes a bulb light, using a 12V 0.1A bulb and the 12V AC power supply.

The Hardware



Power supply:

- Drives current around the circuit;
- Has two terminals (connection points) one ‘positive’ the other ‘negative’;
- Current flows from the positive terminal to the negative terminal.

DC power supply - (DC = direct current):

- One terminal is always positive, the other always negative;
- ‘One-way traffic’ - current always flows the same way around the circuit.

AC power supply - (AC = alternating current):

- One terminal positive, the other negative and then they swap, repeatedly;
- ‘Two-way traffic’ - current flows clockwise, then anticlockwise around the circuit.

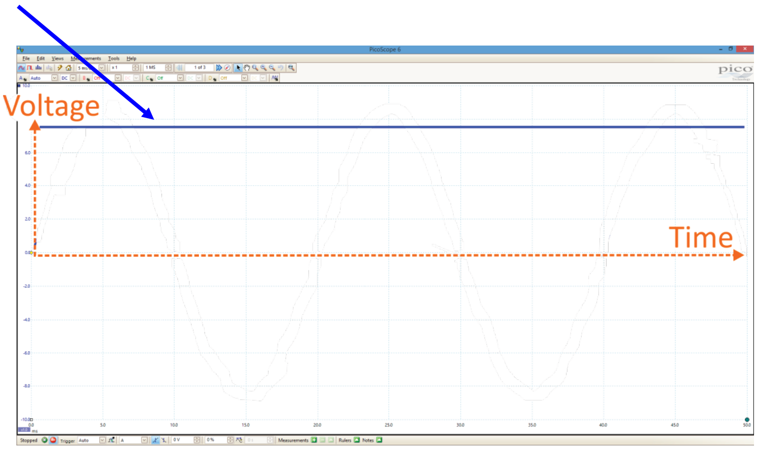
Power Supplies - 1

There are two types of power supply. One delivers DC power and the other AC power. The difference between them is best shown by looking how the voltage changes over a period of time, i.e. looking at a voltage / time graph.

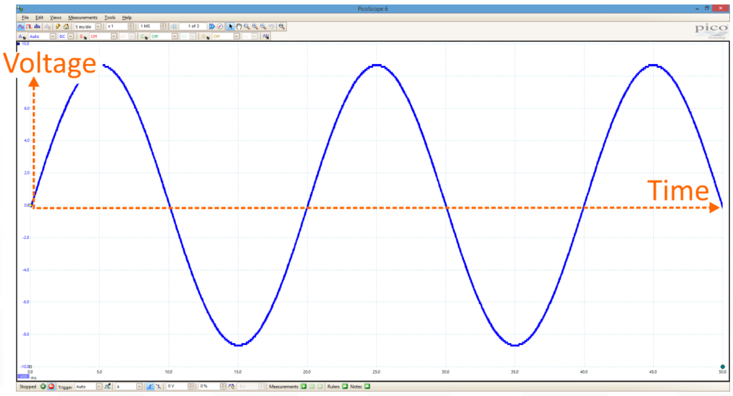
These can be produced using an **oscilloscope.** Used more in electronics, they display the signal as a graph, with voltage on the vertical axis and time on the horizontal axis.

Some digital oscilloscopes, like the 'Picoscope', which produced the graphs shown below, generate signals which are then processed by a computer connected to it.

DC power - the **voltage** stays steady over a period of time.



AC power - the voltage changes all the time and even goes negative sometimes, forcing the current to flow in the opposite direction.



Power Supplies - 2

AC or DC - which is used?

Each has its uses!
Electricity is usually generated and transmitted as AC because:
- Alternators (AC) are usually more efficient than dynamos (DC);
- Transformers, which work only on AC, can modify voltage and current efficiently.

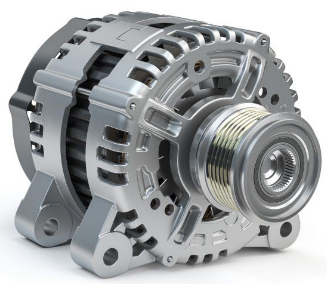
Electronic devices - mobile phones, computers, televisions etc. usually require DC.

AC power:
can be converted into DC using the processes of rectification and regulation.

DC power:
can be converted into AC using a device called an inverter.

DC power supplies:
- **Battery** - chemical reactions generate DC voltages, e.g. 'lead-acid' batteries;
- **Solar cell** - photo-voltaic ('solar') cells convert light energy into DC electricity ;
- **Dynamo** - a rotating coil of wire near a magnet generates DC using a 'commutator' to connect the coil to the rest of the circuit.

AC power supplies:
- Alternator - another example of a rotating coil of wire near a magnet;
- A 'slip-ring' connects to the rest of the circuit;
- The coil can be driven by:
- High-pressure steam, in a power station;
- Wind in a wind-generator;
- Falling water in a hydro-electric power station.



Power Supplies - 3

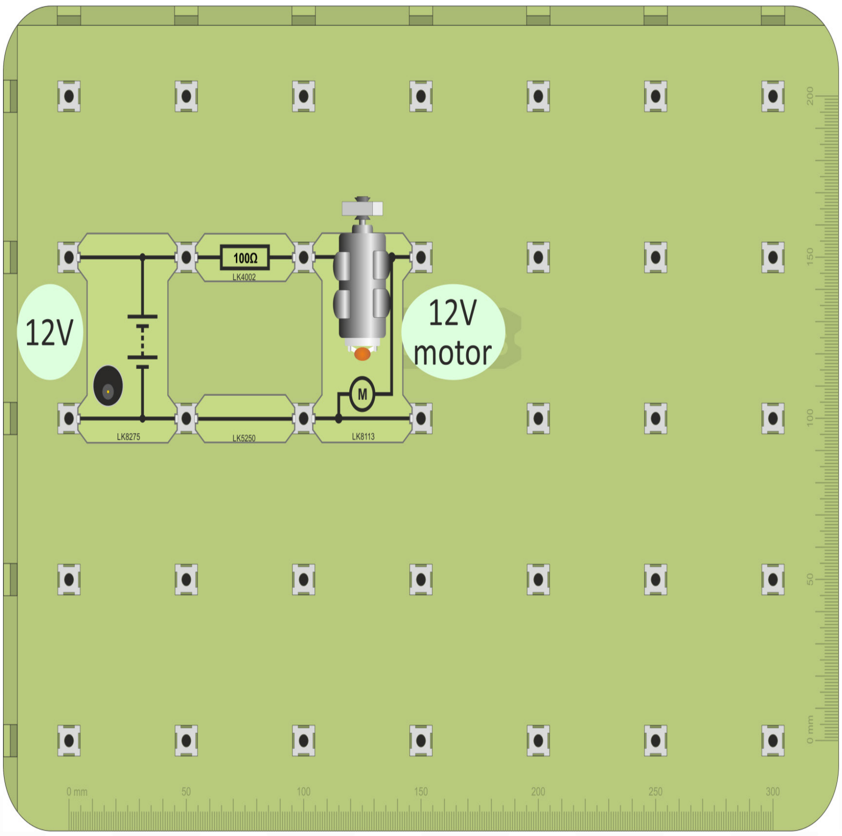
AC or DC - does it matter?

Answer - Yes - it almost always does!

The next investigation shows that they work in different ways. The task - connect a 12V DC motor firstly to a 12V DC power supply and then to a 12V AC supply.

DC and then **AC**

1. Build the layout shown below. The 100Ω resistor is used to reduce the voltage across the motor.
2. Connect the 12V DC power supply and switch on.
3. Notice that the motor behaves normally and rotates at high speed.
4. Now replace the DC power supply with a 12V AC power supply and switch on.
5. The motor does not rotate. Hold the plastic gear wheel - you can feel it vi-brating backwards and forwards. It is trying to rotate one way and then the other, in step with the alternating current.

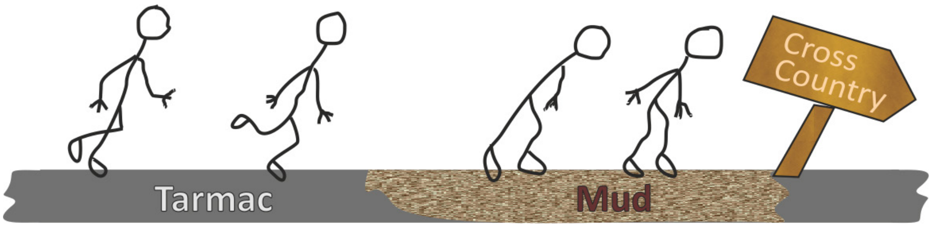


6. Answer the questions in the Student Handbook.

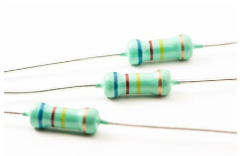
The Resistor

We can change the flow of water using a tap. With electricity, we change the flow using a resistor.

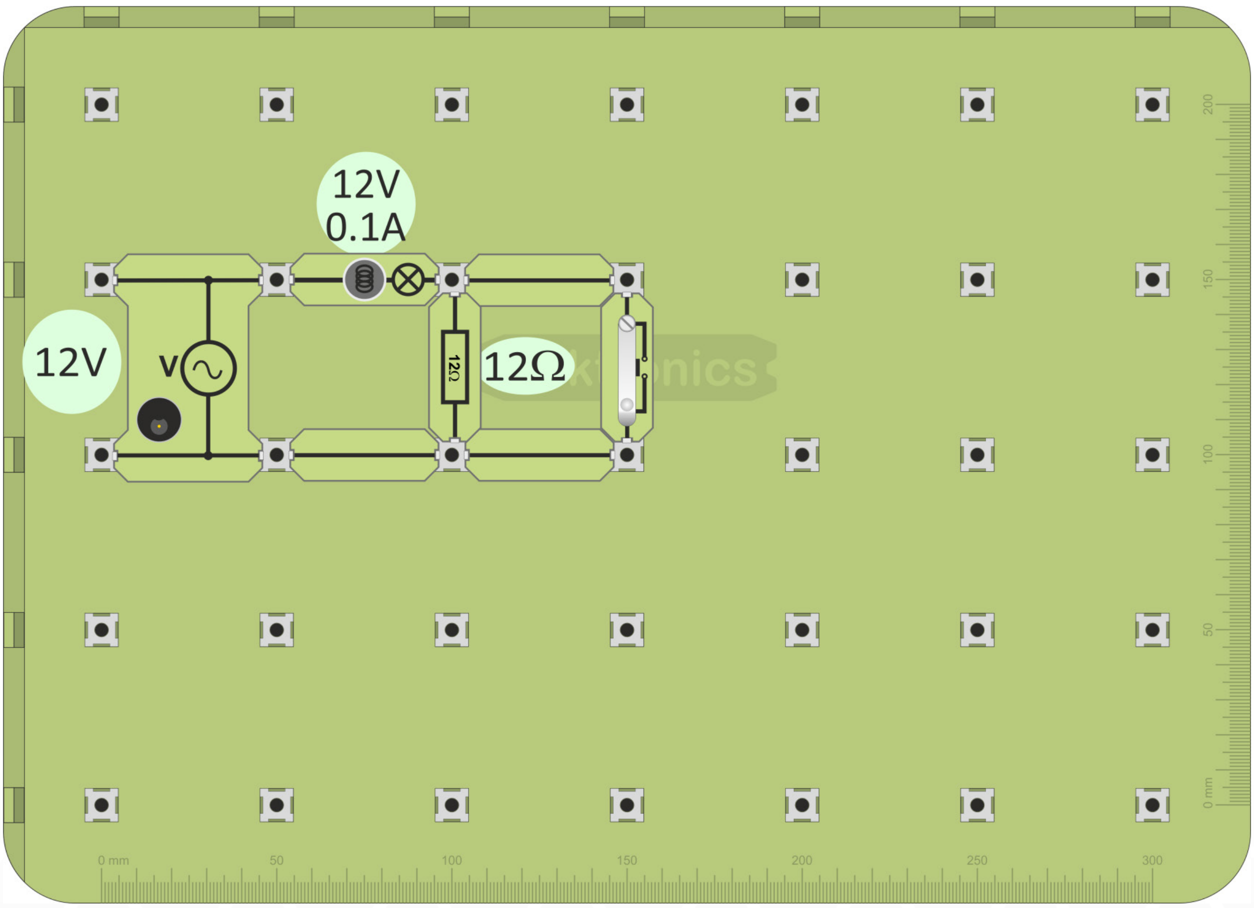
For electrons, adding resistance is like asking you to run in mud. It takes more energy!



Commercially-made resistors often look like the one opposite. The colour of the stripes is significant, but that is for later!



1. Build the layout shown below.
2. Connect the 12V power supply and switch on.
3. To see the effect of the resistor, press the push-switch.



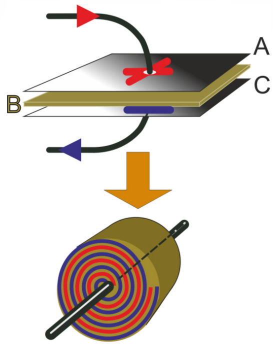
4. Now answer the questions in the Student Handbook.

The Capacitor

A capacitor consists of two metal plates, (A and C in the diagram), separated by an insulating sheet, (B).

To save room, this 'sandwich' is rolled up into a 'Swiss roll', in such a way that the metal sheets do not touch.

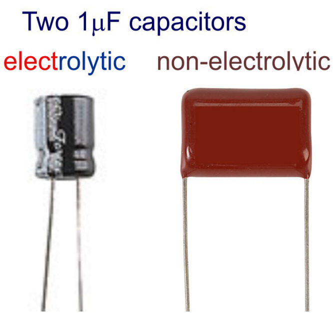
When connected to a power supply, current flows from the power supply onto one plate and from the other plate back to the power sup-ply, for a short time.



This leaves one plate positively charged and the other negatively charged by the same amount. The capacitor stores this charge until it can flow around a circuit.

Capacitors are rather like 'buckets' that store electric charge. As they fill up, the voltage across them increases until they are fully charged (the 'bucket' is full.) The size of the 'bucket' is given by the capacitance. This is measured in units called farads (F) though capacitors used for most pur-poses are measured in microfarads (μF, - millionths of a farad) or smaller. The wider the bucket, the more water it takes to raise the level. The bigger the capacitance, the more electrical charge it takes to raise the voltage.

The bigger the capacitance, the more electrical charge it takes to raise the voltage.



Capacitors come in two main types - electrolytic and non-electrolytic. However, electrolytic capacitors are polarised - they have positive terminal and negative terminals and must always be connected the right way round. This means that they cannot be used in AC circuits. (In the photograph at the top of the page, the arrows point in the direction of the negative terminal.)

Non-electrolytic capacitors can be connec ted either way round, but are physically larger for a given value of capacitance.

Take care!

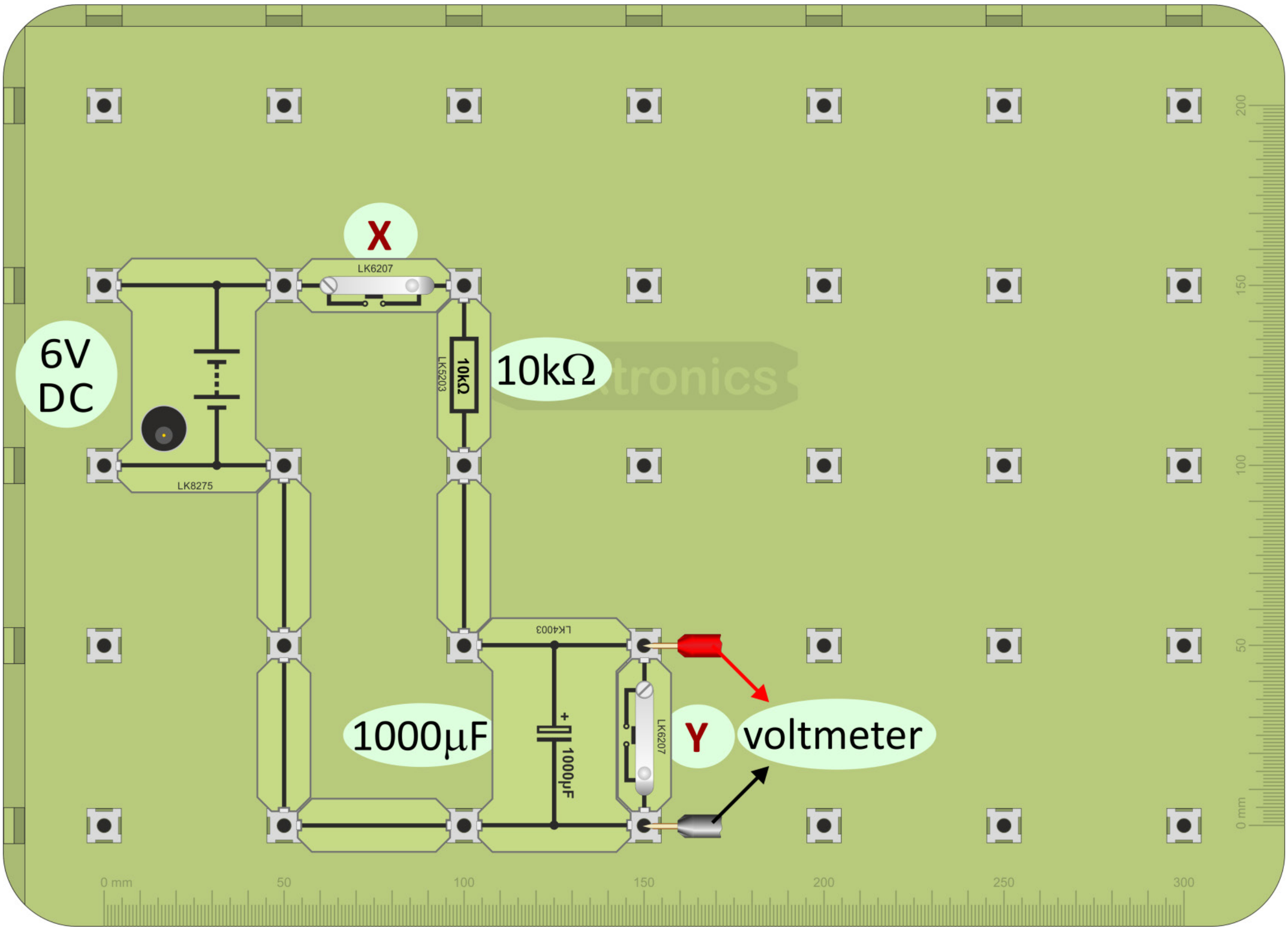
As well as taking care not to connect electrolytic capacitors the wrong way round, you need to check the 'working voltage' rating for the capacitor. This is the maximum safe voltage that can be used with it.

Charging a Capacitor

The next investigation looks in more detail at how the voltage across a capacitor changes as it 'fills up' with electrical charge.

DC

1. Build the layout shown below.



Take care to connect the capacitor the right way round!

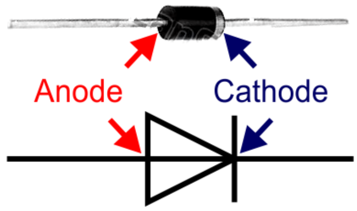
2. Press and hold down switch X. Watch the voltmeter reading as you do so. (To repeat the test, first press switch Y to discharge the capacitor.) Estimate how long it takes to charge to 3V.
3. Try other values of resistor and capacitor. Can you see a pattern in your observations?
4. Answer the questions in the Student Handbook.

The Diode

Rectification is the name of the process used to turn AC into DC. It usually relies on the fact that current can flow only one way through a diode.

The name 'diode' tells us that it has only two ('di...') electrodes ('...ode'). These are known as the **anode and the cathode.**

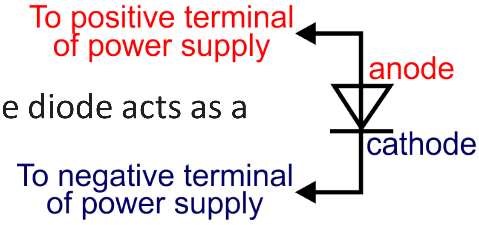
The diagram shows a photograph of a common type of diode together with its circuit symbol.



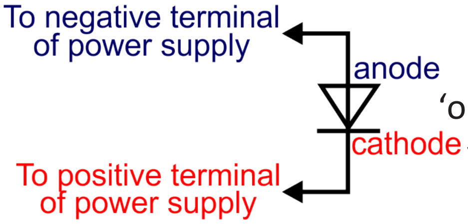
The cathode is identified by a silver stripe on the body of the diode.

When the **anode** is more positive than the **cathode,** the diode is **'forward-biased'.** When the **cathode** is more positive, it is **'reverse-biased'.**

Forward bias



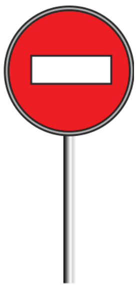
Reverse bias



The diode acts as a 'one-way valve'.

It allows current to flow through it only when it is forward- biased.

When reverse-biased, it does not conduct at all (for low voltages.)

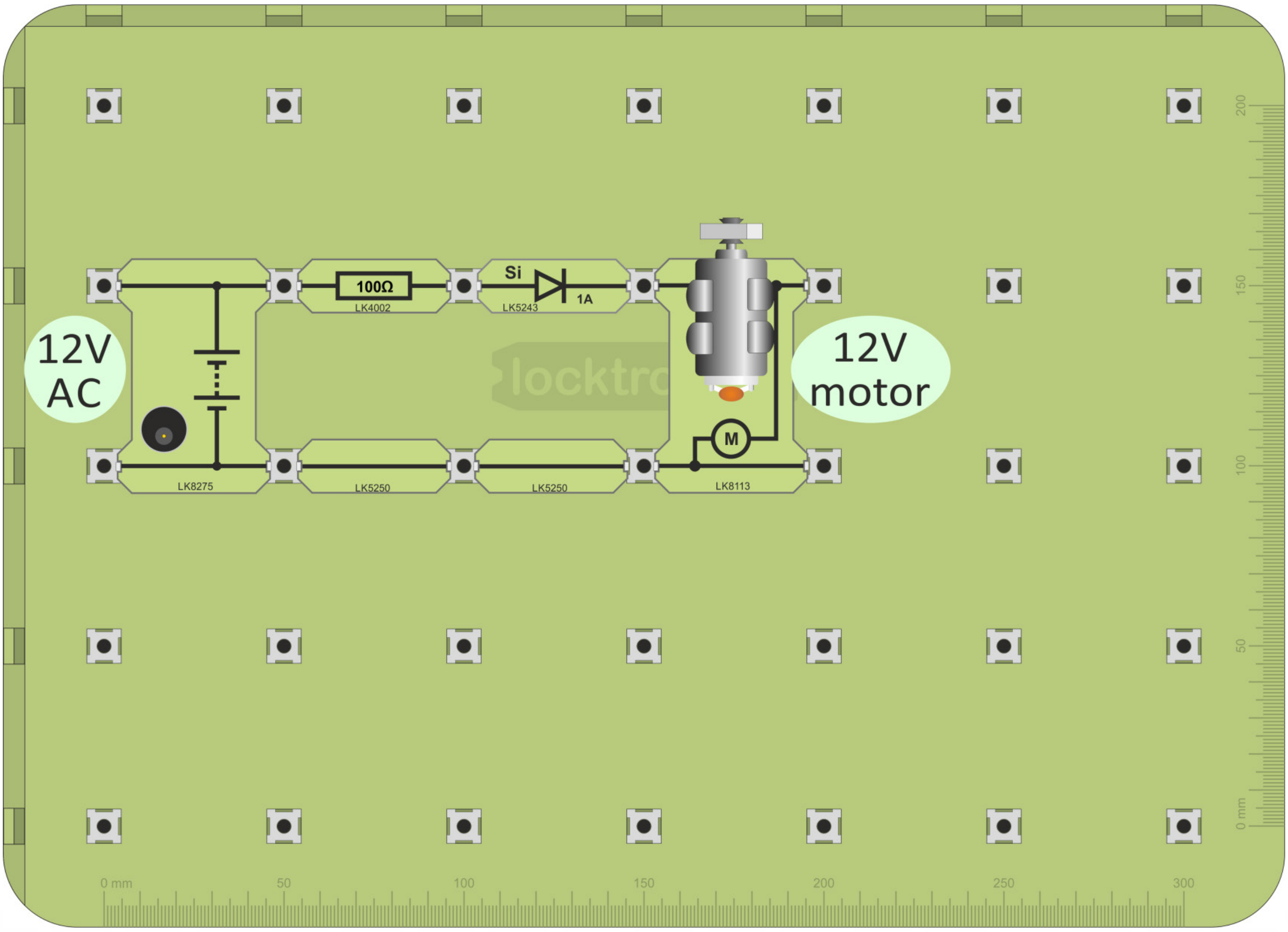


Rectification

We have just seen that the motor does not work when the electricity supply is AC.

The next investigation shows that a diode converts the AC power from the power supply to DC, which can operate the motor.

1. Build the layout shown below which is virtually identical to the one you just used, but has a diode added. Once again, the 100Ω resistor is included to reduce the voltage across the motor.
2. Connect the 12V AC power supply and switch on.

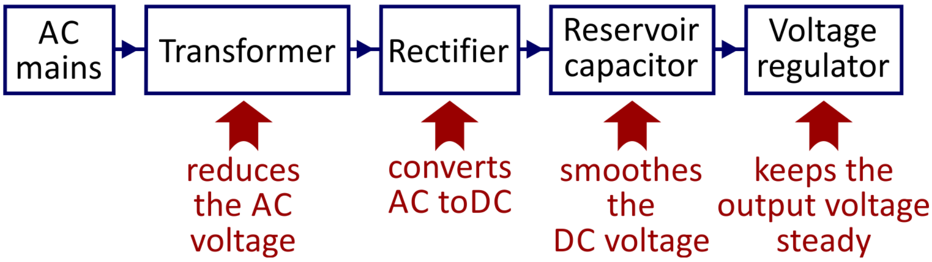


3. Check whether the motor is turning or just twitching. If it is turning, then the electricity supply to it must be DC. If it is twitching, then the supply is still AC.
4. Answer the questions in the Student Handbook.

Low Voltage DC Power Supply

The aim is to convert a high-voltage (240V) AC mains supply into a low voltage (12V, typically) DC supply that can be used with electronic equipment.

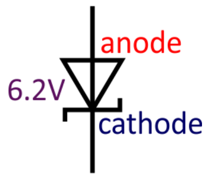
This process can be divided into the stages, shown in the block diagram:



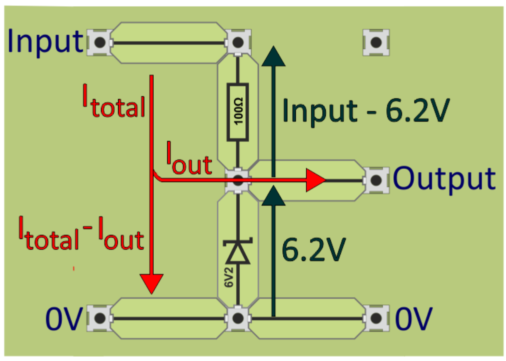
We have seen that a diode can be used as the rectifier and that a capacitor behaves rather like a bucket of charge, topping up the output when needed.

An ideal power supply maintains a steady voltage no matter what current is taken from it. The extent to which a real power supply achieves this is measured by a property called its voltage regulation.

Zener diodes are designed to 'break down' and conduct electricity at a particular value of reverse-bias voltage. They maintain that voltage for a wide range of currents. This makes them useful as voltage regulators in power supplies. The circuit symbol for a zener diode is shown in the diagram, together with the voltage that it tries to sustain when reverse-biased.



One form of voltage regulator consists of a resistor and zener diode in series with it. The zener diode is connected in reverse bias. The regulator in the diagram, using a 6.2V zener diode and a 100Ωresistor is designed to give an output voltage of 6.2V, leaving therest of the input voltage across the resistor.



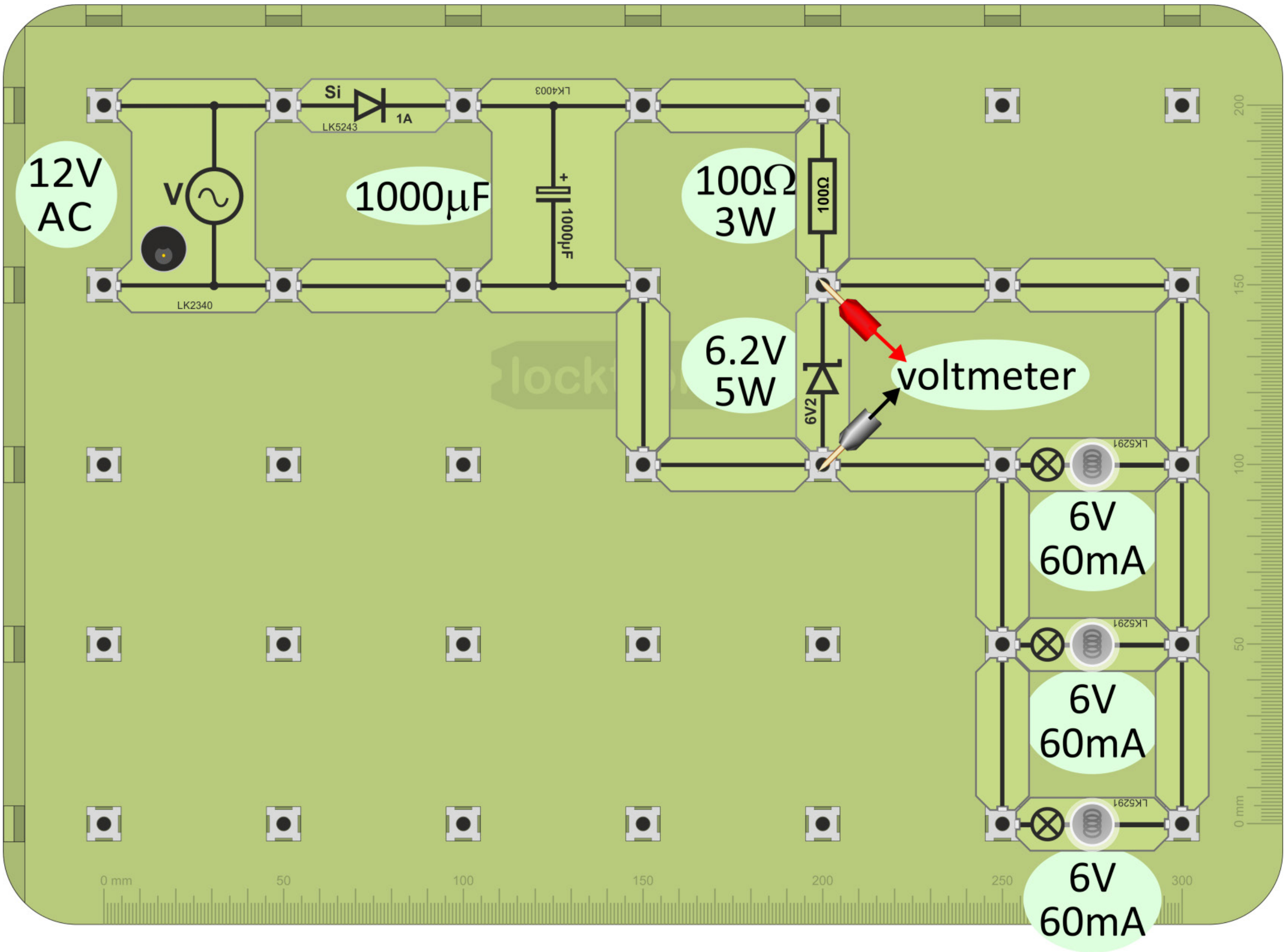
The current through the resistor divides between the output and the zener diode.

When the output current is zero, the full current flows through the zener diode.

In this situation, the power dissipated in the zener diode is a maximum and the diode will be at its hottest.

The Zener Diode Voltage Regulation

1. Build the layout shown below. Notice the high power ratings of the resistor and zener diode. Be sure to connect the zener diode as shown, in reverse bias. To begin with, unscrew the MES bulbs in their holders so that they do NOT light up.
2. Connect the 12V AC power supply and switch on.



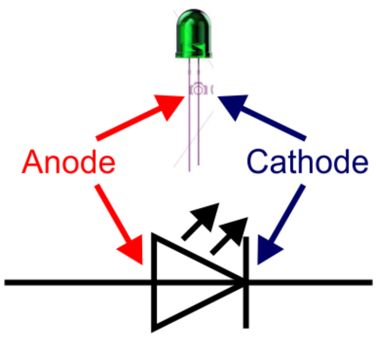
3. Set up a multimeter as a voltmeter reading up to 20V DC. Connect it to meas-ure the output from the voltage regulator. Watch what happens to the meter reading as you work through the next steps of the investigation.
4. Screw in each bulb in turn so that they light up. As you do so, notice the effect on the other lamps that are already lit (and on the voltmeter reading).
5. Answer the questions in the Student Handbook.

The LED

The LED (light-emitting diode) is similar to the power diode in that it conducts electricity only when forward-biased. However, when a current passes through it, some of the energy in it is transformed into light. Whereas the filament lamp gets so hot that it glows, the LED creates light without creating a high temperature.

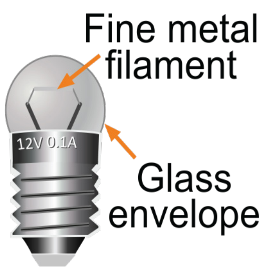
This gives LEDs a much higher energy efficiency (around six times higher than filament lamps.)

The diagram shows a photograph of a green LED together with its circuit symbol.



The cathode is usually the shorter of the two legs.

The colour of the light from the LED comes directly from the generation process and depends on the chemical elements used in the semiconducting crystal at its heart.



In the traditional filament lamp (e.g. torch bulb) light is produced because the wire filament (usually tungsten) is heated to such a high temperature (~25000C) that it glows yellow hot.

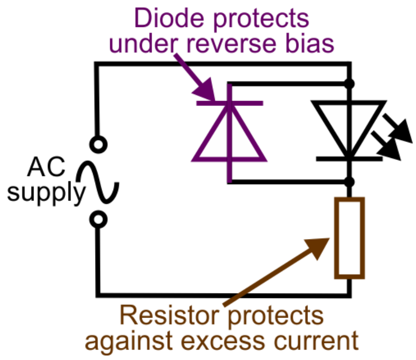
To reduce evaporation of the metal, the glass envelope is filled with an inert gas at low pressure. They are not energy efficient (typically 2-3% of the energy supplied to it is emitted as light) as most energy goes into heating the filament.

LEDs have a number of advantages over filament lamps:
- Lower energy consumption - no hot filament;
- Longer lifetime - no expansion and contraction of the wire filament;
- Physically robust:
- No glass envelope;
- No delicate filament;
- Smaller size;
- Faster switching.

Protecting the LED

LEDs come in a variety of colours, shapes and intensity. However, none can withstand high voltages, either for forward-bias or for reverse-bias.

A typical LED cannot withstand more than about 3V under forward-bias and around 5V when reverse-biased. Usually, the power supply voltage is greater than this.

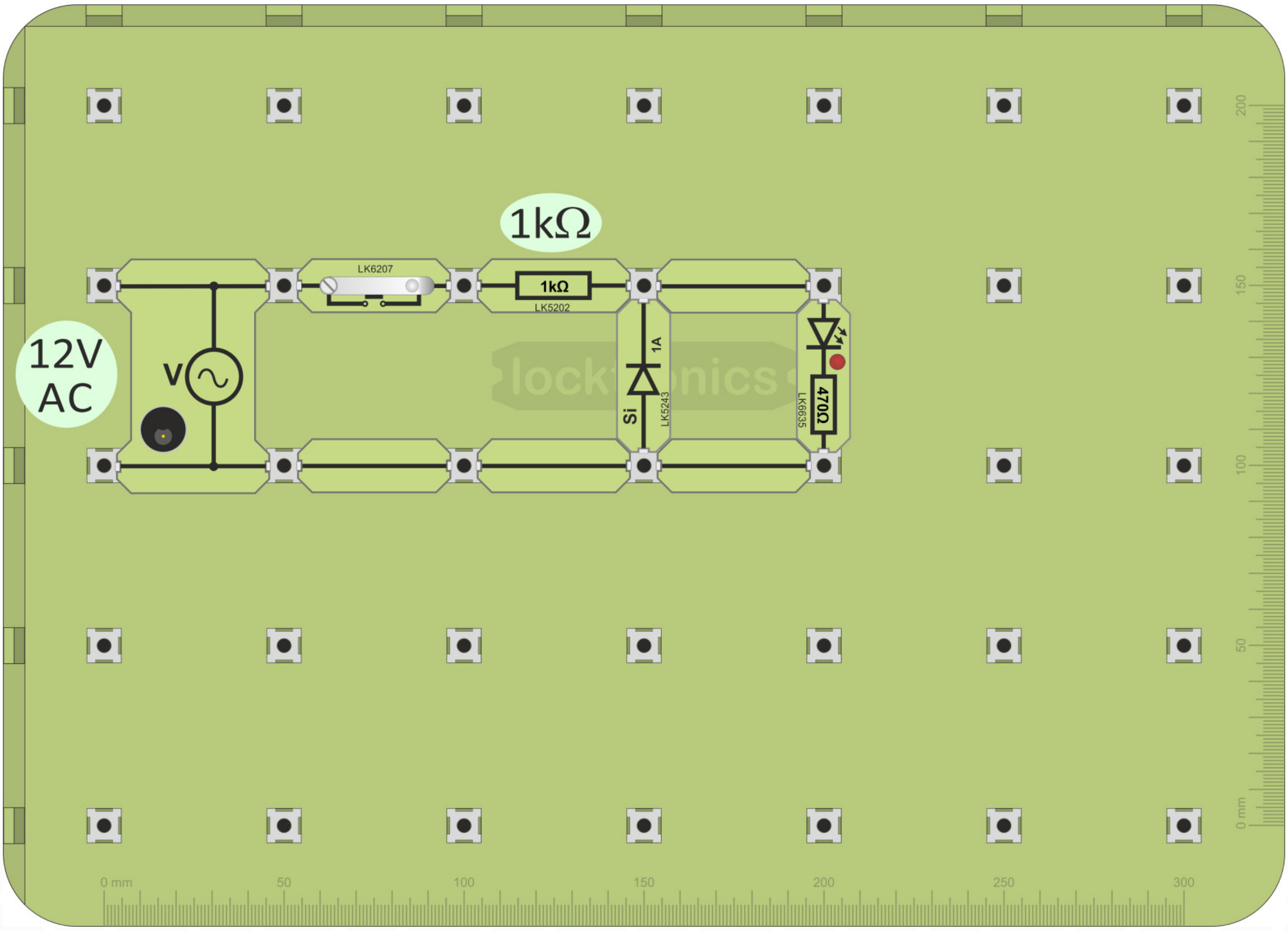


A series resistor is used to protect the LED when forward-biased.

When reverse biased, a diode can protect it, as the diagram shows:

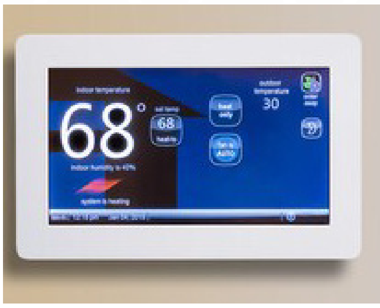
1. Build the layout below, taking care to connect the diode the right way round!
2. Connect the 12V AC power supply and switch on.
3. Press the push-switch to light the LED

AC



4. Now answer the questions in the Student Handbook!

Sensors



To control something, we need to be able to measure it!

Electronic instrumentation plays a vital role in this. Very often, at the heart of such instrumentation is a sensor connected in a voltage divider subsystem.

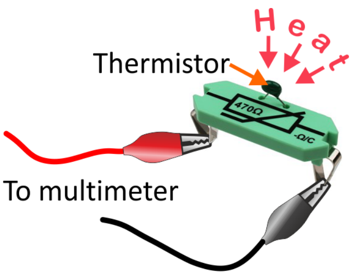
We have seen that resistors are used to protect other components from excessive currents. They can also be used in voltage dividers to split up the voltage from a power supply into smaller predictable portions.

This is particularly useful when one of the resistors is a sensing component, such as a LDR (light-dependent resistor,) or a thermistor, (temperature-dependent resistor.)

The output voltage can represent temperature, light-level, pressure, humidity, strain or other physical quantities, depending on the type of sensor used.

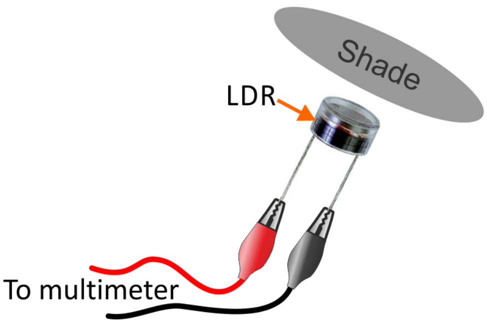
A. Investigating the thermistor:

1. Connect the thermistor carrier to the multimeter, set to measure resistance up to 2 kΩ.
2. Measure its resistance at room temperature.
3. Hold the thermistor between thumb and forefinger to warm it and notice the effect of the increasing temperature on its resistance.



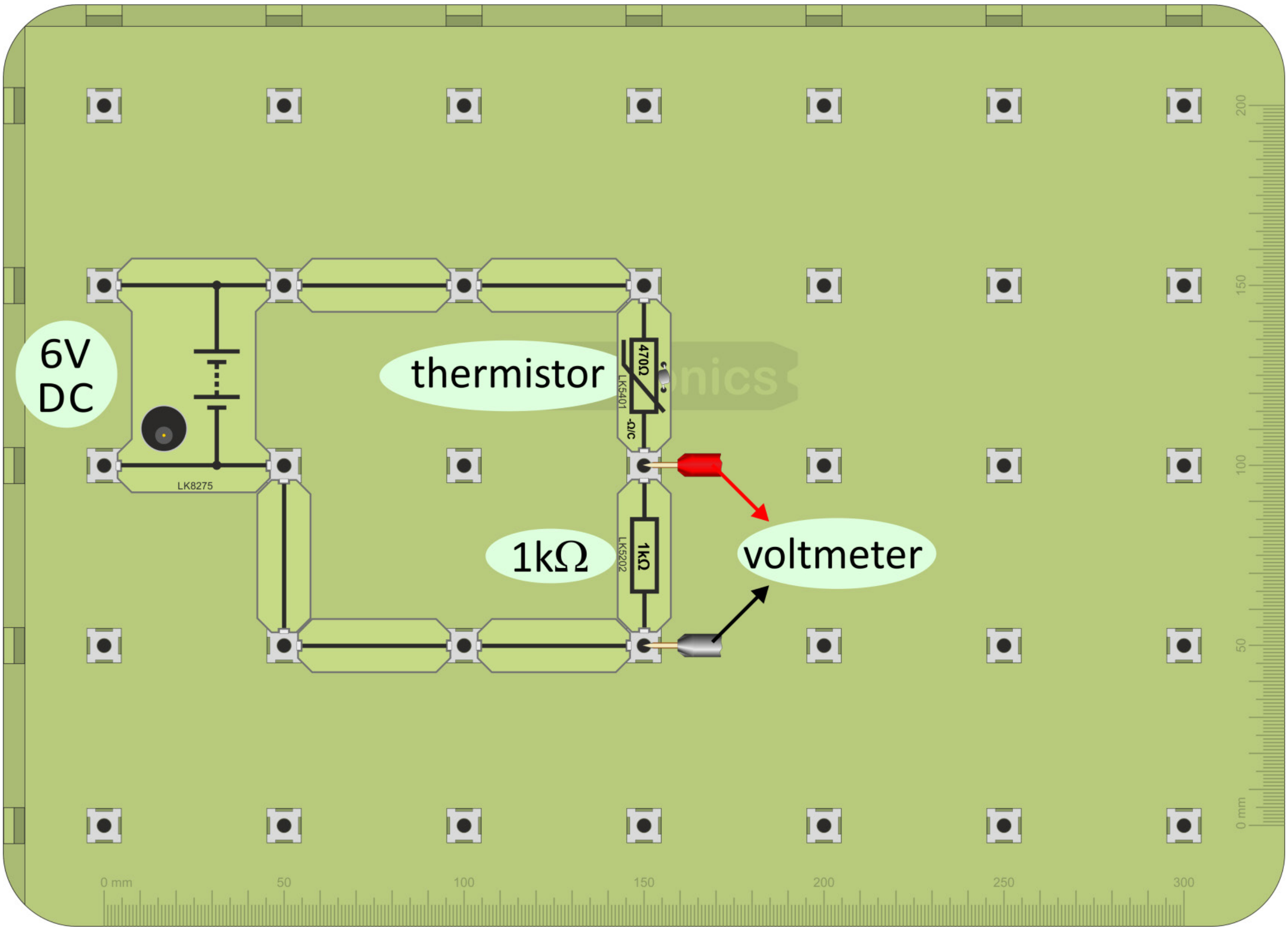
B. Investigating the LDR:

1. Next, connect a LDR to the multimeter.
2. Measure its resistance under normal room lighting.
3. Shade the LDR with your hand and notice the effect on its resistance as you do so.
4. Now answer the questions in the Student Handbook!



Temperature-Sensing Unit

1. Build the layout below.
2. Set up a multimeter to read DC voltages up to 20V and connect it across the 1kΩ resistor, as shown.
3. Set the DC power supply to 6V, connect it and switch on.

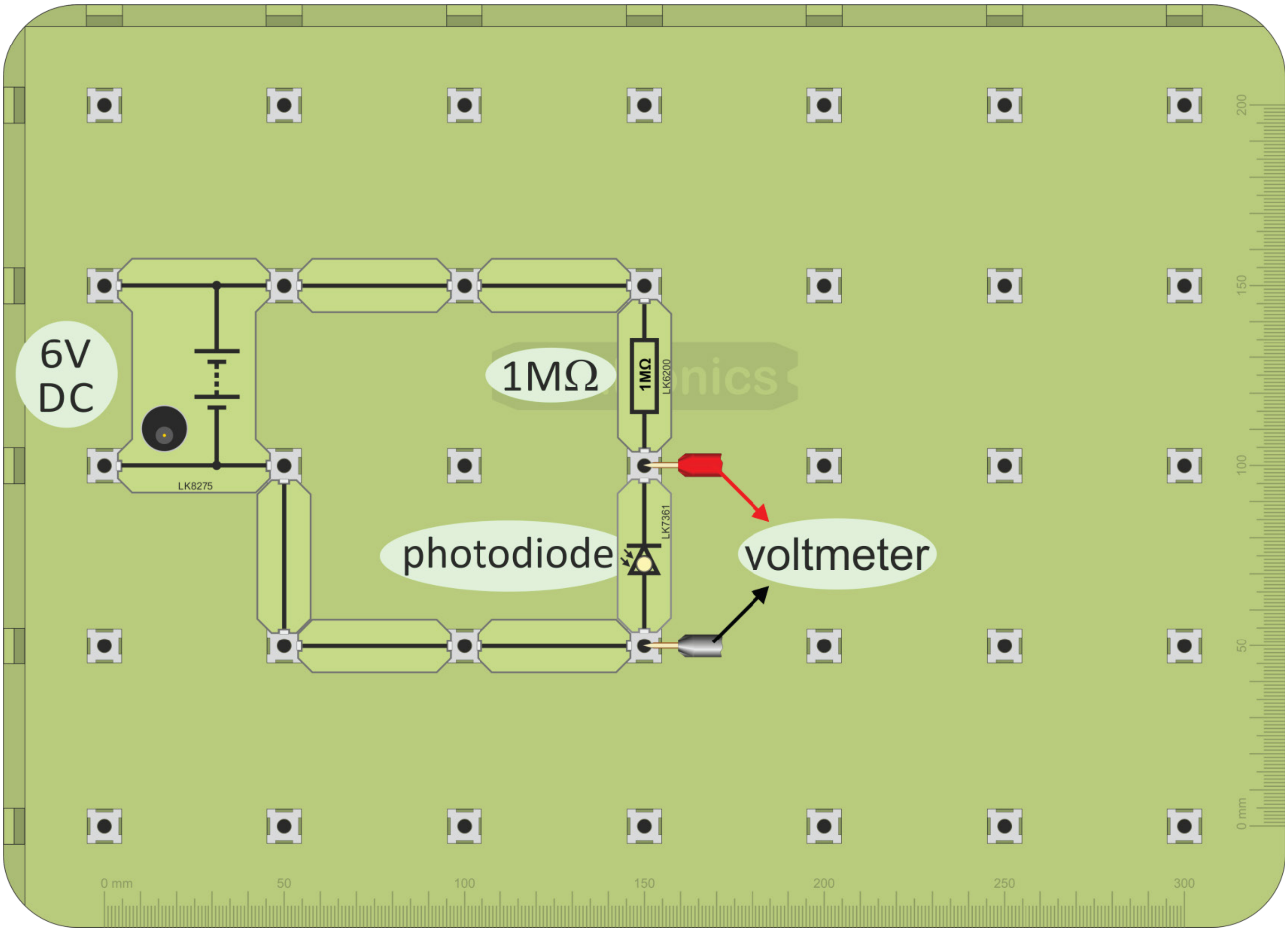


4. The output voltage from the sensing-unit is taken as the voltage across the 1kΩ resistor. Measure this voltage with the thermistor at room temperature.
5. Warm up the thermistor by holding it between your finger and thumb. Watch the voltmeter as you do so.
6. Swap over the thermistor and resistor, but leave the voltmeter where it is, so that it is now connected across the thermistor. Warm it up, as before. Notice the effect on the output voltage as you do so.
7. Now answer the questions in the Student Handbook!

Light-Sensing Unit

1. Build the layout below.
2. Set up a multimeter to read DC voltages up to 20V and connect it across the photodiode, as shown.
3. Set the DC power supply to 6V, connect it and switch on.

DC

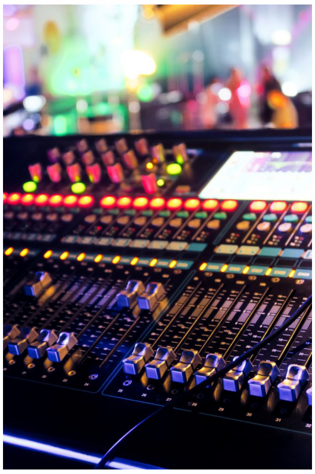


4. The output voltage is now taken as the voltage across the photodiode. Measure this voltage under normal room lighting.
5. Reduce the light level by shading the photodiode with your hand. Watch the voltmeter as you do so.

Challenge:
Rearrange the circuit to create the opposite effect on output voltage when the photodiode is shaded.

6. Now answer the questions in the Student Handbook!

The Potentiometer - Structure



The potentiometer, usually called 'pot', is widely used to control :

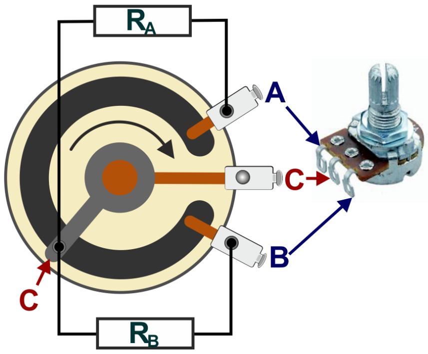
- Loudness and tone in audio devices;
- Brightness, in lighting systems;
- Speed and position, in motors etc.

They are available in a variety of formats - linear and rotary - single-turn and multi-turn ...

The photograph shows part of an audio mixing desk, used in a recording studio. It uses both linear (slider) and rotary pots.

The following diagram illustrates the internal structure of a rotary pot.

When the spindle is rotated, a metal 'wiper' slides across a 'C'-shaped track, made from a carbon compound, or from a flattened spiral of re-sistance wire.



The three terminals create two variable resistors:

- **R_A**, between terminal **A** and terminal **C**;
- **R_B**, between terminal **B** and terminal **C**.

When the slider rotates, the length of track between the terminals changes, altering the resistance of the variable resistors. When it moves clockwise in the diagram, for example, **R_A** gets smaller and **R_B** increases.

The resistance between **A and B** is the full resistance of the track and is fixed.

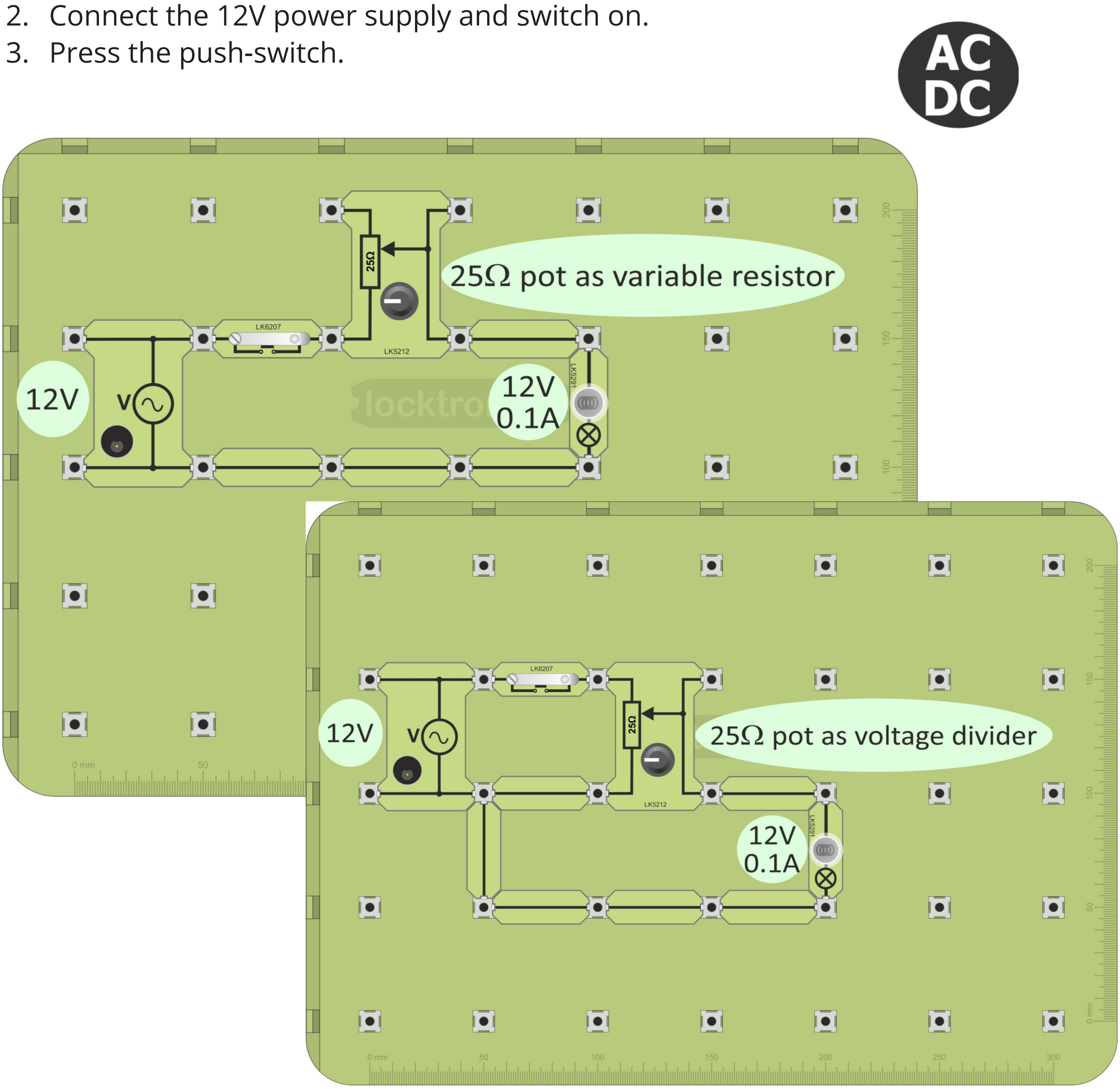
The pot is used in two ways:

- As a variable resistor, using only two terminals, either **A and C or B and C;**
- As a voltage divider, using all three terminals.

The investigations on the next page illustrate the difference between these uses.

Two Ways to Use a Potentiometer

1. Build the first layout shown below, which uses the 25Ω pot as a variable resistor. Like a resistor, it has only two terminals.
2. Connect the 12V power supply and switch on.
3. Press the push-switch.



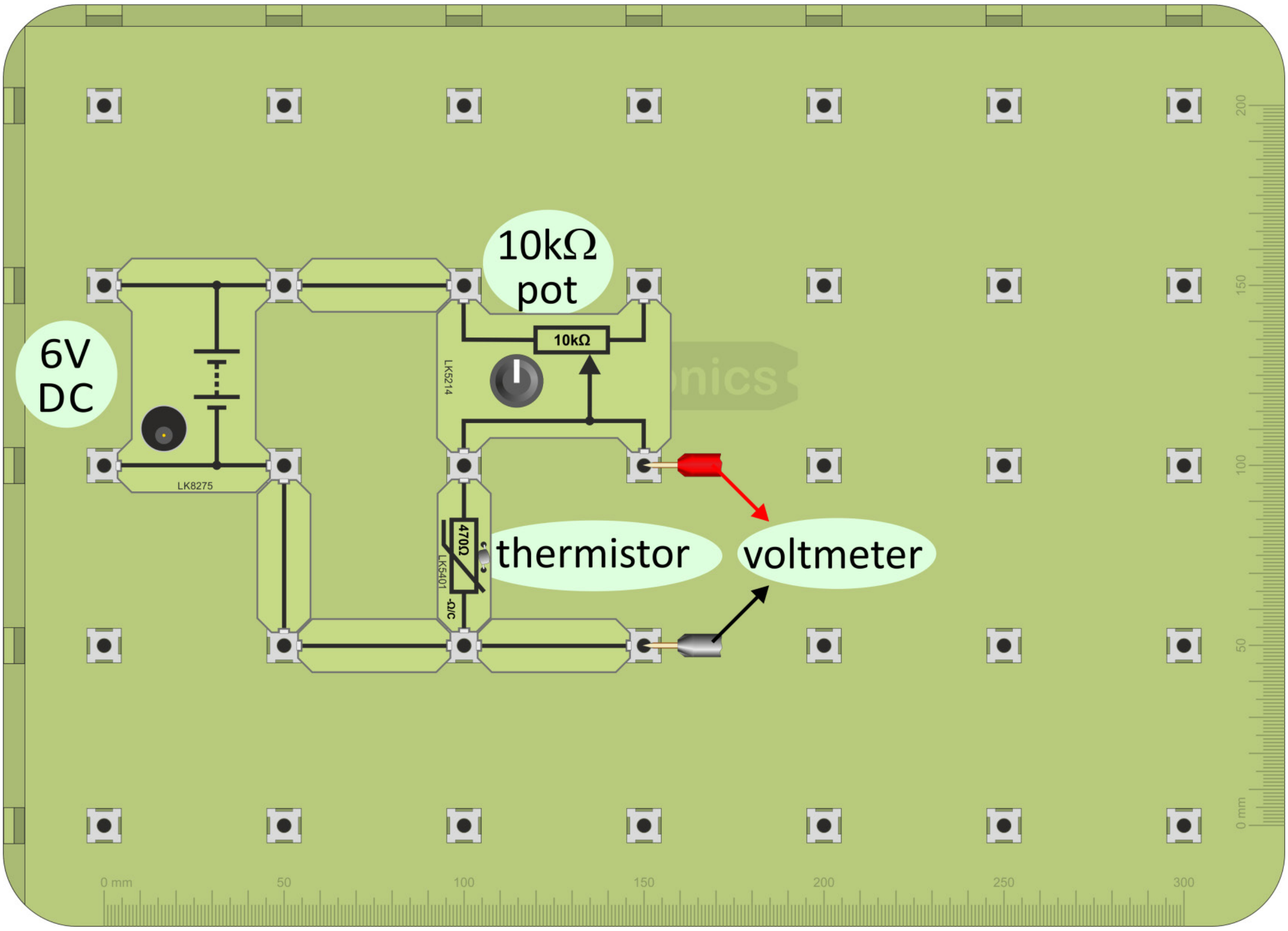
4. Turn the knob on the pot to see the effect this has on the bulb.
5. Now build the second circuit. This one uses the pot as a voltage divider - all three terminals are used.
6. Connect the 12V power supply, switch on and press the push-switch.
7. Turn the knob on the pot. Compare the effect of this arrangement with the

Improved Temperature-Sensing Unit

A pot is often used as a variable resistor as part of a sensing unit.

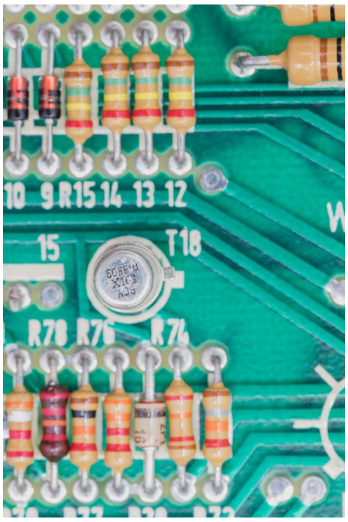
1. Build the layout shown below, which uses a 1kΩ pot as a variable resistor within a temperature-sensing unit.
2. Set up a multimeter to read DC voltages up to 20V and connect it to measure the output voltage, as shown.

DC



3. Set the DC power supply to 6V, connect it and switch on.
4. Turn the knob on the pot from one extreme position to the other. Notice the effect on the output voltage.
5. With the pot set roughly mid-way around its travel, test that the system still works in the same way as a temperature-sensing unit.
6. Answer the questions in the Student Handbook.

The Transitor



Though rarely seen by itself, the transistor is at the heart of nearly all modern electronic systems.

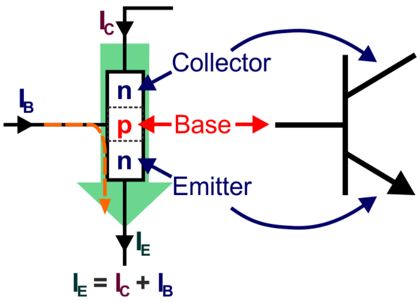
It is made from a single crystal of a semiconducting material such as silicon. In its pure form, silicon does not conduct electricity very well - hence the name semiconductor. Its relatively high electrical resistance falls when selected impurities are added. Moreover, it conducts in ways specific to the type of impurity added.

One type makes it conduct rather like a metal, such as copper, using a 'sea' of free electrons. This type of silicon is called 'n-type' (as it conducts using free, negatively-charged electrons.)

The other type enables conduction using electrons which are normally trapped in the silicon. The impurities create 'holes' (missing electrons) in the crystal structure. Since electrons are negatively-charged, a lack of an electron seems to have a positive charge. Silicon containing this kind of impurity is called 'p-type'.

A transistor is a sandwich of 'p-type' and 'n-type' silicon created in a single crystal.

It has three terminals, called 'collector', 'base' and 'emitter'.



One version is the npn transistor, where the collector and emitter are 'n-type' and the base is 'p-type'.

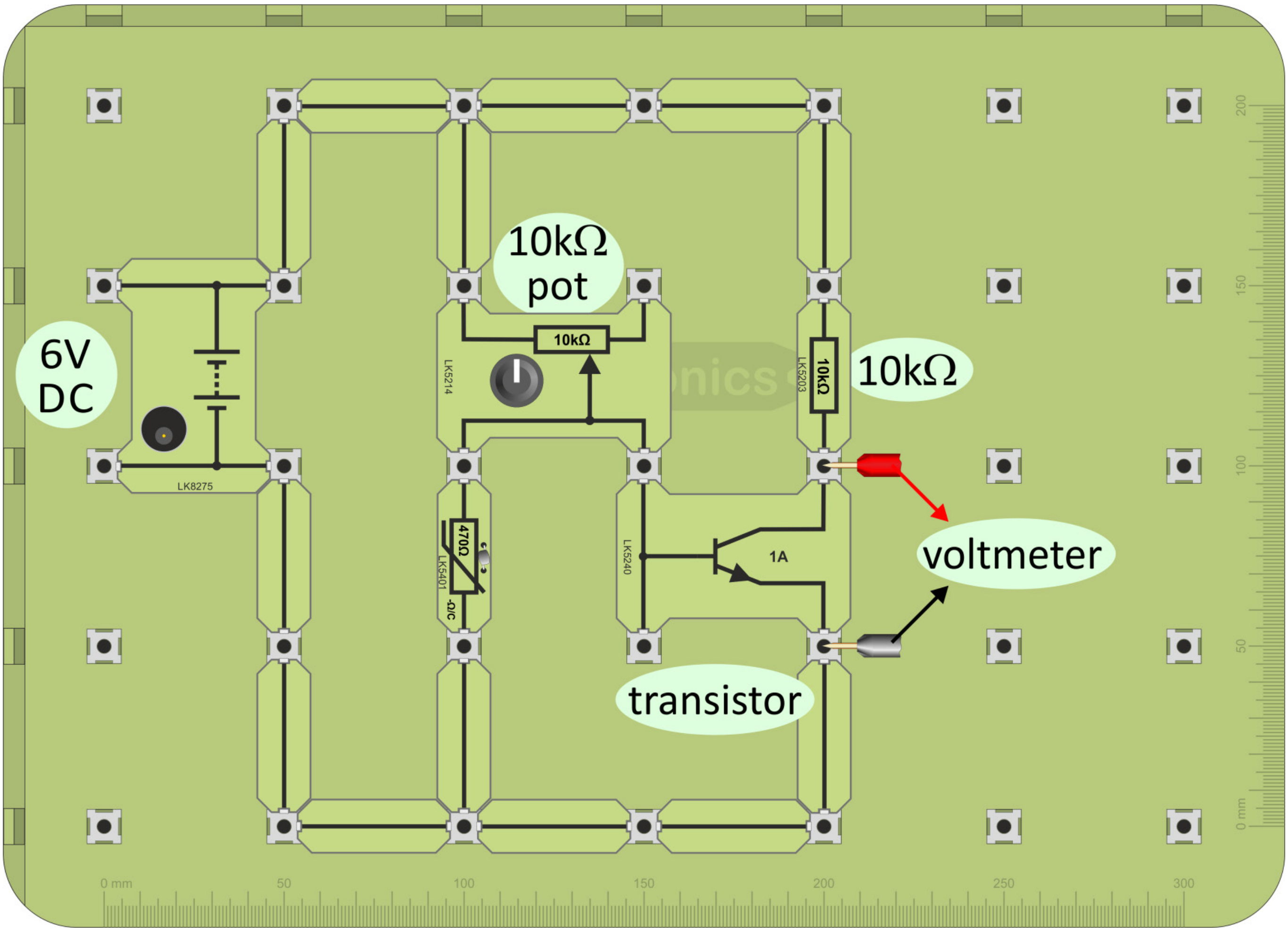
A transistor is a current amplifier. A small current (I_B) flowing into the base controls a much bigger current (I_C) flowing into the collector. A small increase in base current can produce a large increase in collector current, and so on... . These two currents combine to make up the emitter current (I_E).

Adding a Transitor Amplifier

A sensing unit can be made more sensitive by adding a transistor amplifier.

1. Build the layout shown below. It contains the temperature-sensing unit studied earlier, using a 10kΩ variable resistor. Its output is connected to atransistor amplifier.

DC



2. Connect a multimeter, set to read DC voltages up to 20V, to measure the output of the amplifier, as shown.
3. Set the DC power supply to 6V, connect it and switch on.
4. Adjust the variable resistor so that the output voltage is around 3V.
5. Warm up the thermistor between finger and thumb and watch the multimeter reading as you do so. It changes rapidly.
6. Connect the voltmeter across the thermistor so that you can compare this with the rate at which the output of the temperature-sensing unit changes.
7. Answer the question in the Student Handbook.

A Simple Time Delay Circuit

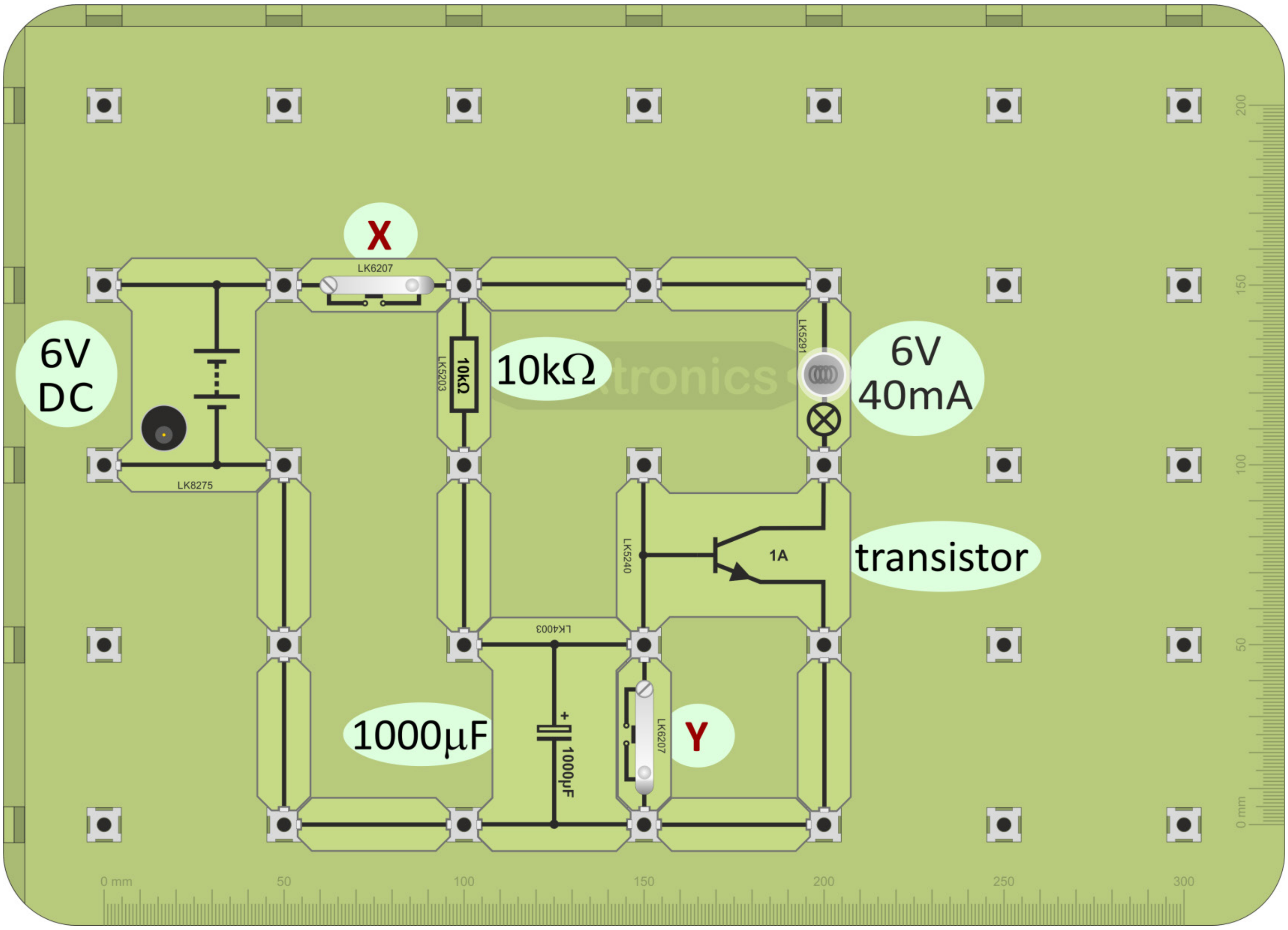
Capacitors form the basis of a number of time-delay circuits.

1. Build the layout shown below, an extension of the one you just used.

Take care to connect the capacitor the right way round!

The transistor acts as an electronic switch. It takes only a small current from the resistor-capacitor pair and so has little effect on the time delay.

DC



2. Press and hold down switch X. The bulb lights after a short delay. (Once again, to repeat the test, press switch Y to discharge the capacitor.)
3. Try other values of resistor and capacitor.
4. Answer the questions in the Student Handbook.

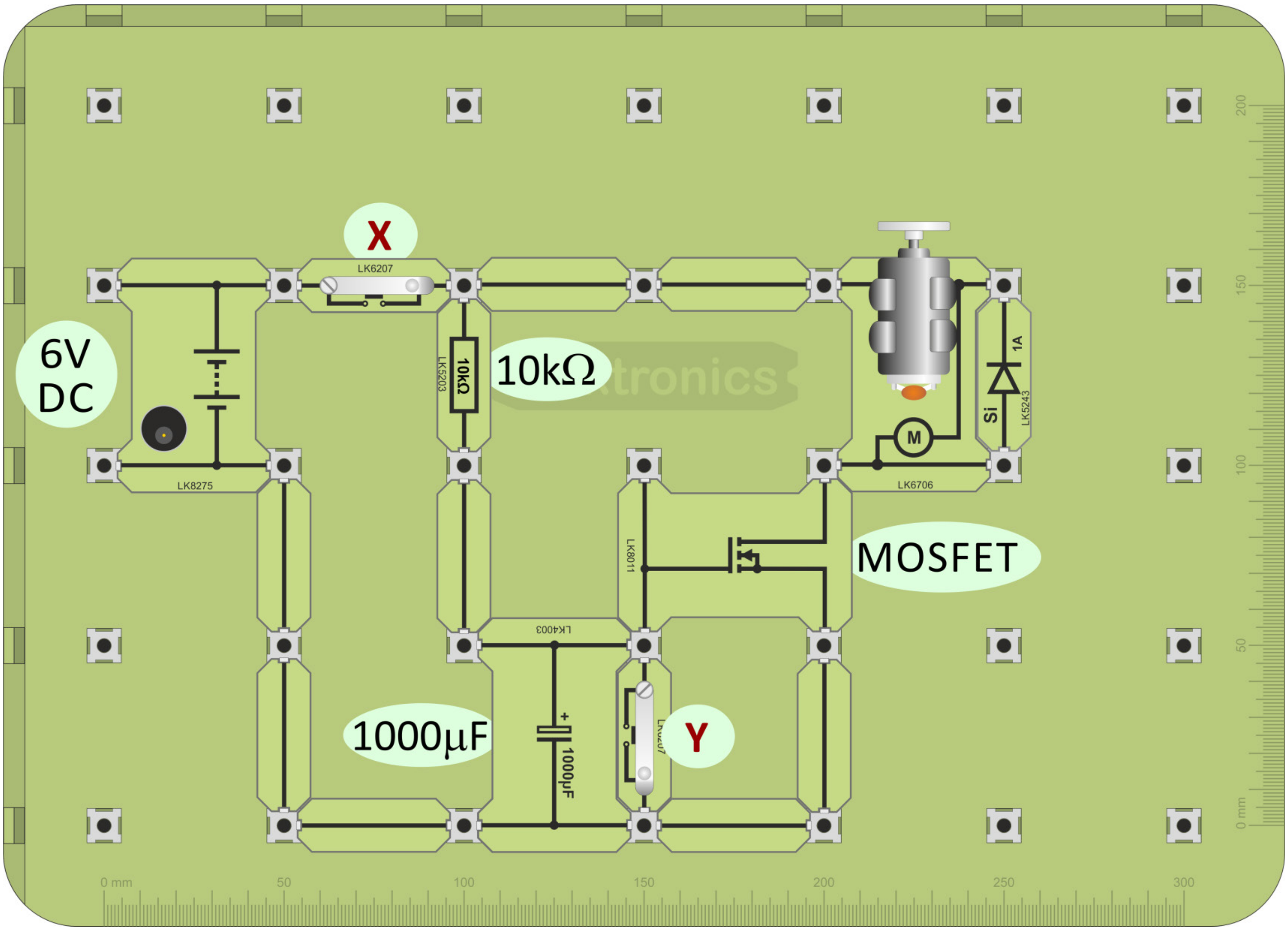
Another Simple Time Delay Circuit

This uses a MOSFET (Metal-Oxide-Semiconductor-Field-Effect-Transistor), another type of transistor which draws an even smaller current from the resistor-capacitor network and can handle a higher load current. The diode offers protection against the high voltage, created when the motor is switched off ('back e.m.f.)

1. Build the layout shown below. It is a modification of the one you just used - just swap the transistor for a MOSFET transistor and add the diode.

Again - take care to connect the capacitor the right way round!

DC



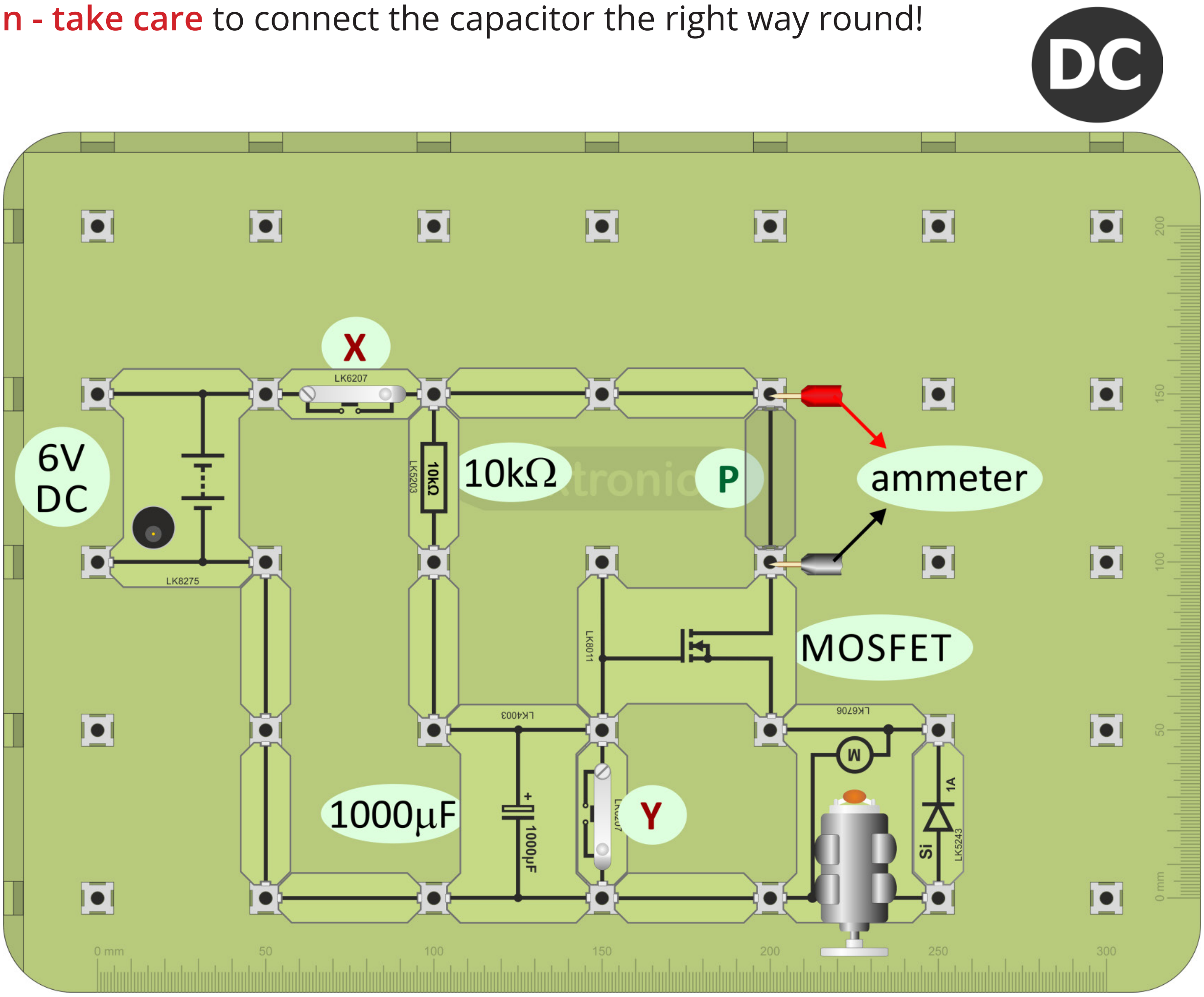
2. Press and hold down switch X. The motor starts to run after a short delay. (To repeat the test, first press switch Y which discharges the capacitor.)
3. Answer the questions in the Student Handbook.

Soft-Start Motor Circuit

The current in a DC motor is usually a maximum when power is first applied. A 'soft-start' circuit limits the initial current and torque as the motor turns on. This reduces mechanical wear-and-tear on the motor and gearbox and interference on the power supply. Usually, 'soft-start' circuits create a voltage ramp that starts the motor rotating slowly and then builds up . The next circuit illustrates one approach.

1. Build the layout shown below. It is similar to the one you just used. The position of the motor and diode has changed. The circuit is now known as a 'source-follower'.

Again - take care to connect the capacitor the right way round!



2. Press and hold down switch X. The motor starts off slowly and then speeds up. (To repeat the test, first press switch Y which discharges the capacitor.)
3. To see exactly what is happening, remove the connecting link labelled P and replace it with a multimeter, set up as an ammeter to measure up to 200mA. Press switch Y to discharge the capacitor and then hold down switch X. Watch how the current through the motor builds up slowly.
4. Answer the questions in the Student Handbook.

Lamp Dimmer - 1

Lamp dimmers are common devices in homes and offices. Turning the knob adjusts the brightness of the lamp(s) connected to it, by turning the spindle on a pot, housed behind it.

You saw earlier that a pot can control the brightness of a lamp, when connected either as a variable resistor or as a voltage divider. When connected as a variable resistor, the resistance of the pot must be chosen so that the brightness of the lamp can be reduced to zero.

However, both methods waste energy. In the voltage divider, current flows through the resistance of the pot all the time, generating heat and wasting energy. When connected as a variable resistor, the same thing happens, unless the resistance is turned down to zero, i.e. the lamp is at full brightness.

A better way to control brightness is to switch the lamp on and off rapidly.

Ideal switching device:

When **off**, its resistance is **huge**, so the current through it is ~ zero.
When **on,** its resistance is tiny, so the voltage across it is ~ zero.

Electrical Power:

means energy converted every second.

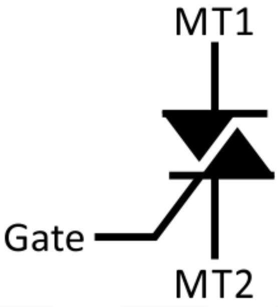
Power = **current** x **voltage**

Look at the information in the two boxes!

Putting this together shows that an ideal switching device dissipates no power. It wastes no energy.

The triac is a widely-used switching device. With three terminals, a gate, (the control terminal), MT1 and MT2 ('MT' = 'Main Terminal'), it can conduct current in either direction and so conducts AC.

Electrically controlled, it is normally off until the voltage applied to its gate terminal rises above a threshold around +0.7V or falls below a threshold around -0.7V. The gate current needed is tiny, a few milliamps. As a result, it dissipates very little power. When the AC voltage drops to zero, the triac turns off until the gate voltage reaches the other threshold.

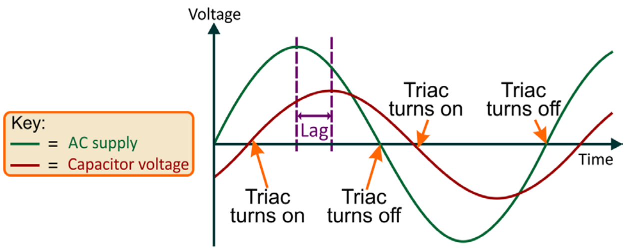


Phase Control

Usually, the gate voltage is created using 'phase control'.

We have seen that a capacitor takes time to charge up when connected in series with a resistor. In other words, the voltage across the capacitor lags behind the supply voltage. This is true in both AC and DC circuits.

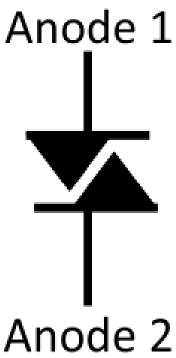
The graph shows this lag in an AC circuit and the resulting behaviour on the triac.



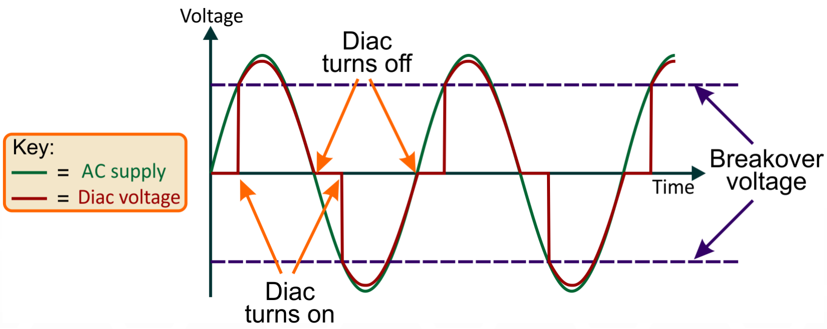
Connecting the voltage from the capacitor to the gate of the triac means that there is a delay, after the AC supply rises above (or below) 0V, before the triac switches on. When the AC voltage falls to zero, the triac, and lamp, turn off.

Using a variable resistor, the delay (lag) can be varied and as a result, the lamp is switched on for longer / shorter in each cycle of the AC supply, varying its brightness.

Although not included in the circuit on the next page, it is common to find another semiconducting device connected in the gate circuit. This is the diac, a two terminal device. The diagram shows its circuit symbol.



Rather like two back-to-back zener diodes, it will conduct in either direction, but only once the supply voltage reaches a certain value, called the 'breakover' voltage.



As the breakover voltage is typically around 30V, it is not possible to investigate them in low voltage circuits. Their benefits include reduced interference to power supplies and reduced triac heating, in high power systems, where the rapid turn-on offered by the diac reduces the average power dissipated in the triac.

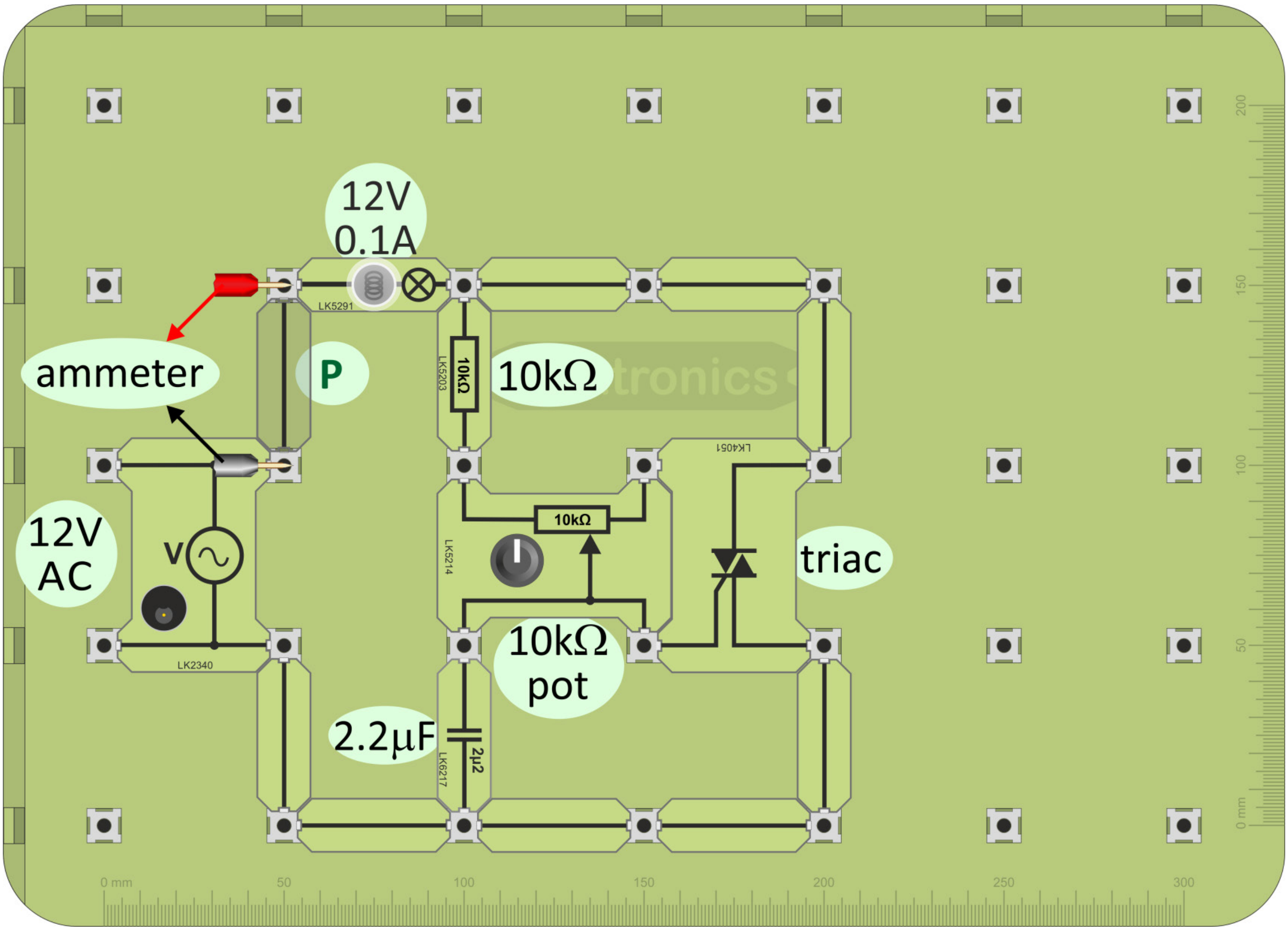
Lamp Dimmer - 2

1. Build the layout shown below.

The capacitor is non-electrolytic and can be connected either way round.

Notice that the top-right terminal on the 10k pot is connected to an unused terminal on the triac. The only connection between them is that between the gate and the slider of the pot (lower right terminal.)

AC



2. Turn the knob on the variable resistor and notice the effect on the brightness of the bulb.
3. To see the effect in more detail:
- Remove the connecting link labelled ‘P’;
- Replace it with leads from a multimeter set up as an ammeter to read AC current up to 200mA;
- Turn the knob on the variable resistor and watch the effect on the current through the lamp.
4. Answer the questions in the Student Handbook.

APPENDIX

Appendix 1 - Measuring Voltage

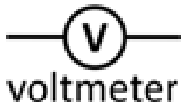
The picture shows one form of multimeter. It has a wide range of uses -which varies from model to model - but usually includes measuring AC and DC voltage and current

When using a multimeter, before you switch it on:
- Take care to plug the probes into the correct sockets;
- Select the correct range.

('Auto-ranging' versions select the best range automatically.)

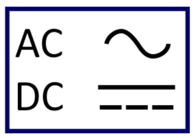
Voltage:
- Is a measure of the force pushing the electrons around the circuit;
- Measures energy lost or gained as an electron moves through part of a circuit
- Is measured with a voltmeter connected in parallel with the component.

The circuit symbol for a voltmeter is shown in the diagram.



Using a multimeter to measure voltage:
Multimeters can measure both AC and DC.

The following symbols distinguish between them:



- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**V**' socket.
- Select the 20V DC range by turning the dial to the '**20**' mark next to the '**V** ⎓ ' symbol. (It is good practice to set the meter on a range that is much higher than the reading you are expecting. Then refine it by choosing a lower range to suit the voltage you find.)

- Plug the wires into the sockets at the ends of the component under investigation.
- Switch on the multimeter when you are ready to take a reading.
- A '-' sign in front of the reading means that the meter wires are connected the wrong way round. Swap them over to get rid of it!

Appendix 2 - Measuring Current

When using a multimeter to measure current, plug the probes into the **'A' and 'COM'** sockets, or equivalents.

Then select the correct range, either from the **'A~'** section, for AC current or the ' **A**' section, for DC current.

Finally, switch on. ⎓

Current:

- Measures the number of electrons passing any point in the circuit each second;
- Measures the rate of flow of electrical charge in the circuit;
- Is measured with an ammeter connected in series with the component.

The circuit symbol for a ammeter is shown in the diagram.

Using a multimeter to measure current:

- Plug one wire into the black '**COM**' socket.
- Plug another into the red '**mA**' socket.
- Select the 200mA DC range by turning the dial to the '200m' mark next to the **'A** ⎓ 'symbol. (Again, it is best to set the meter on a higher range to begin with. Then Break the circuit where you want to measure the current, by removing a link, and then plug the two multimeter leads in its place.
- Switch on the multimeter when you are ready to take a reading.
- A possible problem: The ammeter range is protected by a fuse located inside the body of the multimeter. This may have 'blown', in which case the ammeter will not work. Report any problems to your instructor so that it can be checked.

Appendix 3 - Measuring Resistance

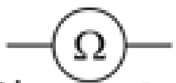
When using a multimeter to measure resistance, the component must be removed from the circuit first!

Once again, before you switch on:

- Take care to plug the probes into the correct sockets, the **'Ω' and 'COM'** sockets;
- Select the correct range.

Resistance

- Is a hindrance to the flow of electrons around the circuit;
- Removes energy from each electron as it moves through the resistor;
- Converts this energy into heat;
- Is measured in units called 'ohms' (symbol - 'Ω') or kilohms (kΩ), using an ohmmeter. (1 kilohm = 1 000 ohms.)



Ohmmeter

Resistance

- Plug one wire into the black '**COM**' socket.
- Plug another into the red **'Ω'** socket.
- Turn the dial to select a resistance range, such as 200kΩ. (Once again, it is good practice to set the meter on a range higher than the reading you are expecting and then refine it to a lower range.)
- Make sure that the component under investigation is not connected to any other.
- Plug the wires into the sockets at the ends of the component.
- Switch on the multimeter when you are ready to take a reading.

STUDENT HANDBOOK

Page 6 - AC or DC - which is used?

Electricity is usually generated and transmitted as AC because:
- Alternators (AC) are usually more efficient than dynamos (DC);
- Transformers, which work only on AC, can modify voltage and current efficiently.

Electronic devices - mobile phones, computers, televisions etc. usually require DC.

AC power: Is converted into DC using the processes of rectification and regulation.
DC power: Can be converted into AC using a device called an inverter.

DC power supplies:
- **Battery -** chemical reactions generate DC voltages, e.g. 'lead-acid' batteries;
- **Solar cell -** photo-voltaic ('solar') cells convert light energy into DC electricity ;
- **Dynamo -** a rotating coil of wire near a magnet generates DC using a 'commutator' to connect the coil to the rest of the circuit.

AC power supplies:
- **Alternator -** a coil of wire rotating near a magnet;
- A 'slip-ring' connects to the rest of the circuit;
- The coil can be driven by:
- High-pressure steam, in a power station;
- Wind in a wind-generator;
- Falling water in a hydro-electric power station.

Page 7 - AC or DC - does it matter?

Describe the effect of connecting a 12V DC motor to:

- A 12V DC power sup**ply:**

____

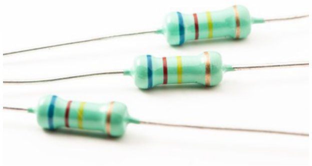
____

- A 12V AC power supply:

____

____

Page 8 - The resistor:



We change the flow of electricity using a resistor. For electrons, adding resistance is like asking you to run in mud.

It takes more energy!

What happened to the brightness of the lamp when you pressed the switch?

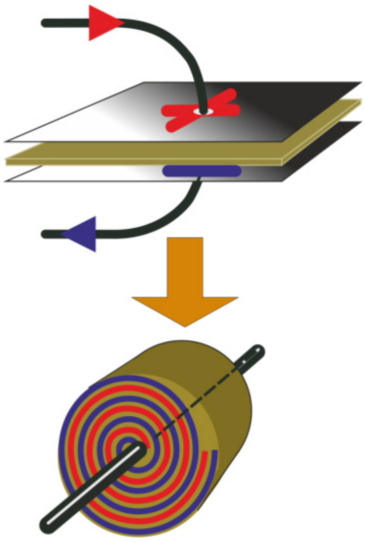
____

Explain why this happened, using the words 'resistance' and 'current' in your answer:

____

____

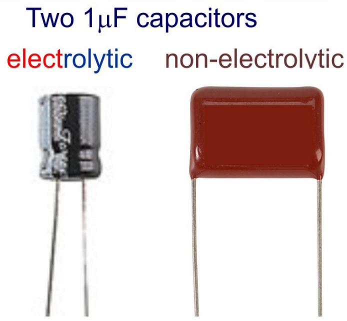
Page 9 - The capacitor:



A capacitor consists of two metal plates, separated by an insulating sheet, rolled up into a 'Swiss roll', in such a way that the metal sheets do not touch.

When powered, current flows from the power supply onto one plate and from the other plate back to the power supply, for a short time. This leaves one plate positively charged and the other negatively charged by the same amount. The capacitor stores this charge until it can flow around a circuit.

Capacitors are rather like 'buckets' that store electric charge. As they fill up, the voltage across them increases until they are fully charged (the 'bucket' is full.) The size of the 'bucket' is given by the capacitance, measured in units called farads (F). For most purposes, the capacitors used are much smaller, with values measured in microfarads (μF, - millionths of a farad) or smaller. The wider the bucket, the more water it takes to raise the level. The bigger the capacitance, the more electrical charge it takes to raise the voltage.



Capacitors come in two main types:

- Electrolytic;
- Non-electrolytic.

Electrolytic capacitors are polarised - with positive and negative terminals. They must always be connected the right way round. They cannot be used in AC circuits.

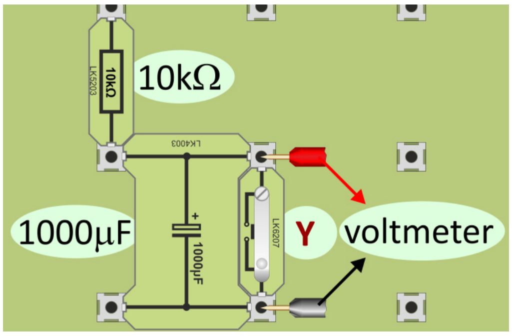
Non-electrolytic capacitors can be connected either way round, but are physically larger for a given value of capacitance.

Take care!

As well as taking care to connect electrolytic capacitors the right way round, you need to check the 'working voltage' rating for the capacitor. This is the maximum safe voltage that can be used with it.

Page 10 - Charging a capacitor:

How long did the capacitor take to charge up to 3V? ______________________________



What happens to this time when you increase the size of the resistor?

____

____

What happens to this time when you decrease the size of the capacitor?

____

What happens when you press switch Y?

____

Describe one important safety measure you need to take when building this circuit.

____

____

Page 11 - The diode:

Rectification is the process used to turn AC into DC. It usually relies on the fact that current can flow only one way through a diode.

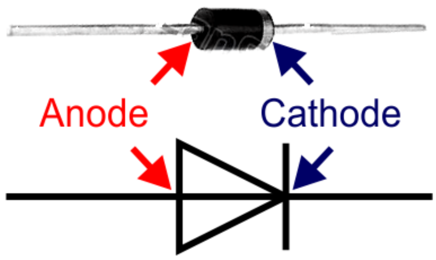
A diode has two terminals, known as the **anode** and the cathode.

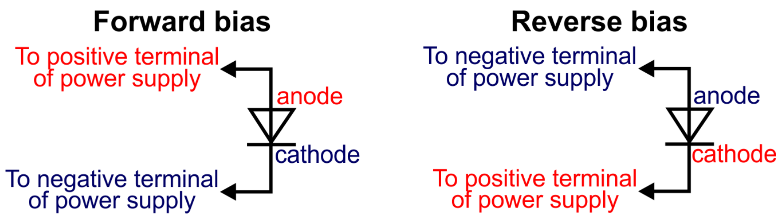
The diagram shows a photograph of a common type of diode together with its circuit symbol.

The cathode is identified by a silver stripe on the body of the diode.

When the anode is more positive than the cathode, the diode is 'forward-biased'.

When the cathode is more positive, it is 'reverse-biased'.





The diode acts as a 'one-way valve':
It allows current to flow through it only when it is forward-biased.
When reverse-biased, it does not conduct at all (for low voltages.)

Page 12 - Rectification:

Explain to a fellow student how you know that the diode converts AC to DC:

____

____

____

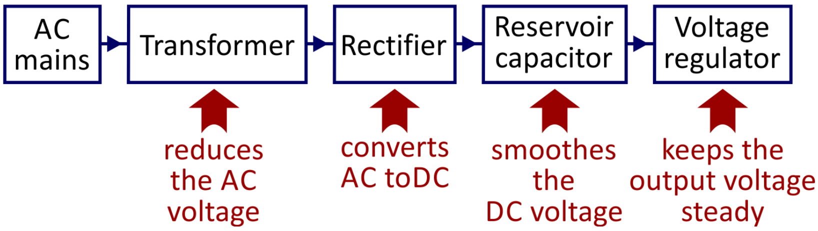
____

____

Page 13 - Low voltage DC power supply:

The aim is to convert a high-voltage (240V) AC mains supply into a low voltage (12V, typically) DC supply that can be used with electronic equipment.

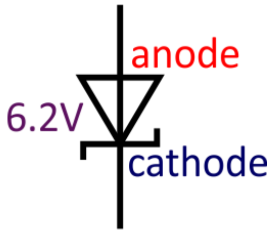
This process can be divided into the stages, shown in the block diagram:



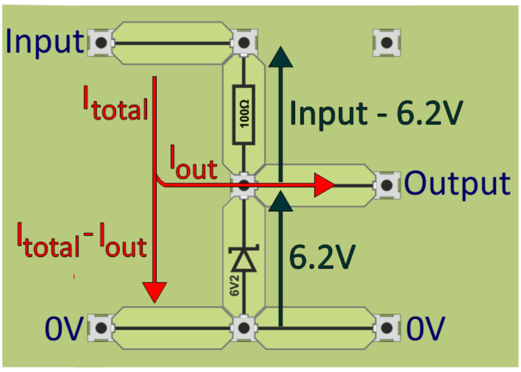
We have seen that a diode can be used as the rectifier and that a capacitor behaves rather like a bucket of charge, topping up the output when needed.

An ideal power supply maintains a steady voltage no matter what current is taken from it. The extent to which a real power supply achieves this is measured by a property called its **voltage regulation.**

Zener diodes are designed to 'break down' and conduct electricity at a particular value of reverse-bias voltage. They maintain that voltage for a wide range of currents. This makes them useful as voltage regulators in power supplies. The circuit symbol for a zener diode is shown in the diagram, together with the voltage that it tries to sustain when reverse-biased.



One form of voltage regulator consists of a resistor and zener diode in series with it. The zener diode is connected in reverse bias. The regulator in the diagram, using a 6.2V zener diode and a 100Ω resistor is designed to give an output voltage of 6.2V, leaving the rest of the input voltage across the resistor.



The current through the resistor divides between the output and the zener diode.

When the output current is zero, the full current flows through the zener diode. In this situation, the power dissipated in the zener diode is a maximum and the diode will be at its hottest.

Page 14 The zener diode voltage regulator:

Describe what happens to the brightness of the bulbs as more and more bulbs are lit:

____

____

____

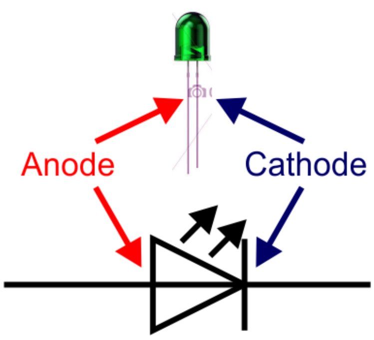
What is the voltmeter reading when:

- No bulbs are lit; ________________________
- One bulb is lit; ________________________
- Two bulbs are lit; ________________________
- Three bulbs are lit. ________________________

Page 15 - The LED:

The LED conducts only when forward-biased. Then some of the electrical energy is transformed into light. The filament lamp gets so hot that it glows. The LED creates light at low temperature, giving it a much higher energy efficiency.

The diagram shows a green LED with its circuit symbol. The **cathode** is usually the shorter leg. The colour of the light depends on the chemical elements used.

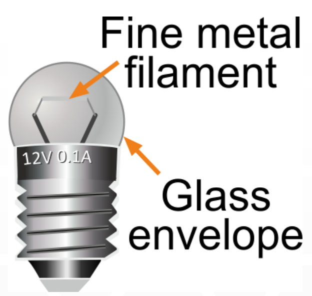


In the filament lamp (e.g. torch bulb) light is produced because the wire filament (usually tungsten) is heated to such a high temperature (~2500ºC) that it glows yellow hot.

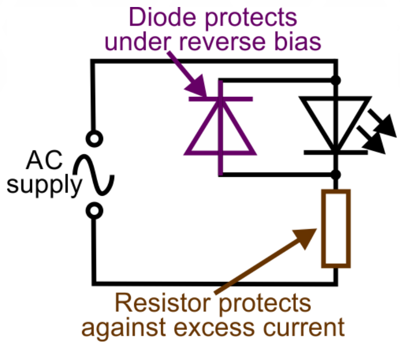
To reduce evaporation of the metal, the glass envelope is filled with inert gas at low pressure.

Advantages of LEDs:

- Lower energy consumption - no hot filament;
- Longer lifetime - no expansion and contraction of the wire filament;
- Physically robust - no glass envelope - no delicate filament;
- Smaller size;
- Faster switching.



Page 16 - Protecting the LED:



A typical LED cannot withstand more than about 3V under forward-bias and around 5V when reverse-biased.

A series resistor protects the LED when forward-biased.

When reverse biased, a diode, connected as shown in the diagram, can be used to protect it.

What is the purpose of the 1kΩ resistor in series with the LED?

Explain how and when the diode connected in 'reverse-parallel' protects the LED:

Page 17 - Sensors:

What happens to the resistance of the thermistor when its temperature rises?

What happens to the resistance of the LDR when the light level drops?

Page 18 - Temperature-sensing unit:

With the thermistor in its initial position, what happens to the output voltage when the temperature rises?

How can you reverse this behaviour?

Page 19 - Light-sensing unit:

With the photodiode in the position shown in the diagram, what happens to the output voltage when the light level falls?

___

Describe how you modified the circuit to reverse this behaviour?

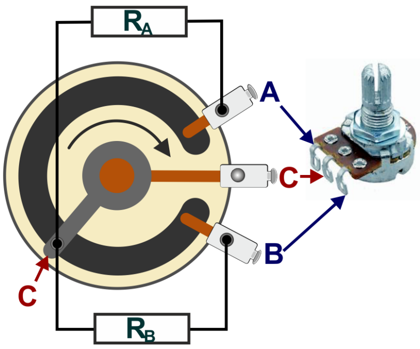
___

___

___

Page 20 - The potentiometer structure:

The diagram illustrates the internal structure of a rotary potentiometer (pot).



When the spindle is rotated, a metal 'wiper' slides across a 'C'-shaped track, made from a carbon compound, or resistance wire.

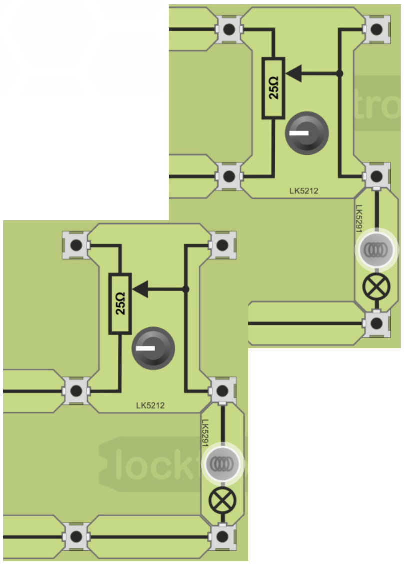
The three terminals create two variable resistors:
- R_A, between terminal **A** and terminal **C**;
- R_B, between terminal **B** and terminal **C**.

When the slider rotates, the length of track between the terminals changes, altering the resistance of the variable resistors.

When it moves clockwise in the diagram, for example, R_A gets smaller and R_B increases. The resistance between **A and B** is the full resistance of the track and is fixed.

The pot is used in two ways:
- As a variable resistor, using only two terminals, either **A and C or B and C;**
- As a voltage divider, using all three terminals.

Page 21 - Two ways to use a pot:



The upper diagram shows a pot used as a voltage divider - (all three terminals used.)

The lower diagram shows it used as a variable resistor. (Resistors have only two legs - so does this!)

Compare the effect of adjusting the pots in each case:

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Page 22 - Improved temperature-sensing unit:

A more flexible arrangement is to use a variable resistor in place of the fixed resistor, used in the earlier version.

With the knob turned fully clockwise, what was the output voltage?

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With the knob turned fully anti-clockwise, what was the output voltage?

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With the knob at the mid-position, what was the effect of warming up the thermistor?

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Page 23 - The transistor:

The transistor is made from a single crystal of a semiconducting material such as silicon. When pure, silicon does not conduct electricity very well - hence the name semiconductor. Its resistance falls markedly when selected impurities are added. It then conducts in a way that depends on the type of impurity added, either:

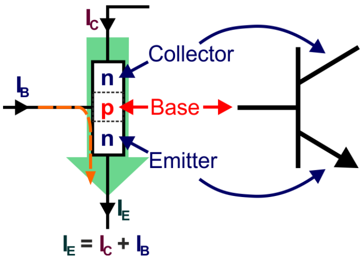
- Using a 'sea' of free electrons, rather like a metal, such as copper; (This is called 'n-type' as it conducts using free, negatively-charged electrons;)
- Using electrons which are normally trapped in the silicon. (The impurities create 'holes' (missing electrons) in the crystal structure which behave as if they are positively charged. This is called 'p-type'.)

A transistor is a sandwich of 'p-type' and 'n-type' silicon created in a single crystal.

It has three terminals, called 'collector', 'base' and 'emitter'.

One version, the npn transistor, has a collector and emitter made from 'n-type' and the base from 'p-type'.

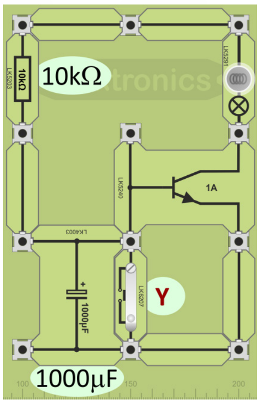
A transistor is a current amplifier. A small base current (IB) controls a much bigger collector current (IC). A small increase in base current can produce a large increase in collector current, and so on... . These two currents combine to make up the emitter current (IE).



Page 24 - Adding a transistor amplifier:

Describe the change in performance when a transistor amplifier is added to the output of the temperature-sensing unit.

Page 25 - A simple time delay circuit:



What is the advantage of adding a transistor to the resistor-capacitor network studied on the previous page?

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Estimate the delay between pressing the switch and the lamp lighting.

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Describe one modification to the circuit that makes this time delay longer.

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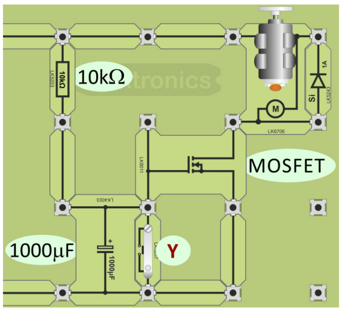
Page 26 - Another simple time delay circuit:

What is the advantage of using a MOSFET in this application?



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What is the purpose of the diode connected in parallel with the motor?

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How long was it before the motor started spinning? ______________________

Describe how to restart the timing process.

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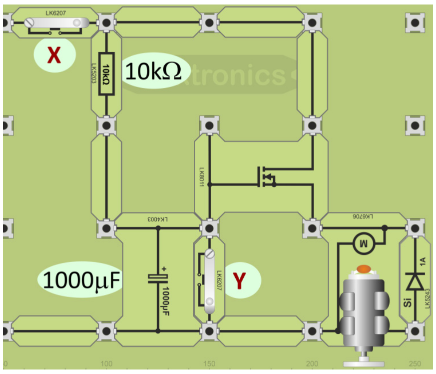
Page 27 - Soft-start motor circuit:

How did the behaviour of the motor in this circuit differ from that in the circuit above?



Why are there two switches, **X and Y?**

What is the job of the diode?

Page 28 - Lamp dimmer - 1:

Ideal switching device:
When **off**, its resistance is **huge**, so the current through it is ~zero.
When **on,** its resistance is tiny, so the voltage across it is ~zero.

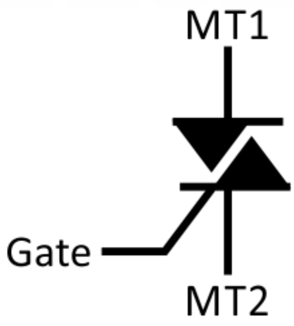
Electrical Power:
means energy converted every second.
Power = **current** x **voltage**

One way to control the brightness of a lamp is to use a pot, connected either as a variable resistor or as a voltage divider. However, both ways waste energy as heat.

In the voltage divider, current flows through the resistance of pot all the time, generating heat .

As a variable resistor, the same thing happens, unless the resistance is zero, i.e. the lamp is at full brightness.

A better way to control brightness is to switch the lamp on and off rapidly using a triac. With three terminals, a gate, (the control terminal), MT1 and MT2 ('MT' = 'Main Terminal'), it can conduct current in either direction.



Electrically controlled, it is normally off until the voltage applied to its gate terminal rises above a threshold around +0.7V or falls below a threshold around -0.7V.

The gate current needed is tiny, a few milliamps. As a result, it dissipates very little power. When the AC voltage drops to zero, the triac turns off until the gate voltage reaches the other threshold.

Explain why no power is dissipated in an ideal switch.

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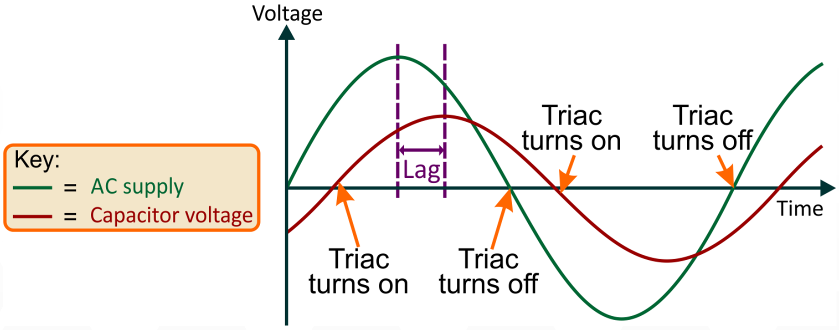
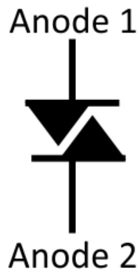
Page 29- Phase control:

A capacitor connected in series with a resistor takes time to charge up. In other words, the voltage across the capacitor lags behind the supply voltage. The graph shows this lag in an AC circuit and the resulting behaviour on the triac.

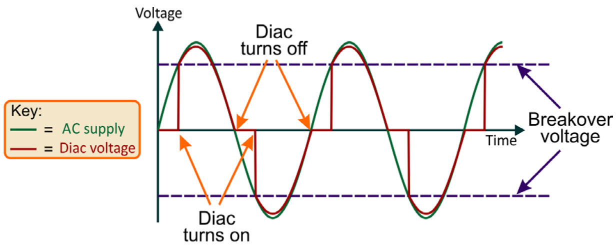


Connecting the voltage from the capacitor to the gate of the triac means that there is a delay, after the AC supply rises above (or below) 0V, before the triac switches on. When the AC voltage falls to zero, the triac, and lamp, turn off. Using a variable resistor, the delay (lag) can be varied and as a result, the lamp is switched on for longer / shorter in each cycle of the AC supply, varying its brightness.

It is common to find another semiconducting device, the diac, connected in the gate circuit. The diagram shows its circuit symbol.

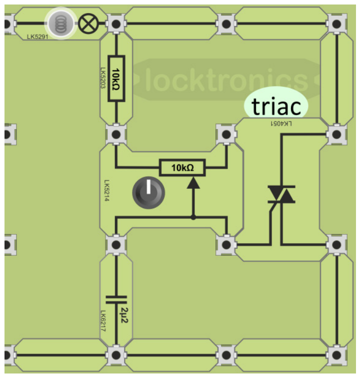


Rather like two back-to-back zener diodes, it conducts in either direction, but only once the supply voltage reaches the ‘breakover’ voltage, typically around 30V.



Their benefits include reduced interference to power supplies and reduced triac heating, in high power systems, where the rapid turn-on offered by the diac reduces the average power dissipated in the triac.

Page 30 - Lamp dimmer - 2:



The capacitor is non-electrolytic and can be connected either way round. The top-right terminal on the pot is connected to an unused terminal on the triac. The only connection between them is that between the gate and the slider of the pot (lower right terminal.)

What is the effect of turning the pot spindle clockwise?

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What is the maximum and minimum current through the bulb?

___

Notes

Notes

ELECTRIC COMPONENTS AND CIRCUIT

CP2813

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