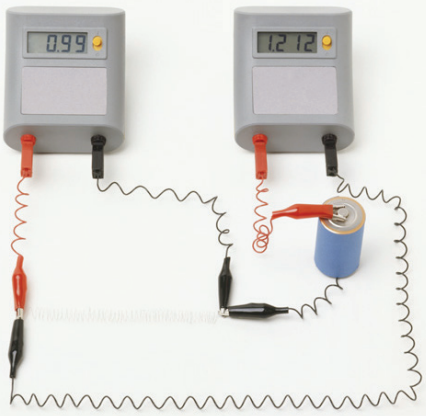
Circuits

Section 1: Ohm's Law

• What is Ohm's law?

Ohm's law gives the relation between current, resistance and voltage. It states that the current which flows through a component is equal to the potential difference across the component, divided by its resistance. Ohm's law is based on the work of the German physicist Georg Ohm who published a similar equation in 1827.

Ohm's law can be applied to circuits containing large numbers of components, like resistors or bulbs, as long as the overall resistance can be calculated. However, if the circuit contains components like capacitors and inductors, and an Alternating Current (AC) supply is used, Ohm's law in this form is not sufficient and has to be modified to use a more complex term, known as impedance instead of resistance.



A circuit with an ammeter and voltmeter

• Suggested Film

- Electric Eels

Extension Questions

Q1. What is current?

Current is measured in amperes and describes the amount of charge, in coulombs, which passes a point in one second. It is measured using an ammeter.

Current can be composed of a flow of positive or negative charge. In metals the current is due to a flow of electrons, although current can also be due to a flow of ions (charged atoms or molecules).

Current can either be direct or alternating. Direct Current (DC) travels in one direction, but AC changes direction, often many times per second.

Q2. What is voltage?

The voltage at a point is the electric potential – the energy one coulomb of charge would have if it were at that point. It is measured in volts(V) where 1 volt is equivalent to 1 joule of energy per coulomb. If charge is free to move it will flow between two points which have different voltages. The difference in the voltage between the two points is known as the potential difference (or sometimes simply as the voltage) and, in general, the larger the potential difference the larger the current which flows between the two points.

The mains supply uses a potential difference of 230V, but batteries use far lower voltages. Car batteries provide a potential difference of around 12V between the two terminals.

• What is resistance?

Resistance is measured using an ohmmeter and is a measure of the opposition to electrical current. The unit of resistance is the ohm. If a potential difference of 1V is applied across two points on a conductor, and this results in a current of 1 ampere, the resistance between the two points is 1 ohm.

Metals are used to make leads and cables because they are good conductors, which means they have very low resistance. Conductors contain charges, which are able to move, and so have a low resistance to electrical current. Insulators have very high resistance. They resist the flow of electrical current as they do not contain charges which are free to move.

• Suggested Film

- Resistance

Extension Question

Q3. What is a superconductor?

Materials which exhibit superconductivity have zero electrical resistance. This means, in theory, if a current were to flow in a loop made of a superconductor it would persist forever. Initially, the practical applications of superconductivity were limited, as it was only known to occur in a few materials and at very low temperatures, close to absolute zero (-273.15°C or 0 Kelvin). However, in 1986 materials were discovered which displayed superconductivity at higher temperatures. The discovery of superconductivity above -196°C (77 Kelvin) was significant, as this is the boiling point of liquid nitrogen, which is widely used and inexpensive, and this can be used to cool materials to these temperatures.

In a normal conductor electrons lose energy when they collide with atoms as they pass through the material. In low temperature superconductors this does not occur. The electrons form “Cooper pairs” which do not lose energy to the material. The mechanism behind high temperature superconductors is not well understood, despite more than 20 years of research, but is of great interest. Current superconductors all operate at more than one hundred degrees below room temperature, but there is hope that one day it will be possible to produce a superconductor that operates at room temperature.

Section 2: Circuits

• What is a short circuit?

Circuit breakers are essential safety mechanisms, which protect an electrical circuit from current overload

If a connection is made between two points, which results in a very low resistance between the points, this means a very large current will flow for a relatively small potential difference. This can cause problems as it can cause overheating or damage to components.

Short circuits can be caused when the insulation on a wire fails and the wire makes a connection, which allows the current to flow along a new path that has a much lower resistance. If a piece of conducting material is added to a circuit this could also create a new path for the current and cause a short circuit.

Fuses and circuit breakers are designed to break the circuit if too much current flows, and so can be used to prevent damage and overheating occurring as a result of a short circuit.

• Suggested Film

- Rock Star Shock

Extension Question

Q4. What is an open circuit?

If there is not a continuous path between the two terminals of a circuit then current will not flow. This is known as an open circuit. There will be a very large resistance across the gap, or break, in the circuit and so an ohmmeter can be used to detect these breaks in the circuit and diagnose faults. Fuses and circuit breakers are designed to create breaks in circuits to prevent current flowing when there is a fault in the circuit.

• What is a series circuit?

The simplest circuit is known as a series circuit. In this type of circuit each component is connected one after the other, so the current has to pass through each in turn and is the same at every point in the circuit. One disadvantage of this type of circuit is that if one component fails, creating an open circuit, current will not flow through the rest of the components. This would create a problem if, for example, bulbs were connected in series. If one bulb were to fail the others would also switch off. Similarly, each of the bulbs could not be controlled individually as a switch would stop current flowing in the entire circuit. For this reason, the applications of simple series circuits are limited.

• Suggested Films

- Circuits

- FactPack: How to Draw a Circuit

Extension Question

Q5. What is a parallel circuit?

In a parallel circuit components are connected in parallel and so there is more than one path along which the current can follow. The current will split and the amount of current flowing through each path, or branch, will be determined by the relative resistance of each path.

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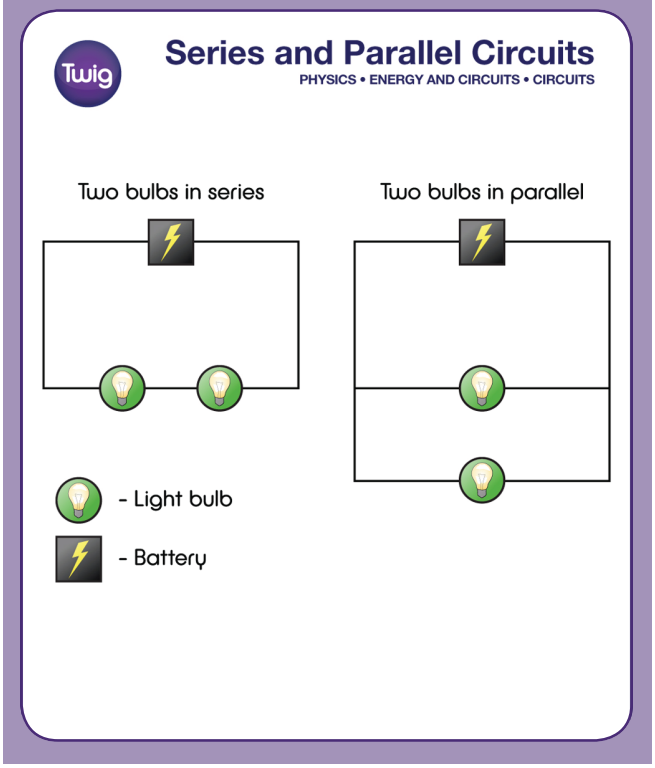


One of the advantages of a parallel circuit is if a component fails, creating an open circuit, the components in parallel will continue to function, as current will still be able to flow around the circuit. This is why lights are often connected in parallel.

Another advantage of a parallel circuit is that the potential difference, or voltage, across each component is the same. This means that if a circuit contains two identical bulbs connected in parallel, the voltage across each of the bulbs will be the same as the voltage across the supply. If the bulbs were connected in series the voltage across each would be half of the voltage across the supply and the bulbs would not be as bright.

For these reasons parallel circuits are used more often than series circuits. For example, lights in a house are usually connected in parallel.

Extension Question

Q6. What is a ring main circuit?

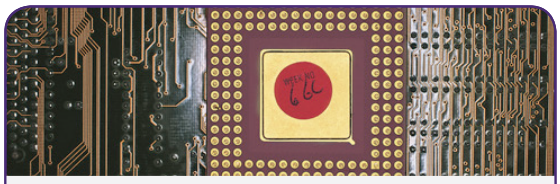
In the UK, sockets are not wired in simple series or parallel circuits. Instead, they use a special form of parallel circuit called a ring main. This is similar to a parallel circuit, but instead of using a wire from each terminal, a ring circuit uses two loops, each connected to one of the terminals. Sockets are connected between the two loops. The advantage of a ring main circuit is that it allows thinner wire to be used as the current is lower. This is because the current can come from the terminal and pass along the loop in two directions to reach the socket. This means that the current in the loop can be half as large as it would be if it were flowing in a single wire.

Section 3: Electronics

• What is a computer chip?

Electronic equipment does not generally use large numbers of components wired up in a circuit. Instead, components are etched into a semiconductor material, usually silicon, and the entire circuit is printed as one unit, which is known as an integrated circuit (or a chip). This means that complex circuits can be made very cheaply. This also allows the construction of extremely small circuits, which can be built using a very small amount of material.

The processors that are found inside computers (and most modern electronic equipment) contain extremely complex integrated circuits.



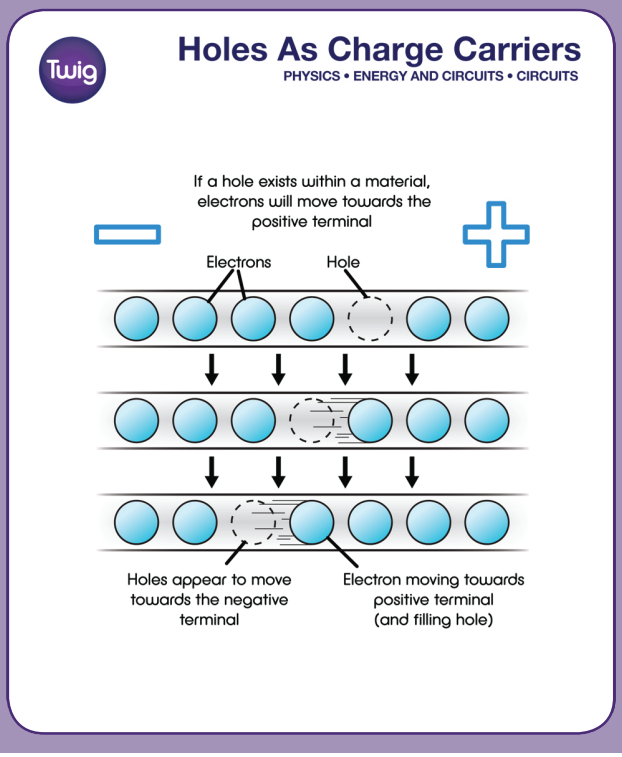
A computer chip on a mainframe board

• Suggested Film

- Moore's Law

• What is a semiconductor?

DIAGRAM 02:



A material which has less electrical resistance than an insulator, but more than a conductor, is known as a semiconductor. Silicon is the most commonly used semiconductor.

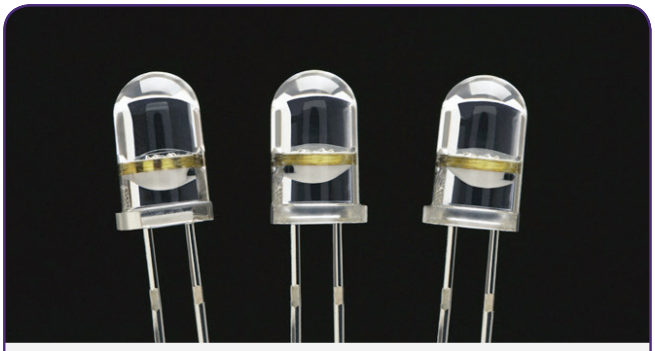
The addition of even small amounts of impurities to a semiconductor can significantly affect its resistance. The addition of impurities to a semiconductor can influence its behaviour. This is known as doping. Because of this property semiconductors can be used to build devices including transistors, diodes and solar cells.

When charge flows through a semiconductor it is not always carried by electrons. If a semiconductor has an excess of electrons then these can act as the charge carriers. These are known as n-type semiconductors. Alternatively, if there is a deficit of electrons it is also possible that the gaps where electrons are 'missing' can act as charge carriers. An electron can move to fill the 'gap' as it heads to the positive terminal. This leaves a gap which the electron has vacated. This is then filled by another electron, leaving another gap. This means that the gap moves towards the negative terminal, acting like a positive particle. This is known as a 'hole' and is the charge carrier in p-type semiconductors.

• What is a diode?

A diode is an electrical component which is made of an n-type and p-type semiconductor that are joined together, and which only allows current to flow in one direction.

If a diode is used in a circuit and set up so that the n-type material is connected to the negative terminal and the p-type material is connected to the positive terminal then current will flow. The electrons from the n-type material will pass through the p-type material on their way to the positive terminal and the holes from the p-type material will pass through the n-type material on their way to the negative terminal. This is known as forward bias.



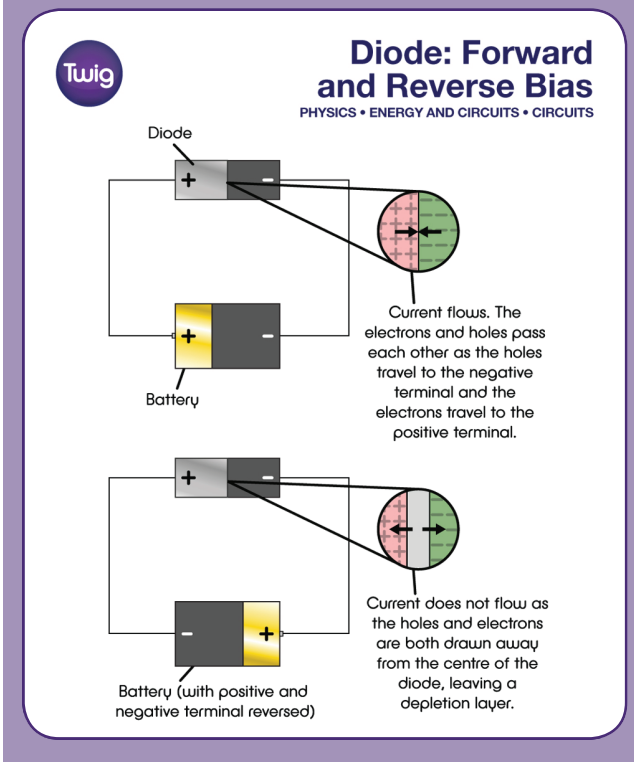
Light Emitting Diodes (LEDs)

However, if the diode is connected the other way round, the electrons from the n-type material will travel directly to the positive terminal and the holes from the p-type material will travel directly to the negative terminal. No current will flow as this will lead to a depletion layer forming at the junction between the two materials which will contain no charge carriers. This is known as reverse bias.

• Suggested Films

- **Diodes and Transistors**
- **Hi-Fi Engineering**

DIAGRAM 03:



Extension Question

Q7. What is a transistor?

There are many types of transistors, but a transistor can be composed of three pieces of semiconductor material, connected at two junctions. Each of the three pieces of semiconductor will be either p-type or n-type and will be connected in the order pnp or npn. This means that whatever direction the transistor is connected in one of the junctions will act like a diode, which is reverse biased, and so no current will flow. However, if a third connection is made at this junction and a sufficient voltage is applied then this problem will no longer occur and the current will flow.

This means that transistors can be used as switches, switched on and off by the voltage at this connection, known as the base. Alternatively, they can be configured for use as amplifiers, using a small change in the base voltage to produce large changes in the output voltage.

When transistors began to replace vacuum tubes it meant that circuits could be dramatically reduced in size. The integrated circuits of modern processors contain billions of transistors along with other electronic components.

Extension Questions

Q8. What is a light emitting diode?

If a diode is forward biased, so that current can flow, the holes from the p-type material and the electrons from the n-type material can meet at the junction between the two materials. If this occurs, the electrons and holes can recombine and this can cause light to be emitted. Diodes can be designed to ensure that this occurs and this type of diode is known as a Light Emitting Diode (LED). These LEDs have many advantages over conventional filament bulbs: they can be made very small, use very little energy, and last much longer.

LEDs are used for many applications including lights on electronic equipment, the infrared lights on remote controls, television screens and domestic lighting.

Q9. What is a capacitor?

A capacitor is an electrical component which consists of two plates separated by a gap. Sometimes a vacuum is used in this gap but it is more common to use an insulator called a dielectric.

We might expect that no current would flow in a circuit containing a capacitor, as there is a break in the circuit. However, current will flow for a short time. We can imagine that as electrons leave the negative terminal and arrive at one plate the electrons on the other plate are repelled and head to the positive terminal. This process continues until the build-up of electrons is so large that they repel any more electrons that try to reach the plate from the negative terminal. Because of this, current flows normally initially before quickly dropping to zero. The time taken for the current to fall is always the same for a given capacitor and circuit, and so capacitors can be used for timing. Capacitors can be used to construct very simple circuits, which will produce a regular pulse as the capacitor charges and discharges. These pulses can be used for timing in electronics.

If alternating current, which changes direction continuously, is used and it has a high frequency the capacitor will not reduce the current to zero. This is because there will not be enough time for charge to build up on the plates of the capacitor and stop the current flowing before the direction of the current switches direction. For this reason capacitors can be used to block DC current while allowing AC to pass.

• Quizzes

Circuits

Basic

• Which of the following is not needed for a useful circuit?

A – a complete circuit

B – a magnetic field

C – a voltage source

D – components which will put the electricity to good use

• What are resistors designed to do?

A – control the flow of current

B – produce light

C – store charge

D – produce magnetic fields

• What are capacitors designed to do?

A – control the flow of current

B – produce light

C – store charge

D – produce magnetic fields

Advanced

• What is a disadvantage of series circuits?

A – they require very large currents

B – if the circuit is broken no current will flow

C – capacitors do not work in series circuits

D – they require very large voltages

• What is the current like in a series circuit?

A – it is different through each component

B – it varies continuously

C – it increases over time

D – it is the same at all points

• Why are house lights usually connected in parallel circuits?

A – if one light is turned off the others stay on

B – series circuits cannot carry enough current

C – parallel circuits use less wire and so are cheaper

D – the power loss in series circuits is too large

Resistance

Basic

• What is resistance?

A – the energy of an electron at a given point

B – a measure of how difficult it is for the current to flow

C – the amount of charge passing a point in one second

D – the amount of charge stored by a component

• What is the resistance like in an insulator?

A – very high

B – zero

C – very low

D – it varies over time

• What units are used to measure resistance?

A – amperes

B – watts

C – volts

D – ohms

Advanced

• What is Ohm's law?

A – it relates voltage, resistance and current

B – it relates power, voltage and current

C – it relates power, resistance and voltage

D – it describes the power loss in a component

• How does the length of a wire relate to the heat loss?

A – a short wire will have greater heat loss

B – there is no relationship between the length of a wire and heat loss

C – a long wire will have greater heat loss

D – the effect depends on the type of wire

• Why can rubber help to protect against electric shocks?

A – rubber provides an easy path to earth

B – it is an insulator and so hinders the flow of current

C – it allows small currents to flow but blocks large currents

D – it has a low resistance

Diodes and Transistors

Basic

• What are semiconductors?

A – materials which have zero resistance

B – materials which are conductors but are non-metals

C – materials which are neither good conductors nor insulators

D – materials which are insulators but which are metallic

• Why are semiconductors useful?

A – they can be used to generate powerful magnetic fields

B – they only allow very small currents to flow

C – they only allow large currents to flow

D – they can be used to build transistors and diodes

• What is a diode made of?

A – two layers of silicon sandwiched together

B – a coil of wire

C – three layers of silicon sandwiched together

D – two coils of wire and a metal core

Advanced

• Why do battery-operated devices often contain diodes?

A – they prevent damage if the batteries are fitted in the wrong direction

B – they reduce the current flowing to the device

C – they increase the current flowing to the device

D – they turn the direct current from the batteries into alternating current

• What can be used to convert alternating current to direct current?

A – a transistor

B – an LED

C – a complex arrangement of diodes

D – a complex arrangement of transistors

• How are transistors often used?

A – to produce magnetic fields

B – to block current flowing in the “wrong” direction

C – to store charge

D – as switches

• Which type of component can be used in amplifiers?

A – diodes

B – transistors

C – capacitors

D – resistors

Diodes and Transistors

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• What is a diode designed to do?

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• How many transistors and diodes can be fitted on a computer chip?

A – dozens

B – hundreds

C – thousands

D – millions

• How small are the smallest transistors?

A – a few centimetres across

B – a few millimetres across

C – just under a millimetre

D – thinner than a human hair

Advanced

• Answers

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