National 5 Physics

Electricity and Energy

CONSERVATION OF ENERGY

Types of Energy

You should know from S1/S2 that there are several different types of energy:

- Gravitational Potential
- Elastic Potential
- Chemical Potential
- Electrical
- Light
- Sound
- Kinetic
- Nuclear

Watch it

youtu.be/NsDEgmxH8wl

youtu.be/mhIOylZMg6Q

You should also remember that all energy is measured in joules (J).

Law of the Conservation of Energy

The amount of energy in a system is **fixed**. Energy cannot be created or destroyed, only changed from one form into another. For instance a lift turns electrical energy into kinetic energy which is then turned into gravitational potential energy.

‘Loss’ of Energy

Even though energy cannot be destroyed it is normal to find that the energy put in is not the same as the energy out. For instance a lift uses a certain amount of electrical energy raising the lift. You can measure the electrical energy put in and calculate the gravitational potential energy of the lift. You would expect, given the law of the conservation of energy, that the two energies would be the same. However you would find that the energy put in is **more** than the energy. Where has this energy gone?

In real world situations no change of energy is perfect. There is always some sort of energy ‘loss’. This is nearly always because some of the energy is changed into heat energy which is then transferred outside the system. For the example of the lift the lift’s motor produced heat which then transfers to the room around the lift. Because this heat energy is almost impossible to recover we say that some energy has been ‘lost’.

Summary

Energy is always conserved, but some can be lost, as heat, to the surroundings.

Kinetic Energy

Kinetic energy is the energy contained within a moving object. It is defined as being equal to one half multiplied by the mass of the object multiplied by the square of the object's speed. The formula for kinetic energy appears on the formula sheet and is given below:

$$E_k = \frac{1}{2}mv^2$$

Kinetic energy measured in

Mass measured in kilograms (kg)

Speed measured in metres per second

Example

A runner reaches full speed during a 100m race. If the runner has a mass of 75kg, calculate the amount kinetic energy he has. In addition state the energy change that his body performs in reaching this speed.

Practice Problems

1. What is the kinetic energy of a 70kg footballer running at $5ms^{-1}$?

2. What is the kinetic energy of a 90kg rugby player running at $4ms^{-1}$?

3. An unknown mass has a kinetic energy of 400J when it is travelling with a velocity of $20ms^{-1}$. What is the mass?

4. A lorry (mass 3000kg) is moving at constant velocity. If it has a kinetic energy of 150,000J — how fast is it travelling?

5. A car has a kinetic energy of 200 000J when it is travelling at $20ms^{-1}$. What is the mass of the car?

6. A model race car of mass 10kg is travelling along a circuit at a constant velocity. If it has a kinetic energy of 3125J — how fast is it travelling?

Gravitational Potential Energy

Gravitational potential energy is a measure of how much extra energy an object has when it is raised up off the ground. It is equal to the mass of the object times the height is has been raised by times the gravitational field strength of Earth (which is 9.8Nkg^{-1}). The formula appears on the formula sheet and is shown below:

Gravitational potential energy measured in joules

Gravitational field strength measured in newtons per kilogram (Nkg^{-1}). On Earth

$$E_p = mgh$$

Mass measured in kilograms (kg)

Height that the object has been raised by

Example

A woman of mass 60kg climbs a set of stairs. There are 20 stairs each measuring 0.15m in height. How much gravitational potential energy does she gain?

Practice Problems

1. A 6kg box is raised through a height of 10m. Calculate the gain in gravitational potential energy of the box.

2. A student of mass 50kg climbs a set of stairs. Each step is 0.2m high and there are 18 steps. Calculate the gravitational potential energy gained by the student.

3. How high must you raise a 50kg mass before it has a potential energy of 100,000J?

4. A crate has a potential energy of 2,000J when it is 70m above the ground. What is the mass of the crate?

5. How high must you raise a 1kg mass before it has a potential energy of 20J?

Calculations Using the Law of the Conservation of Energy

Example

Oranges hang from a branch of a tree. An orange has a mass of 200g and is at a height of 7m above the ground. The orange falls to the ground.

a) Calculate the gravitational potential energy it has when it is hanging from the tree.

b) Assuming that air resistance is negligible, what will be the kinetic energy of the orange just before it hits the ground?

c) How fast will the orange be travelling just before it hits the ground.

Practice Problems

1. A ball of mass 0.5kg is dropped from a tower which is 75m high.

   a) Before the ball is dropped, how much gravitational potential energy does it have?

   b) Assuming all energy is transferred to kinetic energy, calculate the speed of the ball just before it reaches the ground.

2. A model rocket is fired straight up with an initial speed of 8m/s. the rocket has a mass of 0.2kg.

   a) Calculate the initial kinetic energy of the rocket.

   b) The mass of the rocket does not change. The rocket reaches its maximum height. What is the gravitational potential energy gained by the rocket?

   c) Use your answer from *b* to calculate the maximum height reached by the rocket.

3. A car is being driven along a road at $15ms^{-1}$. The total mass of the car and driver is 900kg.

   a) Calculate the kinetic energy if the car and driver.

   b) The brakes are applied and the car is brought to rest outside a shop. Describe the energy change that has taken place.

   c) How much heat energy will be stored in the brakes when the car stops?

   d) About ten minutes later, the driver comes out of the shop and thinks he notices a problem with the brake disk and feels the disc. It feels cool. Where has the heat energy gone?

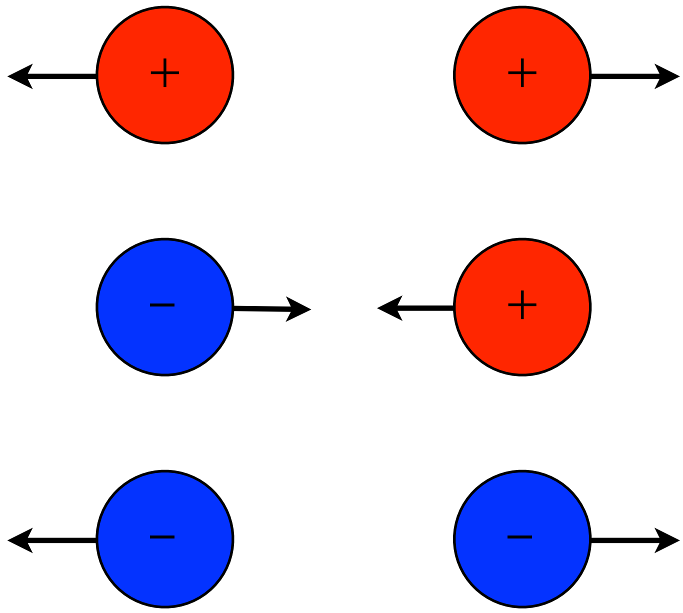
Electrical Charge Carriers and Current

Electrical Charge

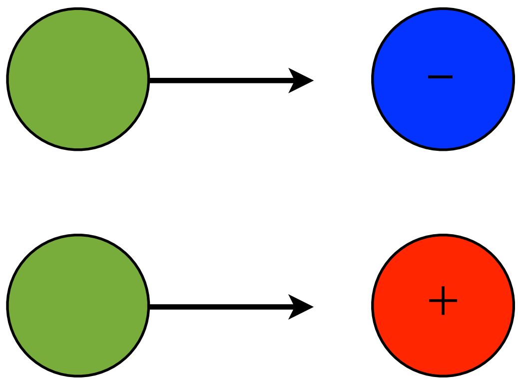
Electrical charge exists in two distinct types — **positive** charge and **negative** charge. It is also possible for an object or particle to have no electrical charge at all, we call these objects electrically **neutral**.

Positively charged objects will repel other positively charged particles. However they will be attracted to negatively charged objects. Similarly negatively charged objects will repel other negatively charged particles but they will be attracted to positively charged objects. This can be remembered as two simple rules:

- Like charges **repel**
- Opposite charges **attract**

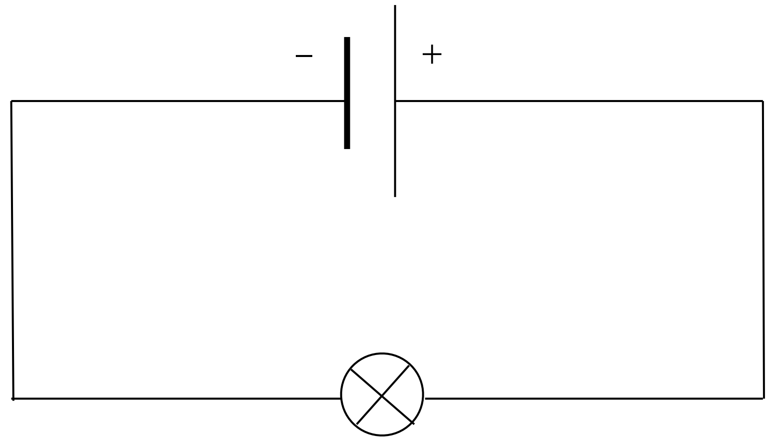


Neutrally charged objects are attracted to **both** positively charged and negatively charged objects.

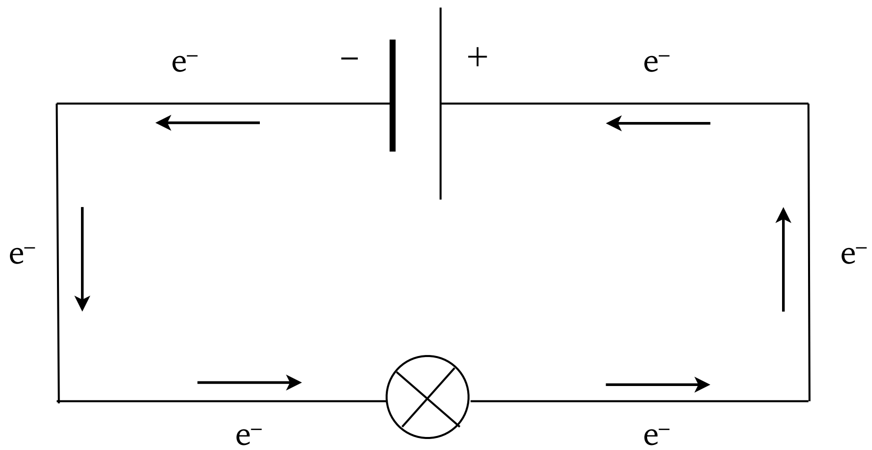


Current

Electrical current is simply the flow of charge carriers. In a standard electrical circuit the charge carriers are **electrons**. As an example consider the circuit below:



Electrons are **repelled** away from the negative terminal of the battery and **attracted** to the positive terminal of the battery. To move from the negative terminal to the positive terminal they need to move around the circuit through the lamp (as shown below).



We call this negative to positive current **electron flow** or more usually just **current**.

However scientists used to think that charges flowed from positive to negative. If these scientists were alive today they would probably argue that they were still correct and that an absence of an electron (or hole) flows from positive to negative. Nevertheless it was thought that current flows from positive to negative for many years and circuit symbols and diagrams often make more sense if you do think about current flowing from positive to negative. Today we call this **conventional current**. At National 5 we will only ever talk about electron flow but if you look at English or American materials they almost exclusively use conventional current. Remember:

- **Current (Electron Flow)** — negative to positive
- **Conventional Current** — positive to negative

Current, Charge, Time Formula

We define current as the amount of charge flowing past a point in a circuit per second. Current is measured in amperes, or amps for short. One amp is equal to one coulomb (the unit of charge) per second. The formula for this is on the formula sheet and is given below:

$$Q = It$$

Charge measured in

Current measured in amperes or

Time measured in seconds (s)

Example

A lamp has a current of 1.5 amperes flowing through it while lit. How much charge flows through the lamp in 50 seconds?

Practice Problems

1. The current in a heater is 7 amperes. How many Coulombs of charge flow through the heater in 30 seconds?

2. The total charge that flows in a circuit is 12C. The time taken for this charge to flow is 6s. What is the current flowing in the circuit?

3. A car headlamp uses a current of 2A. How long must the lamp be switched on for 10C to pass through it?

4. A hair dryer is switched on for 5 minutes and the current flowing is 3A. How much charge flows through the hairdryer in this time?

5. What is the current when 4C of charge passes a point in 0.4s?

6. How much charge passes through a cow if it touches an electric fence and receives a pulse of 20 milliamperes (mA) for 0.1 seconds?

7. A torch lamp passes 720C of charge in 1 hour. What is the current in the lamp?

Alternating and Direct Current (a.c./d.c.)

When current flows from negative to positive we call this **direct current**. Direct current is supplied by batteries and some specialist power supplies. However the electricity in a mains socket does not have a positive and negative terminal — instead it uses **alternating current**.

Alternating current does not have a positive and negative, instead the direction of the current changes, usually many times a second. In the United Kingdom mains electricity uses alternating current with a frequency of 50Hz. This means that in one second the current changes from flowing in one direction to another and back 50 times.

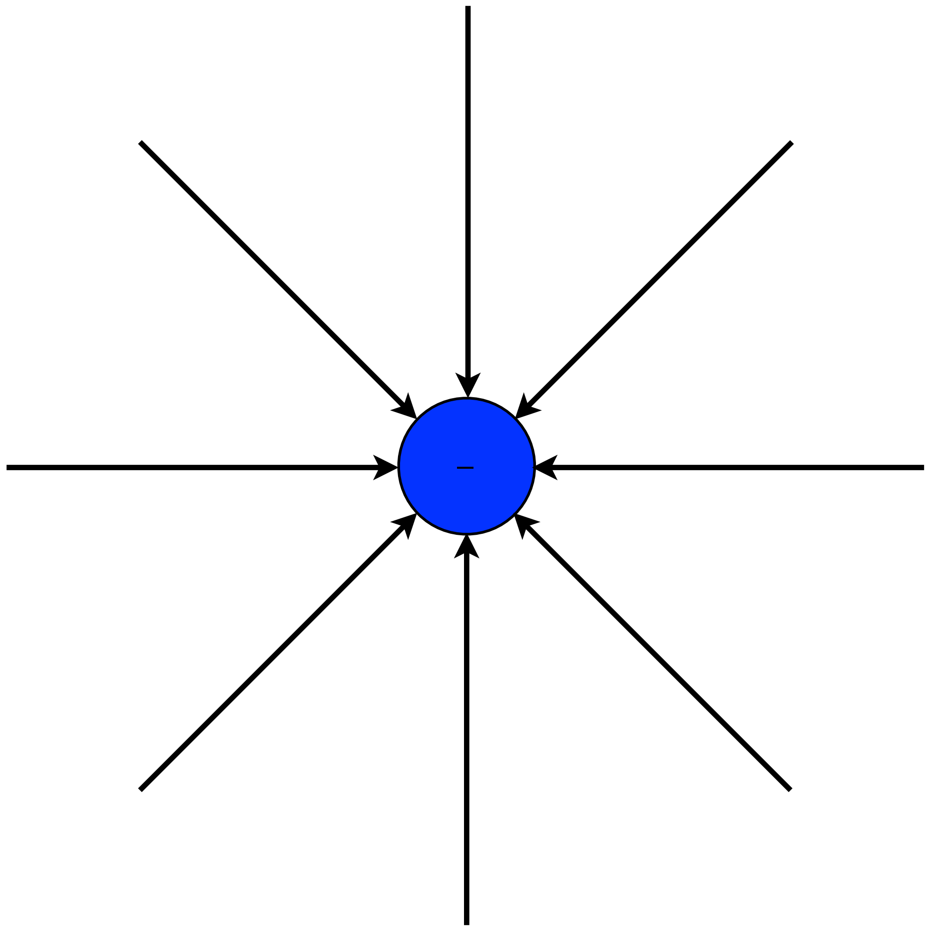
Circuits that use alternating current do not have positive and negative terminals, instead they use **live** and **neutral** terminals and wires. Some high voltage circuits will also include an **earth** wire as a safety measure. In the U.K. there is a common standard defining the colour of insulation on these wires:

- Live — **Brown**
- Neutral — **Blue**
- Earth — Yellow and **Green** stripes

Electric Fields and Potential Difference

Electric Fields

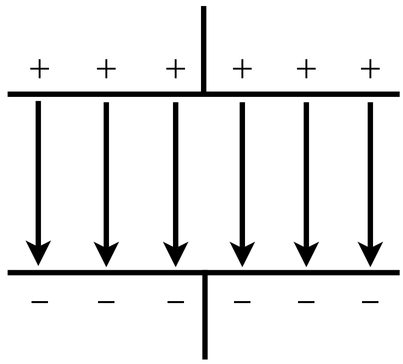
Any electrically charged object emits an **electric field**. The strength of the electric field depends on how much charge the object has — and how far away from the object you are. The shape of the field is determined by the shape of the object. These fields can exert a force on other charged particles. We can visualise electric fields by drawing arrows showing what direction an imaginary **positive** test charge would travel. For instance: Below is the electric field around a negatively charged sphere, like a Van der Graph generator or an electron:



A positive charge placed anywhere around this negatively charged sphere would be attracted towards it — just as we would expect.

Parallel Plates

There is a special type of electric field that we can create when we set up two metal plates (one positive and one negative or neutral) parallel to each other and separated by an insulator. The field between this arrangement of parallel plates looks like this:

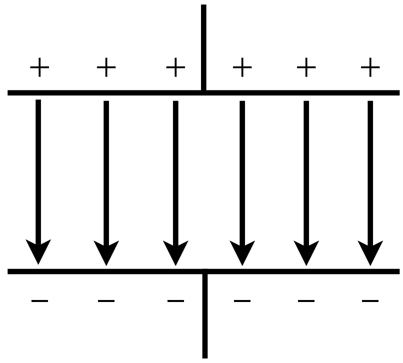


A positive charge anywhere between the two plates will be attracted towards the negative plate and repelled from the positive plate. In other words a positively charged particle would move towards the negative plate. Conversely a negatively charge particle would move towards the positive plate.

Imagine that you could put a negatively charged particle (say an electron) on the negative plate. It would want to move towards the positive plate. If it was allowed to travel across the gap it would gain kinetic energy. However if it cannot move across the gap it will try to find another route to the positive plate — for instance through an electrical circuit.

Potential Difference/Voltage

Consider again the two parallel plates:



Imagine we tried to drag a positively charged particle from the negative plate to the positive plate. Energy had to be given to the charged particle to move it against the direction of the electric field. In Physics we would say work is done (we will revisit the idea of work in the Dynamics and Space unit).

Imagine that the particle is now released from the positive plate. Before the charged particle is released it has electrical potential energy and when it is released this is converted to kinetic energy.

We say that the plates have a **voltage** across them or **potential difference** between them. If a potential difference is applied to either end of a conductor electrons will flow towards the positive end and away from the negative end — causing a current.

When electrons move through an electrical component (such as a lamp) they may convert some of their electrical energy into other forms (such as light). This means they will 'loose' some electrical energy and so their voltage will be less. This can be measured and the amount of potential difference or voltage across a component is linked to the amount of energy lost by the electrons in the component. The higher the voltage the more energy lost by the electrons.

Extension — Voltage formula

Voltage can be thought of as the amount of energy a charged particle has per coulomb of charge. One volt is defined as one joule per coulomb. There is a formula for this, though it is **not** needed at National 5 for calculations it can be useful when answering “explain” type questions.

$$V = E \div Q$$

Voltage measured in volts (V) or joules per

Electrical energy (or work) measured in

Charge measured in coulombs (C)

Ohm's Law

Ohm's Law Experiment

Aim: To determine the relationship between voltage and current.

Hypothesis: As current increases the voltage increases/decreases.

Method: Set up the circuit as shown by your teacher and record the readings of current and voltage in the table below:

Voltage (V)	Current (A)

Analysis: Draw a scatter graph with a line of best fit of your results with voltage on the y axis and current on the x axis. Then calculate the gradient of your line of best fit.

Conclusion: As current increases the voltage increases/decreases.

How does the value of the gradient compare with the resistance of the resistor used in the experiment?

Resistance

As seen in the previous experiment the gradient of a V/I graph is equal to the resistance of a component. Resistance is a measure of how hard it is for electrons to flow through a component or wire. Resistance is measured in ohms (Ω).

Lots of things can affect the resistance of a component or wire. For an ordinary conducting wire the following factors affect resistance:

- Length — the **longer** wire the **higher** the resistance
- Area — the **smaller** the cross sectional area of a wire the **higher** the resistance
- Material — some conductors are better than others!
- Temperature — the **higher** the temperature the **higher** the resistance

The relationship between temperature and resistance is particularly important as some components heat up in use, changing their resistance. Some materials can be cooled so much that their resistance drops to zero — becoming a **superconductor**.

Georg Ohm (16 March 1789 – 6 July 1854)

Ohm’s Law Formula

Today we summarise Georg Ohm’s work on voltage and current as a formula stating that the voltage across a component (or conductor) is equal to the current flowing though the component multiplied by the resistance of the component. It appears on the formula sheet and is given below:

$$V = IR$$

Voltage measured in volts (V)

Current measured in amps (A)

Resistance measured in ohms (Ω)

Example

A battery supplies a lamp of resistance 10Ω with a current of 0.2A. What is the voltage supplied by the battery?

Practice Problems

1. A current of 2A flows through a heating element of resistance 60Ω. What is the voltage supplied to the element?

2. A bulb is rated at 2.2V and 0.2A. What is its resistance when it is used at its correct rating?

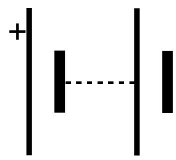
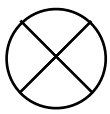
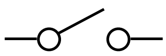
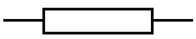
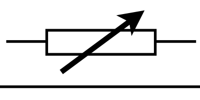
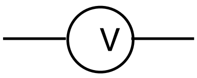
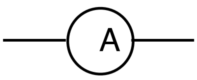
3. An electrical supply of 12V is supplied to a 10kΩ resistor. What current flows in the resistor?

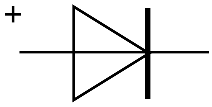
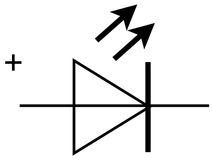
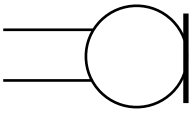
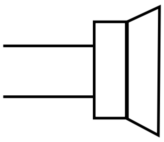
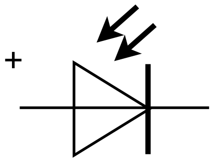
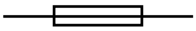
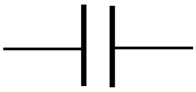
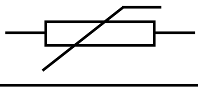
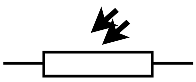
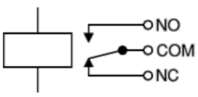
4. The voltage supply to a circuit is doubled but the resistance is kept the same. How does this affect the amount of current that flows in the circuit?

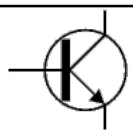
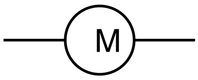
Practical Circuits

Circuit Symbols

It would be impractical and confusing to draw an electrical circuit as a picture. Instead all electrical components are represented by unique and standardised symbols connected with lines (representing wires) in a **circuit diagram**. Below are the symbols you will need to recognise, what they represent, what that component does and an example use.

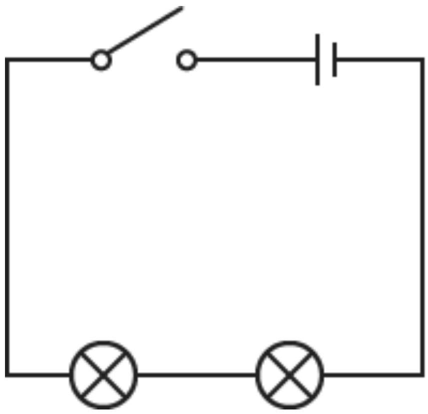
Symbol	Component	Function	Example Application
	cell	providing voltage	combining into a battery
	battery	providing voltage	powering circuits
	lamp	producing light	lighting
	switch	controlling current (on/off)	various
	resistor	controlling resistance (fixed)	potential dividers
	variable resistor	controlling resistance (variable)	dimmer switch
	voltmeter	measuring voltage	fault finding
	ammeter	measuring current	electrical safety

Symbol	Component	Function	Example Application
	diode	controlling current direction	a.c. to d.c adapters
	light emitting diode (LED)	producing light	on/off indicator lights
	microphone	converting sound to electrical signals	telephone
	loudspeaker	producing sound	headphones
	photodiode	detecting light	light gate
	fuse	limiting current	standard U.K. plug
	capacitor	storing charge, smoothing, time delays	various
	thermistor	detecting temperature changes	thermostats
	light dependant resistor (LDR)	detecting light changes	street lighting
	relay	circuit connecting switch	car ignition

Symbol	Component	Function	Example Application
	transistor	controllable switch	logic gates, computers
	motor	producing rotational motion	electric car

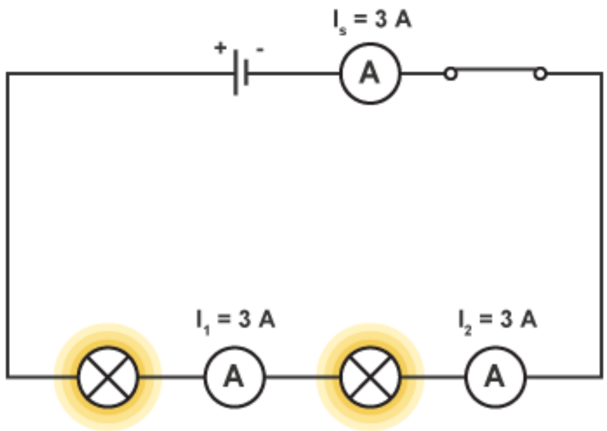
Series Circuits

Series circuits are constructed by 'daisy chaining' components together. The circuit shown below is an example of a typical series circuit:



Current in a Series Circuit

The current in a series circuit is the **same** at every point in the circuit.

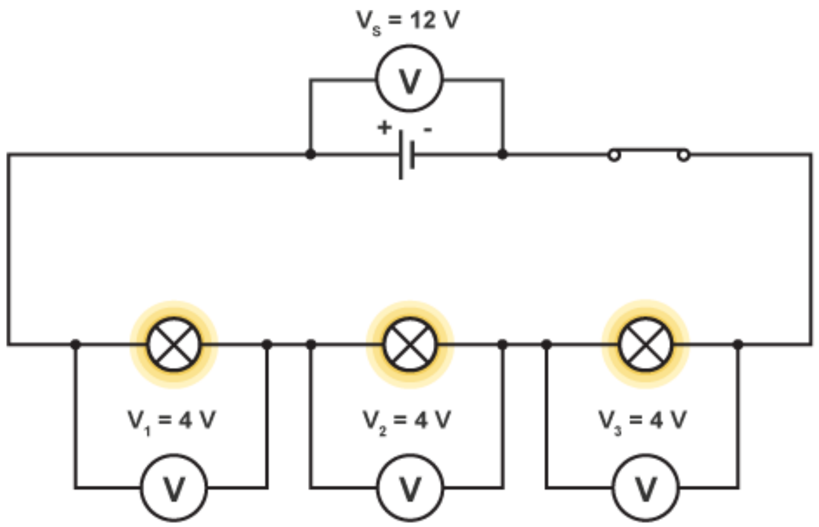


Voltage in a Series Circuit

The voltages in a series circuit are ‘shared’ amongst the components. The voltages across all of the components in the circuit add up to the voltage of the supply. There is a formula to help you to remember this but it is not on the formula sheet:

$$V_{\mathrm{S}} = V_1 + V_2 + \ldots$$

Below is an example of this rule in a series circuit:



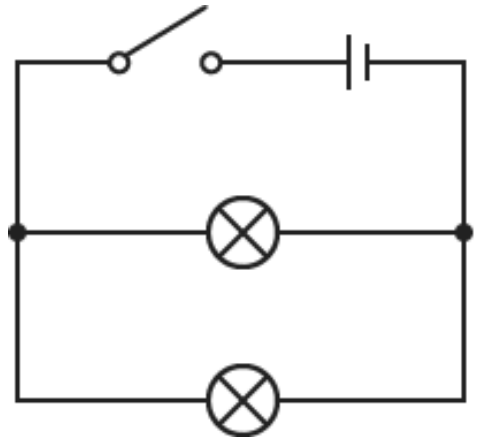
Resistance in a Series Circuit

The total resistance of a series circuit is equal to the sum of all of the resistances of the components. There is a formula for this and does appear on the formula sheet:

$$R_{\mathrm{T}} = R_1 + R_2 + \ldots$$

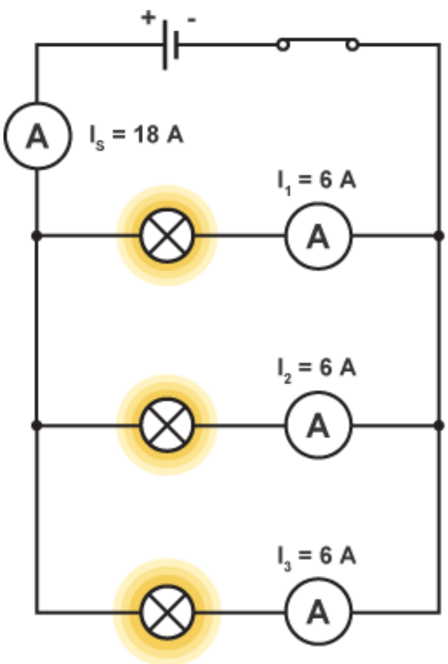
Parallel Circuits

Parallel circuits are constructed by placing each component on its own 'branch'. The circuit shown below is an example of a typical parallel circuit:



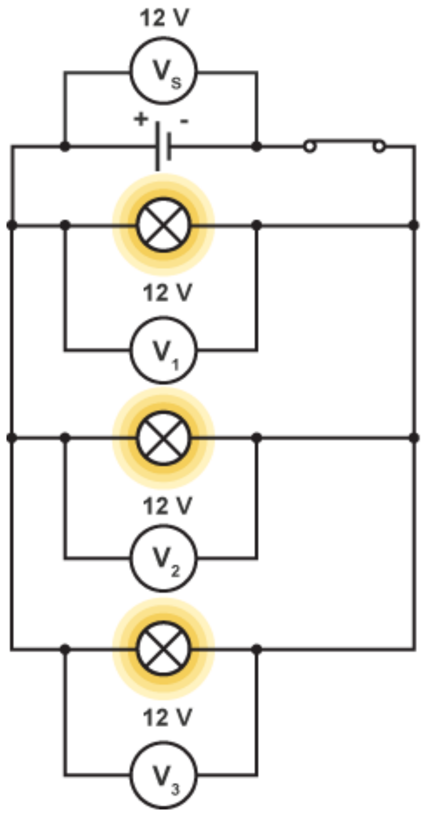
Current in a Parallel Circuit

The currents in each of the branches add up to the current entering and leaving the power supply.



Voltage in a Parallel Circuit

The voltage on every branch of a parallel circuit is the **same**. If the branches are connected directly to the power supply then the voltage in each branch will be the same as the voltage across the power supply.



Resistance in a Parallel Circuit

The total resistance of a parallel circuit is a little tricky to calculate. **One over** the total resistance is equal to the sum of **one over** the resistance of each brach. The formula for this appears on the formula sheet and is given below:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

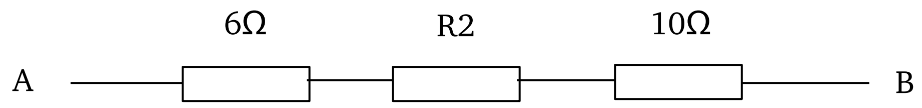
Practice Problems

1. A resistor of 3Ω is in series with another resistor of 3Ω. What is the total resistance?

2. The two 3Ω resistors are now joined in parallel. What is the total resistance now?

3. The resistance of one Christmas tree light is 24Ω. What is the total resistance of 20 lights in series?

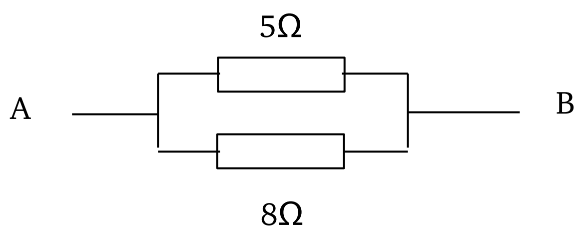
4. In the diagram below, the total resistance across AB is measured and found to be 25Ω.



   What is the resistance of R_2?

5. Two 10Ω resistors are connected in parallel. What is their total resistance?

6. What is the total resistance across AB in the circuit below?



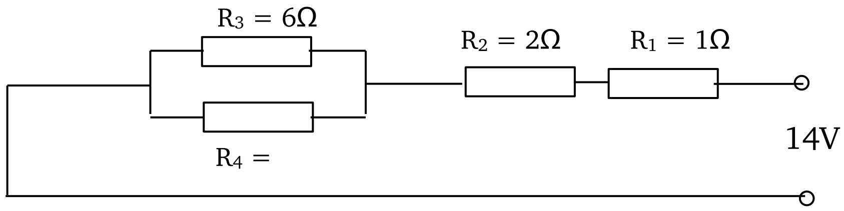
7. Two bars of an electric fire are joined in parallel. If each of the bars has a resistance of 1kΩ.

   a) What is the total resistance?

   b) If the bars are connected to a 230V power pack, what current will be supplied?

   c) What current will flow in each of the bars?

8. Four resistors are connected as shown in the circuit diagram below.



a) What is the total resistance of the resistors in parallel?

b) What is the total resistance in the circuit?

c) The current through R_1 is found to be 2A. What is the current flowing through R_2?

d) If the voltage across R_3 is 8V, what is the voltage across R_4?

e) What is the current flowing through R_3?

Power

Power is defined in Physics as the amount of energy something uses every second. On electrical alliances the power of an appliance is given by its **power rating**. This can be found on the **rating plate**.

As you can see above the power rating of this appliance is 240W. That means it uses 240 joules of energy every second. The W stands for watts — the units of power. 1 watt is equal to 1 joule per second. However power can be calculated for **any** form of energy not just electrical energy.

Power, Energy and Time Formula

Power is equal to energy divided by time. The formula appears on the formula sheet and is given below:

$$P = \frac{E}{t}$$

Energy measured in

Power measured in watts (W) or joules per second (Js^{-1})

Time measured in seconds (s)

Practice Problems

1. If a CD player supplies 100J of sound energy per second, what is its power rating?

2. A heater supplies 3000J of heat energy in 5 seconds. What is its power rating?

3. A miniature water heater is rated at 750W. How many joules of heat energy will it produce each second?

4. A heater is rated at 3kW. How much energy does it supply in one hour of use?

5. A miniature heater for making cups of tea is rated at 150W. If it takes 45kJ to boil the water, how long will this take?

6. A lamp converts 1000J of electrical energy into light energy in 10s.

   a) How much electrical energy does it convert every second?

   b) What is the power rating of the lamp?

7. If it requires 450kJ of energy to boil a kettle of water, how long will this take if the power rating of a kettle is 2kW?

8. An electric shower rated at 10kW is switched on for 5 minutes. How much energy will it use up?

Electrical Power Formula

It is simple to calculate the amount of power an electrical appliance is using. The electrical power used is equal to the current multiplied by the voltage. The formula appears on the formula sheet and is given below:

$$P = IV$$

Power measured in watts (W) or joules per second (Js^{-1})

Current measured in amperes (A)

Voltage measured in volts (V)

Practice Problems

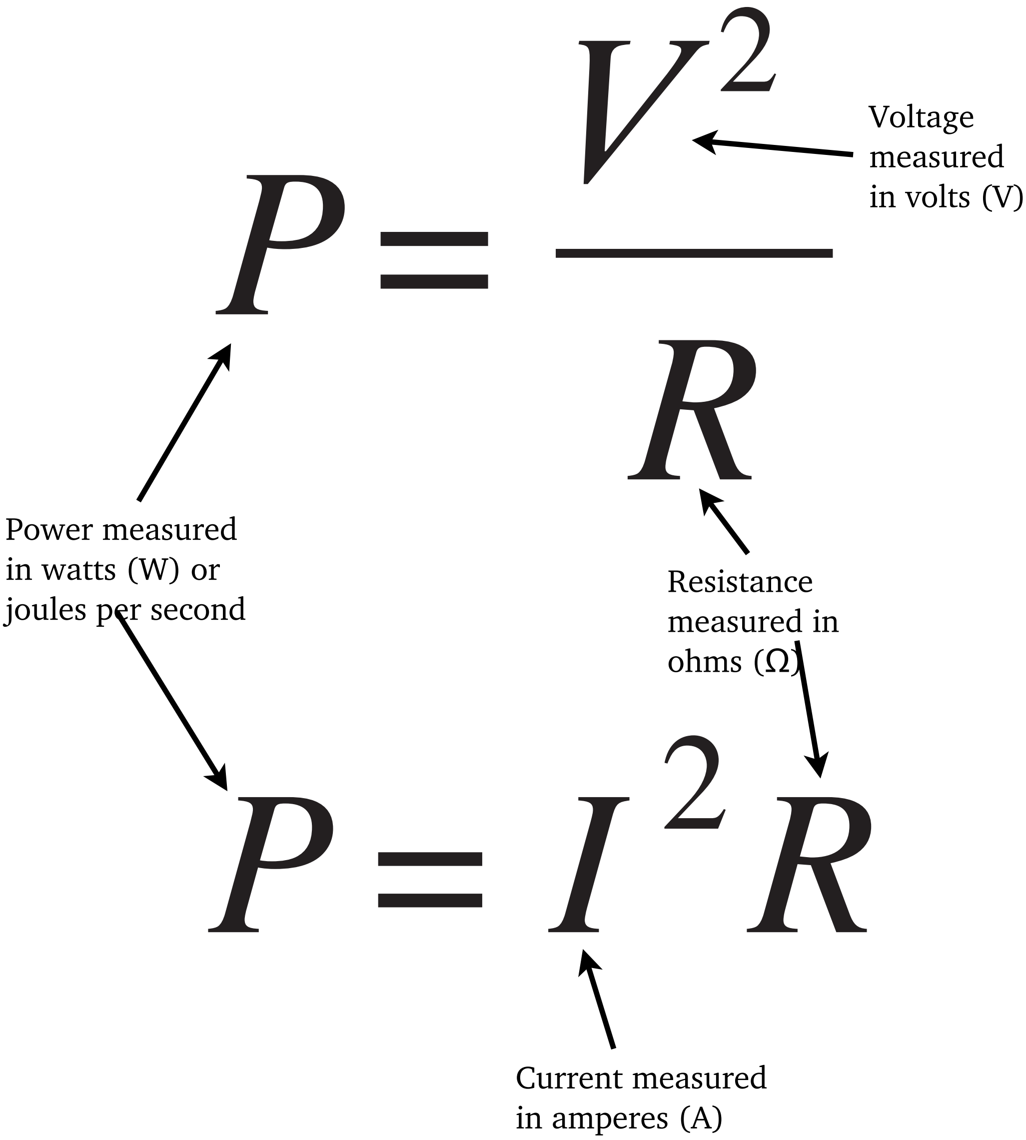
1. What is the power rating of a car sidelight that is supplied with 0.5A of current from a 12V supply?

2. An electric heater is rated at 3kW and is connected to a mains supply of 230V. What is the current that flows through it?

3. What is the supply voltage to a hairdryer which uses a power of 920W and a current of 4A?

More Power Formulae

We can combine P=IV and V=IR (Ohm's Law) to make two additional formulae for electrical power. Both are on the formula sheet and are given below:



Practice Problems

1. What is the power rating of a bulb of resistance 18Ω if the correct current supply is 2A?

2. An engineer is designing a fire and reads a data book stating that a 26.5Ω resistor can safely handle a power of 2kW. What is the maximum current it can safely handle?

3. The heating element of a hairdryer is supplied with 920W of electrical power at a current of 4A. What is the resistance of the element?

4. A 36W bulb has a resistance of 9Ω. What current flows through the bulb when it is operating at its correct power rating?

5. An electric fire operating at its correct power rating of 1kW has an element with resistance of 53Ω. What voltage is required to operate this appliance properly?

6. Find the power ratings of the following appliances:

   a) A 12V bulb that takes a current of 1.5A

   b) A 230V drill that takes a current of 2.5A

7. A 60W car windscreen heater operates at 12V. Find the current it uses.

8. A digital watch has a power rating of 0.12W and takes a current of 0.08A. What would be the voltage of the battery it uses?

9. A mains operated electric oven has two power settings, 3kW (low) and 5kW (high). Calculate the current it uses at both low and high settings.

Specific Heat Capacity

Temperature and Heat

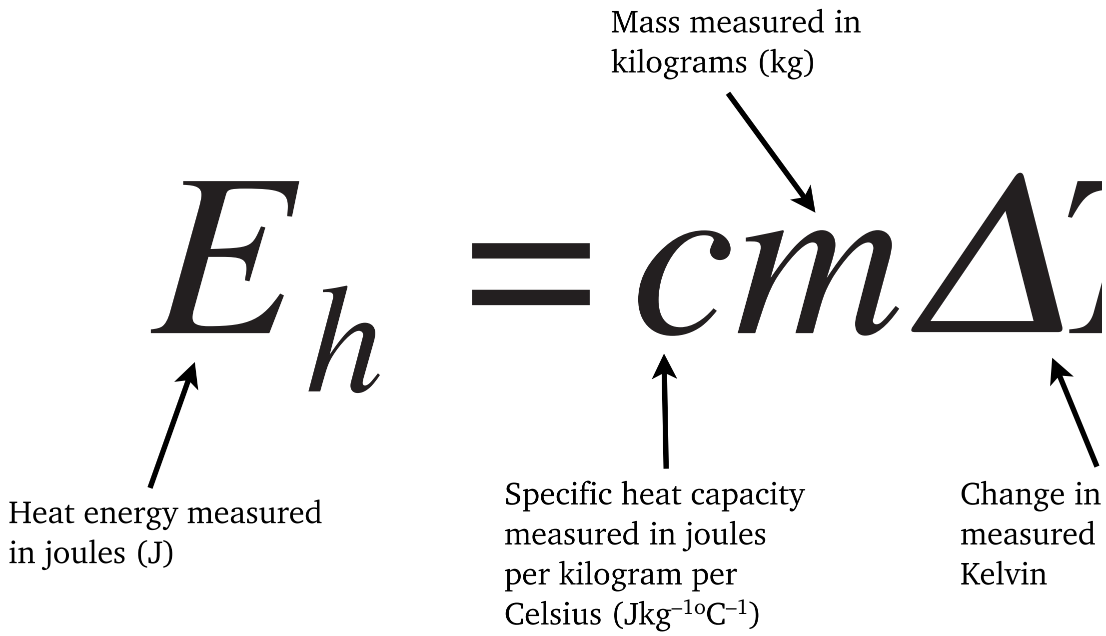
The temperature of an object is a measure of how hot or cold an object is. The hotter an object is the faster the particles inside the object move about. In other words temperature is a measure of the **mean kinetic energy** of the particles in an object. In Physics temperature is measured in Celsius or Kelvin, **never** Fahrenheit. Heat is how much heat **energy** a substance contains. It is linked to temperature but is **not the same**.

Specific Heat Capacity

Different substances require different amounts of energy to heat them up. We measure this by working out the amount of energy required to heat 1kg of a substance by 1°C. This is called the specific heat capacity and is measured in joules per kilogram per degree celsius or $Jkg^{-1}{}^{o}C^{-1}$. For instance the specific heat capacity of water is 4180 $Jkg^{-1}{}^{o}C^{-1}$, water requires 4180J of energy to raise the temperature of 1kg of water by 1°C. Substances with a **lower** heat capacity are **easier** to heat up. Substances with a **higher** specific heat capacity are **harder** to heat up.

Specific Heat Capacity Formula

We can calculate the amount of heat energy in, added to or lost by an object by multiplying the specific heat capacity of an object by the objects mass and the objects **change** in temperature (in Celsius or Kelvin). The formula appears on the formula sheet and is given below:



Example Question

How much heat energy is required to bring 0.2 kg of water to boiling point from 15°C? You may assume that the specific heat capacity of the water is 4180 $Jkg^{-1}°C^{-1}$.

Practice Problems

1. How much energy is required to heat up 1 kg of sea water (of specific heat capacity 3,900$Jkg^{-1}°C^{-1}$) by 1°C?

2. A 4kg bar of aluminium (of specific heat capacity 900$Jkg^{-1}°C^{-1}$) is supplied with 1800J of heat energy. What temperature increase would be measured?

3. A cup of boiling water (of specific heat capacity 4,200$Jkg^{-1}°C^{-1}$) cools down from 95°C to 80°C. If the mass of water in the cup is 0.1kg, how much heat energy is lost?

4. An immersion heater is used to heat 30kg of water at 12°C. The immersion heater supplies 8.6MJ of heat. Ignoring heat losses to the surroundings calculate the final temperature of the water.

5. A 250g block of copper is allowed to cool down from 80°C to 42°C. How much heat energy will it give out?

6. During an experiment, a girl supplies 12,000J of energy to 0.25kg of water in a glass container.

   a) What should the temperature increase be?

   b) She finds the temperature increase is less than expected. Explain why this might have happened.

   c) How could she reduce this heat loss?

7. Which of the following would give out more heat energy?

   A — a 2 kg block of aluminium as it cools from 5°C to 20°C

   B — a 4 kg block of copper as it cools from 83°C to 40°C?

More Practice Problems

1. Fire clay blocks of specific heat capacity 800$Jkg^{-1}°C^{-1}$ are used in a night storage heater.

   a) If 60kg of blocks are heated by 100°C, how much heat energy is supplied to the blocks?

   b) If the heater has an output power rating of 1kW, how long will it take to heat the blocks?

   c) In practice it takes longer to heat the blocks. Suggest a reason for this.

2. Oil filled radiators are a useful means of providing heating in a room. An electrical element heats up the oil inside the radiator which contains 2kg of oil of specific heat capacity 2,500$Jkg^{-1}°C^{-1}$.

   a) If the temperature of the oil is raised from 15 °C to 40 °C, how much heat energy is supplied to the oil?

   b) The heater takes 8 minutes to heat the oil through the above temperature change. What is the output power of the heating element?

   c) The element works at 230V. What is the current in the element while it is heating the oil? Assume the heating element is 100% efficient.

4. An electric cooker has a 500W heating element. It takes the heating element 5 minutes to raise a 1kg pan of water from 20 °C to 60°C.

5. What value does this information give for the specific heat capacity of water?

6. Why is this value lower than it should be?

Kelvin

In Physics we often use the Kelvin temperature scale instead of Celsius. One kelvin and one celsius are the same however the Kelvin scale starts at a different temperature. Whilst zero on the Celsius scale is at the freezing point of water the Kelvin scale has zero at 'absolute zero' — the temperature at which all particle motion stops — which is at -273^oC.

- To go from kelvin to celsius you **subtract** 273
- To go from celsius to kelvin you **add** 273

Practice Problems

1. Convert the following temperatures from celsius to kelvin:

   a) 0^oC

   b) 100^oC

   c) -273^oC

   d) 22^oC

   e) 500^oC

1. Convert the following temperatures from kelvin to celsius:

   a) 300K

   b) 5000K

   c) 267K

   d) 4K

   e) 423K

Gas Laws

Pressure

In Physics pressure is defined as the amount of force per unit area. More simply pressure is equal to the force divided by the area it is acting on. Pressure is measured (in Physics) in either newtons per square metre or pascals. We do not use units such as bars, atmpospheres, pounds per square inch or millimeters (or inches) of mercury in National 5. There is a formula for pressure that appears on the formula sheet and it is given below:

Force measured in newtons (N)

$$P = \frac{F}{A}$$

Pressure measured in newtons per square metre (Nm^{-2}) or pascals (Pa).

Area measured in square metres (m^2)

Note that a P is used for both pressure and power on the formula sheet. Do not confuse the two!

Practice Problems

1. A cube of side 3m is sitting on a bench. If the mass of the cube is 27kg, what is the pressure on the bench?

2. A man of mass 70kg is standing still on both feet. The average area of each foot is $0.025m^2$.

   a) Calculate the force the man exerts on the ground (his weight in N).

   b) Calculate the pressure exerted by the man on the ground.

   c) If the man now stands on only one foot, calculate the pressure this time.

4. A man of mass 60kg is standing on a block of wood measuring $0.28m \times 0.08m$. Calculate the pressure on the ground.

5. A woman of mass 60kg stands on one high heeled shoe. The area of sole in contact with the ground is $1.2 \times 10^{-3} m^2$. The area of the heel in contact with the ground is $2.5 \times 10^{-5} m^2$. Calculate the pressure on the ground.

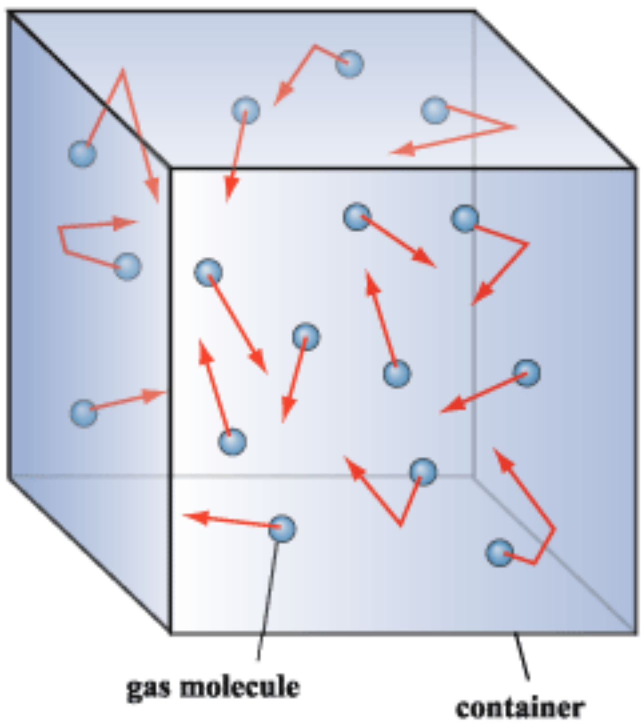
6. Although the man in question 4 and the woman in question 5 had the same mass, they did not have the same pressure. Explain why this is the case.

7. Why is it necessary to wear snow shoes to walk over soft snow?

Kinetic Model of a Gas

In Physics we assume that in gases, small particles are far apart and move in random directions at high speed. On average they are 10 molecular diameters apart and move at speeds of around $500ms^{-1}$. They can collide with the walls of the container and with each other. Increasing the temperature of a gas increases the average speed of the particles. You know from S1/2 that the volume and shape of a gas is determined by the volume and shape of its container.

This model, which can be used to explain a number of properties of a gas, is called the kinetic theory model.



Practice Problems

1. What two things can you say about the movement of the particles in a gas (i.e. speed, direction of movement)?

2. How does raising the temperature of the gas affect the particles in the gas?

3. What determines the “shape” of a gas?

4. If a jar of gas was opened in the middle of your classroom what would the gas do and what would determine the new volume of the gas?

Pressure of a Gas

The particles in a gas often collide with the walls of their container. Billions of them do this every second. Each particle exerts a tiny force on the wall of the container as it collides with it. The addition of the forces from these many collisions can become very large. The average size of this overall force divided by the area of the container gives the pressure of the gas.

Practice Problems

1. Air molecules exert an average force of 6×10^5N on a wall. The wall measures 2m×3m. What is the air pressure in the room?

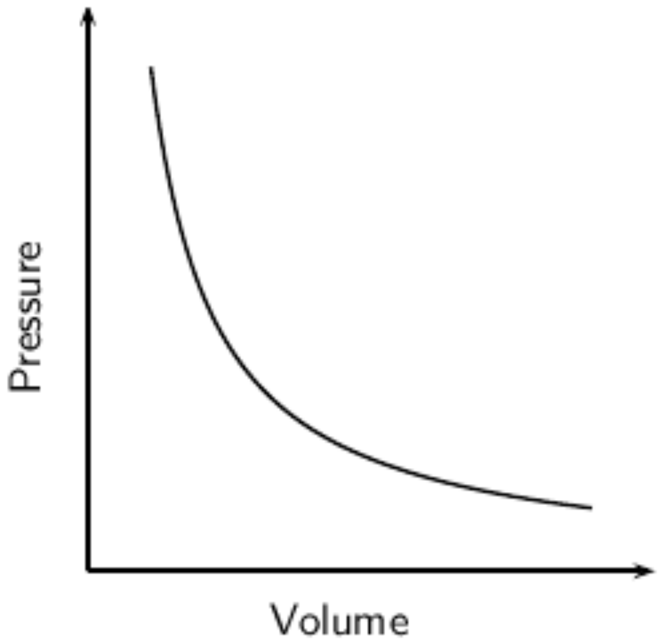
2. Hydrogen molecules at low pressure exert an average force of 3×10^4N on one wall of a cubic container. One edge of the cube measures 2m. Calculate the pressure of the hydrogen.

3. The pressure of air at sea level is approximately 1×10^5Pa. What is the average force that air molecules exert on a wall at sea level measuring 3m×5m?

4. Comment on the force exerted on an identical wall 10,000m above sea level.

Boyle's Law (Pressure and Volume in a Gas)

If a gas is compressed, its volume is **decreased**, then the particles within the gas will become closer together. This means that they will hit the walls of their container more often. In turn this will **increase** the pressure of the gas. Conversely if a gas is expanded, its volume is **increased**, then the pressure will **decrease**.

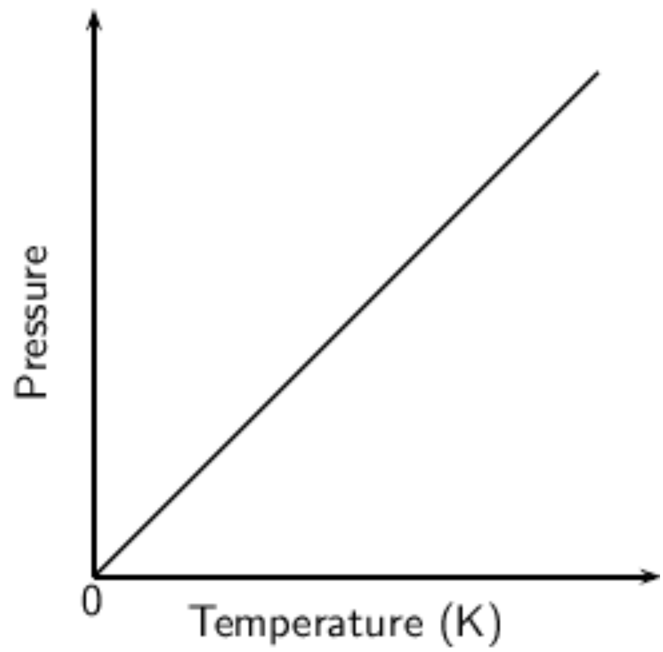


Amontons' Law (Pressure and Temperature in a Gas)

If a gas is heated and its temperature **increases** the particles in the gas will strat to move faster. This means that they impact on the walls of the container with more force which causes the pressure of the gas to **increase**. Conversely if a gas has its temperature **decreased** then its pressure will also **decrease**. This is why deodorant sprays feel cold!

Amontons' Law only works when the temperature is measured in **Kelvin**.

When dealing with gasses **always use Kelvin**.

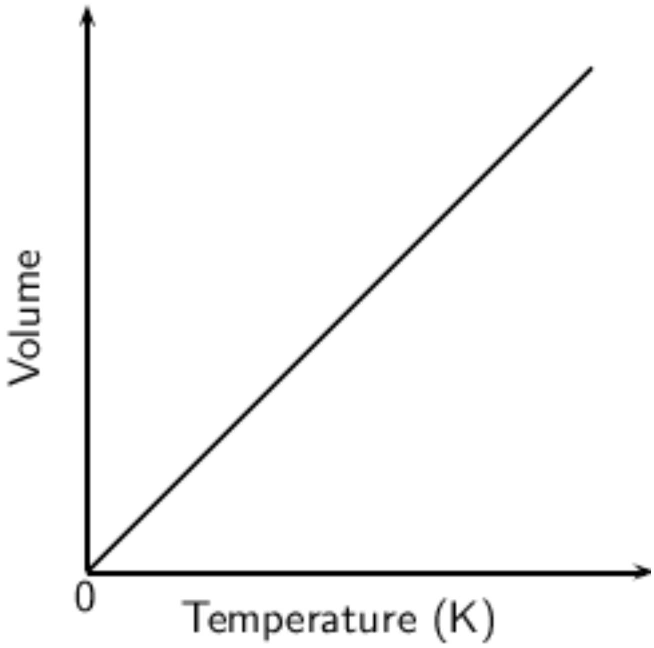


Charles' Law (Volume and Temperature in a Gas)

If you **decrease** the temperature of a gas then the particles in the gas will start to slow down. They will push less hard on their container and if it is able to do so the container will shirk, **decreasing** its volume. Likewise if you **increase** the temperature of a gas then the particles will move faster and push harder on their container, making it expand and **increasing** its volume.

Charles' Law only works when the temperature is measured in **Kelvin**.

When dealing with gasses **always use Kelvin**.



The Combined Gas Law

Boyle's Law, Amonton's Law and Chales' Law can all be combined into a single relationship that links the pressure, volume and temperature of a fixed mass of gas. It states that the pressure of a gas multiplied by its volume and then divided by its temperature in **kelvin** is equal to a constant. This formula appears on the formula sheet and is given below:

Pressure measured in pascals (Pa)

Volume measured in metres cubed (m^3)

$$\frac{PV}{T} = constant$$

Temperature measured in kelvin (K)

A constant number

The value of the constant never changes for a certain fixed mass of a particular gas. However it is common to deal with situations where one of the variables is fixed. This makes things much simpler!

Boyle's Law Formula

When the temperature of a gas is fixed we can use a simplified version of the combined gas law formula. If we only look at situations where we have an initial and a final state of a gas then things become simpler still and we are left with the following formula:

Volume before Volume after

$$P_1V_1 = P_2V_2$$

Pressure before Pressure after

As long as you use the **same** units for volume for both V_1 and V_2 you can use any unit of volume you wish — saving you the hassle of converting cm^3 into m^3 or a similar tricky conversion.

Example

100cm^3 of air is contained in a syringe at atmospheric pressure (1×10^5Pa). If the volume is reduced to 50cm^3, without a change in temperature, what will be the new pressure?

Practice Problems

1. $100cm^3$ of air is contained in a syringe at atmospheric pressure (1×10^5Pa). If the volume is reduced to $20cm^3$, without a change in temperature, what will be the new pressure?

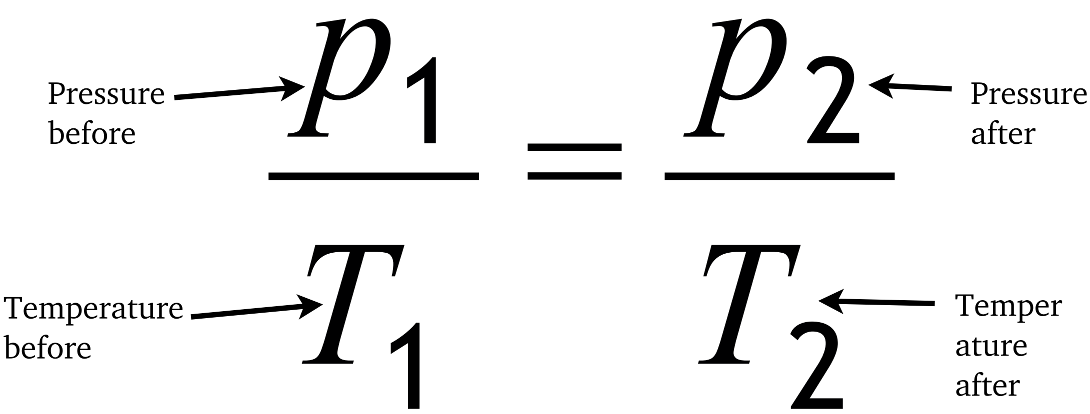
2. If the piston in a syringe containing $300cm^3$ of gas at a pressure of 1×10^5Pa is moved outwards so that the pressure of the gas falls to 8×10^4Pa, find the new volume of the gas.

3. A weather balloon contains $80m^3$ of helium at normal atmospheric pressure of 1×10^5Pa. What will be the volume of the balloon at an altitude where the air pressure is 8×10^4Pa?

4. A swimmer underwater uses a cylinder of compressed air which holds 15 litres of air at a pressure of 12000kPa. Calculate the volume this air would occupy at a depth where the pressure is 200kPa.

Amontons' Law Formula

When the volume of a gas is fixed we can use a simplified version of the combined gas law formula. If we only look at situations where we have an initial and a final state of a gas then things become simpler still and we are left with the following formula:



As long as you use the **same** units for volume for both V_1 and V_2 you can use any unit of volume you wish — saving you the hassle of converting cm^3 into m^3 or a similar tricky conversion. However, remember that all of the temperatures must be measured in **kelvin**.

Practice Problems

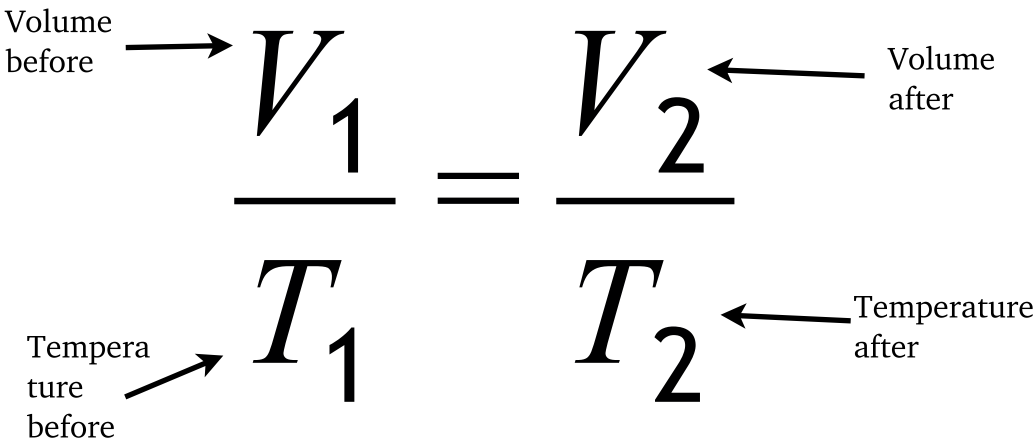
1. A cylinder of oxygen at 27°C has a pressure of 3×10^6Pa. What will be the new pressure if the gas is cooled to 0°C?

2. An electric light bulb is designed so that the pressure of the inert gas inside it is 100kPa (normal air pressure) when the temperature of the bulb is 350°C. At what pressure must the bulb be filled if this is done at 15°C?

3. The pressure in a car tyre is 2.5×10^5Pa at 27°C. After a long journey the pressure has risen to 3.0×10^5Pa. Assuming the volume has not changed, what is the new temperature of the tyre?

Charles’ Law Formula

When the pressure of a gas is fixed we can use a simplified version of the combined gas law formula. If we only look at situations where we have an initial and a final state of a gas then things become simpler still and we are left with the following formula:



$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Remember that all of the temperatures must be measured in **kelvin**.

Practice Problems

1. $100cm^3$ of a fixed mass of air is at a temperature of 0^oC. At what temperature will the volume be $110cm^3$ if its pressure remains constant?

2. Air is trapped in a glass capillary tube by a bead of mercury. The volume of air is found to be $0.1cm^3$ at a temperature of 27^oC. Calculate the volume of air at a temperature of 87^oC.

3. The volume of a fixed mass of gas at constant temperature is found to be $50cm^3$. The pressure remains constant and the temperature doubles from 20^oC to 40^oC. Explain why the new volume of gas is not $100cm^3$.

4. A fixed mass of gas is cooled from 100^oC to 20^oC. The pressure is kept at atmospheric pressure throughout. If the initial volume is $6cm^3$, calculate the final volume.

Combined Law Problems

Example: A balloon contains 1.3m^3 of helium at a pressure of 100kPa at a temperature of 27^oC. If the pressure is increased to 250kPa at a temperature of 127^oC, calculate the new volume of the balloon.

Practice Problems

1. A sealed syringe contains 100cm^3 of air at atmospheric pressure 1×10^5Pa and a temperature of 27^{o}C. When the piston is depressed, the volume of air is reduced to 20cm^3 and this produces a temperature rise of 4^{o}C. Calculate the new pressure of the gas.

2. 200cm^3 of carbon dioxide at 27^{o}C is heated to 127^{o}C. If the initial pressure is 6×10^5Pa and the final pressure is 1×10^6Pa, what is the volume after heating?

3. Hydrogen in a sealed container was heated from 77^{o}C to 400K. If the gas was allowed to expand during heating from 50cm^3 to 120cm^3 and the pressure after expansion was 2×10^5Pa, what was the pressure before the container was heated?

4. The pressure of a fixed mass of nitrogen is increased from 1.3×10^5Pa to 2.5×10^5Pa. At the same time, the container is compressed from 125cm^3 to 100cm^3. If the initial temperature of the gas was 30^{o}C, find the final temperature of the gas.

5. Oxygen at atmospheric pressure (1×10^5Pa) is heated from 400K to 500K in a sealed container. If the volume increases during heating from 80cm^3 to 100cm^3, find the final pressure of the oxygen.

More Practice Problems

1. A 1kg sample of air is contained in a gas tight cylinder. The cylinder has a moveable piston. The sample of air is at a temperature of 0°C and under a pressure of 101kPa. The density of air at 0°C and a pressure of 100kPa is $1.28 kgm^{-3}$.

2. Calculate the volume of air in the cylinder.

3. The air in the cylinder is now heated to a temperature of 70°C. The pressure of the air is kept constant at 101kPa. Calculate the new volume of the air in the cylinder.

4. What is the density of the air in the cylinder when the temperature of the air is 70°C and pressure of the air is 101kPa?

Electricity and Energy

You need to know:

	✓ ? ✘
That there are two types of charge; positive and negative	
That like charges repel each other	
That unlike charges attract one another	
The simple model of an atom	
That in an electric field a charged object will experience a force	
How to use the $Q = It$ formula	
That electrons are free to move in a conductor	
The difference between conductors and insulators	
Example conductors and insulators	
How to explain current in terms of moving charges	
That voltage is the energy per unit of charge	
What the circuit symbols, functions and applications of the following are: Cell, battery, resistor, variable resistor, fuse, switch, lamp, ammeter, voltmeter, LED, LDR, thermistor, transistor.	
Weather ammeters and voltmeters are connected in series or parallel and how to add them into a circuit diagram	
How to use Ohm's Law (the $V = IR$ formula)	
That the resistance of a resistor can change if its temperature changes	
That in a series circuit the current is the same at all points in the circuit	
That all the voltages in a series circuit add up to the supply voltage	

	✓ ? ✘
That the currents in a parallel circuit add up to the supply current	
That the voltage across each ‘branch’ of a parallel circuit is the same as the supply voltage	
How to calculate the total resistance of series and parallel crcuits (the $R_T = R_1 + R_2$ and $1/R_T = 1/R_1 + 1/R_2$ formulae)	
The energy transformations in common electrical components	
That the resistance of a thermistor decreases as temperature increases	
That the resistance of an LDR decreases as the intensity of light increases	
That an LED will only light if connected a certain way round in a circuit	
That transistor can be used as a switch	
How to use the $P = E/t$ formula	
How to use the $P = IV$ formula	
How to use the $P = IR^2$ formula	
How to use the $P = V^2/R$ formula	
That energy is conserved	
How to use the $E_k = 1/2\ mv^2$ formula	
How to use the $E_p = mgh$ formula	
That temperature is a measure of the mean kinetic energy of the particles in a substance	
The difference between temperature and heat	
That different materials require different amounts of heat energy to raise the temperature of the same amount of mass	
How to use the $E_h = cm\Delta T$ formula	

	✓ ? ✘
That pressure is the force per unit area	
How the kinetic model of a gas explains the pressure of a gas	
How the kinetic model of a gas explains the relationship between pressure, temperature and volume	
How to convert temperatures between celsius and kelvin	
How to use the PV/T = constant formula	