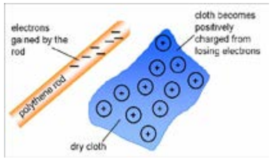
STATIC ELECTRICITY

- Static electricity is caused by an electrical ('electrostatic') charge building up on insulating materials – this charge could build up on a human too! All atoms contain electrically charged particles called protons (+) and electrons (-). The positive charges on the protons are balanced by the negative charges on the electrons and atoms have no overall charge.
- When two insulating materials are rubbed together, friction is generated and electrons may be transferred from one material to the other (note: protons can't be transferred because they are fixed in the nuclei of atoms):
- The material gaining electrons now has more electrons than protons so has an overall negative charge and the material losing electrons now has more protons than electrons so will have an equal positive charge.
- Objects charged with static electricity can attract each other if the charges are opposite or repel each other if the charges are the same.



- If you rub a balloon on a jumper you can get it to stick to a wall – this process is called charging 'by induction' and the charge produced is an induced charge.. When the balloon is rubbed against the jumper, electrons are transferred from the jumper to the balloon to the balloon which becomes negatively charged. When the balloon is placed against the wall, the electrons in the wall are repelled by the balloon's negative charge and move away.
- The positive charge left behind on the wall (the 'induced charge') attracts the negative charge on the balloon and the balloon sticks to the wall

Conductors can't hold Static Charge

- Insulating materials (e.g a polythene rod) do not conduct electricity 'electrons that are transferred cannot move through the material so they stay close together at the end of the polythene rod and static charge builds up at the end of the polythene rod.
- Conducting materials (e.g a metal rod) conduct electricity and electrons that are transferred spread themselves out through the metal rod and the extra static charge is difficult to detect.

USES AND DANGERS OF STATIC ELECTRICITY

Electrostatic charge can build up by just by walking on a carpet. As the shoes rub along the carpet, electrons are transferred from the carpet to the person and person becomes negatively charged.. If the person then touches a conducting material (e.g metal object), the person feels a small electric shock as electrons flow from the person, through the metal object to the earth. The direction in which electrons flow depends on the charge of the object. After earthing the person is discharged so no longer has an electrostatic charge..

Lightning

Large charges of static electricity can build up on clouds, causing electrons to flow through the atmosphere between the clouds and the ground (electrons can flow in either direction from ground to clouds or from clouds to ground. This produces the huge spark that we see as lightning.

Overcoming the dangers of electrostatic charges

To reduce the dangers of the build-up of static electricity there needs to be a path between the object with electrostatic charge and the ground, through which electrons can flow for electrons to flow along it. The ‘path’ must be made of a material that conducts electricity and in most cases, it’s made of metal. This earthing process discharges the object and prevents sparks being produced

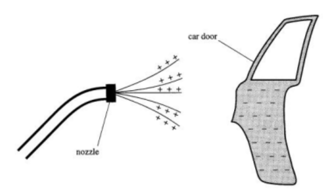
e.g refuelling aircraft

As fuel flows through a refuelling pipe, static electricity can build up and The aircraft can also build up a static charge as it flies through the air and bonding line (a metal wire) is used to connect the aircraft to the earth before it is refuelled. This discharges the aircraft of any electrostatic charge that may have built up so that no sparks are produced.

A similar problem can occur when tankers deliver fuel to filling stations: and In this case, the hose used to fill the underground fuel tanks is made of a conducting material so no sparks are produced.

Uses of static electricity

Static electricity can be used in electrostatic spray painting to make the spray spread out. The metal spray nozzle is connected to the positive terminal of an electricity supply and droplets of paint pick up a positive charge. The positively charged droplets repel each other and spread out. The object to be painted is given a negative charge and the paint droplets are attracted to the surface of the object



Questions on Static Electricity

- When two materials are rubbed against each other which sub-atomic particle might transfer from one to another?
- Why don’t protons transfer from one material to another?
- When would two materials repel? Attract?
- Why do conductors not hold onto static charge?

Questions on Uses and Dangers of Static Electricity

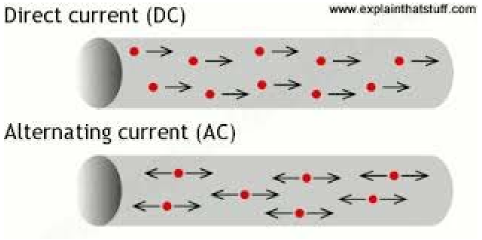
- Why does a charge build up simply by walking across a carpet?
- Lightning is the discharge of charge that builds up in the clouds but how does this charge build up?
- What do aircraft and petrol lorries use to ensure static charge doesn’t build up?
- Explain how spraying a car uses static electricity.

ELECTRIC CURRENTS

In conducting materials (e.g. metals), some of the electrons from each atom are free to move about producing an electric current. In a piece of metal, the free electrons all move round in different directions.

When a metal wire is placed in a complete electrical circuit the cell (battery) pushes the free electrons in one direction around the circuit. Cells and batteries supply current that flows in only one direction called ‘direct current’

Generators produce ‘alternating current’ – i.e electrons change direction many times each second. An electric current is the rate of flow of charged particles



Units of Charge – measured in coulombs (C)

Units of Current – measured in amperes (or amps, A)

The size of the electric current depends on how much charge is passing a point in a circuit each second. 1 ampere is a flow of 1 coulomb of charge per second

The equation linking charge and current:

charge (coulombs, C) = current (amps, A) x time (seconds, s)

$$Q = I \times t$$

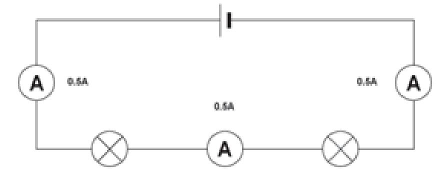
i.e the more charge that passes a point in a circuit per second, the greater the current

e.G a current of 5A flows for 10s-how much charge has flowed through the circuit?

Charge = 5 x 10 = 50 C

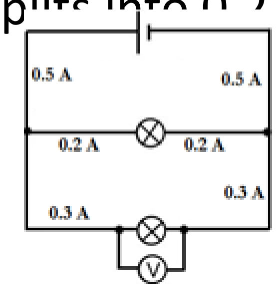
Current in Series and Parallel Circuits

Series circuits consist of just one continuous loop – they have no junctions.



Parallel circuits have different branches, which form separate loops

In a parallel circuit, when current reaches a junction, the current splits into two. In diagram when the 0.5 A current reaches the junction, it splits into 0.2 A and 0.3 A



Note: current is conserved - none is lost.

Measuring current

The size of a current (in amps) is measured using an ammeter.

Ammeters are always placed in ‘series’ with other components in a circuit. Ammeters have low resistance and so the electrons aren’t used up and the current leaving the cell is the same as the current that flows back into the cell.

An ammeter can be placed anywhere in a series circuit as it will always give the same reading.

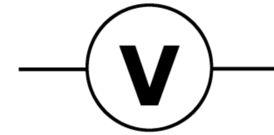
Questions on Electric Current

- What makes the electrons all flow in the same direction in a circuit?
- Describe the direction of electron flow in a generator?
- Name the units for charge and current.
- What is the equation that links charge and current?
- How much charge flows when a current of 10A flows for 2 minutes?

Questions on Series and Parallel Circuits

- What is the difference between series and parallel circuits?
- What does an ammeter do?
- Where would you place an ammeter in a circuit?
- What property does an ammeter have that makes it useful?
- In a series circuit what can you say about the current all the way round?

Measuring voltage



Potential difference (the voltage) is measured using a voltmeter.

Voltmeters measure the **difference** in energy between the electrons going into the component and those coming out so they're always placed in parallel with the component (on a separate branch).

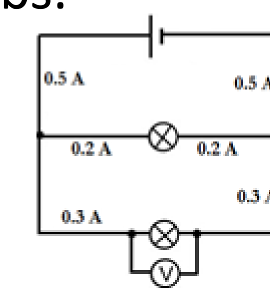
e.g in the diagram, the voltmeter is measuring the potential difference (i.e the difference in energy between electrons going in and those coming out) across the light bulb.

The higher the potential difference, the more energy emitted from the cell so the bigger the current and the brighter the bulb.

The potential difference is the energy transferred (to a component) for each unit of charge that passes through that component.

Energy is measured in joules, charge is measured in coulombs.

1 volt = 1 joule per coulomb



RESISTANCE

Resistance is a way of measuring how hard it is for electricity to flow measured in ohms (Ω).The higher the total resistance in a circuit, the smaller the current and the current flowing in a circuit can be changed by changing the resistance which can be done by using a variable resistor (or by putting a different resistor into the circuit).

The size of the current flowing in an electric circuit depends on the potential difference of the cell/power supply and the resistance of the circuit.

Relationship between resistance, current and voltage:

Potential difference (volts, V) = current (amps, A) x resistance (ohms, Ω)

$$V = I \times R$$

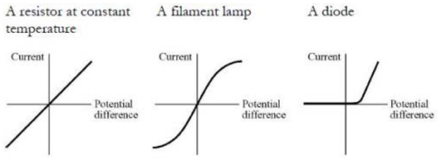
I.e the bigger the voltage and the smaller the resistance, the bigger the current

Question: What potential difference is needed to make a 2A current flow through a 10 Ω resistor? Potential difference = 10 x 2 = 20 V

Some electrical components change their resistance depending on the potential difference

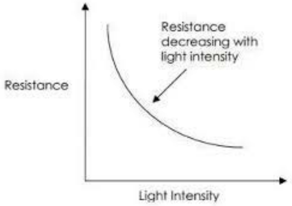
1. *Filament lamps* :As the potential difference increases, the filament lamp gets hotter and its resistance increases so the current vs voltage graph flattens off at high voltages

2. *Diodes*: Conduct electricity in one direction only if a potential difference is applied in the other direction, no current will flow. The resistance of fixed resistors isn't affected by the potential difference in the presence of a fixed resistor there's a directly proportional relationship (i.e straight line graph) between current and voltage

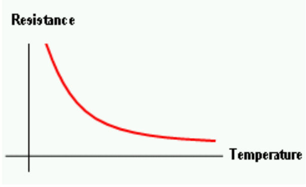


Some electrical components change their resistance depending on the conditions surrounding them

Light-dependent resistor (LDR): Its resistance is large in the dark and decreases when light is shone on it. The greater the light intensity, the smaller its resistance.



Thermistors- as the temperature increases, their resistance decreases or increases.



Questions on Measuring Voltage

- Name the piece of apparatus used to measure the voltage or potential difference.
- Why is this piece of equipment placed in parallel?
- What are the units for energy and charge?
- What is 1 volt?

Questions on Resistance

- Define resistance.
- What is the unit of resistance?
- Write down the equation that links V, I and R.
- What is the resistance in a circuit if the voltage is 230V and the current flowing is 11 Amps?
- Draw the current:voltage graphs for a diode, filament lamp, an LDR and a negative temperature coefficient thermistor.

TRANSFERRING ENERGY

When current flows through a resistor, energy is transferred to the resistor and it becomes warm e.g. in a motor, the main energy transfer is from electrical energy to kinetic (movement) energy. However, some energy is lost/wasted as heat energy.

Explanation for this transfer of heat energy. A current in a wire is a flow of electrons and as the electrons move in a metal, they collide with the ions in the lattice, transferring (heat) energy to them. This transfer of heat energy can be beneficial e.g in electric fires and kettles

However, this heating effect of an electric current can cause problems in some electrical appliances can produce so much waste heat energy that they could cause burns if touched. Wires can catch fire if too much current flows and for this reason, plugs are fitted with fuses which melt and break the circuit if current gets too high.

Calculating Power and Energy

Power is the energy transferred every second. The unit of power is joules per second, or watts (W).

For electrical appliances, the power can be worked out from the current and the potential difference.

electrical power (watts, W) = current (amps, A) x potential difference (volts, V)

$$P = I \times V$$

e.g. a kettle uses the mains electricity supply at 230V. The current is 13 A. What is the power of the kettle?

Power = 13 x 230 = 2990 W

The total energy transferred by an appliance depends on its power and for how long it's switched on for . The energy transferred can be calculated using the equation.

Energy transferred (joules, J) = current (amps, A) x potential difference (volts, V) x time (seconds, s)

$$E = I \times V \times t$$

e.g the kettle in the above example takes 2 minutes to boil some water. How much energy does it transfer?

2 minutes = 120 seconds

energy transferred by kettle = = I x V x t = 13 x 230 x 120 = 358,800J or 358.8 KJ

VECTORS AND VELOCITY

Displacement versus Distance

In a 200m race, all runners cover a 200m distance

However, the track is curved so the distance in a straight line between the start and finish is less than this – this distance is called the 'displacement'.

Displacement is measured in a straight line so unlike distance (which only has a size), displacement has both a size and direction.

Speed

The speed of an object tells you how quickly it will take to travel a certain distance.

Speed can be calculated from the equation:

speed (m/s) = distance (m) / time (s)

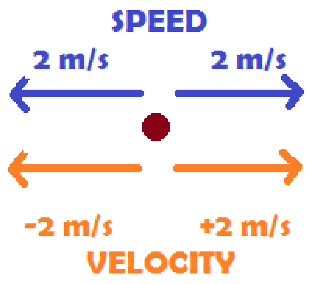
Like distance, speed only has a size (magnitude) but no direction.

Velocity

Velocity tells you how quickly an object is moving, and it also tells you in which direction it's moving. If object is moving forwards – positive velocity. If object is moving backwards – negative velocity

Velocity, like speed, is measured in m/s

Quantities like displacement and velocity which have a size and direction are called **vector** quantities



Questions on Transferring Energy

- What happens to a resistor when current flows through it?
- Explain in terms of electrons and ions why the above happens.
- What happens to a fuse wire if too much current flows?
- What is the unit of Power?
- Write down the equation that links Power to current and voltage.
- If a washing machine has a power of 30KW and runs off mains electricity of 230V, how much energy is used during its shortest wash cycle of 45 minutes?

Questions on Vectors and Velocity

- What is the difference between displacement and distance?
- What is the difference between speed and velocity?
- Write down the equation for speed.
- If a car travels 250 metres in 25 seconds what is its speed?

Distance-time graphs:

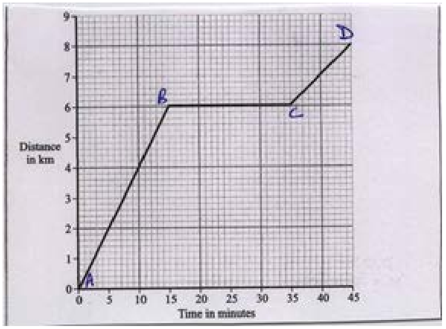
A graph in which distance is plotted against time is called a distance-time graph

Time and distance are used to calculate speed and from a distance-time graph, we can tell how fast an object is moving.

- *Horizontal lines mean object is stationary*
- *Straight, sloping lines mean the object is travelling at a constant speed*
- *The steeper the line, the faster the object is travelling*
- *The speed of the object can be calculated from the gradient of the line*
- speed = gradient = change in distance / change in time

e.g. Between A and B and between C and D, person is jogging at a steady speed

- The person is stationary (not moving) between points B and C
- Speed person is jogging at between points C and D:
  - Point C: 35 minutes, 6km
  - Point D: 45minutes, 8km
  - →speed = gradient = change distance / change in time
  - →speed = gradient = 2 / 10 = 0.2 km/min = 12 km/hour



ACCELERATION

Moving things speed up or slow down all the time and this change in velocity is called acceleration.

Acceleration has both a size and direction and is a vector quantity. Positive acceleration means the object is speeding up and negative acceleration means the object is slowing down

Acceleration can be calculated from the equation:

acceleration (m/s^2) = change in velocity (m/s) / time taken (s)

change in velocity = final velocity (v) - initial velocity (u)

$a = (v – u) / t$

e.g. a racing car starts from 0 m/s and reaches a velocity of 50 m/s in 5 seconds. What is its acceleration?

Acceleration = $a = (v – u) / t$

$a = (50 – 0) / 5 = 10\ m/s^2$

$10\ m/s^2$ means that each second the velocity of the car increases by 10 m/s

e.g. during landing, a space shuttle slows down from 70 m/s to 20 m/s in 20s. Calculate its acceleration:

Acceleration = $(20 – 70) / 20 = -50/20 = -2.5\ m/s^2$

The minus sign shows that the space shuttle is slowing down (i.e negative acceleration)

Questions on Distance-Time Graphs

- What is a distance- time graph?
- What does a straight line mean on a distance time graph?
- If a motorbike is racing a bike which vehicle will have the steepest line on a distance time graph?
- What feature of a distance time graph gives the speed?

Questions on Acceleration

- Is acceleration a vector or scalar?
- What is the unit for acceleration?
- Write down the equation for acceleration.
- What does acceleration $=-0.5\ m/s^2$ mean?
- What does the gradient of a velocity time graph show?
- If a boat goes from rest to 60mph in 30 seconds calculate its acceleration.

Velocity-Time Graphs

A velocity-time graph shows how the velocity of an object changes with time. A horizontal line means the object is travelling at a constant velocity. The higher the line, the higher the velocity

A straight sloping line shows the object is accelerating:

Steeper line = greater acceleration

Upwards slope = acceleration

Downwards = deceleration

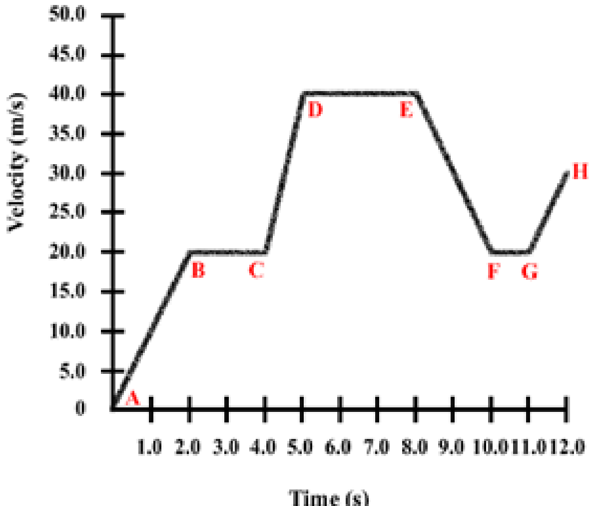
A: Stationary car

A&B, C&D, E&F, G&H: accelerating

E&F: deceleration, car slows

B&C, D&E, F&G: constant velocity

D&E: highest velocity



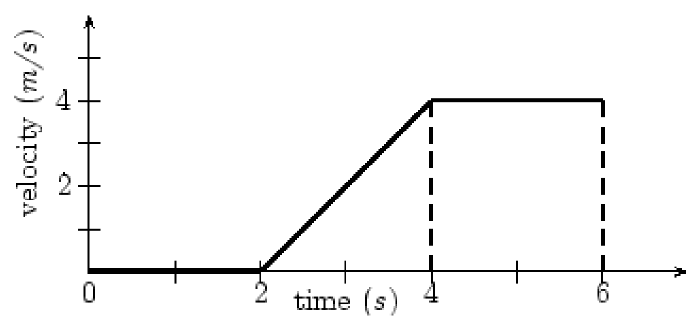
The acceleration of an object between two points can be calculated from a velocity-time graph, using the equation on the previous page

e.g. acceleration between points C and D (on diagram above):

- final velocity = 40 m/s. Initial velocity = 20 m/s. Time = 1 second
- acceleration = 20 / 1 = 20 m/s^2

Calculating distance from a VT graph

- The area under a velocity-time graph tells us the distance the object has travelled
- To calculate the area under a velocity-time graph…
  - you split the area under the graph into shapes (squares and triangles), calculate each bit separately, and then add everything together
  - Area of triangle = ½ base x height…→ area = 1 x 4 = 4m
  - Area of square = base x height…→area = 2 x 4 = 8m
  - distance travelled = 8m + 4m = 12m



Questions on VT Graphs

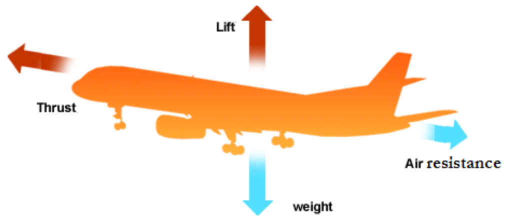
- Which axis does velocity go on?
- What does the gradient represent?
- If a line is flat, what does it mean?
- If a line is steeper, what does this mean?

Calculating distance questions

- How do we calculate the distance from a velocity-time graph?
- How would you calculate the area under a rectangle?
- How would you calculate the area under a triangular part of the graph?

Forces

Forces make objects change speed, shape or direction. A force (N – Newtons) is a vector quantity (it has both a size and direction)



Different types of forces:

- Upthrust/lift – these act upwards (in air). Weight (gravity)
- Friction/air resistance/drag – against the direction of movement
- Thrust/driving force – these act in the direction of movement. They are forces produced by engines that push vehicles forwards
- Push/pull – these are forces that also act in the direction of movement, but are generated by direct contact between objects (not by engine power)

Action and reaction forces - whenever two objects touch, they interact with each other.

- the forces they exert on each other are equal in size and opposite in direction
- These forces are known as 'action' and 'reaction' forces, an 'action-reaction' pair

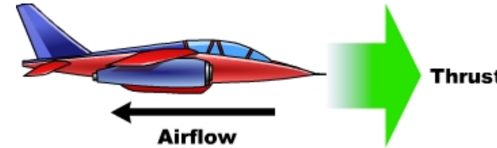
A book resting on a table: the weight of the book exerts a downward force on the table – this is the 'action force'. The table exerts an equal and opposite (i.e upward) pushing force on the book - this is the 'reaction force'. Without this reaction force, the book would fall through the table

Action and reaction forces are used to propel rockets: Gases are pushed out from the rear of the rocket – this is the action force. The reaction force from the gases pushes the rocket forwards.

Free-body force diagrams: shows the different forces acting on an object

- The arrows show the direction in which the forces act
- The length of the arrows shows the size of the forces (the longer the arrow, the bigger the size of the force)

RESULTANT FORCES



When more than one force acts on an object, the effect is the same as if they were combined into a single force – the 'resultant force'. To work out the resultant force, you add together all the forces acting in one direction, and then subtract them from all the forces acting in the opposite direction

Balanced forces: Forces that are equal but act in opposite directions are 'balanced'

- When all forces are balanced, the resultant force on an object is zero the object's movement, shape or direction will not change. If stationary, it will remain. If it was moving, it continues to move at the same velocity (same speed and same direction)

Unbalanced forces: if not equal, acting in opposite directions, forces are unbalanced

- When forces are unbalanced, the resultant force on an object is not zero. The object will accelerate in the direction of the resultant force. The thrust is the force produced by the plane's engines, moving the plane forwards. As the plane flies, air molecules push against the plane, producing an opposite force called air resistance. The thrust is greater than the air resistance (as thrust arrow is longer):
- If air resistance was greater than the thrust force, there would be a resultant force in the direction of air resistance. There would be a (negative) acceleration in the direction of the air resistance

Note: remember when answering questions on forces that there are no air particles in space (space is a vacuum). There is no air resistance in space

Forces - Questions

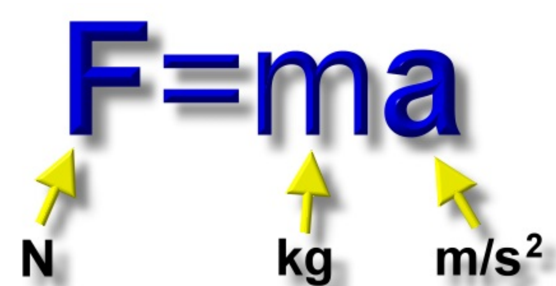
- What is a force?
- In which direction does friction or drag work?
- What is an action-reaction force?
- Where is the action-reaction on a book resting on the table?
- What does a larger arrow represent on a free-body diagram?

Resultant forces - Questions

- How do you work out the resultant force acting on an object?
- What will happen to a bus moving at 20mph with no net force?
- If the thrust on a rocket is greater than air resistance, what will happen to its velocity?
- Why does no air resistance act in space?

Forces and Acceleration

- The rate at which an object accelerates depends on:
  - the size of the (resultant) force – the greater the resultant force, the greater the acceleration of the object
  - the mass of the object – the greater the mass of the object, the smaller its acceleration
- equation linking acceleration, force and mass:
  - Force (N) = mass (kg) x acceleration (m/s^2)
  - F = m x a
  - 1 newton is the force needed to accelerate a mass of 1kg by $1m/s^2$
- A car's acceleration is 3 m/s^2. It weighs 1500kg. What is the force provided by the engine?
  - Force = 1500 x 3 = 4,500 N



Mass and Weight

Mass (measured in kg) is the quantity of matter there is in an object and does not change

Weight (measured in N) is a measure of the pull of gravity on an object. If gravity changes, weight also changes

- The strength of gravity is called the 'gravitational field strength' (N/kg)
- On earth, the gravitational field strength is 10N/kg. Each kilogram is pulled down with a force of 10N
- The weight of any object on earth can be calculated using the equation:
  - weight (N) = mass (kg) x gravitational field strength (N/kg). W = m x g

What is the weight of a 75kg person on Earth? weight = 75 x 10 = 750 N

What is the weight of a 75kg person on the moon? The moon's gravitational field strength is about 1.5N/kg. Weight = 75 x 1.5 = 112.5 N

- Notice how person's mass (75kg) is the same on the moon as it is on Earth - mass never changes (it's not affected by gravitational field strength)
- Person's weight instead is much lower on the moon (112.5 N) than on Earth (750 N) because the gravitational field strength is much smaller on the moon than on the Earth

Forces and Acceleration - Questions

- What does the amount of acceleration depend on?
- If there is a bigger resultant force, what happens to the acceleration?
- What does a Newton represent?

Mass and Weight - Questions

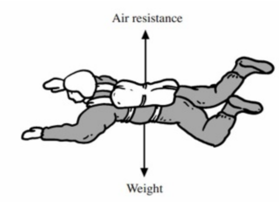
- What is mass?
- What is weight?
- What is the strength of gravity, and its units?
- How do we calculate the weight of a person on Earth?

Acceleration of falling objects:

- Larger masses need more force to get them to accelerate than smaller masses (force = mass x acceleration)
- As the mass increases, so does the force from gravity (weight)
- (weight = mass x gravitational field strength)
- On Earth, there are air particles, which generate air resistance:
  - if a hammer and a feather are dropped, the hammer hits the ground first because it is slowed down less by air resistance
- However, in space there are no air particles and so no air resistance:
  - in a vacuum, all objects (regardless of their mass) accelerate down towards the Earth by the same amount
  - if a hammer and a feather are dropped in space, they hit the ground at the same time

Terminal velocity

- When a skydiver first starts to fall, the main force acting on the skydiver is their weight (downwards), there is very little air resistance acting in the opposite direction (upwards)
  - large resultant force downwards
  - skydiver accelerates quickly towards the ground



- As the skydiver gains velocity, the size of the air resistance force increases
  - the resultant force downwards is smaller
  - skydiver is still accelerating down towards the ground, but the size of the acceleration is smaller
- Eventually the weight and air resistance become balanced…
  - resultant force is now zero
  - skydiver stops accelerating, the skydiver continues to fall towards the ground, but now at a constant velocity
- This constant (maximum) velocity reached when the air resistance force balances the weight is called the 'terminal velocity'

Acceleration of Falling objects - Questions

- Do larger masses require more or less force to accelerate at the same rate?
- Weight = ?
- If mass increases, what happens to the weight?
- Why will a hammer and feather not fall at the same rate on Earth?

Terminal Velocity - Questions

- What two forces act on a skydiver?
- Initially, what happens to the motion of a sky diver?
- What happens to the air resistance with a greater speed?
- Eventually, what happens to the forces?
- What Terminal Velocity?

Stopping Distances

Thinking Distance - when a driver sees a problem, the car travels some distance before the driver reacts and applies brakes

Braking distance - Once the brakes are applied, the car will travel some distance before it comes to a stop

- Overall 'stopping distance' for a car = thinking distance + braking distance

Factors affecting stopping distances:

1. Person's reaction time :

- The slower a person's reaction time, the longer the thinking distance. Tiredness, illness, or taking drugs or alcohol can all slow down reaction times

2. Speed of the vehicle:

- The faster the vehicle is travelling, more distance covered

3. State of the car's brakes and road conditions:

- For a car to come to a stop there must be friction created between the car's tyres and the road
  - More friction, smaller braking distance
  - Friction depends on condition of car brakes (better brakes, more friction), condition of road (if lose gravel or wet, less friction). Due to longer braking distances in wet conditions, drivers should leave more of a gap before the car in front

4. Mass of the vehicle:

- More mass, more force is needed to make it slow down, longer braking distance

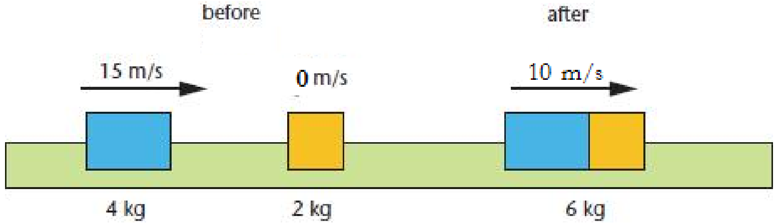
Momentum

- Momentum is a measure of how strongly something is moving
  - Momentum (kg m/s) = mass (kg) x velocity (m/s)
  - The heavier the vehicle and the faster it is travelling, the greater its momentum
- What is the momentum of a monster truck (mass = 4500kg) when travelling at 12m/s, in an eastward direction? Momentum = 45000 x 12 = 54,000 kg m/s east
- Momentum has a size and direction so is a vector quantity (state a direction):

Conservation of momentum: when a moving object collides with another object:

- their masses are added together, their combined speed will be slower
- However, the total momentum of both objects is the same before the collision as it is after the collision - this is known as ‘conservation of linear momentum’

- Before collision: Object on the left has a momentum = 15 x 4 = 60 kg m/s to the right. Object on the right has a momentum = 0 x 2 = 0 kg m/s
- After collision: Combined objects have a momentum = 10 x 6 = 60 kg m/s to the right
- The combined momentum of the objects before and after the collision is the same
- This demonstrates that when objects collide, momentum is conserved (i.e it is transferred to the other object without any being lost)



Stopping Distances - Questions

- What is the thinking distance?
- What is the braking distance?
- What is stopping distance?
- What 4 factors affect stopping distance?
- How does alcohol affect the stopping distance?
- How does friction affect stopping distances?

Momentum Questions

- What is momentum?
- What are the units of momentum?
- Is momentum scalar or vector?
- Is momentum conserved or lost?

MOMENTUM AND SAFETY

When travelling in a car, passengers are going at the same speed as the car. If a car brakes suddenly, there's a rapid change in momentum, and a strong force is applied to the passengers - this can result in serious injury (passengers can smash their heads against the windscreen)

The 'rate of change of momentum' is equal to the force applied to the object - The rate of change of momentum = Force (N) = change in momentum (kg m/s) ÷ time taken for that change (s).
Force $F = (mv – mu) \div t$

Vehicle safety measures:

1. Seat belts:
   - In an accident, seat belts stretch, passenger's velocity is slowed down more gradually
   - it takes longer for passenger's momentum to be slowed to zero. The force applied to the passengers is less and there is reduced chance of injury

However, in high speed accidents, the force is so great that the seat belt by itself could still cause injury

2. So cars are fitted with airbags, which also reduce the rate of change of momentum

3. Cars also have crumple zones. In an accident, the material in these crumple zones squashes and folds. This crumpling and folding reduces the momentum of the car over a longer period of time (i.e reduces the rate of change of momentum).So the impact forces on the passengers are less and there is reduced chance of serious injury

WORK AND POWER

'Work' is done when energy is transferred from one form to another. Car brakes 'do work' by transferring kinetic energy to thermal energy

The amount of 'work' done is equal to the amount of energy transferred

Energy and work are measured in joules (J)

Work done (joules, J) = force (newtons, N) x distance moved in the direction of the force (metres, m). E = F x d

Power is the rate of doing work – measured in watts (W)

Power (watt, W) = work done (joule, J) / time taken (second, s). P = E / t

- 1 watt = 1 joule of work done per second
- I.e the more work done per second, the more power generated

Questions on Momentum and Safety

- What is the formula for force in terms of momentum?
- How do seat belts work?
- How do crumple zones work?

Questions on Work and Power

- What units do we use to measure work?
- What is the formula for work done?
- What units do we use to measure power?
- What is the formula for power?

POTENTIAL AND KINETIC ENERGY

Gravitational potential energy is energy that is stored because of an object's position in a gravitational field.

On Earth, if something can fall (e.g a person on a diving board) it has gravitational potential energy

Gravitational potential energy (J) = mass (kg) x gravitational field strength (N/kg) x vertical height from ground (m). GPE = m x g x h

KINETIC ENERGY

Kinetic energy is another name for movement energy

kinetic energy (J) = ½ x mass (kg) x (velocity)^2 (m/s^2) $KE = \frac{1}{2} \times m \times v^2$

Conservation of energy:

When energy is transferred from one form to another, energy is conserved (i.e total amount always remains the same…none is lost)

As an object falls, its gravitational potential energy is converted into kinetic energy. When an object with gravitational potential energy falls down, the amount of kinetic energy it has just before it hits the ground is equal to its initial gravitational potential energy (as all the GPE has been converted to KE).

Questions on Potential and Kinetic Energy

- Define gravitational potential energy.
- What is the formula for gravitational potential energy?
- Calculate the gravitational potential energy for an object of mass 5kg, at a height of 100m, when the value of g= $10 m/s^2$

Questions on Kinetic Energy

- What is the formula for kinetic energy?
- What is the conservation of energy principle?
- What is the relationship between gravitational potential energy and kinetic energy, as an object falls?

BRAKING DISTANCES, CONSERVATION OF ENERGY, AND WORK DONE

Brakes ‘do work’ by transferring kinetic energy to thermal energy

When the vehicle stops, it has no more kinetic energy. Energy is conserved (All the kinetic energy has been converted to thermal energy)

The work done to bring a vehicle to rest is equal to its initial kinetic energy

- i.e the greater the initial velocity of the vehicle, the greater its initial kinetic energy (recall: KE = ½ x m x v^2), so the more work that needs to be done to bring the vehicle to rest
- This explains why the faster a vehicle is travelling, the longer its braking distance

Ionising radiation

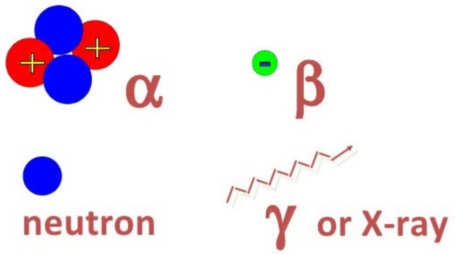
Radioactive substances have unstable nuclei that emit ionising radiation (randomly). They release energy and decay to become more stable. Ionising radiation - enough energy to cause atoms to lose electrons and become ions. Three main types of ionising radiation:

Alpha particles: (2 protons, 2 neutrons (helium nucleus, no electrons, +2 charge))

- Very ionising (i.e they easily make atoms lose electrons and become ions)
- Each time ionising particles ionise an atom, they lose some energy, so alpha particles lose energy quickly so don't travel far into matter - 'short penetration distance'.
- Alpha particles can be stopped by a few centimetres of air or a few mm of paper

Beta particles: (Electrons, negatively charged)

- Moderately ionising
- Lose energy slower than alpha particles, so they can penetrate further into matter than alpha particles can
- Beta particles can be stopped by a few millimetres of aluminium



Gamma rays: (High-frequency electromagnetic waves – speed of light, no charge)

- Weakly ionising (much less than both alpha and beta particles)
- Lose energy very slowly, so can penetrate further into matter than both alpha and beta particles can.
- Gamma rays need thick lead to stop them

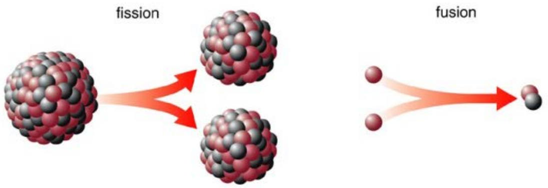
Questions on Braking

- What energy transfer occurs with braking?
- How much kinetic energy does a car have when at rest?
- Why does moving at a higher speed increase the braking distance?

Ionising radiation Questions

- What is an alpha particle made of?
- What is a beta particle made of?
- What is gamma radiation?
- Which is the most penetrating?
- Which is the most ionising?
- What is gamma radiation stopped by?

Nuclear reactions



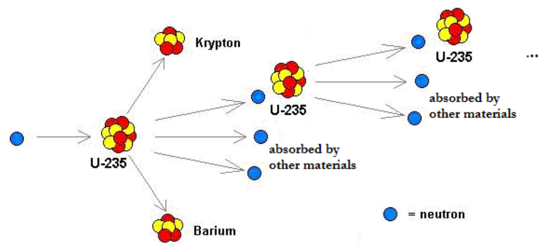
The process of radioactive decay releases energy

- when alpha and beta particles are emitted from unstable nuclei at high speeds, kinetic energy is released
- when gamma rays are emitted from unstable nuclei at the speed of light, the energy released is in the form of electromagnetic radiation

Some large unstable nuclei can split into two smaller nuclei called daughter nuclei – this process is called nuclear fission.

When a uranium-235 absorbs a neutron it becomes unstable and immediately splits it into two smaller daughter nuclei, and two or more neutrons are released.

Nuclear fission releases a huge amount of energy. Most energy released is in the form of kinetic energy because both daughter nuclei and neutrons are moving at high speeds. Some thermal energy is also released



Nuclear fission

Uncontrolled chain reactions:

When a uranium-235 nucleus splits, neutrons released are absorbed by other uranium-235 nuclei:

- These other uranium-235 nuclei will split into two smaller daughter nuclei and release more neutrons
- These neutrons can then be absorbed by yet more uranium-235 nuclei..
- In these 'uncontrolled chain reactions', lots of energy is released (through nuclear fission) in a very short time – this occurs in an atomic bomb

Controlled chain reactions:

If some of the neutrons released during nuclear fission are absorbed by other materials, then chain reactions can be controlled

- when a uranium-235 nucleus splits, all neutrons except for one are absorbed by other materials
- only one neutron from each fission event can be absorbed by another uranium-235 nucleus
- The chain reaction is now 'controlled' because the chain reaction continues at a constant rate, the amount of energy produced through nuclear fission is regulated

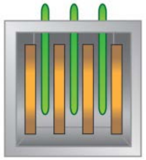
Controlled chain reactions occur in nuclear reactors.

Nuclear Reactions Questions

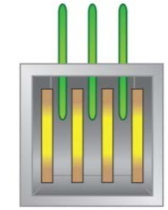
- How does the process of nuclear decay release energy?
- What element is used in nuclear fission?
- Does nuclear fission release a lot of energy?
- What form is this energy in?

Nuclear Fission Questions

- How does the chain reaction from Uranium 235 continue?
- What is the difference between controlled and uncontrolled chain reactions?
- Which type of reactions occur in nuclear reactors?



Nuclear fission in nuclear reactors



Nuclear reactors in nuclear power stations convert (nuclear) energy contained in the nuclei of uranium and plutonium ions into thermal energy using nuclear fission.

The rate at which nuclear energy is transferred to thermal energy is kept constant by controlling the fission chain reaction

- This is done by ensuring that only one of the neutrons released by the decay of a uranium nucleus is absorbed by another uranium nucleus
- To achieve this, the extra neutrons that are released have to be absorbed – this is done by control rods in the reactor core.

Control rods contain elements that absorb neutrons

- If the rate of fission needs to be decreased, more control rods are moved into the core, more neutrons are absorbed by control rods, fewer neutrons can be absorbed by other uranium nuclei (and vice versa)

When the control rods are fully lowered into the reactor core, they absorb all the neutrons the chain reaction stops and the reactor shuts down

Neutrons emitted from the fission of a uranium-235 nucleus are moving very fast

To make them more likely to be absorbed by other uranium-235 nuclei, they need to be slowed down – this is done by moderators in the reactor core

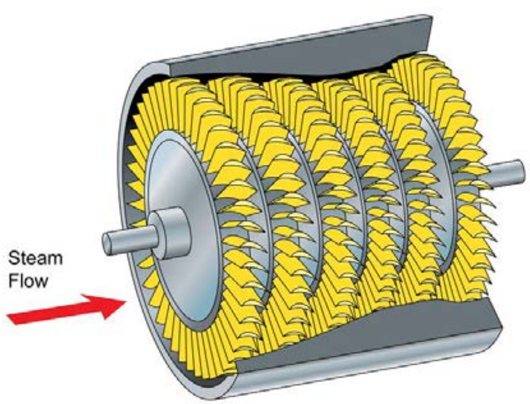
Generating electricity:

1. Thermal energy from the core is transferred to the coolant (usually water at high pressure), which is pumped through the reactor
2. This super-heated water is pumped to a ‘heat exchanger’ where it’s used to produce steam
3. The steam drives a turbine, which turns a generator
4. The generator transfers kinetic energy into electrical energy

Radioactive waste:

The products of nuclear fission (i.e the daughter nuclei and radioactive isotopes) are radioactive

Over time, radioactive waste builds up in the reactor core



Fission in Nuclear Reactors Questions

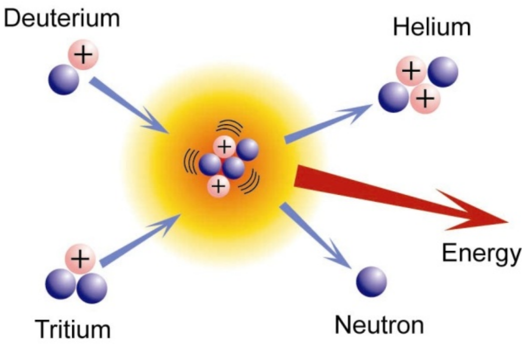
- What kind of energy do nuclear reactors use?
- What is a control rod? What does it do?
- How does a reactor shut down?
- What do moderators do?

Generating Electricity Questions

- How is electricity generated from the energy released by nuclei?
- What is the energy transfer?
- What is radioactive waste?

NUCLEAR FUSION

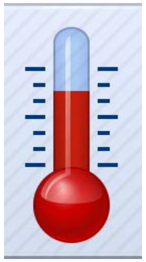
- Nuclear fusion occurs when small nuclei combine to form larger nuclei
- E.g when hydrogen nuclei fuse to form helium:
  - There are two isotopes of hydrogen:
    - Hydrogen-2 called deuterium (1 proton, 1 neutron)
    - Hydrogen-3 called tritium (1 proton, 2 neutrons)
  - When tritium and deuterium nuclei fuse, helium is formed:
    - Helium has 2 protons and 2 neutrons
    - One neutron is freed from the nucleus, releasing a huge amount of energy
- So much energy is released in nuclear fusion reactions that they are the energy source for stars, including our Sun
- Nuclear fusion is being investigated by scientists as a possible energy source for the future:
  - Unlike nuclear fission, nuclear fusion doesn’t produce any radioactive waste products so would be a better alternative



Conditions for fusion:

- Nuclei of both deuterium and tritium are positively charged (due to presence of 1 proton in each nucleus) as a result they repel - ‘electrostatic repulsion’
- So in order for deuterium and tritium nuclei to overcome the electrostatic repulsion and collide, the conditions must be right:

- **1. High pressure:**
  - For nuclei to fuse, they need to get very close to each other
  - The Sun has a very strong gravitational field, which creates high densities (i.e lots) of nuclei at its centre so making collisions more likely to happen
  - These conditions are not naturally present on Earth, but very high pressures can be produced inside fusion reactors



- **2. High temperature:**
  - If nuclei are travelling fast enough, some can overcome their electrostatic repulsion and collide
  - The higher the temperature, the faster the nuclei move so the more likely they are to overcome their electrostatic repulsion and collide
- Unfortunately, the conditions that are required for nuclear fusion (very high temperature and pressure) are difficult to achieve and are very expensive so it will be some time before fusion energy will become a viable energy source

***Note* - Cold fusion:**

- Scientists 20 years ago claimed to have carried out nuclear fusion at 50°C – this became known as ‘cold fusion’
- The possibility of carrying out nuclear fusion at low temperatures was exciting at the time because it would be more convenient and less expensive
- However, attempts to repeat the original findings have failed as a result most scientists do not believe cold fusion can happen

Nuclear Fusion - Questions

- Define nuclear fusion
- Why is nuclear fusion better than nuclear fission as an energy source?
- Given an example of nuclear fusion energy source in nature
- Why are isotopes useful in nuclear fusion?

Conditions for Fusion - Questions

- What is the name of the force which keeps nuclei apart in normal conditions?
- Describe the two conditions are needed to allow nuclear fusion to occur?
- Explain how the two conditions provide the opportunity for fusion
- Why is nuclear fusion not a common source of energy on Earth?
- What is the name of the potentially exciting development in nuclear fusion which has yet to be proven in the laboratory?

CHANGING IDEAS

- When radioactivity was first discovered in the late 1800s, scientists did not know it was dangerous:
  - Becquerel suffered burns, but he did not realise that this damage was due to the ionising radiation
  - Marie Curie died from leukaemia (a type of cancer) most likely the result of her not taking any precautions
- After these events, scientists began to link cancer and other health problems to the effects of ionising radiation
- We now know that a large amount of ionising radiation can cause tissue damage - e.g reddened skin ('radiation burns')

- Over long periods of time, ionising radiation can damage the DNA inside cells – this damage is called a 'mutation'
- DNA contains the instructions controlling a cell (i.e the genetic material); when mutations occur, they can cause cells to malfunction, which can lead to cancer

Handling radioactive sources:

- The risk of harm decreases with distance from the source - radioactive substances are always handled with tongs, and kept away from other people
- Protective clothing is worn in case the radioactive source happens to come into contact with the skin
- The most penetrating radiation (gamma rays) can be stopped by a sheet of lead - radioactive sources are usually kept in a lead-lined container

NUCLEAR WASTE

Types of waste:

- The fission products from the uranium fuel used in nuclear power stations are very radioactive
- For the first 50 years – waste is called high level waste (HLW) as it produces large amounts of ionising radiation
- For the next tens of thousands of years – waste is called intermediate level waste (ILW) as the waste is moderately radioactive
  - ILW includes metal cylinders that once contained the uranium fuel
- For the next tens of thousands of years after that – waste is called low level waste (LLW) as waste is only slightly radioactive so can be disposed
  - LLW includes clothing and cleaning materials from nuclear power stations
  - Hospitals are also a source of LLW because of the radioactive isotopes that are used in radiotherapy to treat cancer

Storage and disposal of nuclear waste:

- HLW: Transported inside thick concrete and steel containers to absorb the radiation. It is then stored in canisters and sealed in glass to prevent it from escaping
- ILW: taken out of canisters and sealed in glass, still stored inside concrete and steel containers
- LLW: once material is LLW it can be disposed of 3 ways:
  1. Fire it into space – problem: launch vehicle could fall back to earth →spreading radioactive material everywhere
  2. Dump it in barrels in the sea – problem: barrels can corrode and release radioactive materials into the water
  3. Bury it in special landfill sites – this is the favoured method, but site of burial must be geologically stable (i.e have a very low risk of earthquakes)

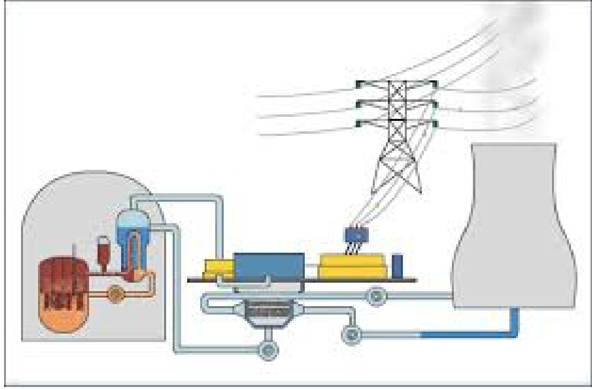
Changing ideas - Questions

- What injuries can you get from exposure to radiation?
- What is a change in DNA called and why is it signficant?
- What precautions should be taken when handling radioactive substances?
- How would you stop the most penetrating radiation?

Nuclear Waste - Questions

- Why is it difficult to dispose of nuclear waste?
- Describe the different states of waste and indicate how long they are in that state
- For each state of waste, describe the methods used to contain in a safe manner
- Give three methods of disposing of radioactive waste and suggest a potential risk with each method.

Advantages/Disadvantages of nuclear power



Advantages of nuclear power:

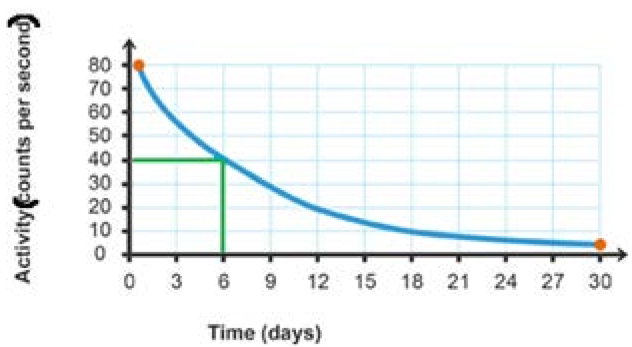
- Nuclear power stations themselves don’t directly produce carbon dioxide so nuclear power doesn’t contribute to global warming
  - However, energy is needed to make some components of nuclear reactors therefore indirectly some carbon dioxide may be produced
- Nuclear power is produced consistently (i.e not dependent on weather conditions)
- Nuclear power won’t run out for many years and it’s a very efficient process

Disadvantages of nuclear power:

- Nuclear waste has to be stored for tens of thousands of years (i.e until the radioactivity has decreased to ‘LLW’) before it can be disposed
  - During this time, if any of it leaks into the environment it can have serious effects on health – e.g tissue damage, cancer
- Some people think that nuclear power is unsafe because of the risk of accidents:
  - E.g in Chernobyl, 1986 - a nuclear power station exploded, spreading radioactive material across Europe

HALF LIFE

- Radioactive substances have unstable nuclei that emit ionising radiation (alpha particles, beta particles and gamma rays) – this is a random process
  - As unstable nuclei emit ionising radiation, they lose (release) energy and decay to become more stable
- The 'activity' of any radioactive substance is the number of nuclear decays (i.e. the number of unstable nuclei that emit ionising radiation and then become more stable) per second – it is measured in Becquerel (Bq)
  - 1 Bq is equal to one nuclear decay per second - the more unstable nuclei in a sample, the faster its rate of decay→the higher its 'activity'
- The 'half-life' is the time taken for the 'activity' for a radioactive substance to decrease by half (i.e it's the time taken for half of the nuclei in a sample of a radioactive isotope to decay and become more stable)
  - The shorter the half-life, the quicker the isotope decays
- The half-life of a radioactive sample is found by recording its activity over a period of time - this is done using a Geiger-Muller (GM) tube:
  - A GM tube is connected to a counter – every time ionising radiation is detected, it gives out a click
  - The 'count rate' is the number of clicks per second
  - The time it takes for the count rate to halve is the half-life
- The half-life can be calculated from a graph:
  - Activity of radioactive substance is initially 80 counts per second
  - It takes 6 days for its activity to reduce to 40 - its half-life is 6 days



Advantages/Disadvantages of nuclear power - Questions

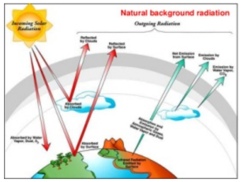
- Do nuclear power stations contribute to global warming?
- Is nuclear power dependent on the weather?
- Is there a limited time which nuclear power can supply our energy needs?
- Is it easy to close a nuclear power plant?
- Are nuclear power plants safe?

Half Life - Questions

- When an atom decays, what ionising radiation particles/rays are emitted?
- Describe the measurement of radiation and indicate the unit of measure.
- What instrument would you use to measure radiation?
- Define the term ‘half life’ of a substance.
- Name a good method of determining the half life

BACKGROUND RADIATION

- We are constantly exposed to low levels of ionising radiation from space and from naturally radioactive substances in the environment - this is called 'background radiation'
- When scientists measure the activity of a source:
  - They first need to measure the background radiation
  - The background radiation is then subtracted from measurements to give the corrected reading of the source's activity



Sources of background radiation:

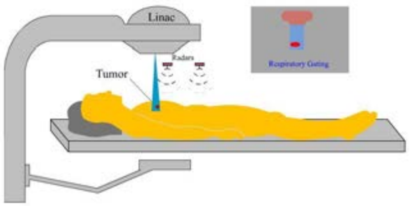
1. Radon gas is the main source of background radiation:
   - When uranium in rocks decays, it produces other radioactive isotopes that also decay – one of these is radon
   - Radon diffuses into the air from rocks and soil and can build up in houses, especially if there is poor ventilation
   - The amount of radon in the air depends on the type of rock and its uranium content and the radon content (and therefore the background radiation) varies according to where you are in the UK
2. X-ray scans, gamma ray scans and radiotherapy treatment for cancer contribute to background radiation
3. Some foods naturally contain small amounts of radioactive substances. Some background radiation comes from space
4. High energy charged particles come out of stars, supernovae, neutron stars and black holes:
   - They are known as 'cosmic rays' and are a form of ionising radiation
   - Many cosmic rays are stopped by the upper atmosphere but some still reach the Earth's surface

USES OF RADIATION

Diagnosis of cancer:

- A tracer solution containing a source of gamma rays is injected into the body and it collects on the cancer cells. A gamma ray detector is used to find the cancer cells. Why gamma rays are used:
  - Gamma rays are used for this because they are weakly ionising, most penetrating and so pass straight through the body, allowing them to be detected

Treatment of cancer:



- Radiotherapy – a beam of gamma ray radiation is fired at cancer cells, killing them

Sterilisation of equipment:

- It is important to have clean surgical instruments to use in hospitals
- The usual method is to heat them (as microorganisms are killed by the heat)
- Some instruments, e.g plastic syringes, cannot be sterilised using heat (as they would melt), they can be irradiated with gamma rays to kill any micro-organisms present

Irradiating food:

- All foods contain bacteria – these bacteria are what eventually cause all food to decompose (i.e to go off)and cause food poisoning
- Some types of foods (fruit, vegetables, fish and poultry) are irradiated with gamma rays to kill bacteria:
  - This makes the foods safer to eat and also means that they can be stored for longer before going off
  - Irradiating the food also kills any pests (e.g insects) that may be in it

Smoke alarms:

- A smoke alarm contains a source of alpha particles – usually a radioisotope called americium-241. If the radiation detector is blocked by smoke then a circuit is broken and the alarm triggered.

Checking thicknesses:

- The thickness of the paper is controlled by a detector, which counts the rate at which beta particles pass through the paper

Tracers in the environment:

- To detect leaks in water pipes underground, a gamma source is added to the water. A GM tube follows the path of the pipe, measuring the levels of radiation

Background Radiation - questions

- Describe the meaning of the phrase ‘background radiation’
- Why is it important to measure the background radiation and how is it used in experiments?
- Is the background radiation a constant – explain your answer?
- Name as many sources of background radiation as you can.

Uses of Radiation - Questions

- How is radiation used to find and treat cancer?
- Suggest two applications for the ability of radiation to kill microbes and why is better than other methods
- How the properties of radiation which make measuring the thickness when manufacturing paper