N5 Physics Crash Course

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Waves

Definitions

Peak (Also Known as the Crest): The **Highest point** of a wave

Trough: The **Lowest point** of a wave

Amplitude: The distance from **peak to peak** or from **trough to trough**

Wavelength: **Length** of a wave

Period: The time it takes for **one wave** to pass a point

Frequency: The **number of waves** passing a **point per second**

Ultrasound: Sound with a very high frequency beyond human hearing

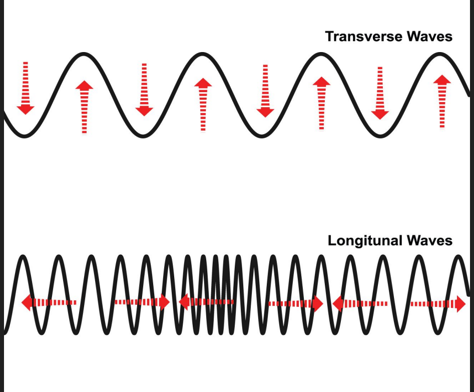
Waves

Longitudinal: The Particles **Vibrate in the same direction** that the wave is travelling.

Transverse: The particles **vibrate at 90° to the direction** the wave is travelling.

An Example of a **longitudinal** wave are **sound waves**

Some examples of **transverse** waves are **Light, Any EM Wave & Water Waves**.



Frequency

Frequency Formula: $f = N/t$ (f: frequency (Hz), N: Num of Waves, t: time (s))

Frequency Formula 2: $f = 1/T$ (f: Frequency (Hz), T: Period (s))

1. Calculate the frequency of a wave with a period of 0.05 s
   - $f = 1/T$
   - $f = 1/0.05$
   - $f = 20$ Hz
2. A girl stands on the end of a pier and counts the number of waves in a given time. She counts 45 waves in 100 seconds. Calculate the frequency of the waves
   - $f = N/t$
   - $f = 45/100$
   - $f = 0.45$ Hz

Period

The period of a wave is the time it takes for one wave to pass a point

Period Formula: T = 1/f (T: Period (s), f: Frequency (Hz))

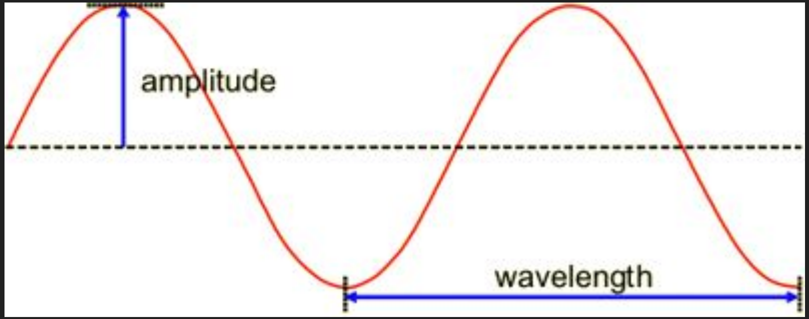
Some Examples

1. Calculate the time period of a wave with a frequency of 50Hz
   - 1 / 50
   - **T = 0.02 s**
2. Calculate the time period of a wave with a frequency of 400Hz
   - 1 / 400
   - **T = 0.0025 s**

Amplitude & Wavelength

The Amplitude is measured from the baseline to the crest or from the baseline to the trough and is a measure of how much energy a wave has.

Wavelength is measured from peak to peak or trough to trough and is represented by λ (Lambda) and is the length of a wave.



Wave Equation

Formula: $v = f \times \lambda$ (Condensed: $v = f\lambda$) (v: Wave Speed (ms^{-1}), f: Frequency (Hz), λ: Wavelength (m))

Examples

1. What is the speed of a wave with the frequency of 20 Hz and a wavelength of 10m
   - $v = f\lambda$
   - $v = 20 \times 10$
   - $v = 200\ ms^{-1}$
2. What is the speed of a wave with the frequency of 123 Hz and a wavelength of 21m
   - $v = f\lambda$
   - $v = 123 \times 21$
   - $v = 2583\ ms^{-1}$

EM Spectrum

The Electromagnetic Spectrum

Increasing Frequency --------------------->						
Radio	Micro	Infrared	Visible	Ultraviolet	X-Ray	Gamma Ray
<--------------------- Increasing Wavelength						

As the Frequency Increases, the Wavelength Decreases

As the Wavelength Increases, the Frequency Decreases

Refraction

When light enters a medium it **slows down**. This causes the light to move **towards the normal**. The **wavelength decreases**.

When the **light** enters a **less dense** medium, it **speeds up**. This causes the light to move **away from the normal**. The **wavelength increases**.

The Frequency Remains Constant (Does not Change)

Refraction: When light **changes speed** as it **moves from one medium to another**.

Diffraction

Diffraction refers to what happens to a wave when it encounters an obstacle.

Waves diffract more through small gaps.

Waves with longer wavelengths (and lower frequency) diffract more.

Long wave radio waves diffract more than short radio waves.

Radiations

Definitions

Activity: The **number** of **radioactive decays per second**

Half Life: The **length of time taken** for the **activity** of a source to drop **half its original value**.

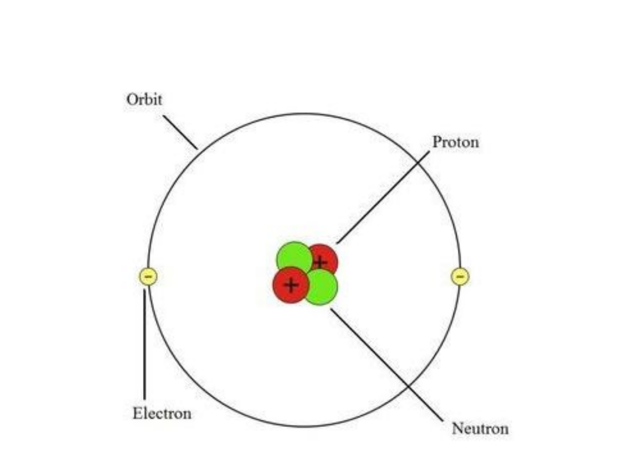
Ionisation: The **addition or removal** of an **electron** from an **atom**

Absorbed Dose: The measure of how **much radiation a tissue has been exposed to**.

Equivalent Dose: The **Biological Risk caused by the energy and type of radiation**.

Equivalent Dose Rate: The measurement used to judge the **safe amount of time someone can be exposed to radiation for**.

The Structure of an Atom



Particle	Charge	Mass	Location
Electron	-1	0	Outside Nucleus
Proton	+1	1	Inside Nucleus
Neutron	0	1	Inside Nucleus

Ionisation & Background Radiation

Ionisation is the **addition** or **removal** of an **electron** from an **atom**.

Background Radiation is **radiation** that is all around us from **natural sources** or from **man made sources**

Natural Sources of Background Radiation

- Cosmic Rays
- Animals
- Rocks
- Soil & Plants

Man Made Sources of Background Radiation

- Medical
- Nuclear Power

Types of Radiation

There are different types of radiation

Radiation Type	Symbol	Relative Charge	What is it?	Where does it come from?	Range in air	Blocked by	How ionising is it	Weighting Factor
Alpha	α	+2	A Helium Nucleus	Unstable Atoms Nucleus	Few cm	Paper	Highly Ionising	20
Beta	β	-1	A Fast Moving Electron	Unstable Atoms Nucleus	15 cm - 1 m	Aluminium	Ionising (< Alpha)	1
Gamma	ɣ	0	A High Energy EM Wave	Emitted alongside Alpha and Beta	1000s of km	Lead	Weakly Ionising	1

Activity & Absorbed Dose

Activity is the **number** of **radioactive decays per second**

Activity Formula: A = N/t (A: Activity (Bq), N: Num of Atoms, t: Time (s))

Example

1. Calculate the activity of a radioactive source with a count rate of 100 per minute
   - A = N/t
   - A = 100/60
   - A = 1.67Bq

Absorbed Dose is a measure of **how much radiation a tissue has been exposed to**. It is calculated from the energy the tissue absorbs and the mass of the tissue.

Absorbed Dose Formula: D = E/m (D: Absorbed Dose (Gy), E: Energy (J), m: mass of tissue (kg))

Example

1. Calculate the Absorbed Dose if the tissue weighs 1.5kg and the energy that tissue was exposed to was 10.6mJ
   - D = E/m
   - D = 0.0106/1.5
   - D = 0.0071Gy (7.1×10^{-3})

Equivalent Dose & Equivalent Dose Rate

Equivalent Dose is the **biological risk caused by the energy and the radiation type**. It is measured in Sieverts (Sv).

Formula: $H = DW_R$ (H: Equivalent Dose (Sv), D: Absorbed Dose (Gy), W_R: Weighting Factor))

Example

1. Calculate the equivalent dose if a person was exposed to 1.4mGy of Alpha Radiation
   - $H = DW_R$
   - $H = 0.0014 \times 20$ (Weighting Factor is found in data sheet)
   - $H = 0.028$ Sv ($2.8\text{x}10^{2}$ Sv)

The type of Ionising Radiation, The Type of tissue or organ exposed or the absorbed dose are all factors that must be taken into consideration when calculating the equivalent dose.

Equivalent Dose Rate is the measurement that **helps judge the safe amount of time someone can be exposed to radiation for**. This can vary and **time doesn't have to be in seconds**.

Formula: $H_T = H/t$ (H_T: Equivalent Dose Rate (Sv s^{-1}), H: Equivalent Dose (Sv), t: Time (s, mins, hrs etc)

Example

1. Calculate the Equivalent Dose Rate if someone absorbed 0.75 μSv in 5 hrs
   - $H_T = H/t$
   - $H_T = 0.75/5$
   - $H_T = 0.15$ μSv h^{-1}

Half Life

Half Life is the length of time taken for the activity of a source to drop half its original value.

Interpreting a Half Life Graph is simple

First find half the original activity on the y axis and then draw a line to the curve

From that same point, draw a vertical line to the x axis

The value that this line goes through is the half life of a source

Measuring Half Life

First, Record the background count rate/Activity

Then Place the radioactive source at a fixed distance from the Geiger-Müeller Counter.

Then Record the Count Rate from the radioactive source at regular time intervals.

Afterwards, Subtract the background count from your readings.

Finally, Plot a graph for the corrected count rate against time and determine the half life.

Half Life Calculations

Some Worked Examples

1. A Radioactive Material has a half life of 10 days. If the original activity is 240 Bq. What will be the activity after 40 days?
- 240 Bq → 120 Bq → 60 Bq → 30 Bq → **15 Bq** (In 10 Day Intervals)

2. If a radioactive material has a half life of 300 years, how long will it take for the activity to fall to 5 Bq if the original activity was 80 Bq?
- 80 Bq → 40 → 20 → 10 → 5 Bq (In 300 Year Intervals)
- t = 300 x 4
- **t = 1200 years**

3. The activity of a source starts at 200 MBq. After 20 days it has fallen to 12.5 MBq. Calculate the half life of this source
- 200 MBq → 12.5 MBq
- 100: 1, 50: 2, 25: 3, 12.5: 4
- **20 / 4 = 5 days**

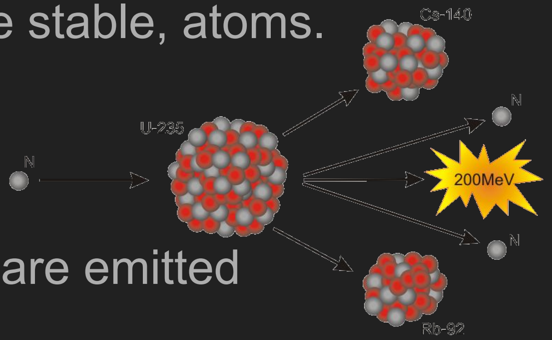
Safety

When Handling Radioactive Materials, you must ensure you are safe whilst doing so. Here are some ways of mitigating radiation absorption

- Increase the distance between you and the sources using tongs
- Work behind Lead Shielding (i.e a screen or apron)
- Keep the time working with the source to a minimum

Nuclear Fission

As well as decaying Spontaneously, an **unstable atom** can be **forced to decay** by **firing a neutron at it**. This is called **Nuclear Fission**. This reaction causes the unstable atom to split into more neutrons and other, more stable, atoms. Sometimes referred to as daughter products



Once a nucleus has divided by fission, the neutrons that are emitted

Can **strike other neighbouring nuclei**, which causes them to split releasing energy each time. This results in a **chain reaction**.

Nuclear Energy

Pros and Cons

Advantages	Disadvantages
Not dependant on weather conditions	Radioactive waste can have a half life of thousands of years
Uses less fuel than fossil fuels	Decommissioning Nuclear Power Stations is very expensive
No Carbon Dioxide or greenhouse gases are produced	If an accident occurs at a nuclear power station, radioactive materials could be released into the environment.

Industry	Used For	How it works	Risks
Medicine	Radiotherapy	Concentrated Gamma Beams are fired at cancer cells, killing them	Healthy Cells are damaged as well.
	Sterilisation	Medical equipment such as syringes are exposed to a source of gamma to kill bacteria and germs on it. This will not make the syringe radioactive	None
	Tracers	These tracers are injected or drank. They are concentrated on organ being examined and emit gamma to be picked up by a gamma detector	Slight Risk of Developing Cancers
Plumbing	Pipes	A leaking pipe can be detected by adding a tracer to the liquid, some of it will leak and more radiation will be detected. This will indicate a leak	Water pipes can be contaminated by radiation
Agriculture	Testing Fertilisers	A Radioactive tracer is added to the fertiliser. The progress of the tracer can be monitored	Risk of Contaminating the soil with radiation.

Nuclear Fusion

Nuclear Fusion is the process of fusing two smaller nuclei into one bigger nucleus e.g 2 Hydrogen Nucleus into 1 Helium Nucleus.

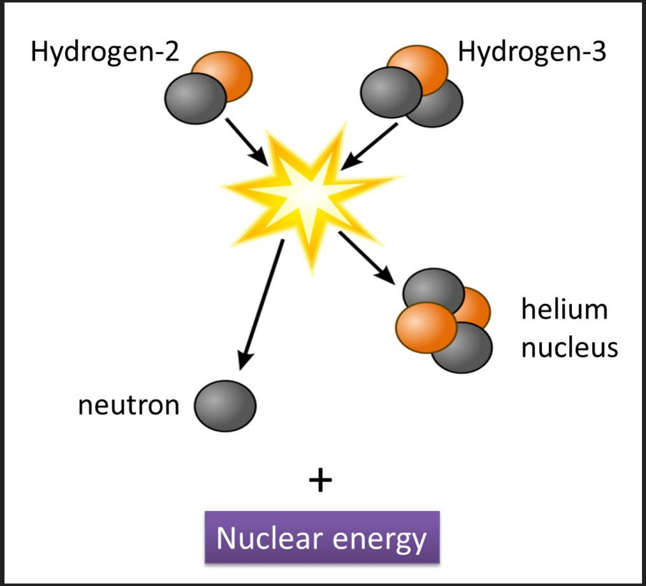
In the future this could theoretically be used as a

Clean source of energy but right now, more energy is

Put into fusing the nuclei together than is gotten back.

The reactors capable of fusing nuclei are expensive

To build and maintain long term.



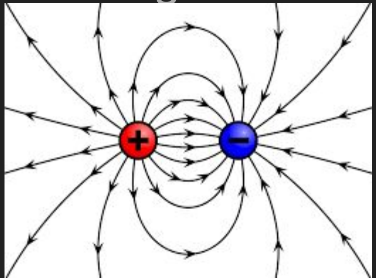
Electricity

Electric Charge

Electricity is the movement of electrons

Charged Particles	Nature of Charge	Found	Attracted To	Repelled By
Electron	Negative	Orbiting Nucleus	Positive	Negative
Proton	Positive	Nucleus	Negative	Positive

Electric Fields are shown as arrows that show the direction a positive charge would move in.



Electric Charge

Formula for Charge: $Q = It$

Q = Charge (C)

I = Current (A)

t = Time (s)

An electric current is when charges move along a field line. These field lines can be inside wires and electrical circuits. The value of the current depends on how many charges are moving per second.

Example

1. $Q = It$
   - 2×20
   - 40 C

AC/DC Supplies

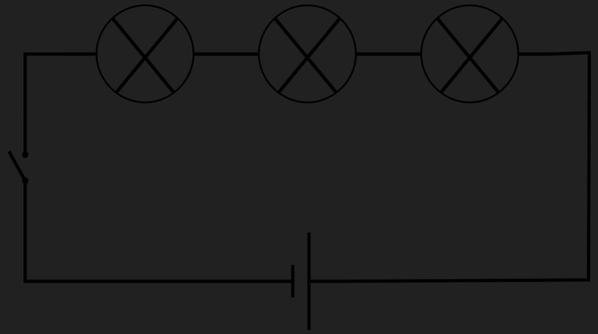
DC	AC
Electrons flow in one direction only	Electrons constantly changing direction
Cells, Batteries, Lab Packs are all DC	Mains, Signal Generator
VPeak = V constantly	VPeak = V

The AC supply only gives 6V at the peak, the actual voltage it delivers is roughly 70% of the peak. Known as ‘quoted’ voltage of AC supply.

Current

Current has the symbol I and is measured in amps (A). It is measured with an ammeter which must be placed in series.

Example of a Series Circuit



Current is the same in all points on a series circuit

Current is different in different points on a parallel circuit: $I_3 = I_1 + I_2$

Voltage

Voltage (or potential difference (p.d)) is a measure of how much energy the electrons in the circuit have.

Units: Volts

Measured By: Voltmeter

Place in Parallel

Example of a parallel circuit

Voltage is different in different points on a series circuit: $V_3 = V_1 + V_2$

Voltage is the same in all points on a parallel circuit: $V_3 = V_1 = V_2$

Current & Voltage

Circuit	Current	Voltage
Series	$I_1 = I_2 = I_3$	$V_4 = V_1 + V_2 + V_3$
Parallel	$I_3 = I_1 + I_2$	$V_4 = V_1 = V_2 = V_3$

Series Circuit: Only one path for electrons to take

Parallel Circuit: Electrons can take different paths around the circuit

Current: How much charge passes a point in one second

Voltage: How much energy per coulomb of charge ($V = E/Q$)

Ohm’s Law: Resistance

When current passes through any material, the material opposes the charges moving through. This opposition to current is called resistance. Resistance is measured in Ohms (Ω) after Georg Ohm, the German physicist.

In general, the resistance depends on the type, thickness, and length of material and its temperature.

- Metals are better conductors than nearly all non-metals. Better conductors have lower resistance.
- Thicker objects have lower resistance than thinner objects made of the same material.
- The resistance of an object increases as its length increases.
- As the temperature of conductors increases the resistance increases.

Using Ohm’s Law

The gradient of the line is the Resistance of the object, measured in Ohms, (Ω).

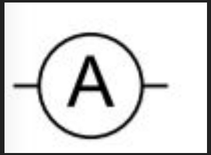
The Resistance can be calculated using: Resistance = Voltage / Current or R = V / I.

(The SQA N5 Relationship sheet and many textbooks rearrange this formula as

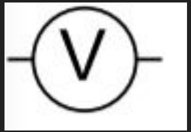
V = IR)

Measuring Current, Voltage & Resistance

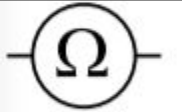
Ammeters measure the current flowing through a component. They are placed in series with the component.



Voltmeters measure the voltage, or potential difference, across a component. They are placed in parallel with the component.

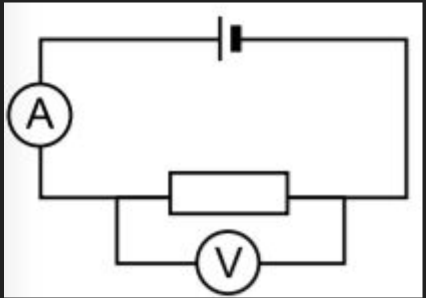


An Ohmmeter measures the resistance of a component. It uses an internal power supply and measures the Voltage and Current it supplies and calculates resistance from those measurements.



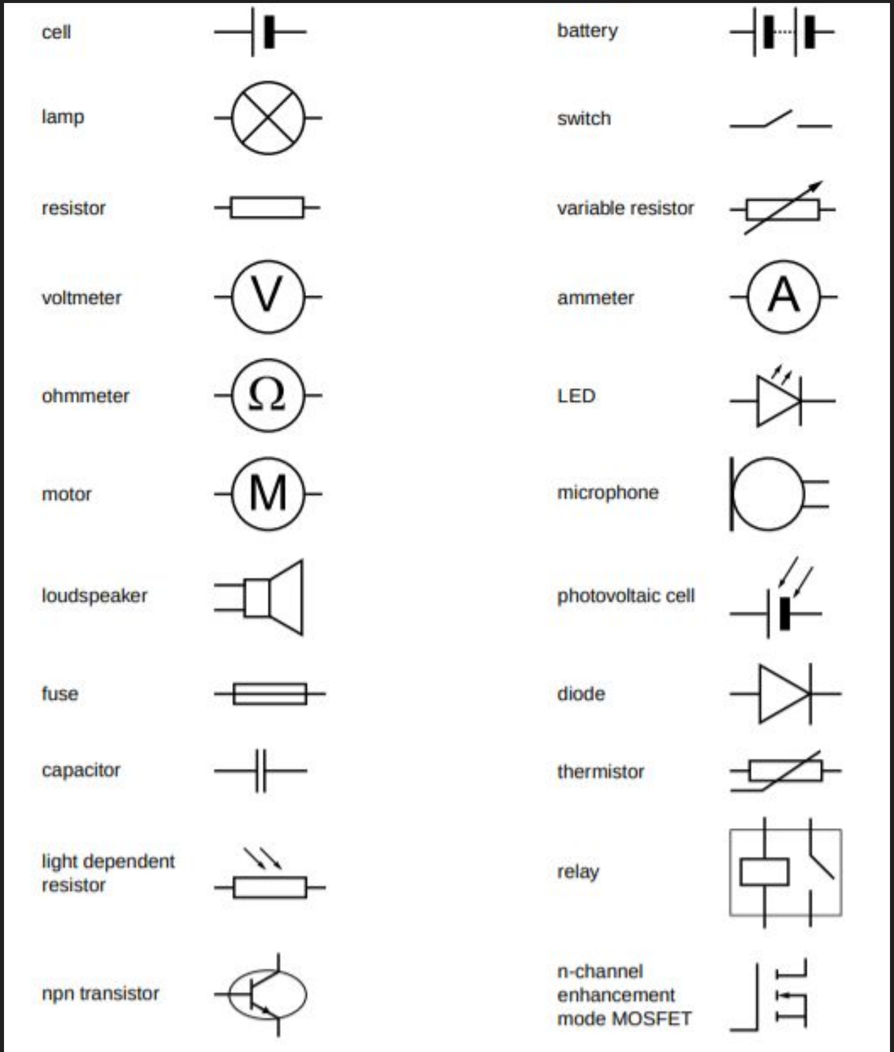
Measuring Current, Voltage & Resistance

To measure the resistance of any component a simple circuit can be made using a battery, voltmeter and ammeter as follows.



Using the ammeter and voltmeter readings the resistance can be found using the Ohm's Law relationship: $R = V/I$

Electrical Symbols



How Transistors in transistor switching circuits work

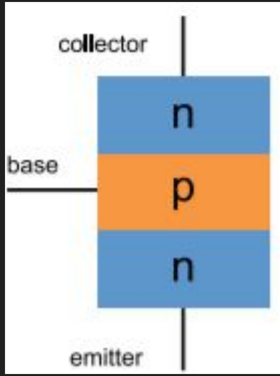
Transistors are voltage controlled electronic switches. A domestic electrical switch switches on and off according to the position of the toggle.

Transistors work on whether the voltage is high or low at a certain point. Transistors can be a single component, as part of a circuit, or part of integrated circuits, thousands at a time on a microchip

Transistors

NPN transistor

An NPN transistor consist of three parts of two types of semiconductor material; n type and n type. Where n and p type join, they create a potential difference where they meet, that must be overcome for current to flow through.



An NPN transistor is set up with an input device connected

to the base and the collector connected to the positive supply

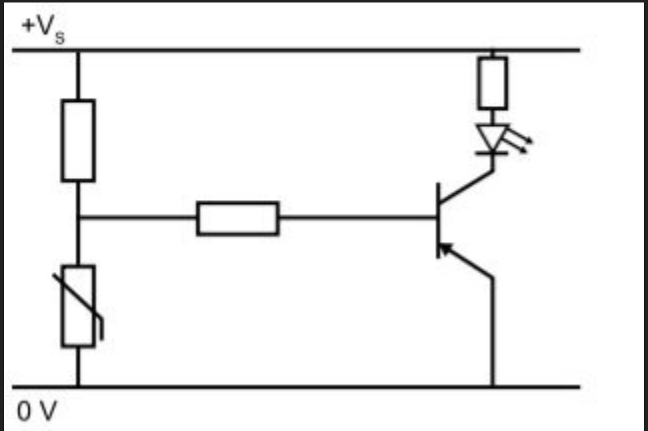
and the emitter connected to the negative supply. To switch

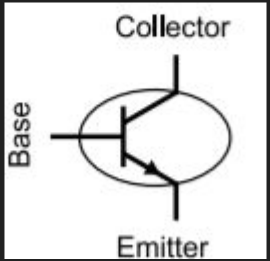
the transistor on the voltage at the base must be above

+0·7 V.This voltage is enough to overcome the potential difference and the electrons flow from through the emitter to the collector.

Transistors

This labelled version of the NPN transistor symbol identifies the parts of the transistor

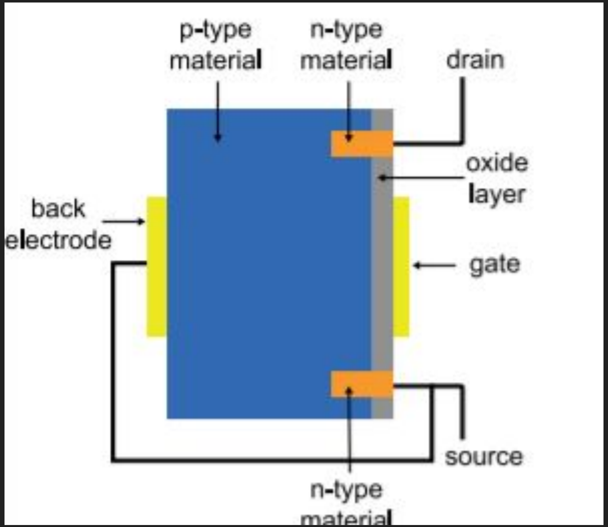




In this circuit the LED will light when the voltage across the thermistor is greater than + 0.7V. The thermistor voltage provides the input voltage to the base. This switches on the transistor and electrons flow from the emitter through the collector to the LED

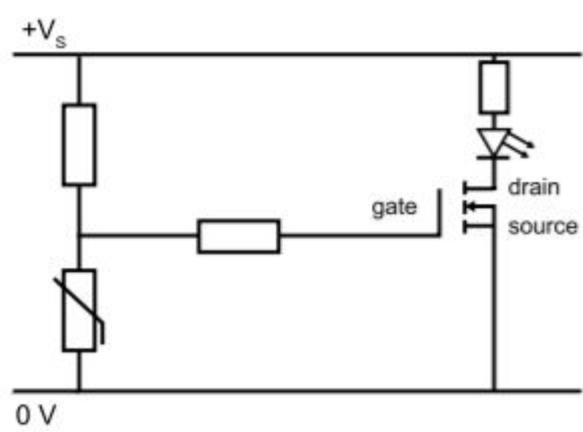
MOSFET Transistors

A Metal Oxide Semiconductor Field Effect Transistor is a different type of transistor switch from an NPN transistor. They operate differently, but both rely on an input voltage to switch them on.



MOSFETs require a positive input voltage greater than +2·0 V applied to the gate. The voltage creates an electric field between the gate and the back electrode. Electrons in the p-type material are attracted to the positive gate. It makes a 'channel' of electrons allowing current to flow through the transistor from the source to the drain.

MOSFET Transistors



In this circuit the voltage across the thermistor provides the input voltage to the gate. When it is above +2·0 V, the transistor switches on and the electrons flow from the source through the channel in the transistor to the drain and onto the LED, lighting it.

Parallel Circuits: Current & Voltage

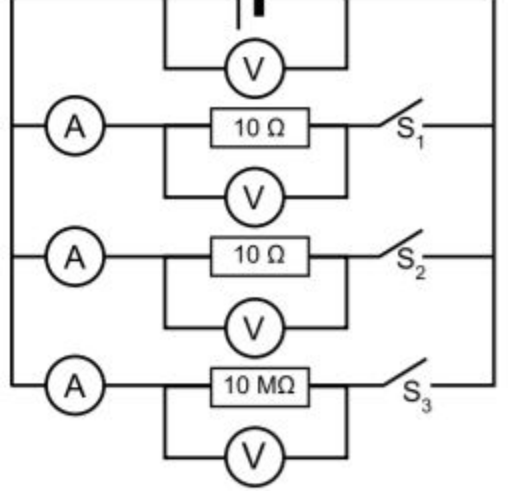
Imagine you are going into a busy concert...

There is only one door to get in, a long line is forming, so the people on the door are trying to get everyone flowing through quickly. A second door opens of the same size, half of those trying to get in now try to get through the second door, the flow doubles as it is now twice as easy to get in.

The number of concert goers hasn't changed, but their flow has increased.

If the organisers opened a door only for wheelchair users not everyone would be able to use it. However, it would make it easier for wheelchair users to get through and again the overall flow would increase.

Parallel Circuits: Current & Voltage



Let's look at this circuit.

This is a parallel circuit, where the current through the

branches is controlled by switches. With S1 only closed.

There is only one branch for the current flow through. The ammeter would show the value of the current that could be calculated using the Ohm's Law relationship.

With S1 and S2 only closed. A second branch opens of the same resistance, half of the charges trying to get around now try to get through the second branch, the flow doubles as it is now twice as easy to get through. The voltage hasn't changed, but the current has increased.

If S3 is also closed there is another branch for the charges to flow through. However, it has a much greater resistance so fewer charges will flow this way, but it would still make it easier for charges to get through and again the overall flow would increase

The relationship for current in a parallel circuit is $I_T = I1 + I2 + I3$

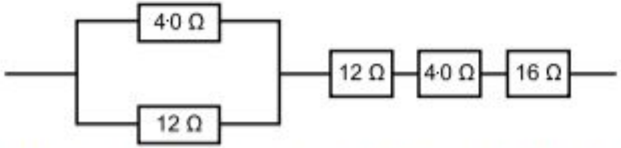
Summary

Quantity	Series Circuit	Parallel circuit
Voltage	$V_T = V_1 + V_2 + V_3$	$V_T = V_1 = V_2 = V_3$
Current	$I_T = I_1 = I_2 = I_3$	$I_T = I_1 + I_2 + I_3$
Resistance	$R_T = R_1 + R_2 + R_3$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Resistance in Complex Circuits

Many useful circuits are made of a combination of series and parallel circuits. To find the voltage, current and resistance in these circuits requires using your problem-solving skills to chunk the problem into smaller parts.

1. Find the total resistance of these resistors.



This circuit is essentially a series circuit with a parallel part. The relationship we should use is $R_T = R_1 + R_2 + R_3 + R_P$

Where R_P is the resistance of the parallel part of the circuit.

Before calculating R_T we first need to find R_P.

We know that:

$R_4 = 4{\cdot}0\ \Omega$

$R_5 = 12\ \Omega$

$$\frac{1}{R_P} = \frac{1}{R_4} + \frac{1}{R_5}$$

$$\frac{1}{R_P} = \frac{1}{4} + \frac{1}{12}$$

$$\frac{1}{R_P} = \frac{3}{12} + \frac{1}{12}$$

$$\frac{1}{R_P} = \frac{4}{12}$$

$$\frac{1}{R_P} = \frac{12}{4}$$

$$R_P = 3\ \Omega$$

So, we now will use these values in our total resistance equation.

We know that:

$R_1 = 12\ \Omega$

$R_2 = 4{\cdot}0\ \Omega$

$R_3 = 16\ \Omega$

$R_P = 3\ \Omega$

$$R_T = R_1 + R_2 + R_3 + R_P$$

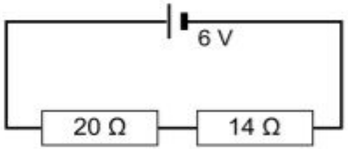
$$R_T = 12 + 4 + 16 + 3$$

$$R_T = 35\ \Omega$$

Voltage Dividers

Voltage (or potential) dividers are a type of series circuit used to control voltages, particularly in electronic circuits. We know that the voltages across the components of a series circuit add up to the supply voltage. In voltage dividers we use fixed value voltage supplies and allow the resistance value of the component to determine the value of the voltage across it.

The most basic voltage divider circuit is made up of two resistors in series with a supply



To find the voltage across each of the resistors our first step would be to find the current in this series circuit using the Ohm's Law relationship.

We know that:
V_S = 6 V
R_1 = 14 Ω
R_2 = 28 Ω

$R_T = R_1 + R_2 = 42\ \Omega$

$V_S = IR_T$
$6 = I \times 42$
$I = \frac{6}{42}$
$I = 0 \cdot 14\ A$

So V_1 = IR_1

$V_1 = 0 \cdot 14 \times 14$
$V_1 = 1 \cdot 96$
$V_1 = 2\ V$

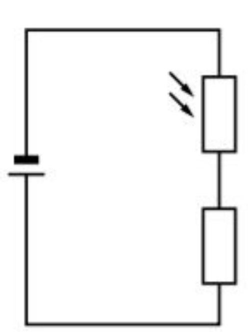
And V_2 = IR_2

$V_2 = 0 \cdot 14 \times 28$
$V_2 = 3 \cdot 92$
$V_2 = 4\ V$

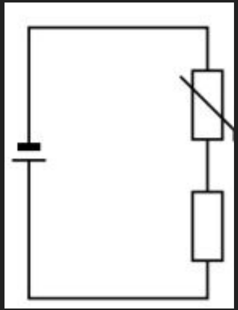
Uses of Voltage Dividers

Voltage dividers are regularly used as sensing devices in electronics. That the voltage changes across components as environmental conditions change means they can be used as input devices.

LDR circuit



Thermistor circuit

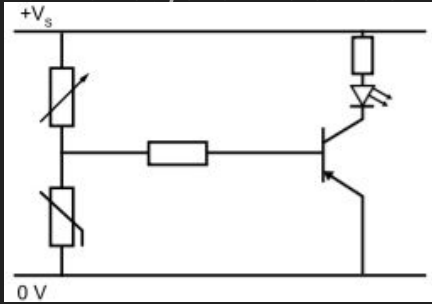


A light dependent resistor (LDR) resistance decreases when more light is incident on it. The lowered resistance decreases the voltage across the LDR. In turn, the voltage across the fixed resistor increases. This might turn on another device such as a lamp.

A thermistor resistance decreases as the ambient temperature increases. The lowered resistance decreases the voltage across the thermistor. In turn, the voltage across the fixed resistor increases. This might turn on another device such as a heater.

Voltage Dividers & Transistors

In this circuit the thermistor sits in a voltage divider as temperature sensing input device

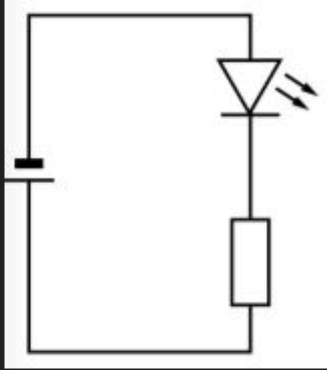


When the temperature decreases the resistance of the thermistor increases. This increases the voltage across the thermistor until it is enough to switch on the base of the transistor. This causes the LED to light. This type of circuit may be used to alert drivers of icy road conditions.

Adjusting the variable resistor can change the temperature that the transistor switches on by adjusting the total resistance of the voltage divider.

By swapping the position of the thermistor and variable resistor the circuit can be altered so that the circuit switches on when it gets warm.

Light Emitting Diode Circuits



Light emitting diodes (LEDs) are an extremely efficient electronic lighting source. They are used from low intensity phone screens and televisions to street and car lighting

They use very little current to operate normally and last longer than conventional light bulbs. They do not generate heat and can reduce electricity bills both in the home, business and for local authorities when used for street lighting. They are easily damaged by larger currents and to ensure they are not damaged LEDs are placed in a voltage divider circuit with a fixed resistor.

The fixed resistor is known as a protective resistor and we use the voltage divider relationships to find their resistance. The LED will have a specified operating voltage and current. The protective resistor needs to be the value that divides the supply voltage correctly. The operating current can allow us to find that value.

Electrical Power

When we talk about things being powerful we often think of large engines of muscles. In physics, powerful objects get work done quickly. Power is the rate at which energy is transferred, it is measured in Watts, (W). One Watt is the same as one Joule per second.

Power is calculated using the relationship, $P = E / t$

Electrical appliances do work when current flows through them. They convert electrical energy into what we would want e.g movement in a motor, or light from a lamp, but also transform it into forms we don't want such as sound from the motor or heat from a lamp.

High power appliances often transform electrical energy to produce heat, for example hair straighteners. We often say these devices consume power.

Electrical appliances often have a power rating, this describes the energy transformed per second when the appliance is working normally.

Power, Current & Voltage

High power items such as cookers and hair dryers typically draw a large current. Current is how many charges flow through a point per second. 1 Ampere is 1 Coulomb per second. A high current means more charges available to carry current round the circuit.

High voltage appliances provide each coulomb of charge with more energy than low voltage appliances. 1 Volt is 1 Joule per Coulomb. Higher voltage appliances can have higher power.

The most powerful appliances have high voltage and high power. If we multiply current and voltage together then we multiply each coulomb per second by the energy per coulomb to find the energy per second, also known as the Power.

i.e. $V \times I = J / C \times C / s = J / s = W$

This means that Electrical Power can be calculated using this relationship, $P = IV$

Ohm’s Law & Power

Ohm's Law states $V = IR$

So, we can write our relationship for Power as $P = I \times I \times R$ or $P = I^2R$

We can also rearrange Ohm's Law so that $I = V / R$, substituting this into $P = IV$ we get $P = V / R \times V$ which simplifies to $P = V^2 / R$

Fuses

Fuses are safety devices used to protect the flex of an appliance or the wiring of a circuit. If too much current was to flow through the flex, the insulation surrounding the copper wire may melt. This could lead to wires being exposed and the potential for someone to touch a live wire or for a fire to start.

Fuses typically are made from a short length of wire. The wire melts if the current exceeds a certain value. The type or thickness of the wire determines the current value at which it melts. The fuse in this picture has a glass surround rather than card. It shows the thin wire that is the fuse

If we know the power and it’s plugged into the 230V mains, then we can find the current using $P = IV$. The fuse value must be large enough to allow the appliance to operate normally. So, if a TV uses 3 A of current, then a 13 A rather than 3 A fuse should be used.

Properties of Matter

Heat & Temperature

"I can't stand the heat!" "It's too hot!" We can hear these expressions on a warm summer's day. Like weight and mass, lots of people talk about heat and temperature as the same thing when in science we regard them as separate things.

Heat is a form of energy transfer, measured in Joules (J). Heat takes energy from a hot place and transfers it to somewhere cooler. Conduction, convection, and radiation can do this. The increase in energy becomes movement in the particles inside an object.

Temperature measures the average kinetic energy of the particles within an object. Temperature is measured in degrees Celsius ($^{\circ}C$) or Kelvin, (K). When heat energy enters an object, the particles move quicker and their average kinetic energy increases. This kinetic energy increase is a rise in temperature

Heat always travels from a hotter area to a cooler one. When it does it takes some of the kinetic energy of the particles in the hotter area and transfers it to the colder area. The particles in the colder area gain the kinetic energy. The hotter area decreases temperature and the colder area increases in temperature. The temperature change in each may not be the same.

The hot gas of the flame loses some of its kinetic energy. The energy transferred as heat to the test tube. Increasing the kinetic energy of the particles in the test tube, so its temperature goes up.

Specific Heat Capacity

When we look at the test tube in the picture above, we would probably predict that the temperature of the liquid would increase more than the temperature of the glass.

Even if they had the same amount of heat transferred to each, the temperature rises are likely to be different for each of them.

In every substance, the particles that make them up are held in different arrangements. These different set ups mean that the particles ability to increase or decrease their movement is unique to the substance. We call this unique term the substance or material's specific heat capacity, c, measured in Joules per kilogram per degree Celsius, ($J\ kg^{-1}\ {}^{\circ}C^{-1}$).

States of Matter

There are three states of matter: Solid, Liquid & Gas

Materials either gain or lose energy as they go from one state to another.

The energy transferred from going from solid to liquid is the same as the energy transferred from going from liquid to solid

The direction of energy flow is what changes.

The process of going from:

- solid to liquid is called fusion
- liquid to gas is called vaporisation

Latent Heat

A puddle with ice in it is a common sight in a Scottish winter. We know that the freezing point of water is 0 $^\circ$C. We also know that the melting point of ice is 0 $^\circ$C. If we look closely at this picture, we find both ice and water in the puddle. How can they exist side by side?

A puddle with ice in it is a common sight in a Scottish winter. We know that the freezing point of water is 0 $^\circ$C. We also know that the melting point of ice is 0 $^\circ$C. If we look closely at this picture, we find both ice and water in the puddle. How can they exist side by side?

Solids and liquids of the same material have similar densities. However, particles in a liquid state have higher energy than those in a solid state. This, in part, allows these particles to flow and act like liquids. The particles must absorb this energy, and it takes time for all the water particles to gain energy to become liquid. During this change the temperature of the water and ice stays constant at 0 $^\circ$C and we can have water and ice at the same temperature beside each other.

In the same way, the puddle doesn't freeze instantaneously. The energy of the particles in the liquid state needs to be lost for them to become a solid. We see this when we put water in the freezer to make ice cubes. If we take them out too soon, we still get water.

Latent Heat

We call the energy required to change the state of 1 kg of material the Specific Latent Heat. Specific Latent Heat is measured in Joules per kilogram, J kg^{-1} The energy required to change state can be calculated from this relationship:

$E_H = mL$

The greater the mass of a substance, the more energy is required to change state.

Turning a liquid into gas requires much more heat energy than turning the same mass of solid into a liquid. Substances have two latent heat values, one for fusion and one for vaporisation.

Heat

The specific heat capacity, specific latent heat and melting point of materials have a significant impact on the design and engineering of vehicles that travel outside the Earth's atmosphere and return

During re-entry, spacecraft loses kinetic and gravitational potential energy. Nearly all of it is converted into heat.

Materials need to be strong enough to deal with the immense forces acting on the vehicle. They also require a high melting point to ensure they don't turn to liquid, and high specific latent heat so that if temperatures do get too high, they can last longer. All this while making sure that the temperature inside the vehicle is cool enough to protect its occupants or payload.

Returning from the space station can cause vehicles to increase in temperature, and potentially melt. Before we look at these examples, let's look at what happens to everyday objects

Heat

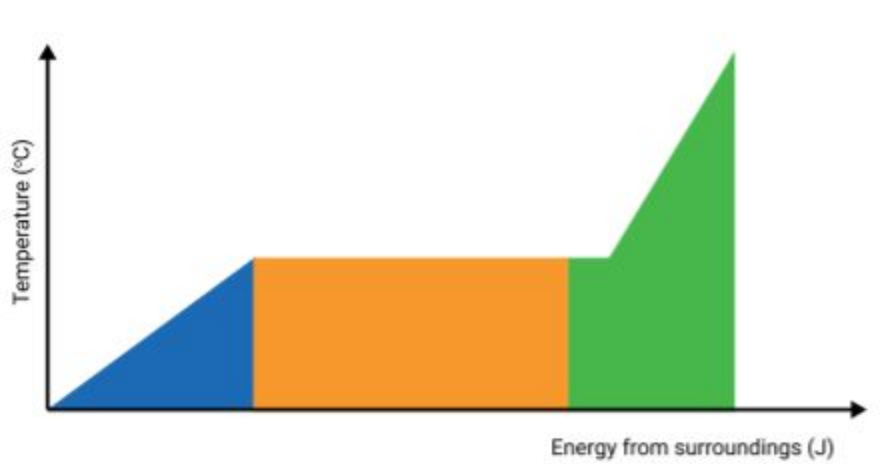
Unfortunately, we have all experienced an ice cream melting. Ice cream is typically stored in freezers at about -10 °C. Depending on the type, ice cream has a melting point of -2 °C. So why does the ice cream not melt immediately on a 22 °C sunny day?

When taken out of the freezer the temperature is below the melting point. The air surrounding the ice cream causes the temperature of the ice cream to increase. The temperature increases until the ice cream reaches its melting point. The rate of increase in temperature is determined by the mass of the ice cream and the specific heat capacity of the solid ice cream.

Once the ice cream has reached its melting point temperature, the temperature of the ice cream stays constant as it changes state. All the heat energy going into the ice cream is turning the solid ice cream into a liquid. The rate of change from solid to liquid is determined by the mass of the ice cream and the specific latent heat of the ice cream.

The liquid ice cream, now a runny mess, increases temperature until it the same temperature as the air around it. The rate of increase in temperature is determined by the mass of the ice cream and the specific heat capacity of the liquid ice cream. We are left with warm ice cream, not as nice as cold pizza.

Heat



A graph of the temperature change may

look like this:

The blue section is when the ice cream is solid, the

heat energy can be determined from $E_H = cm\Delta T$.

• The orange section is when the ice cream is going from solid to liquid, the heat energy can be determined from $E_H = mL$. Notice that the temperature remains constant throughout, this section.

• The green section is when the ice cream is liquid, the heat energy can be determined from $E_H = cm\Delta T$.

The ice cream doesn't melt straight away as this process is not instantaneous.

The same principles apply when we go from liquid to gas, such as boiling water in a kettle. If all the water turned to steam straight away, we'd never get a cup of tea.

Heat & Re-entry

As we mentioned before, as a spacecraft's velocity is reduced on re-entry its kinetic energy is transferred to heat. The more work done, either by increased force or greater distance, the more the craft is slowed, and the greater amount of heat generated.

We can expect the outside of the spacecraft to increase in temperature. In some occasions the layer at the front of craft is designed to change state, to prevent heat conducting into the inside of the craft. But too much would leave nothing to protect the occupants on landing.

Tiles made from silica were used on the space shuttle and many other reusable spacecraft since then. Silica tiles have very high melting points and low thermal conductivity. Tiles have the advantage of being replaceable if any fall off or are damaged during a spaceflight. The black side was good at radiating heat away from the surface.

Gas Laws

Pressure

Pressure is the name given to force applied over an area, when objects push against another object. It can be useful to talk about pressure rather than force, especially a force is spread out over a large rather than small area.

If the surfer tries to stand on the surface of the sea they'll sink. By standing on the surfboard they increase their weight. But more importantly they have spread their weight over a greater area. This means that the water particles can provide enough upthrust to the surfboard to keep the surfer and board afloat.

When an airbag deploys it reduces injury due to the force of impact in two way. As well as increasing the distance the force is applied to do the same work and so reducing the force. The airbag also increases the contact area of the impact between your head and the dashboard reducing the pressure at each point on you

A blunt rod of metal would be hard to push into a piece of wood. But if the end is sharpened to a point, the greater pressure allows it to pierce the surface

When dealing with pressure, like friction, there are times when both high and low pressures are useful.

$p = F / A$

Pressure can be measured in a variety of units. Newtons per square metre, N m-2. This is equivalent to Pascals, Pa. 1 Pascal equals 1 N m^{-2}

Pressure in Gas

Gas particles are always moving around the space they are in.

When they rebound off the side of a container, the container applies a force to the gas particle to change its direction. Newton's third law, for every action there is an equal and opposite reaction, means that the particle must also apply a force on the container. The force each particle can apply may be very small. However, lots of particles can add to create a large force. The air particles in the tyres of a bus keep the bus off the ground.

The 27 km ring of the Large Hadron Collider at CERN sits on a cushion of air to protect from the effects of the nearby airport shaking the ground and the moon causing tides in the rock surrounding it.

The Kinetic Model

Kinetic model of gases explains pressure, temperature, and volume, by looking at the motion of the particles of gas. The kinetic theory model is based on the idea that gas pressure results from particle collisions with the walls of a container at different speeds.

The kinetic model uses some assumptions as it makes these explanations.

Particles are all the same size and spherical.

Particles move in random directions.

Particles do not experience other forces e.g. magnetism or gravity.

Particles do not lose any kinetic energy when they collide.

Particles have the same mass.

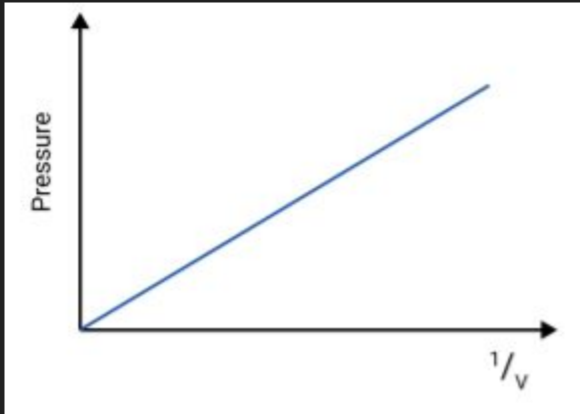
Scottish Botanist Robert Brown saw a pollen grain burst when looking through an optical microscope. The pollen grains jiggled around in the water in random fashion. This type of random movement is now known as Brownian motion. You can see Brownian motion when you look at the vapour above a really hot cup of tea.

Pressure & Volume

When the hand squeezes the ball in the picture, the volume of the ball reduces. As it squeezes in the ball presses harder against the hand, the pressure of the air inside the ball has increased.

Boyle's Law describes the relationship between the volume of a gas and the pressure of the gas inside a container when the temperature and mass of the gas is constant. It says that the pressure of gas inside a container increases as the volume container decreases

The graph of pressure against volume is a curved rather than straight line. This makes it harder to determine a relationship however a graph of p vs 1/V shows a straight line through the origin.



Pressure & Volume

The graph tells us that Pressure is indirectly proportional to Volume, if the temperature and mass of the gas remain constant. The gradient of the line equals a constant that depends on the mass of the gas and the type of gas it is. As the line is constant, we can use this expression to find an unknown pressure or volume.

p_1 is the initial pressure of the gas

V_1 is the initial volume of the gas

p_2 is the final pressure of the gas

V_2 is the final volume of the gas

Pressure is measured in units other than Pascals, (Pa). Volume can be measured in litres, cm^3 and m^3. Provided the units are consistent throughout the calculation, the relationship still holds true.

Pressure, Volume & The Kinetic Model

The kinetic model can explain the relationship between pressure and volume.

As the volume of an object increases, the particles of the gas take longer to reach the sides of the container. Fewer collisions reduces the average Force, reducing the pressure of the gas.

Conversely, a smaller volume means more collisions, a greater average Force and a greater pressure.

Pressure, Volume & The Kelvin Scale

Remember we said that temperature is different from heat. Temperature is a measure of the average kinetic energy of particles in a material.

Remember we said that temperature is different from heat. Temperature is a measure of the average kinetic energy of particles in a material.

These canisters usually come with a warning to store them in a cool dark space. What might happen if someone careless left one out in the sun on a warm summer's day?

The particles inside the canister would get heated and absorb energy. That energy would be transferred to kinetic energy and the particles would start to move faster. They would collide with the sides of the canister more often and with more force. This increases the pressure of the gas on the walls of the canister. Fortunately, these thick walls are designed to stay in shape under pressure. However, if the temperature inside the canister was great enough, the pressure could become so high as to blow the valve off the canister.

The Pressure Law explains the relationship between pressure and temperature for a fixed mass of gas with a fixed volume. This law is often referred to as Gay-Lussac's law.

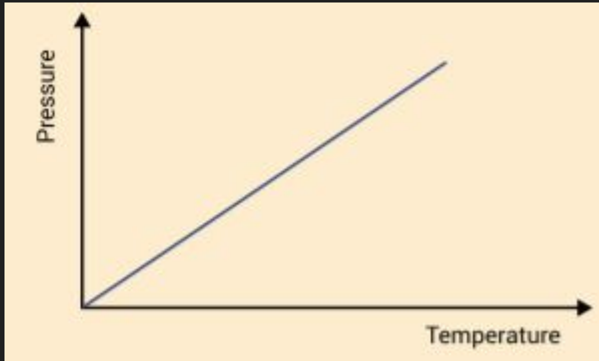
Pressure, Volume & The Kelvin Scale

The Pressure Law / Gay-Lussac's law

The pressure of a gas of fixed mass and fixed volume is directly proportional to the gas's absolute temperature.

It means if a gas's temperature increases, then its pressure does too, when the mass and volume of the gas are held constant.

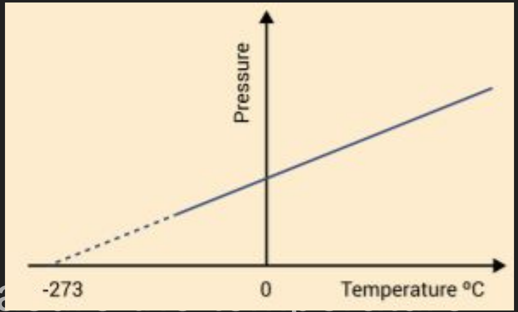
A graph of pressure against temperature looks like this



Pressure, Volume & The Kelvin Scale

The line of the graph goes straight through the origin, directly proportional. This suggests when the temperature is zero then pressure is zero. But the gas in a balloon still exerts pressure on a freezing cold day. So how can this be?

We need to have a new zero.



The problem was not the science, but the scale used to mea
The Celsius scale was useful but did not go low enough. Scientists measured the pressure for as cool a temperature as could be managed. The solid line shows these measurements. The dashed line shows how the scientists extended, (extrapolated), the line to find the Absolute Zero.

This is at -273 °C and absolute zero is the start of the Kelvin scale. One Kelvin, 1 K, is the same increase in temperature as 1 °C. So, 0 °C equals 273 K.

Gay-Lussac's Law

This allows Gay-Lussac's law to be expressed mathematically as:

$P_1 / T_1 = P_2 / T_2$

where:

p_1 is the initial pressure of the gas

T_1 is the initial temperature of the gas in Kelvin

p_2 is the final pressure of the gas

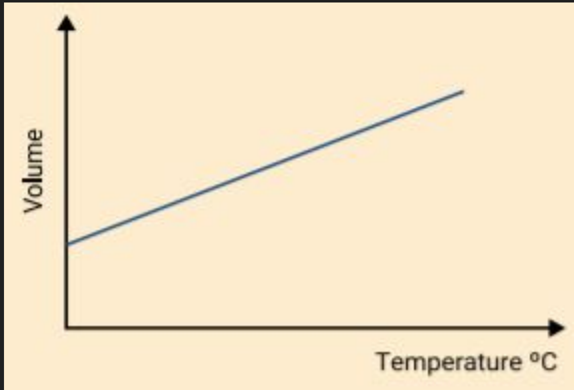
T_2 is the final temperature of the gas in Kelvin

Volume & Temperature

Hot air balloons use the temperature of a gas to rise and fall. They are an application of Charles' Law. When heated, gas particles in a hot air balloon move more quickly. The gases expand and take up more space, increasing the volume of the balloon. The increase in volume creates the conditions that balloons need to rise off the ground. The gas inside the balloons become less dense than the air around them. The decrease in the density causes it to float. If gas cools the density increases and it deflates, returning to the ground.

Charles' Law describes the relationship between the volume of a gas and the temperature of the gas inside a container when the pressure and mass of the gas is constant

It says that the volume of gas inside a container increases as the temperature inside the container increases.



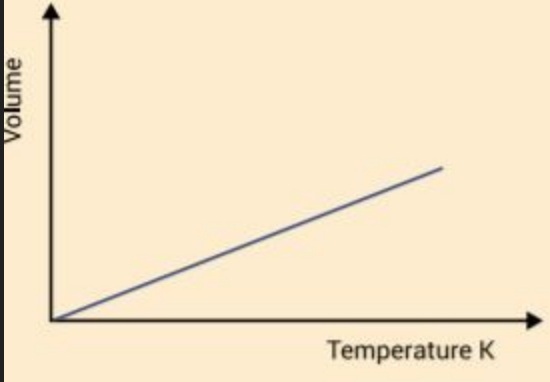
Volume & Temperature

You will see from the simulation that a graph of volume against temperature is a straight line. This is described as a linear relationship as the straight line does not pass through the origin.

This makes sense as the volume of a tyre does not become zero on a cold day. But what would the graph look like if we change the units of temperature from degrees Celsius to Kelvin?

Now the graph describes a directly proportional relationship.

As we approach absolute zero the particles are moving so slowly that they exert little force individually so if the pressure remains constant the volume reduces.



Volume & Temperature

The relationship between volume and temperature is

$V_1 / T_1 = V_2 / T_2$

where:

V_1 is the initial volume of the gas

T_1 is the initial temperature of the gas in Kelvin

V_2 is the final volume of the gas

T_2 is the final temperature of the gas in Kelvin

The General Gas Equation

Three different experiments have given rise to three different equations. What they all have in common is that they are all for a fixed mass of an ideal gas, and that any temperature is measured in Kelvin.

This means the equations combine to form the general gas equation.

$p_1V_1 / T_1 = p_2V_2 / T_2$

Dynamics

Vectors & Scalars

Vectors & Scalars

In physics, we describe the world around us through expressions called formulas and by measurements of quantities. For some quantities, especially in Dynamics and Space, it makes sense to include the direction of travel to describe these quantities.

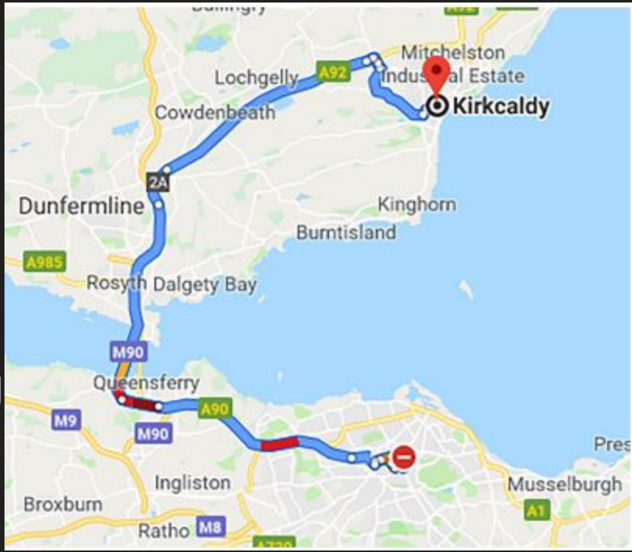
For example, a car changing speed from 20 ms^{-1} to 50 ms^{-1} can have a difference of 30 ms^{-1} or 70 ms^{-1} depending on which direction the car is travelling to start with and the direction in which it finishes.

So, while the starting speed may have the same magnitude, or size, its direction is important. We call the number value, or magnitude alone, the car's speed. Speed is a scalar. The number value along with the direction is the car's velocity. Velocity is a vector.

Vectors & Scalars

Have you ever searched using a maps website or an app for a shop or restaurant online? Often, websites list them by how far away they are. These maps measure the straight-line distance between your location and where you might want to go. The distance quoted is not the actual distance you would travel. Rivers, bridges, and buildings mean that it's unlikely that the route you travel will be a straight line.

Vectors & Scalars



In the example illustrated, travelling from Kirkcaldy to Edinburgh by car means using the Queensferry Crossing.

The distance travelled is 58 km. The straight-line distance, driving through the Forth Estuary, is 19 km, but not very practical.

The straight-line magnitude and direction of a journey is its displacement. As it has a direction, it is a vector.

The 19 km from Kirkcaldy to Edinburgh is the magnitude of the displacement of going between the two. The direction is 5° West of South. We'll explain this more when we look at adding vectors.

Vectors & Scalars

Scalars	Vectors
Speed	Velocity
Distance	Displacement
Mass	Weight
Energy	Force
Time	Acceleration

Distance is the scalar equivalent of displacement and doesn't need a direction. It has the symbol, d, and is measured in metres (m).

Displacement is the effective distance travelled, but it needs a direction. Its symbol is s, and is also measured in metres (m).

Most school days, most of us will go into the same school building. No matter how far away home is, the school stays in the same place. For all the students and teachers, the effective distance they have travelled from morning bell to morning bell is 0 km. Depending on where the students and teachers have been, the distance they have travelled in that day can be very different.

Some of the vectors and scalars you will meet at sorted in the following table.

Speed & Velocity

Speed & Velocity

We are all familiar with speed. At National 5 we want to sharpen up the definition of speed. Speed is the rate of change of distance. As a scalar it does not have a direction. As a scalar it can be used to calculate another scalar, distance, from:

distance = speed × time *or* $s = v \times t$

You need to be careful here. You'll see that both speed and velocity have the symbol v but are different things. You may sometimes see speed written as instead.

Instantaneous & Average Speed

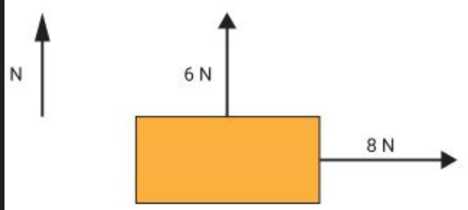
When driving between the centre of Kirkcaldy and the centre of Edinburgh your speed would change at different points in the journey. Even if there were no delays, you would be expected to travel at slower speeds in the city that on the motorway and dual carriageways. The speed at one point in the journey is the instantaneous speed. The speed at that instant of time, or that location. The overall speed for the journey is the average speed.

At National 5 you are expected to be able to describe an experimental method of measuring both the instantaneous and average speed.

Adding Vectors

As vectors have a size and direction, so we draw them using an arrow to indicate both. The point of the vector is call the 'tip' or the 'nose', the starting point is the 'tail'.

Two methods are suitable for adding vectors at right angles. Both start from the same addition rule. When adding vectors we complete one action before starting the next so we add vectors 'nose' to 'tail'.



Solution:

Method 1: Scale diagram

This method is really useful if you are not too confident with trigonometry or are planning to go on to Higher. The following video shows you how to draw an accurate **scale diagram**.

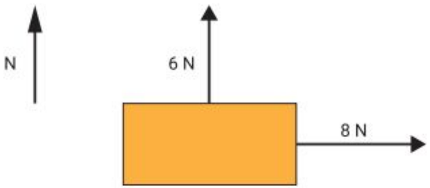
In this method, we measure out the vectors, scaling if necessary. In the video, 1 cm represents 1 N. The size of the resultant is 10 cm, which scales to 10 N. But as it's a vector, it needs a direction. Using a protractor, we find the angle is 53° East of North.

Adding Vectors

Example : Adding vectors at right angles: Pythagoras and trigonometry

Problem:

A box is pulled by two forces as shown. Calculate the resultant force.

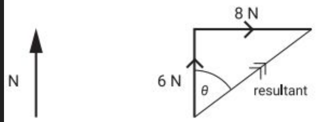


Solution:

Method 2: Pythagoras and trigonometry

If you are confident in using sine, cosine and tan, this method is quick and easy.

First, draw out the nose to tail addition, this time it does not need to be to scale.



Use Pythagoras to find the size of the resultant force, F

$$a^2 + b^2 = F^2$$
$$6^2 + 8^2 = F^2$$
$$100 = F^2$$
$$F = \sqrt{100}$$
$$F = 10N$$

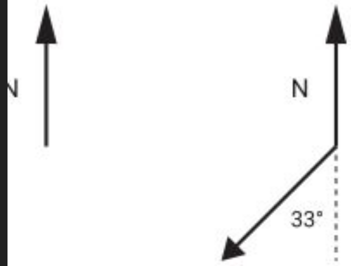
To find the angle, we use trigonometry. We have the length of the opposite and adjacent to the angle θ.

Therefore, from soh, cah and toa, we use tan.

$$\tan\theta = \frac{opposite}{adjacent}$$
$$\tan\theta = \frac{8}{6}$$
$$\theta = \tan^{-1}\left(\frac{4}{3}\right)$$
$$\theta = 53°$$

The Resultant Force is 10 N at 53° East of North.

We use three figure bearings when describing and adding vectors with geographic direction. It makes describing the direction easier than phrases such as 53° East of North. The cardinal points of North, East, South and West are 000°, 090°, 180°, and 270°. So in our previous example, the force is 10 N at 053°.



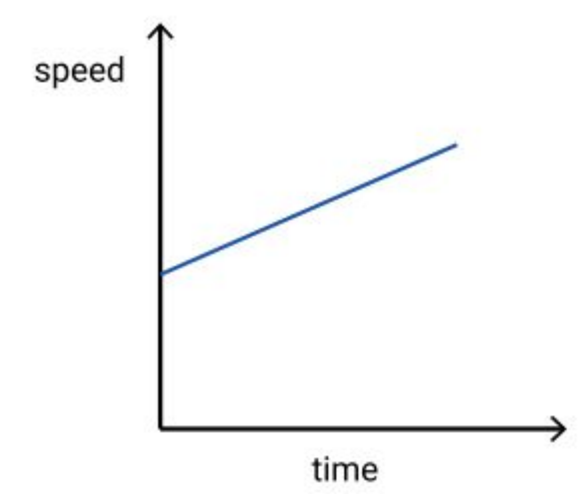
Solution:

In this situation, the vector is 33° West of South. As a three figure bearing 180° + 33° = 213°

Note: in the diagram there is a reference North drawn, with a parallel North drawn at the start of the vector. It is from this reference that all bearings are determined.

Speed-time & Velocity-time graphs

While measurements and calculations provide the values, speed-time and velocity-time graphs make it easier to describe the motion of an object than a table of results. These graphs allow us to make calculations and provide additional information.



We will now look at each of these more closer

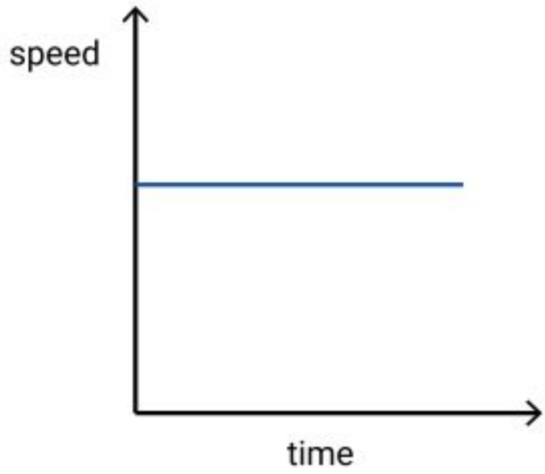
The first graph shows uniformly increasing speed.

The straight line is at an angle to the horizontal.

We will see later how the gradient of the graph allows us acceleration of the motion.

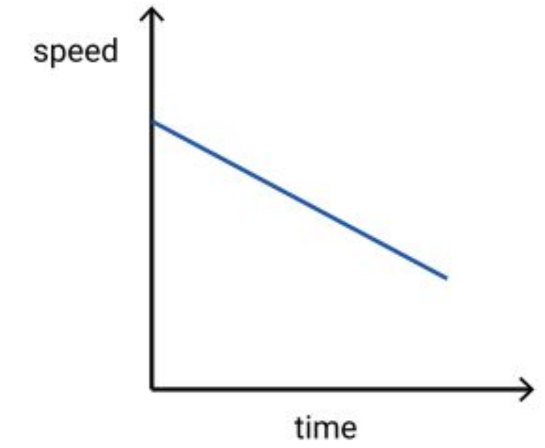
Speed-time Graphs

The second graph shows constant speed. Here the line is parallel to the time axis.



The third graph shows uniformly decreasing speed.

The straight line is angled down to the horizontal. Here the gradient of the graph allows us to calculate the deceleration of the motion.



At National 5 level, the motion you are asked to describe will always be uniform.

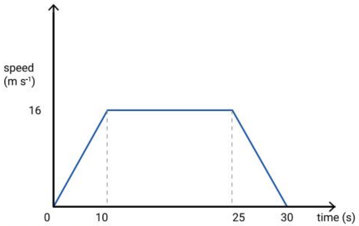
Finding the Distance travelled from a Speed-time graph

The area under a speed-time graph gives us the distance travelled by an object. Remember that both distance and speed are scalars. Rectangles and triangles make up these graphs.

2.

Problem:

The following speed-time graph shows the motion of a bus in traffic.



Describe the motion:

a) between 0 and 10 seconds;
b) between 10 and 25 seconds;
c) between 25 and 30 seconds.

Find the distance travelled and the average speed.

Solution:

a) Between 0 and 10 seconds, the bus is accelerating uniformly.
b) Between 10 and 25 seconds, the bus is travelling at a constant speed.
c) Between 25 and 30 seconds, the bus is decelerating uniformly.

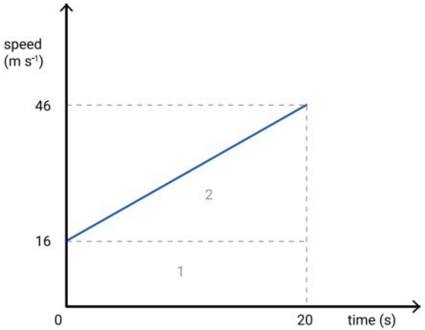
distance travelled = area under distance - time graph

$$\begin{aligned} d &= area\ 1 + area\ 2 + area\ 3 \\ &= (0\cdot 5 \times 10 \times 16) + (15 \times 16) + (0\cdot 5 \times 5 \times 16) \\ &= 80 + 240 + 40 \\ &= 360m \end{aligned}$$

$$\begin{aligned} average\ speed &= \frac{distance}{time} \\ \bar{v} &= \frac{d}{t} \\ &= \frac{360}{30} \\ &= 12 \text{ m s}^{-1} \end{aligned}$$

Problem:

The speed-time graph for a car travelling a long a motorway is shown as follows.



Find the distance travelled and the average speed.

Solution:

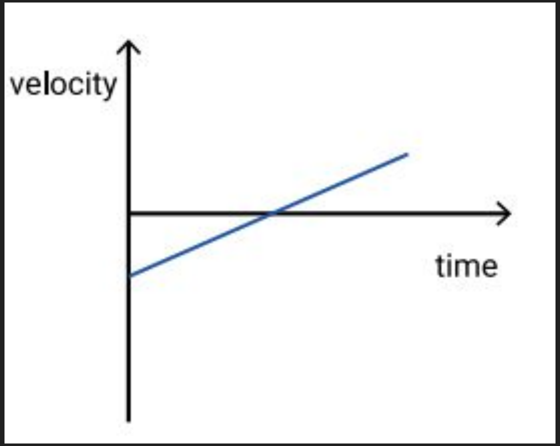
distance travelled = area under distance - time graph

$$\begin{aligned} d &= area\ 1 + area\ 2 \\ &= (20 \times 16) + (0\cdot 5 \times 20 \times (46 - 16)) \\ &= 320 + 300 \\ &= 620\text{m} \end{aligned}$$

$$\begin{aligned} average\ speed &= \frac{distance}{time} \\ \bar{v} &= \frac{d}{t} \\ &= \frac{620}{20} \\ &= 31 \text{ m s}^{-1} \end{aligned}$$

Velocity-time Graphs

Drawn for one dimension of motion. A direction is set as positive. The area under a velocity-time graph gives us the displacement travelled by an object. Remember that both displacement and velocity are vectors.



Again, there are three core graphs to describe motion.

The first graph shows uniformly increasing velocity.

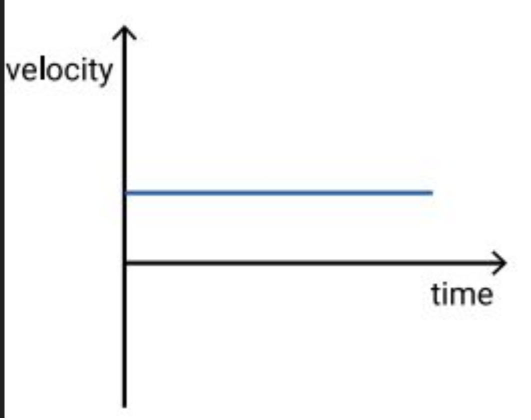
The straight line is at an angle to the horizontal. Note that the object in this motion changes direction when v = 0. The decrease in velocity in the negative direction is the same as an increase in velocity in the positive direction.

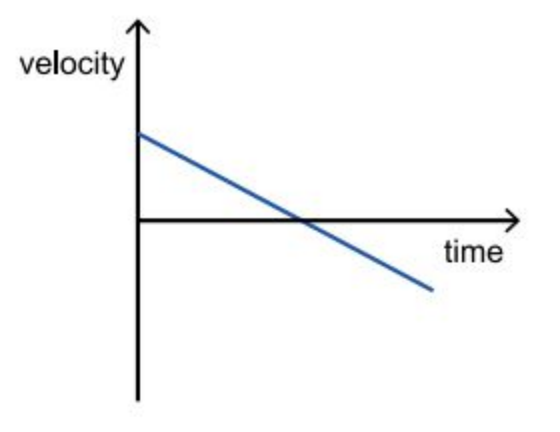
Velocity-speed Graphs

The second graph shows constant velocity

The last graph shows uniformly decreasing velocity.

Again the object changes direction when v = 0.



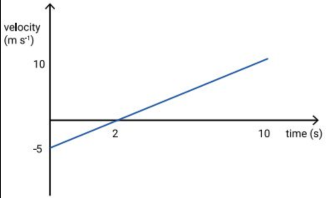


Finding the Displacement Travelled from a Velocity-time Graph

The area under a velocity-time graph gives us the displacement of an object from its original position. Remember that both displacement and velocity are vectors. Rectangles and triangles make up these graphs

Problem:

The following graph describes the motion of remote controlled lawnmower.



Describe the motion:

a) between 0 and 2 seconds;
b) between 2 and 10 seconds.

Find:

i. the displacement of the lawnmower after 10 seconds;
ii. the average velocity of the journey.

Solution:

a) Between 0 and 2 seconds, the lawnmower is accelerating uniformly.
b) Between 2 and 10 seconds, the lawnmower is accelerating uniformly.

i.

$$\begin{aligned} displacement &= area\ under\ velocity - time\ graph \\ s &= area\ 1 + area\ 2 \\ &= (0 \cdot 5 \times 2 \times -5) + (0 \cdot 5 \times (10-2) \times 10) \\ &= -5 + 40 \\ &= 35m \end{aligned}$$

(Here, the positive value is enough to give direction to the vector.)

ii.

$$\begin{aligned} displacement &= average\ velocity \times time \\ s &= \bar{v} \times t \\ 35 &= \bar{v} \times 10 \\ \bar{v} &= \frac{35}{10} \\ &= 3 \cdot 5 \text{ m s}^{-1} \end{aligned}$$

Acceleration

Acceleration

Acceleration is a term we hear a lot in describing when objects move around. When using the term in physics we must be careful to use the language properly.

Acceleration (a) is the rate of change in the velocity of an object. To calculate the vector, we must use the vector quantities of velocity rather than its scalar equivalent speed.

$$acceleration = \frac{change\ in\ velocity}{time\ interval\ for\ the\ change}$$

$$acceleration = \frac{final\ velocity - initial\ velocity}{time\ interval\ for\ the\ change}$$

$$a = \frac{v - u}{t}$$

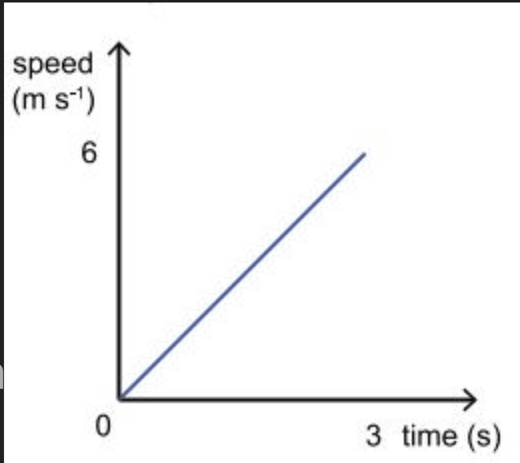
Where v is the final velocity, u is the initial or starting velocity and t is the time for the change to occur

Acceleration

The initial and final velocities are instantaneous velocities. These are the velocities at a location or a point in time, over as short a distance or as short a period as possible.

If a train has an acceleration of 2 m s^{-2}. This means that the train's velocity increases by 2 ms^{-1} every second. So, if it is pulling away from a platform, after the first second it will reach 2 ms^{-1}, after the second second the train's velocity will have increased by another 2 m s^{-1} to 4 m s^{-1}. After the third second the train will be travelling with a velocity of 6 m s^{-1} and so on.

Acceleration



This steady increase is shown on a velocity-time graph like this

The gradient of this line is 2, the same value as the acceleration

We can use the gradient of the line to find the acceleration in all speed-time graphs.

Newton’s Laws

Newton’s 1st Law

Newton's first law rather grandly states "In an inertial frame of reference, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force."

You may have even heard this version "A object will continue in its state of motion either at rest or travelling at a constant velocity, unless acted upon by an external unbalanced force."

The second version is potentially easier to understand. But what does it mean?

In short, an object will keep on doing what it is doing unless something happens to it. A box will sit still on a table unless its pushed or pulled. We say it is in a state of rest. A ball will keep rolling at a constant speed, in a straight line unless it’s pushed or pulled. We say it is in a state of motion.

Both these situations are described as uniform motion. Looking at uniform motion makes it easier for us to understand what forces do.

Newton’s 1st Law

When we push our box on the table it will start to move, it will gain a velocity, and whenever there is a change in velocity there is an acceleration.

In our experience, when a ball is travelling a flat, horizontal surface, we see the ball will slow down and stop. It was Galileo that realised that the ball would keep moving unless there was a force acting upon. Newton was to refine this insight. If the ball is losing velocity, then a force must be acting it on it.

This means a force can change an object's speed.

When the force is acting in the same or opposite direction as an object is travelling it will change its speed. What if the force is acting from the side? We know that if something nudges a ball rolling it will change direction. If we remember that force, acceleration, and velocity are vectors, then the force will accelerate the object to the side the force is directed towards and the ball will move away from the straight line.

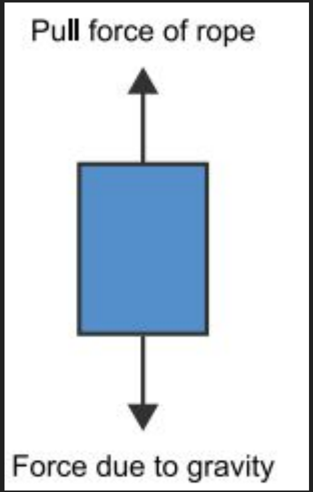
This means a force can change an object's direction.

In this picture, we can see that the can has been crushed by the force applied by gripping it

This means a force can change an object's shape.

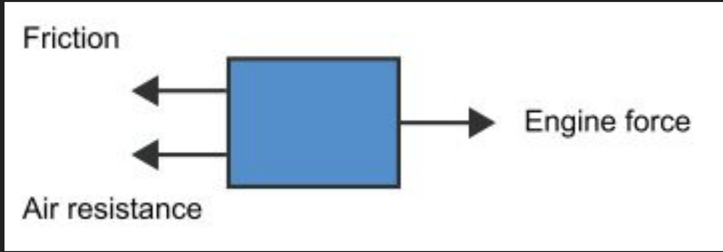
Free Body Diagrams

Free body diagrams give a visual representation of forces applied to an object. The object is drawn as a rectangle and forces are drawn as arrows from the rectangle. For example, a lift being held up by a steel rope.

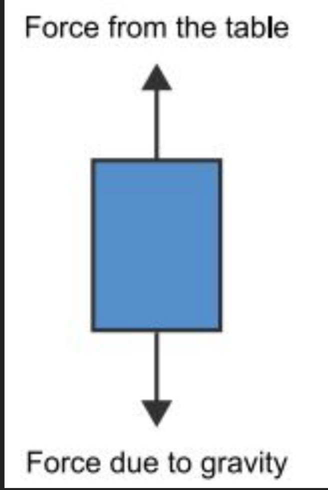


The size of force does not determine the size of the arrow.

Free body diagrams are also useful when there are more than one force acting in the same direction. Like when the friction of the road and air resistance are acting against the engine pushing a car forward.



Balanced Forces



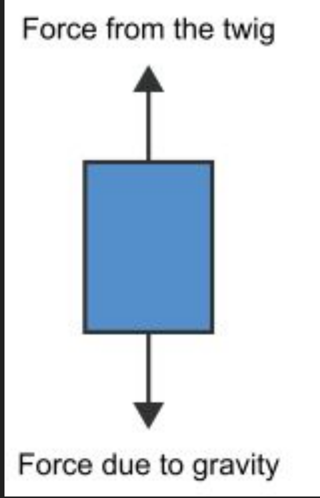
Remember, in the first subtopic in this unit we learned that forces are vectors and are described using a size (magnitude) and direction.

When learning about balanced forces we need to be aware of both the magnitude and the direction.

When a mug is placed on a table there are at least two forces acting on it. The force due to gravity, its weight, and the force from the table holding up the mug.

These two forces are equal in size and opposite in direction. They both act on the mug and cancel each other out. There is no overall or resultant force, we call these forces balanced.

Balanced Forces



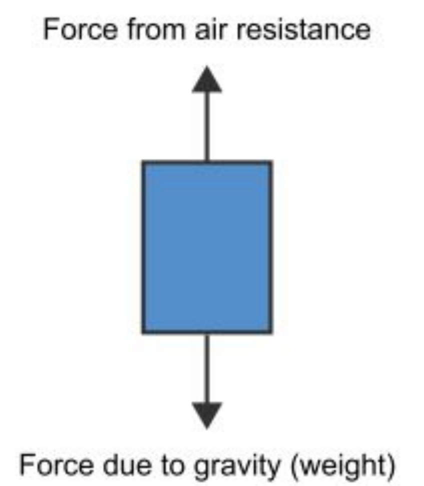
When an apple hangs from a twig we have another example of

balanced forces

The force of gravity acts on the apple, its weight. But the twig provides

an upward force equal and opposite to the weight. This time the forces are pull forces, but they are balanced.

Terminal Velocity



Another example of forces being balanced is a parachutist falling

at a constant speed.

The parachutist accelerates because of the force of gravity.

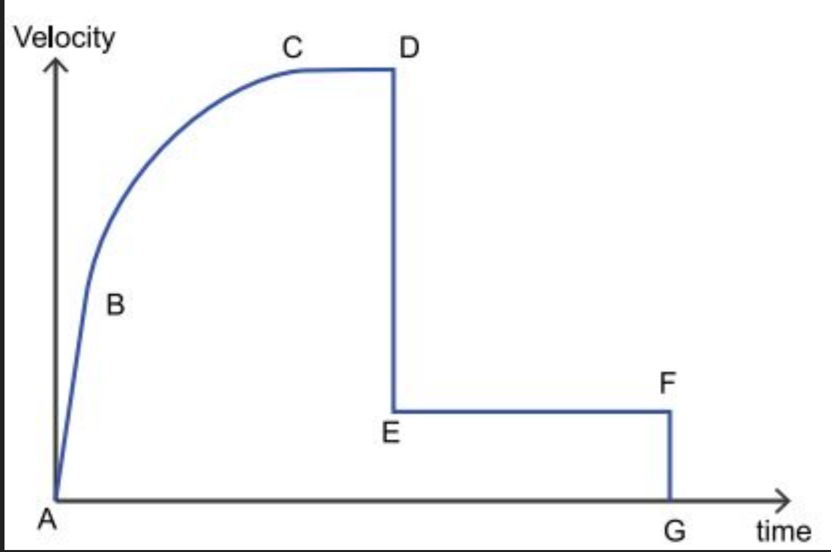
As the parachutist's speed increases, the force of the air resistance pushing up increases.

The parachutist accelerates until the force of the air resistance pushing up is equal to the force due to gravity down. The parachutist will still be falling.

These forces are balanced so the parachutist does not accelerate but falls at a constant speed. This speed is known as their terminal velocity.

The velocity-time graph for a freefall parachutist will look similar to this. The weight of the parachutist and the size of the canopy will determine the values associated with it

Terminal Velocity



At A the parachutist has started their freefall,

they are accelerating and the forces acting

against them are not large as they are

not moving quickly yet. This means they are accelerating slightly less than

9·8 ms^{-1} with a rate that is getting smaller the longer the fall lasts.

The change in acceleration starts to get more marked and at B the curvature of the line becomes increasingly horizontal until at C, where terminal velocity is reached. At this point, the force of the air resistance is equal and opposite to the parachutist's weight. The forces are balanced and the parachutist is falling with a constant velocity.

At D, the parachutist has opened their parachute, there is a rapid deceleration as the canopy's air resistance provides an increased braking force slowing down the parachutist. There is a common belief that the parachutist goes upwards. But this is a trick of the filming we see of it. The camera is on another parachutist and unless the canopy on their parachute opens at exactly the same time, they will continue to keep falling at the same speed as before. This means the slower parachutist appears to go up against what is a moving background.

At E, the parachutist and parachute establish a new, slower terminal velocity, which is safer for landing. The canopy provides more air resistance than when the parachutist was falling at that speed before, so the forces are balanced again. The parachutist falls at a constant velocity until F, where they land, and their speed becomes 0 instantaneously

Terminal Velocity

Terminal velocity can also be experienced by objects moving along a flat surface.

As the school minibus accelerates, the frictional forces such as air resistance increase until they reach the same value as the engine's maximum force. The minibus no longer accelerates as the forces are balanced. The minibus then travels at its terminal velocity.

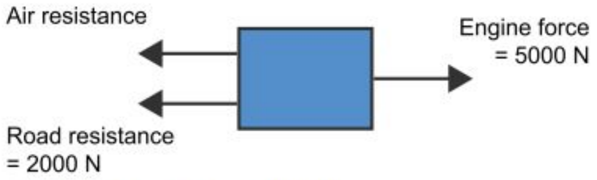
Free Body Diagrams & Numerical Values

Using numerical values with free body diagrams are useful to determine in when forces are balanced.

Problem:

Our minibus has a maximum engine force of 5000 Newtons. At terminal velocity the road resistance is 2000 N. What is the air resistance acting on the minibus?

Solution:



2000 N + Air resistance = 5000 N

Air resistance = 3000 N

Friction & Streamlining

When two objects are in contact there will be friction. Frictional force depends on how hard the objects are pressed together, and how much contact area there is between them.

We usually think of frictional forces as acting against what we want. Rough surfaces will slow a ball in a shorter distance than a smooth surface, or stop a book sliding across a table.

Car tyres use friction to propel the vehicle forward and allow them to change direction. The friction causes the unbalanced force to stop the car travelling in the straight line described in Newton's first law. Wider tyres can provide a greater frictional force and allow cars to corner at a higher speed. The grooves in the tyres surface provide a space for water and oil to go and allow the tyre to be in contact with the road surface.

To improve safety in Formula 1 car racing, large grooves are cut into the tyres; this reduces the surface area of the tyre, reducing the frictional forces they can create. This means the cars must corner at lower speeds than a full surfaced tyre would let them. By reducing the speed, they improve the safety of the drivers in any crash.

Friction & Streamlining

Reducing Frictional Forces

So, while in several situations where friction is useful, there are other situations where we need to get rid of it. Energy can be wasted when an object is moving. Then we need to reduce it.

One method is by lubrication, putting a liquid or gas between the surface so the surfaces lose contact with one another and slide over each other. This is what oil does in an engine or what ice does between the soles of our shoes and the pavement.

When playing air hockey, the jets of air across the table places a gap between the puck and the table. This allows the puck to move quickly across the table, making the game more exciting.

Another method of reducing friction is streamlining. Streamlining is when the shape of the object creates as little resistance as possible from gases or liquids such as air and water. These shapes are typically smooth and curved and we see them often in nature, such as the shape of a dolphin.

Newton’s 2nd Law

Newton's first law of motion describes what happens when forces are balanced, and nothing is changing. Newton's second law describes what happens when objects accelerate, and their velocities change. This is when the object experiences an unbalanced force.

When the driver presses the accelerator of the tractor the tractor and trailer will accelerate due to the unbalanced force produced by the engine. The more the accelerator is pressed, the greater the unbalanced force produced. This will mean the tractor and trailer will accelerate more.

The direction of the acceleration will depend on whether the tractor is in a forward or reverse gear, the tractor and trailer will accelerate in the direction of the unbalanced force given by the tractor.

When more hay bales are added to the trailer, the mass will increase. The same engine force will accelerate the tractor and trailer less than before because of the increased mass.

This is brought together in the relationship: F = m × a where,

- F stands for Force and is measured in Newtons, N
- m is the mass measured in kilograms, kg
- a is the acceleration measured in metres per second per second, m s^{-2}

Newton’s 2nd Law

A force of 1 Newton accelerates a mass of 1 kg at 1 ms^{-2}

The unbalanced force on an object is resultant force that acts on it when all the forces acting on it are added together. Remember that forces are vectors, so you will need to decide what direction is positive when you add them. Friction could be one of these forces, and as it acts against the motion it is often given negative values

Free Body Diagrams

It is a clever idea to sketch one every time you want to describe forces or have a question that involves them.

Problem:

A dog sled team are pulling a sled across the snow. They pull with a force of 1000 N. The snow has a frictional resistance of 600 N.
What is the unbalanced force?

Solution:

First draw the free body diagram. The fortunate thing is we do not have to have any drawing talent. Our sled and dogs, become a rectangle and our forces are drawn to show what direction we have chosen to put them in.

The unbalanced force is simply these forces added together.

$$\begin{aligned} F_{un} &= F_{dogs} + F_{snow} \\ &= 1000 + (-600) \\ &= 400N \end{aligned}$$

Weight & Mass

In everyday language, we will often hear weight used incorrectly. Weight is often used as a term to do with how large and object is, or how fat or thin a person is. In physics, we use the terms weight and mass more specifically.

Mass

Mass measures the number of particles in an object and is measured in kilograms (kg). The mass of an object changes if we take some of the object away, or if we add to the object. The mass of an object does not change when it moves from one place to another.

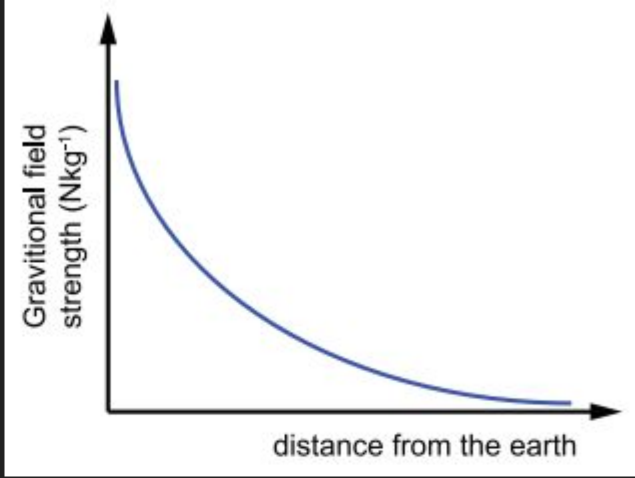
Weight

Weight is the force of gravity acting on an object's mass. We experience this on Earth, so our weight is the Earth's pull on us. Weight has the symbol W. As weight is a force it is measured in Newtons.

On Earth, weight is always directed towards the centre of the Earth. Weight depends on the mass of an object and how far it is from the centre of the Earth for most situations we will deal with. So you weigh less on top of a mountain than you do in the valley, if your mass is the same.

This change in weight is due to the change in gravitational field strength. Gravitational field strength is defined as the weight per unit mass, or the force of gravity per kilogram. It is given the symbol g and is measured in N kg^{-1} On most places on Earth g approximates to 9·8 N kg^{-1}

Weight & Mass



The weight of an object can be calculated using the relationship $W = m \times g$

As an object goes further away from the centre of the Earth, the Earth's gravitational field strength reduces as shown in the graph. If an object moves far enough away the force of gravity reduces until its weight is zero.

Weight & Mass

The gravitational field strength is dependent on the mass of the planet or star something is near. In our solar system the planets have different masses and so have a different value of g on their surface. You would only have just over a third of your weight on Mars compared to your weight on Earth, but you would have more than double your weight on Jupiter.

	Gravitational field strength on the surface in $N\ kg^{-1}$
Earth	9·8
Moon	1·6
Mercury	3·7
Venus	8·9
Mars	3·7
Jupiter	23
Saturn	9·0
Uranus	8·7
Neptune	11
Sun	270

Acceleration due to Gravity

Galileo is credited with discovering that all objects accelerate to Earth at the same rate. What we often see is that heavy objects fall to Earth quicker than lighter objects. However, this is usually due to heavier objects having a greater terminal velocity

If we ignore air resistance, then the only force moving a falling object is its weight. Let us think of two spheres of different weights being dropped, like in our picture.

If the smaller sphere has a mass of 0·5 kg and the larger one a mass of 5 kg, we can easily find the unbalanced force on them as it would equal their weights.

$$F_{un} = \text{weight of object}$$
$$F_{un} = mg$$
$$F_{un} = 0 \cdot 5 \times 9 \cdot 8$$
$$F_{un} = 4 \cdot 9N$$

$$F_{un} = \text{weight of object}$$
$$F_{un} = mg$$
$$F_{un} = 5 \times 9 \cdot 8$$
$$F_{un} = 49N$$

Weight & Mass

$$a = \frac{F}{m} \qquad a = \frac{F}{m}$$

$$a = \frac{4 \cdot 9}{0 \cdot 5} \qquad a = \frac{49}{5}$$

$$a = 9 \cdot 8 \text{ m s}^{-2} \qquad a = 9 \cdot 8 \text{ m s}^{-2}$$

With no other forces acting the spheres will have an acceleration due to gravity of $9{\cdot}8$ m s^{-2}

Adding Forces at Right Angles

So far in this topic we have looked at forces being added either or negatively in one direction. Left or right, North or South. But to turn corners and change path we require unbalanced forces from other directions.

When adding forces in more than one direction we use the same strategies that we used in Vectors and scalars > Adding vectors

Weight & Mass

Problem:

During a flight, an aircraft travels with an engine force of 150 kN due North and then encounters a crosswind of 40 kN due east.

By scale diagram, determine the resultant force on the aircraft.

Solution:

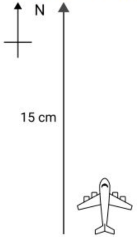
Step 1: Draw your reference North

Step 2: Determine a scale for your diagram that is easy to use and fits on the page

For this diagram, we are going to use the scale 1 cm to represent 10 kN.

Parallel to the reference North, we are going to draw a line to represent the engine force.

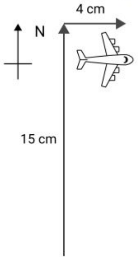
Engine force = 150 kN, using our scale of 10 kN per cm, this gives a line 15 cm long.



Step 3: We now need to add the crosswind

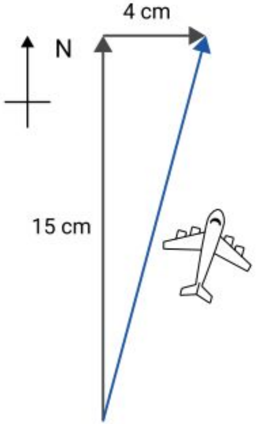
Cross wind = 40 kN, using our scale of 10 kN per cm, this gives a line 4 cm long.

To draw this line, measure an angle of 90° from the arrow end of the engine force diagram. This would be to the right to represent East in our diagram.



Step 4: Draw the resultant force vector

Draw a line from the start of the first vector to the end of the last vector.



Step 5: Find the value of the resultant vector

Using a ruler find the length of the resultant vector. We find it is 15·5 cm.

The value of the resultant vector is 15·5 cm $\times$ 10 kN cm^{-1} = 155 kN

Step 6: Find the direction of the resultant vector

To measure this, find the angle between the start of the engine force vector and the resultant force vector using a protractor.

The value is 15°.

Step 7: Write the final answer

F = 155 kN @ 15° from North.

Newton’s 3rd Law

Ouch! We've all had this happen to us in P.E., hopefully the only pain has been your embarrassment. But this photograph is a great demonstration of Newton's third law

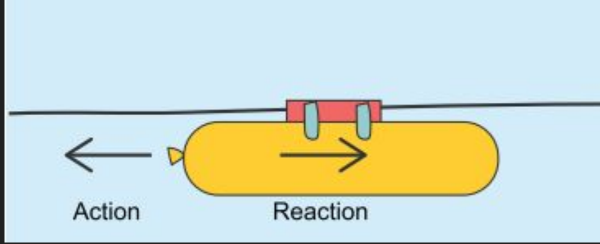
The ball is exerting a force on the face, we know that because we have felt it. But look at the ball, it is changing shape too. The face must be exerting a force on the ball

Newton's third law says, 'That every action has an equal and opposite reaction.' That means for every action force there must be a reaction force. In our example, the force of the face stopping the ball, means that there is a force from the ball changing the shape of the face.

More generally, if object A exerts a force on object B, object B will a force of the same magnitude but the opposite direction on object A.

As these forces always act together they are known as Paired Forces or Newton Pairs.

Rockets & Jet Engines



Have you ever blown up a balloon and watched it fly away before you tied it?

You were watching Newton's third law in action. The elasticity of the balloon tries to get the balloon back to its original shape and forces the air out of the balloon, in return the air particles push the balloon in the other direction with the same force

Rockets work in the same way

Some people believe that rockets work by the gases coming out the engine pushing off the ground. But that would mean rockets would not work when they are away from the ground

What really happens is that the rocket's engines force heated exhaust gases out of the tail of the rocket. These gases push back on the rocket forcing the rocket body in the opposite direction.

Jet engines use Newton's third law twice to be so effective.

The air is drawn in by a fan or turbine at the front of the engine, the air sucks the engine forward. The engine burns fuel using the oxygen drawn in and the hot exhaust gases are pushed out the back of the engine. These gases push the engine forward.

Conservation of Energy

Thermodynamics

Thermodynamics is a branch of physics that relates heat and temperature and their relationship to energy and work.

The First Law of Thermodynamics says that energy cannot be created or destroyed but changes form as work is done. When you climb the stairs at school, the chemical energy from your breakfast becomes gravitational potential energy. How much depends on your mass, and the mass of what you are carrying, and how high the stairs go. It would also depend on what the gravitational field strength is, but I am guessing you go to school on Earth, so there would be little difference there.

Work done is the term for energy changed. We also talk of the energy being transferred. It is given the symbol E_w and is measured in Joules, J. When you climb the stairs you apply a Force, in this case at least equal to your weight, over a distance, the height of the stairs.

The work done, E_w when energy is transferred is the Force times the distance travelled.

$$E_w = F \times d$$

For you climbing the stairs it is your weight times the height. The heavier you are the more you need to work, the higher the stairs, the more you need to work.

Thermodynamics

If the laptop was to fall off the desk, where would that potential energy go? We know that the laptop will accelerate to the floor. According to the principle of conservation of energy, as it falls its potential energy becomes Kinetic Energy, E_w

Kinetic Energy is the energy of an object's movement. We can calculate it using the formula: $E_k = \frac{1}{2}mv^2$

So what speed does our laptop land on the floor at?

Potential Energy lost = Kinetic Energy gained

In a friction and air resistance free world, the laptop could slide

down a tablecloth and the speed at the bottom would be the same.

$$E_p = E_k$$

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

$$19 = 1 \cdot 3 \times v^2$$

$$v^2 = \frac{19}{1 \cdot 3}$$

$$v = \sqrt{14 \cdot 6454}$$

$$v = 3 \cdot 8 \text{ m s}^{-1}$$

Energy Loss

In the real world our examples do experience air resistance and friction. What difference would that make?

The air resistance and friction act against the direction of travel. They will reduce the acceleration by performing work on the trolley. The potential energy is 'lost' as heat. The kinetic energy at the bottom of the slope is less than friction free version and so the speed is less too.

This is because work is being done by the frictional forces and these are calculated by using: $E_w = F \times d$

Projectile Motion

Projectile Motion

Any object launched by a force through the air is a projectile. That force could be gravity, such as when an apple falls from a tree. Once a projectile has been launched the only force acting on it is the force of gravity

At National 5, all our projectiles are launched horizontally, (flat). This means all our projectiles are falling and start at their highest height.

What forces are acting on the ball in the picture? The ball is being pulled towards the Earth as it has Weight. The ball is being pulled up by the hand. If the hand applies a force equal to the weight, the forces are balanced, and the ball is does not accelerate.

What happens if the hand lets go? The only force applied to the ball is its Weight. This force is unbalanced and so the ball accelerates to Earth. The vertical velocity and displacement of the ball depends only on the time the ball has been falling for.

Projectile Motion

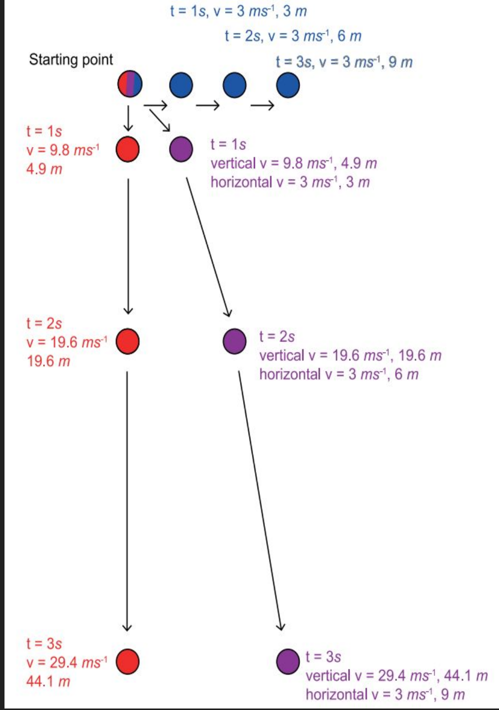
After a ball has been released horizontally in our National 5 world with no air resistance, there are no forces acting on it horizontally

This means that the ball does not increase or decrease speed horizontally as it travels through the air. The initial velocity of the ball horizontally is the same as the final speed of the ball, a constant speed. Horizontally, the distance travelled depends only on the speed of the ball and the time its in the air for, $s = v \times t$

The object causing the first ball to fall is the Earth, and yes, it is still there in the second instance. The second ball will fall too. We have already learned that all objects accelerate to Earth at $9 \cdot 8\ ms^{-2}$

Both the first ball being dropped vertically, and the second ball launched horizontally will accelerate towards Earth at $9 \cdot 8\ ms^{-2}$ That one is moving horizontally makes no difference to the rate at which they fall.

Projectile Motion



The red ball in the diagram shows the path of the ball when there is no horizontal velocity. The ball increases its vertical speed by 9·8 ms^{-1} every second, and the change in displacement increases every second too The blue ball shows the path of a ball travelling horizontally without any gravity affecting it. Its velocity remains constant as there are no forces acting upon it.

The purple ball shows the path of the blue ball when gravity does act on it. It still travels at the same horizontal velocity, there is still no force acting to accelerate it. Its vertical motion now matches the red ball. It accelerates at 9·8 $m\ s^{-2}$ The path of the ball curves downward. This shape is known as a parabola.

The path is a parabola because the horizontal motion is a constant speed, and the vertical motion is a constant acceleration. That means the horizontal displacement increases at a constant rate whereas the vertical displacement increases at a growing rate.

Finding the Vertical Distance Travelled

We learned before that the area under a graph is useful method for calculating the distance travelled, especially when an object is accelerating such as a projectile accelerating due to gravity.

Space

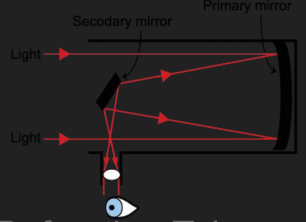
Space Exploration

Messages From Space

When we look at a star or planet in the night sky, most will appear white with various levels of brightness. But telescopes and spacecraft sent to explore the solar system and beyond can break this light down into information about what they are made from, how they travel around the universe and how that allows us to understand our everyday world a little better.

Telescopes

Telescopes collect electromagnetic radiation such as radio waves and microwaves. The modern telescope was originally developed in the Netherlands in the early 1600s. Galileo Galilei famously developed these and was the first to see and record Jupiter three largest moons in 1610. The initial telescopes used refraction, to collect and focus the light through two lenses.



Refracting Telescope

Messages from Space

Reflecting Telescope

Early lenses had problems with the colour separation caused by the refraction, aberrations, which meant that images were not as sharp as desired.

Reflecting telescopes used mirrors to focus the light and have the advantage of not splitting up the light. Isaac Newton built the first practical reflecting telescope in 1668, the Newtonian reflector.

Telescopes are classified by the wavelengths of light they detect and include:

- X-ray telescopes, using shorter wavelengths than ultraviolet light.
- Ultraviolet telescopes, using shorter wavelengths than visible light.
- Optical telescopes, using visible light.
- Infrared telescopes, using longer wavelengths than visible light.
- Radio telescopes, using longer wavelengths than infrared light.

Types of Telescope

X-ray telescopes

The Earth's atmosphere blocks most of the X-Rays that come towards it from space. X-ray telescopes must be mounted on high altitude rockets, balloons, or artificial satellites to get above the atmosphere. X-ray telescopes have detected a massive cloud of gas outside our galaxy. This evidence supports the Big Bang Theory of the origin of the universe as it shows that the galaxies, stars, and planets can form and that the universe is not fixed.

Ultraviolet telescopes

The Hubble satellite contains lots of telescopes, one of which detects ultraviolet. It has helped to explain how stars are formed inside galaxies.

Optical telescopes

As well as explaining how our solar system works, optical telescopes have allowed us to investigate the chemical elements present in stars.

By observing galaxies and stars we can determine that the majority are moving away from us. This suggests the universe is expanding in accordance to the Big Bang Theory.

Infrared telescopes

Like X-Ray telescopes most of these are positioned above the Earth's atmosphere. The atmosphere absorbs these wavelengths. Infrared telescopes allow us to gain greater understanding of star and galaxy formation.

Types of Telescopes Cont

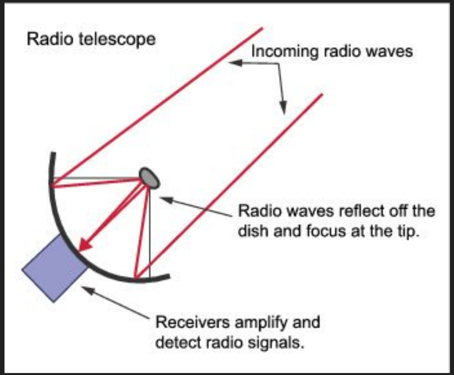
Radio telescopes

You may recognise radio telescopes and they work in a comparable way to a satellite dish. The waves from the star or planet are reflected off the curved reflector and focused on top an antenna or aerial.

Radio waves are emitted from objects such as pulsars and quasars.

Using radio telescopes astronomers have created detailed maps of the universe

and determined its age.



Satellites

The most famous satellite of the Earth is the Moon. A satellite is something that orbits, goes around, a planet. The Moon is a natural satellite.

The first artificial satellite was the Soviet Sputnik 1. Launched in 1957 and the size of a volleyball it orbited the Earth for about three months. Since then nearly 7,000 satellites have been launched.

Sputnik 1 was in a low orbit. Most satellites placed in orbit since are in a low orbit. Low Earth orbits including the International Space Station's (ISS), are about 2000 km above the surface of the Earth and they orbit at least 11 times a day.

Many of satellites orbit over the North and South poles rather than around the Equator. The orbit of a polar orbiting satellite is around 850 km above the Earth's surface. This can be useful when trying to deal with a small area of the Earth's surface, but means the satellite is not always available to a ground station.

As the altitude of the satellite's orbit increases the period, length of time, of the orbit increases. A way to think of this is when you have spun something above your head on the end of a piece of string. When the string is short, the object must move a lot faster to not fall, as the string increases in length the speed it needs to travel at reduces.

Geostationary Satellites

At around 36000 km above the Earth's surface, the length of time for an object to orbit the Earth is 24 hours. This means that a satellite at this height stays above the same point of the Earth throughout its orbit. This is called a geostationary satellite and because its position is so reliable it can be used for many purposes.

What are Satellites Used For

Telecommunications

Telecommunications satellites are used for television, telephone, radio, and internet, and applications. Both government and private companies have launched this type of satellite. There are over 2,000 communications satellites in Earth's orbit, used by both private and government organisations. The purpose of telecommunications satellites is to relay signals around the curve of the Earth allowing communication between widely separated places.

A telecommunications satellite relays and amplifies radio telecommunications signals; it creates a communication channel between a source transmitter and a receiver at separate locations, or ground station on Earth

The first transatlantic telecommunications satellite was Telstar 1, launched in 1962. It was a polar orbiting satellite, which meant that it was only in the correct position a few times a day.

Science fiction writer Arthur C. Clarke predicted a method of communicating through any two points using three satellites. This is the basis of most global satellite communications today. For this to work, it requires ground stations to send messages to a satellite that in turns sends it to another ground station at another ground station on the Earth's surface. The second ground station sends the message to a second satellite to reach another ground station and by doing this the whole of the surface can be reached.

Weather Forecasting

You will probably have seen satellite images on TV weather forecasts. The first images from these satellites were very exciting for weather forecasters as it was only then could they see that what they predicted weather patterns looked like was true. Both polar orbiting and geostationary satellites are used.

The images you have seen that include much of Africa and Europe are from geostationary satellites such as Meteosat. These allow large scale weather systems to be seen and allow forecasters to look several days into the future.

Polar orbiting satellites show a narrower image, such as the UK or Scotland. These provide more detail and allow for more accurate local forecasts to be made.

GPS (Global positioning system)
GPS uses a network of satellites to determine your location. This is used in all sorts of industries from aviation to farming, where in combination with satellites providing data on soils and plant growth farmers can pinpoint what crop to grow where and can be used to steer harvesting equipment.

How has going to Space helped us

Space exploration and the industrialisation of the orbits around the Earth have stretched scientists and engineers to be more innovative

Infrared Ear Thermometers

NASA developed a thermometer using infrared astronomy technology to measure the amount of energy emitted by the eardrum, the same way the temperature of stars and planets is measured. This method avoids contact, virtually eliminating the possibility of cross infection, and permits rapid temperature measurement of new-born, critically-ill, or incapacitated patients.

Memory Foam

Designed to improve crash protection, memory foam was developed with unusual properties. The material widely used in products including mattresses, pillows, aircraft, cars and motorcycles, sports safety equipment, horseback saddles, furniture, and human and animal prostheses. Its high-energy absorption and soft characteristics not only offer superior protection in the event of an accident or impact, but enhanced comfort and support for passengers on long flights or those seeking restful sleep.

Enriched Baby Food

Many baby food formulas contain a nutritional enrichment ingredient that was explored by NASA research into the potential of algae as a recycling agent for long-duration space travel.

Freeze Drying Technology

When preparing for the Apollo missions, which had people in space for the longest time at that point, NASA researched space food. One technique developed was freeze drying. Foods are cooked, quickly frozen, then slowly heated in a vacuum chamber to remove the ice crystals formed by the freezing process. The final product retains 98 percent of the nutrition but only 20 percent of its original weight. Today, freeze dried fruit appears in breakfast cereals, you can buy freeze-dried instant coffee. One benefit of this advancement is easily prepared nutritious meals for vulnerable and housebound adults.

Water Purification

NASA engineers have developed a complex system of devices intended to sustain the astronauts living on the International Space Station. This system, makes use of available resources by turning wastewater from respiration, sweat, and urine into drinkable water. This system is benefiting people all over the world who need affordable, clean water, such as in underdeveloped regions where well water may be heavily contaminated.

Harnessing Solar Energy

Homes are now being fitted with high-performance, low-cost, single crystal silicon solar power cells that allow them to reduce their energy costs and help to reduce pollution. These solar devices provide up to 50 percent more power than conventional solar cells.

The dangers of manned Space Exploration

Space is a very hostile place, it suffers from extremes of temperature, low pressure, high levels of radiation and getting up to and back down from space is extremely hazardous.

Fuel load

Rocket engines use Newton's 3rd Law to propel spacecraft. The engine burns fuel to produce hot gases which are ejected from the engine, the hot gases push back on the spacecraft body sending it forward.

At take off these rockets contain incredible amounts of highly combustible fuel. An Ariane rocket contains around 400 000 kg of fuel at takeoff to get objects into a low Earth orbit, considerably more for a geostationary satellite.

Challenger Disaster

On January 28, 1986, Space Shuttle Challenger broke apart 73 seconds into its flight, killing all seven crew members. The crew was made up of five NASA astronauts and two payload specialists. Christa McAuliffe, a teacher, would have been the first civilian in space.

The spacecraft disintegration began after a joint in its right solid rocket booster failed at lift-off. O-ring seals used in the joint were not designed to cope with the unusually cold conditions that existed at this launch. The seals' failure caused a breach in the joint, allowing burning gas at high pressure from inside the solid rocket motor to reach the outside and damage the Solid Rocket Boosters attachment and the external fuel tank. This led to the Solid Rocket Booster separating from the spacecraft and the structural failure of the external tank. Aerodynamic forces broke up the orbiter.

Exposure to radiation

The Earth's atmosphere provides us with much more than the air we breathe. It does a fantastic job of protecting us from harmful radiations from the sun and other stars.

While in space, astronauts are exposed to radiation mostly composed of high-energy protons, alpha particles, and high-atomic-number ions. They are also exposed to radiation from nuclear reactions in some spacecraft. Galactic cosmic rays from outside the Milky Way galaxy consist mostly of highly energetic protons.

Astronauts are exposed to between 50-2,000 millisieverts (mSv) while on six-month-duration missions to the International Space Station. The risk of cancer caused by ionizing radiation is well documented at radiation doses beginning at 50 mSv and above.

During travel to the ISS and on spacewalks, Mylar coatings built into the suits some protection is offered by the reflective coatings of Mylar that are built into the suits, but a space suit would not offer much protection from a solar flare. So, spacewalks are planned during periods of low solar activity.

The dangers of manned Space Exploration Cont

Pressure Differential

However, during spacewalks and when travelling in capsules to and from the station, the astronaut's spacesuits provide that pressurised environment. It is part of the reason that spacesuits look so bulky.

Micrometeorites are tiny pieces of meteorite that travel through space. Though they are very small the speeds they travel at can mean they can cause a lot of damage, potentially puncturing a spacesuit. To prevent this, spacesuits are made from layers of Kevlar.

The multiple layers and pressurised suits reduce the mobility of astronauts. Engineers from the space programs are continually working on how to make the suits easier to move in.

Re-entry through an atmosphere

One of the most dangerous parts of any space mission is returning the spacecraft, and any passengers to Earth.

As the spacecraft enters the Earth's atmosphere, it will experience an acceleration due to its weight. However, if it were to travel too fast it would have too much Kinetic energy to slow safely as it lands. The Earth's atmosphere contains particles of air and the heat generated due to the frictional forces if the spacecraft was to fall directly down could cause the craft to burn up or expose its occupants to dangerously elevated temperatures. But, this friction causes the object to experience drag, or air resistance, which slows the object down to a safer entry speed. Managing this friction is the key to safe re-entry.

Blunt-body design helps alleviate the heat problem for spacecraft. When spacecraft fall to Earth, with blunt-shaped surface facing down the blunt shape creates a shock wave in front of the vehicle. The shock wave keeps the heat at a distance from the object.

Latent heat

The blunt body design can only do so much. The spacecraft has to be able to absorb much of the heat.

During the 1960s and 1970s the Apollo program coated the command module with special ablative

material that burned up on re-entry, absorbing heat. One ablative process involves the heat shield changing state into a gas. To do this it absorbs the latent heat energy as it vaporises into a gas. The pressure of the gas forces it away from the shield, removing more of the heat energy. This strategy is still used for Soyuz and Orion spacecraft.

The amount of energy required to change the state of an object is called the Specific Latent Heat. It is unique to the material, and is different for fusion, melting, and vaporisation, changing into gas.
The energy required to change stat is $E_H = ml$

E_H is the heat energy measured in Joules, m is the mass measured in Kilograms, L is the specific latent heat, measured in Joules per Kilogram

Challenges of Space Travel

Catapult effect

Spacecraft catapult or slingshot around a planet by entering and leaving the gravitational field of a planet. The spacecraft's speed increases as it approaches the planet but decreases while escaping its gravitational pull. However, as the planet is orbiting the Sun, and the spacecraft is affected by this motion during the manoeuvre. To increase speed, the spacecraft flies with the movement of the planet, taking a small amount of the planet's orbital energy. The slingshot manoeuvre can change the spaceship's trajectory and speed relative to the Sun.

The principle is like bouncing a tennis ball off the front of a moving train. Imagine you are standing on a train platform and throw a ball at 30 km h^{-1} toward a train approaching at 50 km h^{-1}. The train driver would see the ball approaching at 80 km h^{-1} and leaving at 80 km h^{-1} after the ball rebounds off the front of the train., However, that departure is at 130 km h^{-1} relative to the train platform because the of movement of the train; the ball has added twice the train's velocity to its own.

Challenges of Space Travel Cont

Ion Drives

Ion drives use Newton's 3rd law to propel spacecraft. Instead of sending out hot gases like a rocket or jet engine, an ion drive sends out ionised gas particles.

Most thrusters ionise the gas by electron bombardment: a high-energy electron (negative charge) collides with a neutral atom releasing electrons, resulting in a positively charged ion. This makes a plasma made up of positive ions and negative electrons in equal proportions but no overall electric charge. Plasma has some of the properties of a gas but is also affected by electric and magnetic fields. Plasma is the substance inside fluorescent light bulbs used in schools.

To move something with the mass of a spacecraft with a meaningful level of thrust requires a propellant with a high atomic mass. Xenon is most commonly used, which also has the benefit of being unreactive and can be stored at high densities. The positively charged ions are accelerated out of the thruster as an ion beam, producing thrust. An equal number of electrons are expelled through the neutralizer, to make the total charge of the exhaust beam neutral. Without a neutralizer, the spacecraft would build up a negative charge and eventually ions would be drawn back to the spacecraft, reducing thrust.

Ion Drives have been used the mid-1960. From 1998 to 2001, the NASA Solar Technology Application Readiness (NSTAR) ion propulsion system enabled the Deep Space 1 mission, the first spacecraft propelled primarily by ion propulsion, to travel over 163 million miles and make flybys of the asteroid Braille and the comet Borelly.

In 2001, Ariane 5 launched the Artemis telecommunication satellite. Things went wrong during the launch of Artemis. The rocket did not reach the height needed for a geostationary satellite. Fortunately, Artemis was equipped with an equipped with an experimental ion propulsion system. This was meant for carrying out small corrections to the orbit. ESA engineers managed to use this ion drive to get Artemis to its destination.

Ion drives are used to keep over 100 geostationary Earth orbit communication satellites in their desired locations. Three ion thrusters are enabling the Dawn spacecraft (launched in 2007) to travel deep into our solar system. Dawn is the first spacecraft to orbit two objects in the asteroid belt between Mars and Jupiter: the protoplanets Vesta and Ceres.

Star Wars spacecraft use ion drives to propel most starships at sublight velocities. The most famous Empire craft using ion drives were TIE Fighters, which received their name from the number of ion engines they used: Twin Ion Engine.

Challenges of Space Travel Cont

Manoeuvring a spacecraft in a zero-friction environment

Most of our movements require friction to pair with the force we apply either through our bodies or the vehicles we are travelling in. The friction from the sole of our shoes provide the force to prevent our foot slipping backwards and propel us forward. Turning a corner in a car requires the friction of the tyre to provide a reaction force. When a boat slows the friction of the water provides the unbalanced force to decelerate it.

In the vacuum and micro-gravity of Earth orbits means there is a near friction free environment. Ion drives, and rocket engines allow you to accelerate, but to stop or slow that motion the spacecraft must produce the opposing force itself. They require secondary sources of thrust in opposite places or configure to balance out the main sources to achieve this.

When Soyuz craft are docking with the ISS, they must match their speed with that of Space Station and get the docking hatches to meet up to within ten centimetres. That level of precision requires the flight commander to be able to make fine adjustments to the speed, angle, and height of the approach.

Maintaining sufficient energy to operate life support systems in a spacecraft

Astronauts in space have the same physical requirements as we do on Earth. We need access, to fresh water, air with sufficient oxygen, food, heat, and light. Electrical energy is used to operate the equipment of the spacecraft that meet these requirements.

Radioactive materials can produce heat that can power electrical generators. However, this increases the dangers of exposure to radiation for astronauts. There is also the risk that the material may scatter and expose the public if there was an accident during take-off or re-entry.

A more politically popular solution is to use solar cells. Spacecraft use photovoltaic solar cells. These convert the sun's light energy into electricity. Initially solar cells were heavy, cumbersome, and inefficient, making them expensive and difficult to deploy effectively. Space exploration has been responsible for much of the development of photovoltaics, making them thinner, more efficient, and cheaper to produce.

Cosmology

Distances in Space and the light year

Distances in space are huge. Light from our closest star, the Sun, take approximately 8 minutes 20 s to reach the Earth. Which means that the Sun is 150 million kilometres away. The next nearest star is Proxima Centauri is 3.97×10^{16} m away.

To simplify cosmological distances, astronomers use light years. A light year is the distance light would travel in a year, i.e. $3 \times 10^{8} \times 365 \times 24 \times 60 \times 60 = 9.46 \times 10^{15}$ m

Astronomical Names

A Solar System is a Star, such as the Sun, and the planets and other objects that orbit it due to its gravity. Our solar system is called The Solar System. It formed 4.6 billion years ago from a giant interstellar molecular cloud. Most of the system's mass is in the Sun, with much of the other mass contained in Jupiter.

The simplest solar system consists of a Star and a planet. Stars have enough mass to cause fusion. This powers the star to produce light and heat. A planet orbits a star and is massive enough to be made round by its own gravity. It is not massive enough to cause fusion, but a planet has cleared its orbit of other objects.

An exo-planet is a planet in a solar system other than our own. Many astronomers believe that they are the best chance for us to find other lifeforms. The 'goldilocks zone' for exoplanets is an area near some stars where the size of the planet and its temperature could support liquid water with a suitable atmospheric pressure. Liquid water is the basis of all life on Earth.

The SETI Institute is a research organisation whose want "to explore, understand, and explain the origin and nature of life in the universe, and to apply the knowledge gained to inspire and guide present and future generations." SETI stands for the "search for extraterrestrial intelligence". The Institute has three primary centres: The Carl Sagan Center, is devoted to the study of life in the universe. The Center for Education focuses on astronomy, astrobiology, and space science. The Center for Public Outreach produces radio programs and podcasts.

The Carl Sagan Center is named after astronomer and author Carl Sagan, whose "Cosmos" television series did much to build public understanding of astronomy. The Institute's SETI Researchers use both radio and optical telescope systems to search for deliberate signals from technologically advanced extraterrestrial civilizations.

Many planets have a moon. A moon is a natural satellite that orbits its host planet. Some moons in the solar system are larger than planets. Our moon is the largest moon compared to its planet in The Solar System and is believed to have formed when the Earth collided with another Mars sized object.

Solar systems can become parts of collections called galaxies. A galaxy is made up from stars, gas, dust, and dark matter, held together by gravity.

So, a moon can be orbiting a planet due to the planet's gravity. The planet orbits a star due to the star's gravity, and the star orbits the galaxy due to the galaxy's gravity.

The Universe is all of space and time, including planets, stars, galaxies, and all other forms of matter and energy.

Origins of the Universe

Most astronomers agree that the universe was formed around 13.7 billion years ago. In 1927, Georges Lemaître spotted that the expanding universe could be traced back in time to an originating single point. For many years, there was two different theories, the Big Bang, and the Steady State theory. The term 'Big Bang' was originally an insult, made up by a Steady State supporter. The Steady State theory claimed that stars and galaxies had always been there. A wide range of evidence supports the Big Bang theory and its now universally accepted.

The Big Bang theory suggests that the universe started from a hot and dense single point called a singularity. This singularity expanded rapidly forming Hydrogen, Helium, and subatomic particles. Gravity pulled many of these particles together and started to form stars. The stars created heavier elements and the effects of gravity started to form galaxies too.

Edwin Hubble studied the movement of galaxies and concluded that galaxies are drifting apart. This observation matched the idea of an expanding universe, that Lemaître suggested. But where did the energy to cause the expansion come from? For many years, astronomers believed that the rate of expansion was decreasing, or had stopped. However, in 1998, two teams of astronomers discovered that the rate of expansion was increasing. A previously unseen energy source must be acting, this was labelled Dark Energy.

Cosmic microwave background radiation was discovered in 1964. It was further evidence for the Big Bang model, which predicted the existence of background radiation throughout the universe. The areas of darkness and light show fluctuations in the levels of radiation showing different amounts of matter in these areas. The areas with more matter became stars and galaxies.

The Cosmic Background Explorer (COBE), satellite operated from 1989 to 1993. It investigated the cosmic microwave background radiation (CMB) making measurements to help shape our understanding of the cosmos.

COBE's measurements provided evidence in support the Big Bang theory of the universe. George Smoot, and John Mather, two of COBE's principal investigators, received the Nobel Prize in Physics for their work on the project. According to the Nobel Prize committee, "the COBE-project can also be regarded as the starting point for cosmology as a precision science".

How do we get this Information

We have seen that telescopes can detect radio waves from pulsars, visible light from stars and the cosmic microwave background. The universe emits electromagnetic radiation from across the spectrum. Different detectors pick up these signals and the methods we use to interpret them allow us to pick out key pieces of information.

How an object emits electromagnetic energy determines the range of wavelengths they produce. When objects produce light because they are heated they typically produce all the wavelengths of the electromagnetic spectrum. We will see the object as the brightest colour. The brightest colour depends on the temperature of the object and is where we get the terms red hot and white hot from.

When the light passes through a prism it produces a continuous spectrum

Line absorption spectra

When light passes through an atmosphere or a gas cloud, some of its wavelengths are absorbed. When we produce a spectrum from it, bits are missing.

The black lines in this spectrum are caused by certain elements or compounds absorbing them from a white light source. Each element has its own spectral fingerprint. It allows astronomers to identify what elements are in a planet's atmosphere.

Helium was first discovered by looking at our sun's spectrum. The gaps in the spectrum did not match with any of the known elements. Helium is named after the Greek word 'Helios.'

Line Emission Spectra

Not all objects produce continuous spectra. Some objects only produce light with certain wavelengths. The wavelengths produced are determined by the elements and compounds the object is made from. By matching the lines produced with the known spectra of elements we can work out what elements and compounds are in stars.

Congratulations, you made it to the end and are now ready for your exam, make sure to keep revising using these slides and other sources given to you by your teacher and good luck!