Pre A-Level Work: Physics

If you are looking to take A-Level Physics next year then please ensure that you are working through the following tasks.

These tasks are designed to consolidate the knowledge that you already have at GCSE, and begin moving it towards the A Level standard.

Task 1: What do I know already? A3 Sheet

Please open and complete the A3 sheet entitled 'Task 1: What do I know already – A3 sheet' (please note, this does not need to be printed – it can be completed on a sheet of paper, just ensure that the Module and section that you are competing is clear).

Use the Red Pen, Black Pen method for completion – if you are confident of the answer already from GCSE, then use Black Pen, whereas if you have to double check or research the answer use Red Pen.

Over the *next few weeks keep coming back to the Red Pen areas and quizzing yourself* on them – alternatively ask someone at home to quiz you, or make quizlet flash cards for those areas!

Task 2: A Level Physics Topic Builders

This pack aims to further develop some key elements of your GCSE knowledge (that you have consolidated in Task 1), and begin moving them to an A Level application. Open 'Task 2: A Level Physics Topic Builders'.

Please work through the following topics and sections first, *using the mark schemes in the separate document(/s) to mark your answers!*

Page 13-16: Electrical circuits: Charge, current and voltage

Page 17-20: Electrical circuits: Resistance

Page 22-25: Vectors and Scalars

Page 27-28: Mass and Weight

Page 30-32: Forces in Equilibrium

Page 36-38: Motion Graphs

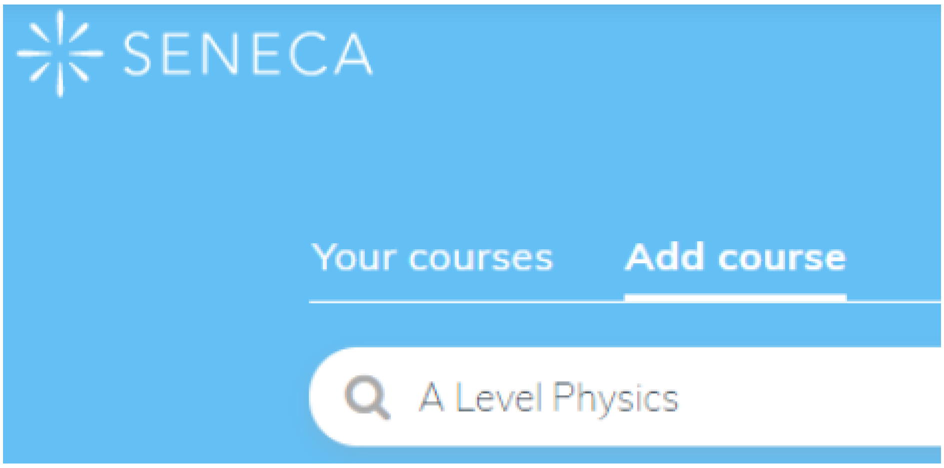
Page 46-48: Energy and Power

Page 49-51: Kinetic Energy and Gravitational Potential Energy

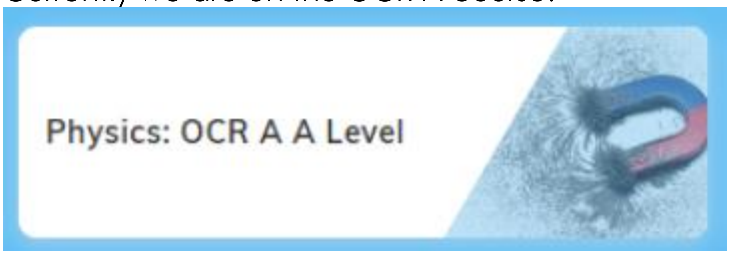
If you would then like to look at any other areas covered in the pack, you are entirely welcome to.

Optional: SENECA Learning

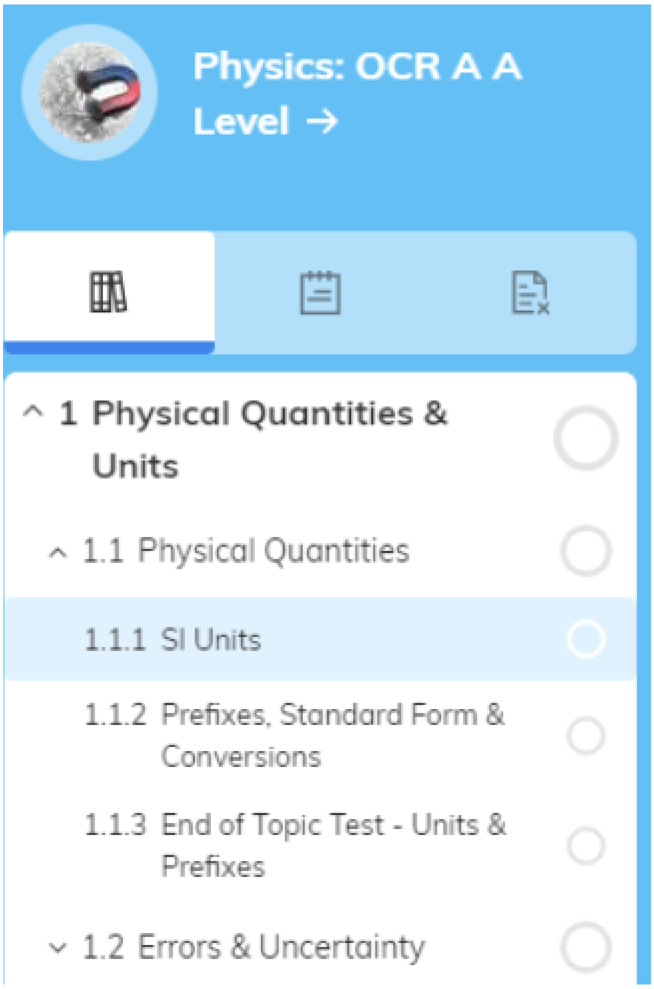
Join the A Level Physics course on SENECA Learning (please see steps below) and start having a look at Topic 1:



Currently we are on the OCR A course:



Select this and work through Topic 1:



Work set by Mrs Murphy and Miss Kelly. If you have any questions then please email.

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WHAT DO I KNOW ALREADY? GCSE CONSOLIDATION

Module 1 Practical skills

Variables

1) What is an independent variable?

____

____

2) What is a dependent variable?

____

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3) What is a control variable?

____

____

4) A scientist drops a block of each of the group 1 metals into water to see how long it takes them to react. Identify the variables.

____

____

Analysing data

1)Calculate the mean time.

Amount of salt (kg)	Time taken to dissolve (s)			
	1	2	3	Mean average
0.1	13	15	14	
0.2	32	34	36	
0.3	45	79	43	
0.4	61	61	64	

2)Plot a graph of the data.

3) Write a conclusion for your data.

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Evaluating experiments

1) What is meant by accuracy?

____

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2) What is meant by reliability?

____

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3) How can the accuracy of an experiment be improved?

____

____

4) How can the reliability of an experiment be improved?

____

____

Module 2 Foundations of physics

Standard units

Quantity	Unit	Symbol
Mass		
	metre	
		J
Speed		
		W
Force		
	Pascal	
		s
Displacement		
		m/s
	Metres per second squared	

Prefixes

Prefix	Abbreviation	Standard form
Pico-		
Nano-		
		$x10^{-6}$
	m	
		$x10^{-2}$
Deci-		
	k	
		$x10^{6}$
	G	
Tera-		

Conversions

Convert the following into standard units.

Diameter of a raindrop = 0.1 mm.	
Mass of a person = 60 000 g.	
An electric current of 400 μA.	
Area of a table = 85 cm x 120 cm.	
The speed of a car = 20 km/h	

Scalar and vector

1) What is a scalar quantity?

____

____

2) What is a vector quantity?

____

____

3) Use the quantities from the standard units table to complete the table below.

Scalar	Vector

WHAT DO I NEED TO KNOW FOR A-LEVEL PHYSICS?

Module 3 Forces and Motion

Forces

1) Calculate the weight of a 5000 kg lunar module on Earth ($g=9.8\ m/s^2$).

2) The acceleration due to gravity on Earth is 16% of that on Earth. Calculate the lunar module's weight on the moon.

3) When the lunar module takes off from the moon's surface, it's engine propels it forward with a force of 14 000 N. Calculate it's acceleration.

Work, energy and power

1) A machine is used to raise a 200 kg block of metal 3.6 m. Calculate the gravitational potential energy gained by the block.

2) State the change in kinetic energy of the block when it has been lifted.

3) Calculate the velocity of the block.

4)The machine transfers 21.3 kJ of energy in 142 seconds. Calculate it's power.

Materials

1) What happens when a force is applied to a spring?

2) State the type of energy stored in a spring.

3) Calculate the energy stored in a spring with a spring constant of 300 N/m that has been extended by 0.2 mm.

Newton's laws of motion

1) State two forces that act to slow down a moving body.

2) Describe the motion of a body that has balanced forces acting upon it.

3) Describe the motion of a body that has unbalanced forces acting upon it.

4) State Newton's 3rd law of motion.

Module 4 Electrons, waves and photons

Electricity: Charge and current

1) Define current and give it's unit.

2) Describe how charge is carried through a circuit.

3) Compare conventional current to actual current.

4) Why are metals good conductors of electricity?

Electricity: electrical circuits

1) Draw the circuit symbols and write the purpose of:

Variable resistor		
Fuse		
Heater		
Ammeter		
Voltmeter		
Thermistor		
Diode		
LED		
LDR		

Waves and Quantum Physics

1) Describe a longitudinal wave and give 2 examples.

2) Describe a transverse wave and give 2 examples.

3) Compare reflection and refraction.

4) List the waves in the electromagnetic spectrum from biggest wavelength to lowest.

WHAT DO I NEED TO KNOW FOR A-LEVEL PHYSICS?

Module 5 Newtonian World and Astrophysics

Thermal physics

1) What is body temperature in °C?

2) What happens to the boiling point of water:

a) in a pressure cooker?

b) at Everest base camp?

3) Why does liquid evaporating from your hands feel cold?

4) Are you heating ice when you change it into water?

Circular motion

1) Name the planets of the solar system.

2) Which way does the Earth rotate?

3) How long does it take for:

a) the Earth to spin on its axis?

b) the Earth to go once round the Sun?

c) the Moon to go once round the Earth?

Gravitational fields

1) Which way does Earth's gravitation field act?

2) Draw a diagram to show Earth's gravitational field.

3) Describe the relationship between an object with mass and the gravitation field it is stood in.

Astrophysics

1) Why are reflecting telescopes able to give clearer images than refracting telescopes?

2) a) What is the numerical value of the speed of light?

b) How far does the Earth travel in one year?

3) List the following in order of increasing mass.

Sun Moon meteorite galaxy comet Earth

4) What happens to the frequency of light from an object moving away from you?

Module 6 Particle and medical physics

Capacitors

1) What is the SI unit of electrical charge?

2) A component has a resistance of 5.0 kΩ and the current in it is 300 μA. What is the p.d. across the component?

3) Assume you start with £20 and each day you spend 10% of what you have at the start of the day. Sketch a graph to show how the amount of money you have changes with time. Why are you never broke?

Electric and magnetic fields

1) Electric field strength is force per unit charge. What unit will be used for this?

2) Two charges are placed near to one another. What force will these be when the charges are:

a) both positive?

b) both negative?

c) one positive and one negative?

3) What is Fleming's left hand rule?

4) Give one example of the use of a magnetic field other than for navigation or as provided by a magnet.

Nuclear and particle physics

1) Draw and describe the structure of an atom.

2) What is an ion?

3) What s Einstein's most famous equation? What does each symbol stand for?

Medical imaging

1)What is a typical wavelength for X-rays?

2) Name two possible effects of ionising radiation on cells.

3) Sketch a ray diagram to show why a point source of X-rays gives a sharp shadow, but a wider source gives a fuzzy shadow.

4) Why is ultrasound scanning the preferred imaging method for pregnant women?

GCSE Physics Checker

1 Electricity

Conductors and insulators

1 Correct examples include: copper, silver, aluminium – any metal! Non-metal examples include: salt solution, carbon in the form of graphite, sea water.

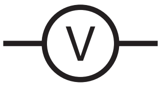
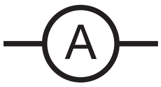
2 Correct examples include: glass, wood, air, rubber, plastic and gas.

3 Electrical resistance.

4 The circuit is broken and electric current can no longer flow around the circuit.

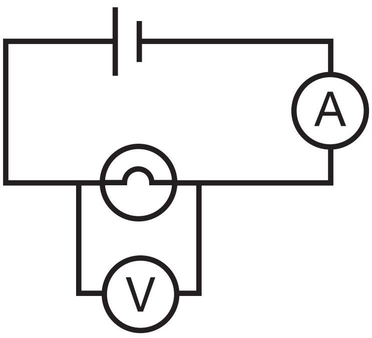
Circuit symbols

5 The completed table:

symbol	name
	cell
	**voltmeter**
	resistor
	**ammeter**
	bulb

Circuits

6 A simple circuit:



7 The long side of a cell symbol is positive. An easy way to remember this: it takes more ink to draw a + sign, and more ink to draw the positive side of the cell.

8 An ammeter measures **current** flowing in a circuit and is always placed in **series** with components in the circuit.

9 A voltmeter measures **potential difference** across a component and is always placed in **parallel** with components in the circuit.

10 Potential difference changes from one side of the cell to the other. Current is the same throughout a series circuit.

Safety

11 Blue, brown and green and yellow.

12 Blue = neutral; brown = live; green/yellow = earth.

13 If a fault develops and the device has a short circuit, the current increases and the higher current flowing through the fuse causes it to melt, breaking the circuit.

14 Turn off the power source and isolate the person from the power supply.

Calculations

15 $R_1 = 500\ \Omega$ $R_2 = 470\ \Omega$

$R_T = R_1 + R_2 = 500 + 470 = \mathbf{970\ \Omega}$

16 $I = 0.78$ A $R = 24\ \Omega$

$V = IR = 0.78 \times 24 = \mathbf{18.72\ V}$

17 $I = 0.055$ A $R = 11\ \text{k}\Omega = 11 \times 10^3 = 11\,000\ \Omega$

$V = IR = 0.055 \times 11\,000 = \mathbf{605\ V}$

18 $V = IR$

Divide both sides by R and cancel: $\mathbf{I = \frac{\mathit{V}}{\mathit{R}}}$

19 $I = 1.2$ A $V = 12$ V

$R = \frac{V}{I} = \frac{12}{1.2} = \mathbf{10\ \Omega}$

20 $I = 0.22$ A $V = 230$ V

$R = \frac{V}{I} = \frac{230}{0.22} = \mathbf{1.045 \times 10^3\ \Omega}$

2 Forces

Examples of forces

1 Weight

2 Surface tension

3 Friction

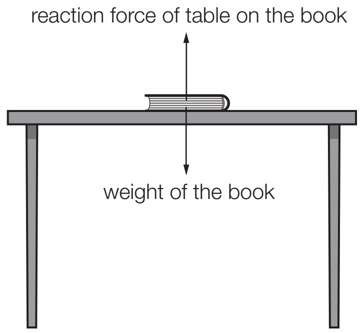
4 Buoyancy or up-thrust

5 Tension

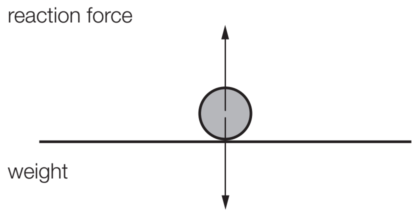
6 Lift

7 Drawing forces:

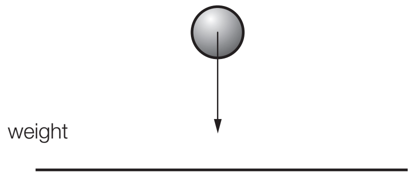
a. A book on a table



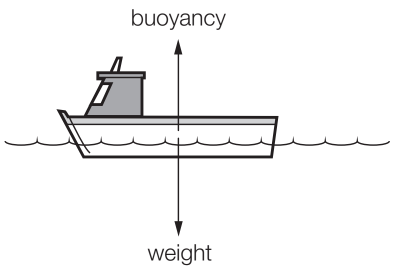
b. A ball on the floor



c. A ball falling towards the ground



d. A boat on the water



Balanced and unbalanced forces

8 Reaction or normal.

9 Same size, opposite directions.

10 The resultant force is zero, so an object remains at rest or at constant velocity.

11 Changes its direction of motion; causes acceleration (or deceleration).

Newton's Laws of Motion

12 An object will remain at rest or will travel at a constant speed in a straight line unless a resultant force acts on it.

13 Force = mass × acceleration: $F = ma$

14 Action and reaction are equal and opposite.

3 Motion

Speed

1 Speed = distance / time: $s = \frac{d}{t}$

2 Metres per second, ms^{-1}

3 $d = 200$ m $t = 19.2$ s $s = ?$

$s = \frac{d}{t} = \frac{200}{19.2} = \mathbf{10.42\ ms^{-1}}$

4 $d = 1.6$ m $t = 26$ minutes $= 1{,}560$ s $s = ?$

$s = \frac{d}{t} = \frac{1.6}{1560} = \mathbf{0.001\ ms^{-1}}$

5 $t = 10$ s $s = 330\ ms^{-1}$ $d = ?$

$d = st = 330 \times 10$ **= 3,300 m or 3.3 km**

6 $d = 1.2$ km $= 1{,}200$ m $s = 24\ ms^{-1}$ $t = ?$

$t = \frac{d}{s} = \frac{1200}{24} = \mathbf{50\ s}$

Acceleration

7 Acceleration = change in speed / time: $a = \frac{s}{t}$

8 ms^{-2}

9 $s = 5\ ms^{-1}$ $t = 3$ s $a = ?$

$a = \frac{s}{t} = \frac{5}{3} = \mathbf{1.67\ ms^{-2}}$

10 $s = 12\ m.s^{-1}$ $t = 1.4$ s $a = ?$

$a = \frac{s}{t} = \frac{12}{1.4} = \mathbf{8.57\ ms^{-2}}$

11 $a = 10\ ms^{-2}$ $t = 8$ s $s = ?$

$s = at = 10 \times 8 = \mathbf{80\ ms^{-1}}$

12 $s = 150 - 100 = 50\ ms^{-1}$ $a = 25\ ms^{-2}$ $t = ?$

$t = \frac{s}{a} = \frac{50}{25} = \mathbf{2\ s}$

Force and motion

13 Stopping distance is the total distance travelled between seeing the reason to stop and actually stopping. Thinking distance (reaction time) is the distance travelled between seeing the reason to stop and pressing the brakes. Braking distance is the distance travelled between pressing the brakes and actually stopping.

14 Any three from: drinking, drugs, tiredness, eyesight, distractions such as mobile phones, texting, arguing.

15 Any three from: road conditions (rain, ice), brake conditions, tyre conditions, load.

16 Any two from: seat belts, airbags, crumple zones, side impact bars.

17 a. Engine thrust is larger than drag, causing acceleration.

b. Drag is larger than engine thrust, causing deceleration.

4 Space and Radioactivity

Space

Earth and moon

1 24 hours or one day.

2 One lunar month or 28 days.

3 Twelve.

4 There is no atmosphere; the vacuum effect of space; the need for air supply; the need for temperature regulation.

5 The moon has weaker gravity due to its lower mass.

6 They are above the atmosphere and so do not suffer from atmospheric distortion. Some regions of the electromagnetic spectrum are absorbed by the atmosphere, so detectors of these regions need to be above the atmosphere, eg x-ray telescopes.

Solar system

7 Copernicus.

8 Heliocentric.

9 Jupiter, Saturn, Uranus, Neptune.

10 Hottest: Venus, Mercury, Earth, Mars: coldest. Venus has a thick atmosphere that traps heat, making the planet's surface hotter than would be expected given its distance from the sun. Otherwise, the closer a planet is to the sun, the hotter the planet's surface.

Stars

11 The sun.

12 Four light years.

13 Gravity. It acts on gas and dust, causing them to clump together; the clump grows until the pressure and temperature in its core is enough to begin nuclear burning.

14 Nuclear fusion. Hydrogen undergoes fusion to become helium, and the process releases energy.

15 Red giants. The sun will expand to become a red giant in about five billion years.

16 A black hole or neutron star.

Radioactivity

Atoms and isotopes

17 Electron = −1; proton = +1; neutron = 0

18 Electron approximately 0.0005 or 1/2000; proton = 1; neutron = 1

19 Deuterium has a neutron in its nucleus along with a single proton, whereas hydrogen only has a single proton. Isotopes vary in the number of neutrons an element has in its nucleus, not the number of protons; the number of protons is determined by the type of element.

20 Number of neutrons = nucleon number − proton number. So: 12 − 6 = 6.

A carbon-12 nucleus has 6 neutrons in it.

Alpha, beta and gamma

21 Alpha = +2; beta = −1; gamma = 0

22 Alpha = 4; beta = 0.0005 or 1/2000; gamma = 0

23 It changes into a different element, due to the loss of protons with alpha decay and the gain of a proton with beta decay.

24 It can damage cells. Ionisation of DNA by radiation leads to increased risk of cells dividing in a faulty manner, in turn leading to tumours and cancers.

Sources and uses of radiation

25 Cosmic rays; soil; rocks; air; food; living things; medical scans; weapons fallout; nuclear power emissions; nuclear accidents.

26 A radioactive substance (a tracer) is injected into the patient. Its passage through the body and its concentration in particular places can be monitored outside the body by the radiation it emits. This can then be shown in 3-D, in combination with other types of scan.

27 Alpha particles are strong ionisers and are absorbed by a few centimetres of air. Smoke absorbs more alpha particles than air alone. Smoke is able to reduce the distance alpha particles can travel before being absorbed. Beta and gamma radiation would not be affected by the presence of smoke. A smoke detector contains a small amount of radioactive material that emits alpha particles, and these help create a small electric current. When smoke enters the detector, it blocks the alpha particles so that the current is reduced, which triggers the alarm.

28 Nuclear power plants employ nuclear fission using uranium. Uranium nuclei can be made to split into two smaller nuclei in a controlled fission reaction. This releases large amounts of energy as heat.

5 Energy and Waves

Energy

1 The joule.

2 Kinetic energy.

3 Two from: fuel, food, batteries.

4 Energy cannot be created or destroyed, only transferred from one form to another.

Energy transfers

5 Electrical energy is transformed into light energy and heat energy.

6 Uranium is radioactive and undergoes fission, causing an energy transfer of nuclear energy to heat energy.

7 Coal is a store of chemical energy; this is released as heat when the coal is burnt. The heat energy is converted to kinetic energy when water is heated to make steam. A generator converts the kinetic energy into electrical energy.

8 Carbon dioxide, methane.

9 Nuclear energy (fission) is a non-renewable energy source, and geothermal energy is a renewable energy source. Both involve nuclear energy, which does not originate with the sun.

Heat and temperature

10 Heat energy breaks the bonds between particles, allowing increased motion. This causes the regular arrangement of particles in a solid to break down.

11 Energy is needed to increase the temperature of ice or water. When a substance melts, the energy is being used to break the bonds between particles in the solid. This 'latent' heat means that the energy is not changing the temperature during melting.

12 Conduction, convection, radiation.

13 Radiation, because both conduction and convection require material to pass through; space is effectively a vacuum, so the sun's heat does not pass through material on its way to Earth.

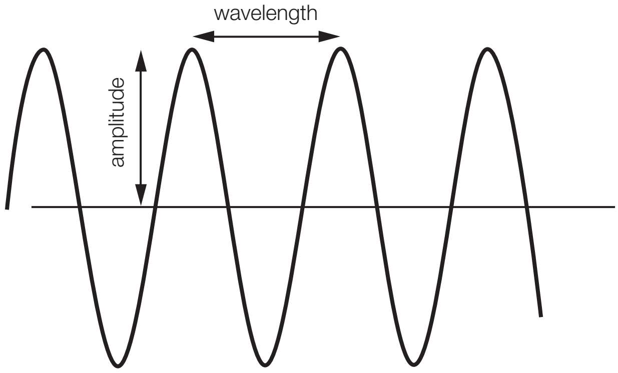
14 A warm bath of water has more heat energy stored in it due to its larger mass, despite being at a lower temperature. Imagine trying to heat a cup's volume of cold water compared with a bath's volume of cold water – there is quite a difference.

Waves

Types of waves

15 Correct examples include: light, radio, x-ray, microwaves, infrared, ultraviolet, gamma rays, water, rope, seismic S waves.

16 Transverse waves:

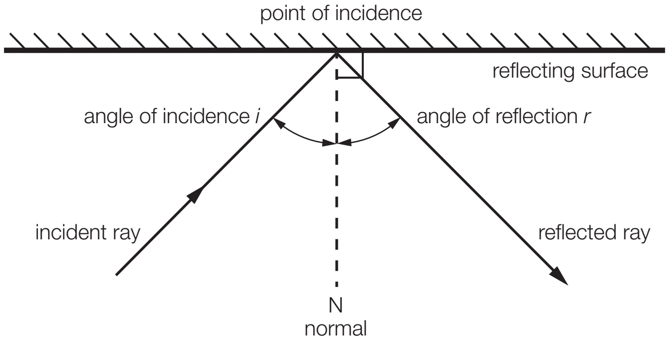


17 Longitudinal.

Properties of waves

18 Two from: refraction, diffraction, interference.

19 Ray of light reflecting off of a plane mirror:



20 The angle of incidence is equal to the angle of reflection.

Basic Skills for the A-level Physicist

7 Large and Small Numbers and Standard Form

1 $100 = \mathbf{10^2}$

2 $100\,000 = \mathbf{10^5}$

3 $10 = \mathbf{10^1}$

4 $1\,000\,000\,000 = \mathbf{10^9}$

5 $0.1 = \mathbf{10^{-1}}$

6 $0.001 = \mathbf{10^{-3}}$

7 $0.000000001 = \mathbf{10^{-9}}$

8 $1 = \mathbf{10^0}$

9 $280 = \mathbf{2.8 \times 10^2}$

10 $2530 = \mathbf{2.53 \times 10^3}$

11 $0.77 = \mathbf{7.7 \times 10^{-1}}$

12 $0.0091 = \mathbf{9.1 \times 10^{-3}}$

13 $1\,872\,000 = \mathbf{1.872 \times 10^6}$

14 $12.2 = \mathbf{1.22 \times 10^1}$

15 $2.4 \times 10^2 = \mathbf{240}$

16 $3.505 \times 10^1 = \mathbf{35.05}$

17 $8.31 \times 10^6 = \mathbf{8\,310\,000}$

18 $6.002 \times 10^{-2} = \mathbf{0.06002}$

19 $1.5 \times 10^{-4} = \mathbf{0.00015}$

20 $4.3 \times 10^{-1} = \mathbf{0.43}$

8 Units in Physics

quantity	symbol	unit	symbol
charge	***Q***	coulomb	**C**
current	***I***	ampere	**A**
time	***t***	second	**s**
potential difference	***V***	volt	**V**
resistance	***R***	ohm	**Ω**
power	***P***	watt	**W**
energy	***E***	joule	**J**
area	***A***	metre^2	**m^2**
distance	***d***	metre	**m**
force	***F***	newton	**N**
velocity	***v***	metres per second	**ms^{-1}**
mass	***m***	kilogram	**kg**
magnetic field strength	***B***	tesla	**T**
capacitance	***C***	farad	**F**

This table can also be photocopied and made into pairs of cards for a matching task to aid revision.

9 Prefixes

1 km, so prefix is k = 10^3 so 2.4 km = **2.4 × 10^3 m**

2 MJ, so prefix is M = 10^6 so 8.1 MJ = **8.1 × 10^6 J**

3 GW, so prefix is G = 10^9 so 326 GW = **326 × 10^9 W**

4 mm, so prefix is m = 10^{-3} so 54,600 mm = **54600 × 10^{-3} m**

5 μm, so prefix is μ = 10^{-6} so 1 μm =**1 × 10^{-6} m**

6 kg, so prefix is k = 10^3 so 240 kg = **240 × 10^3 g**

7 nm, so prefix is n = 10^{-9} so 0.18 nm = **0.18 × 10^{-9} m**

8 mJ, so prefix is m = 10^{-3} so 0.096 mJ = **0.096 × 10^{-3} J**

9 GeV, so prefix is G = 10^9 so 125 GeV = **125 × 10^9 eV**

10 MΩ, so prefix is M = 10^6 so 470 MΩ = **470 × 10^6 Ω**

11 nm, so prefix is n = 10^{-9} so 632 nm = 632 × 10^{-9} m

In standard form, 632 nm = **6.32 × 10^{-7} m**

12 mV, so prefix is m = 10^{-3} so 1,002 mV = 1002 × 10^{-3} V

In standard form, 1,002 mV = **1.002 V**

13 MeV, so prefix is M = 10^6 so 0.511 MeV = 0.511 × 10^6 eV

In standard form, 0.511 MeV = **5.11 × 10^5 eV**

14 kΩ, so prefix is k = 10^3 so 11 kΩ = 11 × 10^3 Ω

In standard form, 11 kΩ = **1.1 × 10^4 Ω**

15 km, so prefix is k = 10^3 so 9212 km = 9212 × 10^3 m

In standard form, 9212 km = **9.212 × 10^6 m**

16 kg, so prefix is k = 10^3 so 1.385 kg = **1.385 × 10^3 g**.

Since the base unit for mass is the kg, answer in standard form is. 1.385 × 10^1 kg – *Trick question!*

17 μm, so prefix is μ = 10^{-6} so 2.3 × 10^2 μm = 2.3 × 10^2 × 10^{-6} = 2.3 × 10^{-4} m

Already in standard form: **2.3 × 10^{-4} m**

18 km, so prefix is k = 10^3 so 0.55 × 10^4 km = 0.55 × 10^4 × 10^3 = 0.55 × 10^7 m

In standard In standard form, 0.55 × 10^4 km = **5.5 × 10^6 m**

19 mm, so prefix is m = 10^{-3} so 4.61 × 10^{-2} mm = 4.61 x 10^{-2} × 10^{-3} = 4.61 × 10^{-5} m

Already in standard form: **4.61 × 10^{-5} m**

20 MJ, so prefix is M = 10^6 so 0.062 × 10^{-5} MJ = 0.062 × 10^{-5} × 10^6 = 0.062 × 10^1 J

In standard form, 0.062 × 10^{-5} MJ = **6.2 × 10^{-1} J**

10 Using your Calculator – Answers

1 **1.349 × 10^5**

2 **1.730 × 10^5**

3 **8.64 × 10^4** seconds

4 **9.632 × 10^4** coulombs

5 **2.592 × 10^{13}**

6 **2.608 × 10^1** (= 26.08)

7 **7.85 × 10^{-7}**

8 **2.60 × 10^6**

9 **9.084 × 10^{-31}**

10 **1.539 × 10^{22}**

11 Rearranging Equations

1

operation	symbol	opposite	symbol
addition	$+$	subtraction	$-$
division	/	multiplication	$\times$
square root	$\sqrt{}$	squared	^{2}
cubed	^{3}	cubed root	$\sqrt[3]{}$
sine	sin	arc-sine	$\sin^{-1}$
cosine	cos	arc-cosine	$\cos^{-1}$
tangent	tan	arc-tangent	$\tan^{-1}$
natural log	ln or $\log_e$	e to the power	e^x
log to the base 10	$\log_{10}$	10 to the power	10^x

2 $A = \pi r^2$ make $\boldsymbol{r}$ the subject:

reverse $\pi r^2 = A$

divide both sides by π $\frac{\pi r^2}{\pi} = \frac{A}{\pi}$

cancel on left-hand side $r^2 = \frac{A}{\pi}$

square root both sides $\sqrt{r^2} = \sqrt{\frac{A}{\pi}}$

simplify $\boldsymbol{r = \sqrt{\frac{A}{\pi}}}$

3 $v = \frac{s}{t}$ make $\boldsymbol{s}$ the subject:

reverse $\frac{s}{t} = v$

multiply both sides by t $\frac{s}{t}t = vt$

cancel on left-hand side $\boldsymbol{s = vt}$

4 $F = ma$ make $\boldsymbol{a}$ the subject:

reverse $ma = F$

divide both sides by m $\frac{ma}{m} = \frac{F}{m}$

cancel on left-hand side $\boldsymbol{a = \frac{F}{m}}$

5 $P = \frac{E}{t}$ make $\boldsymbol{E}$ the subject:

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

multiply both sides by t $\frac{E}{t}t = Pt$

cancel on left-hand side $\boldsymbol{E = Pt}$

6 $E = mc^2$ make ***m*** the subject:

reverse	$mc^2 = E$
divide both sides by c^2	$\frac{mc^2}{c^2} = \frac{E}{c^2}$
cancel on left-hand side	$\boldsymbol{m = \frac{E}{c^2}}$

7 $v^2 = u^2 + 2as$ make ***a*** the subject:

reverse	$u^2 + 2as = v^2$
subtract u^2 from both sides	$u^2 + 2as - u^2 = v^2 - u^2$
simplify the left-hand side	$2as = v^2 - u^2$
divide both sides by $2s$	$\frac{2as}{2s} = \frac{v^2-u^2}{2s}$
cancel on left-hand side	$\boldsymbol{a = \frac{v^2-u^2}{2s}}$

8 $F = G\frac{Mm}{r^2}$ make ***M*** the subject:

reverse	$G\frac{Mm}{r^2} = F$
divide both sides by G	$G\frac{Mm}{Gr^2} = \frac{F}{G}$
cancel on left-hand side	$\frac{Mm}{r^2} = \frac{F}{G}$
divide both sides by m	$\frac{Mm}{mr^2} = \frac{F}{Gm}$
cancel on left-hand side	$\frac{M}{r^2} = \frac{F}{Gm}$
multiply both sides by r^2	$\frac{r^2M}{r^2} = \frac{Fr^2}{Gm}$
cancel on left-hand side	$\boldsymbol{M = \frac{Fr^2}{Gm}}$

9 $F = \frac{1}{4.\pi\varepsilon_0}\frac{Qq}{r^2}$ make ***r*** the subject

multiply both sides by r^2	$Fr^2 = \frac{1}{4\pi\varepsilon_0}Qq$
divide both sides by F	$\frac{Fr^2}{F} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{F}$
cancel on left-hand side	$r^2 = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{F}$
square root both sides	$\sqrt{r^2} = \sqrt{\frac{1}{4\pi\varepsilon_0}\frac{Qq}{F}}$
simplify	$\boldsymbol{r = \sqrt{\frac{1}{4\pi\varepsilon_0}\frac{Qq}{F}}}$

10 $T = 2\pi\sqrt{\frac{m}{k}}$ make ***k*** the subject:

reverse	$2\pi\sqrt{\frac{m}{k}} = T$
divide both sides by 2π	$\frac{2\pi}{2\pi}\sqrt{\frac{m}{k}} = \frac{T}{2\pi}$

cancel on left-hand side $\sqrt{\frac{m}{k}} = \frac{T}{2\pi}$

square both sides $\left(\sqrt{\frac{m}{k}}\right)^2 = \left(\frac{T}{2\pi}\right)^2$

simplify $\frac{m}{k} = \left(\frac{T}{2\pi}\right)^2 = \frac{T^2}{4\pi^2}$

invert both sides $\frac{k}{m} = \frac{4\pi^2}{T^2}$

multiply both sides by *m* $\boldsymbol{k = \frac{4\pi^2}{T^2} m}$

12 Using Equations in Physics

1 Start velocity at rest is $u = 0$ ms^{-1} ; final velocity $v = 10$ ms^{-1} ; time $t = 2.4$ s

Find acceleration = using $a = \frac{v-u}{t}$: no need to rearrange

Calculation $a = \frac{v-u}{t} = \frac{10-0}{2.4} = \frac{10}{2.4} = 4.17$ ms^{-2}

2 Current $I = 50$ mA ; convert to amperes: 50 mA = 50×10^{-3} A;
potential difference V = 3.0 V

Find resistance = R using $R = \frac{V}{I}$: no need to rearrange

Calculation $R = \frac{V}{I} = \frac{3.0}{50 \times 10^{-3}} = 60\Omega$

3 Current $I = 20$ mA $= 20 \times 10^{-3}$ A; time $t = 1$ hour $= 1 \times 60 \times 60 = 3600$ s

Find charge = Q using $Q = It$: no need to rearrange

Calculation $= 20 \times 10^{-3} \times 3600 = 7.2 \times 10^1$ C = **72 C**

4 Resistances: $R_1 = 50\ \Omega$; $R_2 = 20\ \Omega$; $R_3 = 500\ \Omega$

Find resistance $R_T = R_1 + R_2 + R_3$: no need to rearrange

Calculation $R_T = R_1 + R_2 + R_3 = 50 + 20 + 500 =$ **570 Ω**

5 Initial velocity $u = 50$ ms^{-1}; final velocity $v = 230$ ms^{-1}; time $t = 108$ s

Find acceleration = a using $\frac{v-u}{t}$: no need to rearrange

Calculation $a = \frac{v-u}{t} = \frac{230-50}{108}$ **1.67 ms^{-2}**

6 Mass $m = 15$ kg; acceleration $a = 28$ ms^{-2}

Find force = F using $F = ma$: no need to rearrange.

Calculation $F = m.a = 15 \times 28 = 420$ N

7 Current $I = 0.15$ A; potential difference V = 12 V; time $t = 10$ min $= 10 \times 60 = 600$ s

Find energy E: first find charge $Q = It$; then rearrange $V = \frac{E}{Q}$ to give $E = QV$

Calculation $Q = It = 0.15 \times 600 = 90$ C so $E = QV = 90 \times 12 = 1080$ J

Or $E = QV = ItV = 0.15 \times 600 \times 12 =$ **1.08×10^3 J**

8 Constant acceleration is in a straight line, so SUVAT equations are needed.

(SUVAT is the name of a set of equations for calculating motion under constant acceleration in a straight line – ask your teacher if you are unsure.)

Initial velocity $u = 25\ \text{ms}^{-1}$. Upward motion is positive, while acceleration due to gravity acts downwards, so acceleration $a = -9.81\ \text{ms}^{-2}$ at the top of the throw, where velocity $v = 0$

Find height s: use $v^2 = u^2 + 2as$ and rearrange for $s = \frac{v^2 - u^2}{2a}$

Calculation $s = \frac{v^2 - u^2}{2a} = \frac{0^2 - 25^2}{2(-9.81)} = \frac{-625}{-19.62} = \mathbf{31.86\ m}$

13 Measurements and Errors

1 Absolute error is the error due to the measuring device and the skill of its use.
An overestimate is always better than an underestimate.

2 The absolute error as a percentage of the measurement.
% error = (absolute error × 100) / measurement

3 Only percentage errors can be combined.

4 ±0.01 V

5 % error = (0.01 × 100) / 0.75 = 1.3% round up to **2%**

6 Reaction time ±0.5 s

7 % error = (0.5 × 100) / 12.0 = 4.2% rounded up to **5%**

8 Area depends on the square of the radius, so the % error in the area = 2 × % error in the radius.

9 Despite division in the equation, always add errors. % error in resistance = 2 + 3 = **5%**

10 Percentage error for 14.65 nm of 8% is (8 × 14.65) / 100 = 1.2 nm; therefore result = **14.7 ± 1.2 nm**

14 Results Tables

1 Independent variable, dependent variables, calculated variables.

2 Units of each measurement.

3 Absolute error in any measurement taken.

4 Your results table should be similar to the following:

height dropped from	time to fall	average speed
m	**s**	ms^{-1}
±0.01	**±0.5**	
0.5		
0.6		
0.7		

5 You should have spotted the following errors:

diameter	area	radius	resistance	current	voltage
mm	**m^2**	**m**	**R**	**A**	**V**
±0.001				**±0.001**	**±0.001**
0.58					
0.24					
0.72					

Resistance is a calculated quantity so should be the last column.

Radius should be before area

Should be in numerical order: 0.24, 0.58, 0.72

See Chapter 13 on Measurements and Errors for discussion on how errors are calculated.

15 Analysing Results

1 There is no obvious anomaly.

2 Average = (2.2 + 4.2 + 6.3 + 8.4 + 10.7) / 5 = **6.4 V**

3 Range = 17.1 − 2.2 = **14.9 mA**

4 Voltage is the independent variable. Current is the dependent variable.

5 *m* stands for the gradient of a straight line and *c* stands for the intercept with the *y*-axis.

6 If current *I* is plotted on the *x*-axis and voltage *V* on the *y*-axis then the gradient (*y* / *x*) of the straight line is equal to *V* / *I* = resistance.

7 $R = V / I = 1 / (2.2 \times 10^{-3}) = 4.55 \times 10^2 = \mathbf{455\ \Omega}$

8 $R = V / I = 8 / (17.1 \times 10^{-3}) = 4.68 \times 10^2 = \mathbf{468\ \Omega}$

16 Graphs

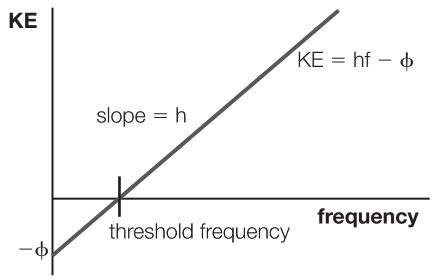
1 Larger than half the size of the piece of paper.

2 3 or 7.

3 The name of the variable and its unit of measurement.

4 Gradient = change in *y* divided by change in *x*.

5 a. $E_{k\,max} = hf - \phi$
b. The gradient is Planck's constant (*h*).
c. The *y*-intercept is the **negative** value of the workfunction ($-\phi$).



Answers

17 Atoms and Nuclei

1 Nucleon number.

2 1 proton; 3 − 1 = 2 neutrons; 1 electron.

3 6 protons; 14 − 6 = 8 neutrons; 6 electrons.

4 11 protons; 23 − 11 = 12 neutrons; 11 electrons.

5 26 protons; 56 − 26 = 30 neutrons; 26 electrons.

6 92 protons; 238 − 92 = 146 neutrons; 92 electrons.

7 17 protons; 37 − 17 = 20 neutrons; 17 electrons.

8 Same number of protons and different number of neutrons.

9 mass = 9.1×10^{-31} kg charge = 1.6×10^{-19} C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{1.6 \times 10^{-19}}{9.1 \times 10^{-31}} = \mathbf{1.76 \times 10^{11}\ Ckg^{-1}}$$

10 mass = 1.67×10^{-27} kg charge = 1.6×10^{-19} C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{1.6 \times 10^{-19}}{1.67 \times 10^{-27}} = \mathbf{9.58 \times 10^{7}\ Ckg^{-1}}$$

11 mass = $4 \times 1.67 \times 10^{-27}$ kg charge = $2 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{2 \times 1.6 \times 10^{-19}}{4 \times 1.67 \times 10^{-27}} = \mathbf{4.79 \times 10^{7}\ Ckg^{-1}}$$

12 mass = $12 \times 1.67 \times 10^{-27}$ kg charge = $6 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{6 \times 1.6 \times 10^{-19}}{12 \times 1.67 \times 10^{-27}} = \mathbf{4.79 \times 10^{7}\ Ckg^{-1}}$$

13 mass = $56 \times 1.67 \times 10^{-27}$ kg charge = $26 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{26 \times 1.6 \times 10^{-19}}{56 \times 1.67 \times 10^{-27}} = \mathbf{4.45 \times 10^{7}\ Ckg^{-1}}$$

14 mass = $235 \times 1.67 \times 10^{-27}$ kg charge = $92 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{92 \times 1.6 \times 10^{-19}}{235 \times 1.67 \times 10^{-27}} = \mathbf{3.75 \times 10^{7}\ Ckg^{-1}}$$

15 mass = $16 \times 1.67 \times 10^{-27}$ kg charge = $2 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{2 \times 1.6 \times 10^{-19}}{16 \times 1.67 \times 10^{-27}} = \mathbf{1.20 \times 10^{7}\ Ckg^{-1}}$$

16 mass = $63 \times 1.67 \times 10^{-27}$ kg charge = $2 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{2 \times 1.6 \times 10^{-19}}{63 \times 1.67 \times 10^{-27}} = \mathbf{3.04 \times 10^{6}\ Ckg^{-1}}$$

18 Subatomic Particles

1 Elementary particles are not made up of other particles.

2 0.511 MeV = 0.511×10^{6} eV 1 eV = 1.6×10^{-19} J
$0.511 \times 10^{6} \times 1.6 \times 10^{-19}$ = $\mathbf{8.18 \times 10^{-14}\ J}$

3 $$48 \times 10^{-19}\ \text{J} = \frac{48 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{30\ eV}$$

4 Up, down, strange, charm, bottom and top.

5 A baryon.

6 An antibaryon.

7 A lepton.

8 A meson.

9 Electromagnetism, Weak Nuclear Force, Strong Nuclear Force, gravity.

10 (Virtual) Photon.

11 W^+ and W^-.

12 Lepton number −1

13 Baryon number +1

14 Baryon number 0

15 Lepton number 0

16 Lepton number +1

17 They contain a strange quark if strangeness = −1 and an antistrange quark if strangeness = +1.

18 The Weak Nuclear Force does not conserve strangeness.

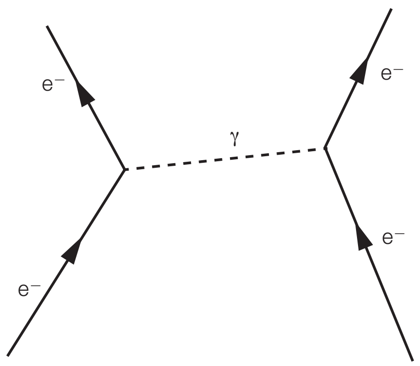
19 Conservation Laws and Feynman Diagrams

1 Gravity, electromagnetism, Weak Nuclear Force, Strong Nuclear Force.

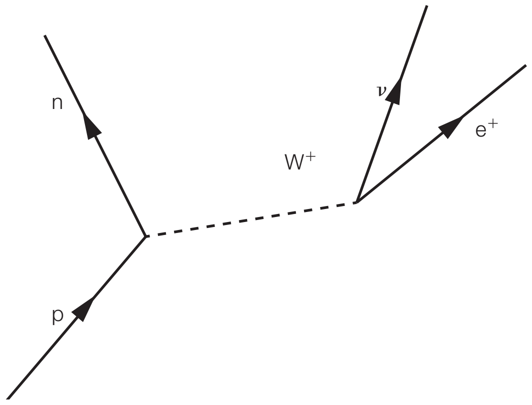
2 Gravity: graviton; electromagnetism: photon; Weak Nuclear Force: W^+, W^-, Z^0; Strong Nuclear Force: gluon.

3 Space (horizontal) and Time (vertical).

4 Two electrons repelling each other:



5 Beta plus decay:



6 Charge, Q; baryon number, B; lepton number, L.

7 a. $e^- + e^+ \rightarrow \pi^+ + \pi^- + \nu + n + \bar{p}$

Charge Q	−1	+1	→	+1	−1	+0	+0	−1	0 = −1	✗

This interaction breaks the law of conservation of charge, so is not possible.

b. $p + \bar{n} \rightarrow \pi^+ + p + \pi^0 + e^- + \bar{\nu}$

Charge Q	+1	+0	→	+1	+1	+0	−1	+0	+1 = +1	✓
Baryon number B	+1	−1	→	0	+1	+0	+0	+0	0 = +1	✗

This interaction breaks the law of conservation of baryon number, so is not possible.

c. $e^+ + \bar{p} \rightarrow p + \pi^- + \bar{n} + \bar{n} + \bar{\nu}$

Charge Q	+1	−1	→	+1	−1	+0	+0	+0	0 = 0	✓
Baryon number B	+0	−1	→	+1	+0	−1	−1	+0	−1 = −1	✓
Lepton number L	−1	+0	→	+0	+0	+0	+0	−1	−1 = −1	✓
Strangeness S	0	+0	→	0	+0	+0	+0	+0	0 = 0	✓

All of the conservation laws are obeyed, so this interaction seems possible.

d. $n + \bar{p} \rightarrow \pi^- + \pi^0 + e^- + e^+ + \bar{\nu}$

Charge Q	+0	−1	→	−1	+0	−1	+1	+0	−1 = −1	✓
Baryon number B	+1	−1	→	+0	+0	+0	+0	+0	0 = 0	✓
Lepton number L	+0	+0	→	+0	+0	+1	−1	−1	0 = −1	✗

This interaction breaks the law of conservation of lepton number, so is not possible.

8 Your answers will depend on the particle interactions you chose to look at. If you are unclear on what is needed, or unsure if you have answered the question correctly, you should ask your physics teacher to look over your answer.

20 Electrical Circuits: Charge, Current and Voltage

1 $Q = It$ Q is charge measured in coulombs, I is current measured in amperes, t is time measured in seconds.

2 $I = 120\ \text{mA} = 120 \times 10^{-3}\ \text{A}$; $Q = 58\ \text{C}$; $t = ?$

$Q = It$ rearrange: $t = \frac{Q}{I} = \frac{58}{120 \times 10^{-3}} = 4.83 \times 10^2\ \text{s} =$ **483 s**

3 $I = 13\text{ A}$; $Q = 0.5\text{ C}$; $t = ?$

$Q = It$ rearrange: $t = \dfrac{Q}{I} = \dfrac{0.5}{13} = 3.8 \times 10^{-2}\text{ s} = \mathbf{0.038\ s}$

4 $I = 50\ \mu\text{A} = 50 \times 10^{-6}\text{ A}$; $t = 10\text{ min} = 10 \times 60 = 600\text{ s}$; $Q = ?$

$Q = It = 50 \times 10^{-6} \times 600 = 3.0 \times 10^{-2}\text{ C} = \mathbf{0.030\ C}$

5 $I = 20\text{ mA} = 20 \times 10^{-3}\text{ A}$; $t = 2\text{ hours} = 2 \times 60 \times 60 = 7{,}200\text{ s}$; $Q = ?$

$Q = It = 20 \times 10^{-3} \times 7{,}200 = 1.44 \times 10^{2}\text{ C} = \mathbf{144\ C}$

6 $Q = 3.80 \text{ x } 10^{3}\text{ C}$; $\text{t} = 5\text{ min} = 5 \times 60 = 300\text{ s}$; $I = ?$

$Q = It$ rearrange: $I = \dfrac{Q}{t} = \dfrac{3.8 \times 10^{3}}{300} = \mathbf{1.27\ A}$

7 $Q = 2.25 \times 10^{2}\text{ C}$; $\text{t} = 5\text{ ms} = 5 \times 10^{-3}$; $I = ?$

$Q = It$ rearrange: $I = \dfrac{Q}{t} = \dfrac{2.25 \times 10^{2}}{5 \times 10^{-3}} = \mathbf{4.5 \times 10^{4}\ A}$

8 $Q = 42\text{ C}$; $t = 2\text{ min} = 2 \times 60 = 120\text{ s}$; $I = ?$

$Q = It$ rearrange: $I = \dfrac{Q}{t} = \dfrac{42}{120} = \mathbf{0.35\ A}$

9 $V = \dfrac{E}{Q}$ or $V = \dfrac{W}{Q}$

V is potential difference measured in volts, *E* or *W* is energy measured in joules, *Q* is charge measured in coulombs.

10 Electromotive force is the energy per unit charge supplied **to** the circuit and potential difference is the energy per unit charge transferred **from** the circuit.

11 $E = 150\text{ J}$; $Q = 4.2\text{ C}$; $V = ?$

$V = \dfrac{E}{Q} = \dfrac{150}{4.2} = \mathbf{35.7\ V}$

12 $E = 6.2\text{ kJ} = 6.2 \times 10^{3}\text{ J}$; $Q = 12.5\text{ C}$; $V = ?$

$V = \dfrac{E}{Q} = \dfrac{6.2 \times 10^{3}}{12.5} = \mathbf{496\ V}$

13 $\varepsilon = 1.5\text{ V}$; $Q = 3{,}600\text{ C}$; $E = ?$

$\varepsilon = \dfrac{E}{Q}$ rearrange: $E = Q\varepsilon = 3{,}600 \times 1.5 = 5.4 \times 10^{3} = \mathbf{5400\ J}$

14 $V = 32\text{ kV} = 32 \times 10^{3}\text{ V}$; $Q = 9.6 \text{ x } 10^{6}\text{ C}$; $\text{E} = ?$

$V = \dfrac{E}{Q}$ rearrange: $E = QV = 9.6 \times 10^{6} \times 32 \times 10^{3} = \mathbf{3.1 \times 10^{11}\ J}$

15 $E = 200\text{ MJ} = 200 \times 10^{6}\text{ J}$; $V = 220\text{ kV} = 220 \times 10^{3}\text{ V}$; $Q = ?$

$V = \dfrac{E}{Q}$ rearrange: $Q = \dfrac{E}{V} = \dfrac{200 \times 10^{6}}{220 \times 10^{5}} = 9.09 \times 10^{2} = \mathbf{909\ C}$

16 $E = 6.45 \times 10^{-8}\text{ J}$; $V = 0.05\text{ V}$; $Q = ?$

$V = \dfrac{E}{Q}$ rearrange: $Q = \dfrac{E}{V} = \dfrac{6.45 \times 10^{-8}}{0.05} = \mathbf{1.29 \times 10^{-6}\ C}$

17 $I = 0.15$ A; $V = 12$ V; $t = 5$ min $= 5 \times 60 = 300$ s; $E = ?$

$Q = It$ is required to find Q first. Then $V = \dfrac{E}{Q}$ is rearranged to give $E = QV$

$Q = It = 0.15 \times 300 = 45$ C so $E = QV = 45 \times 12 =$ **540 J**

Or $E = QV = ItV = 0.15 \times 300 \times 12 =$ **540 J**

18 $I = 125$ mA $= 125 \times 10^{-3}$ A; $V = 5$ V; $t = 30$ min $= 30 \times 60 = 1{,}800$ s; $E = ?$

$Q = It$ is required to find Q first. Then $V = \dfrac{E}{Q}$ is rearranged to give $E = QV$

$Q = It = 125 \times 10^{-3} \times 1{,}800 = 2.25 \times 10^{2} = 225$ C so $E = QV = 5 \times 225 =$ $\mathbf{1.125 \times 10^{3}}$ **J**

Or $E = QV = ItV = 125 \times 10^{-3} \times 1{,}800 \times 5 =$ $\mathbf{1.125 \times 10^{3}}$ **J or 1.125 kJ**

21 Electrical Circuits: Resistance

1 $V = IR$ V = potential difference measured in volts; I = current measured in amperes; R = resistance measured in ohms.

2 $R_T = R_1 + R_2 + R_3$ in series.

3 $\dfrac{1}{R_T} = \dfrac{1}{R_1} = \dfrac{1}{R_2} = \dfrac{1}{R_3}$ in parallel.

4 Ohm's law states that the resistance of a metallic conductor does not change with potential difference provided the temperature is constant.

5 $I = 50$ mA $= 50 \times 10^{-3}$ A; $V = 1.5$ V; $R = ?$

$R = \dfrac{V}{I} = \dfrac{1.5}{50 \times 10^{-3}} =$ **30 Ω**

6 $I = 100$ μA $= 100 \times 10^{-6}$ A; $V = 6.0$ V; $R = ?$

$R = \dfrac{V}{I} = \dfrac{6.0}{100 \text{ x } 10^{-6}} = 6 \times 10^{4}\,\Omega =$ **60 kΩ**

7 $R = 47\,\Omega$; $V = 1.5$ V; $I = ?$

$I = \dfrac{V}{R} = \dfrac{1.5}{47} =$ $\mathbf{3.19 \times 10^{-2}}$ **A**

8 $R = 470$ kΩ $= 470 \times 10^{3}\,\Omega$; $V = 230$ V; $I = ?$

$I = \dfrac{V}{R} = \dfrac{230}{470 \times 10^{3}} = 4.9 \times 10^{-4}$ A $=$ **0.49 mA**

9 $R = 11.0$ MΩ $= 11 \times 10^{6}\,\Omega$; $I = 74.2$ mA $= 74.2 \times 10^{-3}$ A; $V = ?$

$V = IR = 74.2 \times 10^{-3} \times 11 \times 10^{6} =$ $\mathbf{8.16 \times 10^{5}}$ **V**

10 $R = 4.7$ kΩ $= 4.7 \times 10^{3}\,\Omega$; $I = 15$ μA $= 15 \times 10^{-6}$ A; $V = ?$

$V = IR = 15 \times 10^{-6} \times 4.7 \times 10^{3} = 7.1 \times 10^{-2} =$ **71 mV**

11 $R_1 = 50\,\Omega$; $R_2 = 10\,\Omega$; $R_3 = 200\,\Omega$; $R_T = ?$

$R_T = R_1 + R_2 + R_3 = 50 + 10 + 200 =$ **260 Ω**

12 $R_1 = 1\ \text{k}\Omega = 1{,}000\ \Omega$; $R_2 = 470\ \Omega$; $R_3 = 115\ \Omega$; $R_T = ?$

$R_T = R_1 + R_2 + R_3 = 1{,}000 + 470 + 115 = \mathbf{1585\ \Omega}$

In series circuits, all resistors have the same current; hence all of them have the largest current.

13 $R_1 = 10\ \Omega$; $R_2 = 10\ \Omega$; $R_3 = 10\ \Omega$; $R_T = ?$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10} + \frac{1}{10} + \frac{1}{10} = \frac{3}{10}$$

$$R_T = \frac{10}{3} = \mathbf{3.3\ \Omega}$$

14 $R_1 = 50\ \Omega$; $R_2 = 100\ \Omega$; $R_3 = 200\ \Omega$; $R_T = ?$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{50} + \frac{1}{100} + \frac{1}{200} = \frac{4}{200} + \frac{2}{200} + \frac{1}{200} = \frac{7}{200}$$

$$R_T = \frac{200}{7} = \mathbf{28.6\ \Omega}$$

15 $R_1 = 1\ \text{k}\Omega = 1000\ \Omega$; $R_2 = 470\ \Omega$; $R_3 = 115\ \Omega$; $R_T = ?$

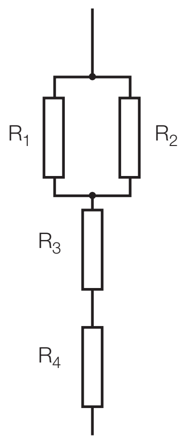
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{1000} + \frac{1}{470} + \frac{1}{115} = 1.18 \times 10^{-2}$$

$$R_T = \frac{1}{1.18 \times 10^{-2}} = \mathbf{84.7\ \Omega}$$

The lowest value resistor has the largest current flowing through it.
So the 115 Ω resistor has the highest current flowing through it.

16 Circuit diagram

a. $R_1 = R_2 =$ **500 Ω in parallel** $R_3 = R_4 =$ **100 Ω in series**
b. $R_1 = R_2 =$ **100 Ω in parallel** $R_3 = R_4 =$ **500 Ω in series**



22 Vectors and Scalars

1 A scalar has only size. A vector has size and direction.

2 Any three from: mass, energy, distance, time, speed.

3 Any three from: velocity, force, acceleration, momentum.

4 a. $12 + 2 =$ **14 ms⁻¹**
b. $12 - 2 =$ **10 ms⁻¹**

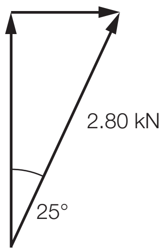
5 a. You should have drawn a diagram similar to those shown.
b. $\sqrt{(56^2 + 15^2)} = \mathbf{58.0\ ms^{-1}}$
c. $\tan^{-1}(15 / 56) = \mathbf{15°}$

6 a. $\sqrt{(55^2 + 35^2)} = \mathbf{65.2\ N}$
b. The forces are not in the same direction so do not add like normal numbers (scalars).

7 $\sqrt{(120^2 + 50^2)} = \mathbf{130\ N}$

8 sine = opposite / hypotenuse cosine = adjacent / hypotenuse
tan = opposite / adjacent

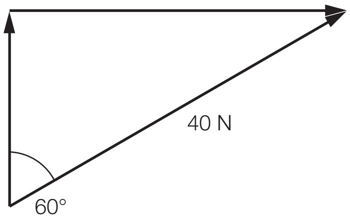
9 $F = 2.80$ kN $= 2.80 \times 10^3$ N; angle to vertical $\theta = 25°$



Horizontal component is opposite the angle, so use sin θ.
$F_x = F\sin\theta = 2.80 \times 10^3 \times \sin 25 = \mathbf{1.18 \times 10^3}$ **N**

Vertical component is adjacent to the angle, so use cos θ.
$F_y = F\cos\theta = 2.80 \times 10^3 \times \cos 25 = \mathbf{2.54 \times 10^3}$ **N**

10 $F = 40$ N; angle to vertical $\theta = 60°$



Horizontal component is opposite the angle, so use sin θ.
$F_x = F\sin\theta = 40 \times \sin 60 =$ **34.6 N**

Vertical component is adjacent to the angle, so use cos θ.
$F_y = F\cos\theta = 40 \times \cos 60 =$ **20 N**

23 Mass and Weight

1 Newton, N.

2 Kilogram, kg.

3 Weight is the force due to gravity on an object.

4 Towards the centre of the Earth. (You should not say 'down' as the direction is different in different parts of the world.)

5 $m = 1$ kg $g = 9.81$ ms^{-2}
$W = mg = 1 \times 9.81 =$ **9.81 N**

6 $m = 55$ kg $g = 9.81$ ms^{-2}
$W = mg = 55 \times 9.81 =$ **540 N**

7 $m = 212.6$ kg $g = 9.81$ ms^{-2}
$W = mg = 212.6 \times 9.81 =$ **2085.6 N**

8 $W = 1$ N $g = 9.81$ ms^{-2}

$W = mg$ rearrange for $m = \frac{W}{g} = \frac{1}{9.81} = 0.102$ kg $=$ **102 g**

9 W = 36 N $g = 9.81$ ms^{-2}

$W = mg$ rearrange for $m = \frac{W}{g} = \frac{36}{9.81} =$ **3.67 kg**

10 W = 0.089 N $g = 9.81$ ms^{-2}

$W = mg$ rearrange for $m = \frac{W}{g} = \frac{0.089}{9.81} = \mathbf{9.07 \times 10^{-3}}$ **kg**

11 $m = 1$ kg $g = 1.6$ ms^{-2}
$W = mg = 1 \times 1.6 =$ **1.6 N**

12 $m = 75$ kg $g = 1.6$ ms^{-2}
$W = mg = 75 \times 1.6 =$ **120 N**

13 $m = 1$ kg $g = 3.7$ ms^{-2}
$W = mg = 1 \times 3.7 =$ **3.7 N**

14 $m = 240$ kg $g = 3.7$ ms^{-2}
$W = mg = 240 \times 3.7 =$ **888 N**

15 $m = 62$ kg $\quad g = 274\ \text{ms}^{-2}$
$W = mg = 62 \times 274 = \mathbf{16988\ N}$

16 $W = 273$ N $\quad m = 40$ kg

$W = mg$ rearrange for $g = \dfrac{W}{m} = \dfrac{273}{40} = \mathbf{6.83\ ms^{-2}}$

24 Forces in Equilibrium

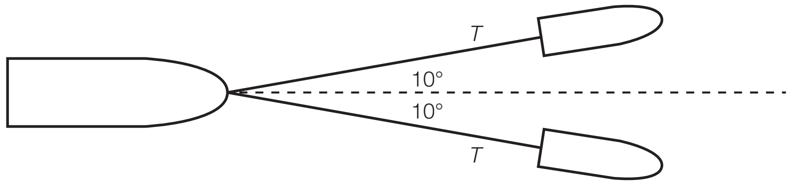
1 The overall force; net force.

2 They are balanced; they add to zero.

3 At equilibrium the forces are balanced, so the reaction force equals the weight = 5 N.

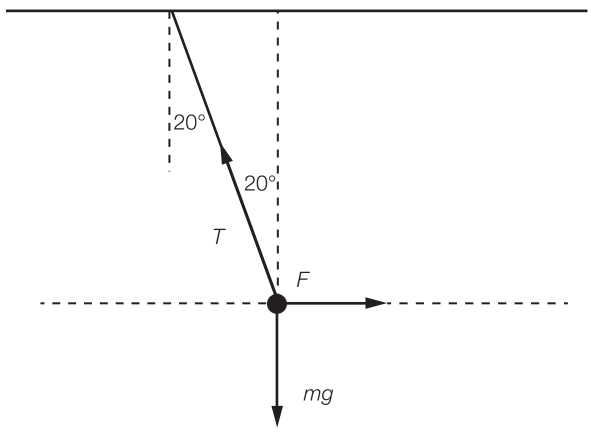
4 At equilibrium the forces are balanced, so the drag force equals the thrust = 2 kN.

5 Diagram of forces:



Resultant force is 50 kN. Component of each tug is $T\cos 10$.
The total force forward is $2 \times T\cos 10$.
$2T\cos 10 = 50000$ N
$T = 50000 / 2\cos 10 = 25400$ N = **25.4 kN**; this is the force in each tug cable.

6 a.



b. Weight = $mg = 0.2 \times 9.8 =$ **1.96 N**
c. $T\cos 20 - mg =$ **0**
d. $F - T\sin 20 =$ **0**
e. $T\cos 20 = mg$ so $T = 1.96 / \cos 20 =$ **2.09 N**
f. $F = T\sin 20 = 2.09 \times \sin 20 =$ **0.71 N**

25 Moments

1 The moment of a force about a point is defined as the force times the perpendicular distance between the pivot and line of action of the force.

2 The principle of moments states that at equilibrium, the sum of the clockwise moments equals the sum of the anticlockwise moments.

3 $F = 3.4$ N $d = 0.85$ m
$M = Fd = 3.4 \times 0.85 =$ **2.89 Nm**

4 $M = 45$ Nm $d = 0.25$ m $F = ?$

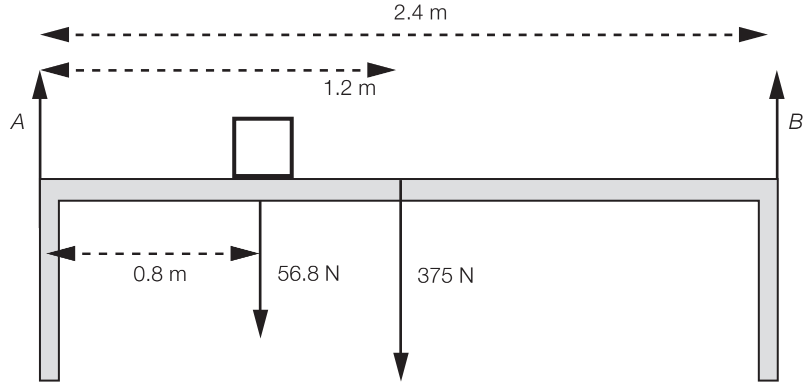
$M = Fd$ so $F = \frac{M}{d} = \frac{45}{0.25} =$ **180 N**

5 $F = 3.2$ N $d = 1.1$ cm $= 1.1 \times 10^{-2}$ m (here d is the distance between the forces)
$M = Fd = 3.2 \times 1.1 \times 10^{-2} =$ **3.5 × 10⁻² Nm**

6 $M = 120$ Nm $F = 80$ N $d = ?$

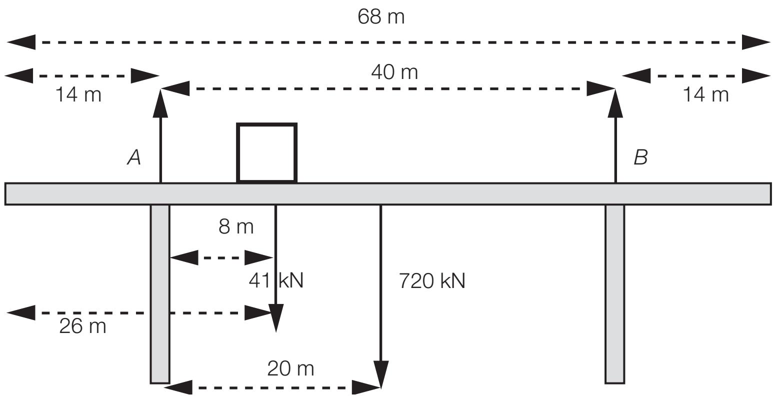
$M = Fd$ so $d = \frac{M}{F} = \frac{120}{80} =$ **1.5 m**

7 Box weight $= 5.8 \times 9.8 = 56.8$ N



Select the left leg of the table A as the pivot.
Sum of clockwise moments = sum of anticlockwise moments.
$(56.8 \times 0.8) + (375 \times 1.2) = (B \times 2.4)$ $B =$ **206 N**
Total weight $= 56.8 + 375 = 431.8$ N In equilibrium so $A + B = 431.8$ N
$A = 431.8 - 206 =$ **225.8 N**

8 Weight of truck $= 4200 \times 9.8 = 4.1 \times 10^4$ N $= 41$ kN



Select the left support A as the pivot.
Sum of clockwise moments = sum of anticlockwise moments. Forces in kN.
$(41 \times 8) + (720 \times 20) = (B \times 40)$ B = **368 kN**
Total weight $= 41 + 720 = 761$ kN In equilibrium so $A + B = 761$ kN
$A = 761 - 368 =$ **393 kN**

26 Motion Graphs

1 Distance / time = velocity

2 Zero velocity

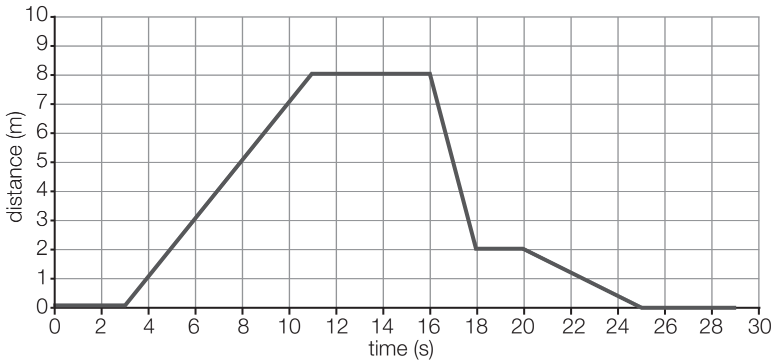
3 Velocity / time = acceleration

4 Zero acceleration = constant velocity

5 a. 8 m covered in 8 seconds; $v = \frac{s}{t}$ $= 8 / 8 =$ **1 ms⁻¹**

b. 2 m

c. Gradient at 22 seconds: $2 - 0 = 2$ m, covered in $25 - 20 = 5$ seconds; $v = \frac{s}{t}$ $= 2 / 5 =$ **0.4 ms⁻¹**



d. Journey from 3 to 25 seconds, so 22 seconds in total

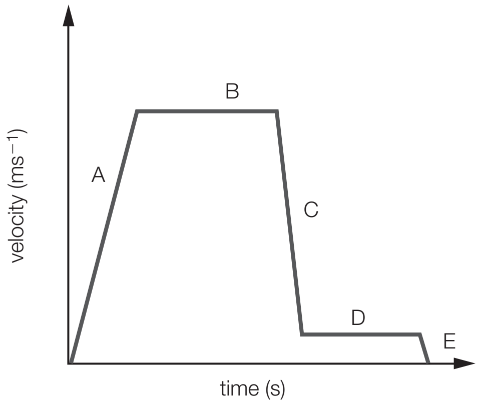
6 a. A: constant acceleration

b. B: zero acceleration

c. C: constant deceleration or negative acceleration

d. Highest speed is at highest part of graph, hence region B.

e. Deceleration is a negative gradient and the largest deceleration is when the gradient is steepest, hence region C.



27 Equations of Motion

1 a = acceleration; s = displacement; u = initial velocity; v = final velocity; t = time

2 $t = 2.4$ s; $u = 0$; $a = 9.8$ ms^{-2}; $s = ?$

$s = ut + \frac{1}{2}at^2 = 0 + 0.5 \times 9.8 \times 2.4^2 =$ **28.2 m**

3 $a = 75$ ms^{-2}; $t = 20$ s ; $u = 0$

a. $v = ?$ $v = u + at = 0 + 75 \times 20 =$ **1500 ms⁻¹**

b. $s = ?$ $s = \frac{(u + v)}{2}t = \frac{0 + 1500}{2}$ $20 = 15\,000$ m $= 15$ km

4 $a = 3.4$ ms^{-2}; $s = 0.8$ m; $u = 0$

a. $t = ?$

$s = ut + \frac{1}{2}at^2$; $ut = 0$, so $s = \frac{1}{2}at^2$; rearrange: $t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2 \times 0.8}{3.4}} =$ **0.69 s**

b. $v = ?$

$v = u + at = 0 + 3.4 \times 0.69 =$ **2.35 ms⁻¹**

5 $u = +1.5$ ms^{-1}; $a = -9.8$ ms^{-2}

a. $v = 0$ at top of jump; $s = ?$

$v^2 = u^2 + 2as$; rearrange: $s = \frac{v^2 - u^2}{2a} = \frac{0 - 1.5^2}{2 \times (-9.8)} =$ **0.11 m**

b. $u = +1.5\ ms^{-1}$; $v = -1.5\ ms^{-1}$; $a = -9.8\ ms^{-2}$; t = ?

$v = u + at$ so $t = \dfrac{v - u}{a} = \dfrac{-1.5 - 1.5}{-9.8} = \mathbf{0.31\ s}$

6 $a = -9.8\ ms^{-2}$

a. $s = 2.2$ m; $v = 0$ at top; $u = ?$
$v^2 = u^2 + 2as$ so $u^2 = v^2 - 2as = 0 - 2 \times (-9.8) \times 2.2 = 43.1$
$u = \sqrt{43.1} = \mathbf{6.6\ ms^{-1}}$

b. $s = 2.2 + 10 = 12.2$ m; $u = 0$; $v = ?$
$v^2 = u^2 + 2as = 0 + 2 \times (-9.8) \times 12.2 = 239$
$v = \sqrt{239} = \pm 15.5 = \mathbf{-15.5\ ms^{-1}}$ since down

c. $u = +6.6\ ms^{-1}$; $v = -15.5\ ms^{-1}$

$v = u + at$ so $t = \dfrac{v - u}{a} = \dfrac{-15.5 - 6.6}{-9.8} = \mathbf{+2.26\ s}$

28 Forces and Motion

1 A body remains at rest, or continues to move with constant velocity in a straight line, unless a resultant force acts.

2 $F = ma$

3 $m = 20$ kg $a = 54\ ms^{-2}$ $F = ?$
$F = ma = 20 \times 54 = \mathbf{1.08 \times 10^3\ N}$

4 $m = 2\ g = 2 \times 10^{-3}$ kg $a = 890\ ms^{-2}$ $F = ?$
$F = ma = 2 \times 10^{-3} \times 890 = \mathbf{1.78\ N}$

5 $F = 15$ N $a = 4.7\ ms^{-2}$ $m = ?$

$F = ma$ $m = \dfrac{F}{a} = \dfrac{15}{4.7} = \mathbf{3.2\ kg}$

6 $F = 46\ kN = 46 \times 10^3$ N $a = 205\ ms^{-2}$ $m = ?$

$F = ma$ $m = \dfrac{F}{a} = \dfrac{46 \times 10^3}{205} = \mathbf{224\ kg}$

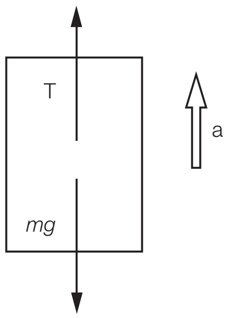
7 $F = 80$ N $m = 50\ g = 50 \times 10^{-3}$ kg $a = ?$

$F = ma$ $a = \dfrac{F}{m} = \dfrac{80}{50 \times 10^{-3}} = \mathbf{1.6 \times 10^3\ ms^{-2}}$

8 $F = 2.3$ N $m = 1000$ kg $a = ?$

$F = ma$ $a = \dfrac{F}{m} = \dfrac{2.3}{1000} = \mathbf{2.3 \times 10^{-3}\ ms^{-2}}$

9 Taking 'up' to be positive; T = tension



a. Forces in equilibrium so $T - mg = 0$ so $T = mg = 1200 \times 9.8$
$= \mathbf{1.18 \times 10^4\ N}$

b. $a = +2\ ms^{-2}$ $T - mg = ma$
$T = mg + ma = 1200 \times 9.8 + 1200 \times 2 = \mathbf{1.42 \times 10^4\ N}$

c. $a = -2\ ms^{-2}$ $T - mg = ma$
$T = mg + ma = 1200 \times 9.8 + 1200 \times (-2) = \mathbf{9.4 \times 10^3\ N}$

29 Energy and Power

1 work done = force × distance moved in direction of force: $W = Fd$

2 power = energy / time $P = \dfrac{E}{t}$ or $P = \dfrac{W}{t}$

3 joule, J

4 watt, W

5 Energy cannot be created or destroyed, only transferred from one form to another.

6 $F = 15$ N; $d = 2.6$ m; $W = ?$
$W = Fd = 15 \times 2.6 =$ **39 J**

7 $F = 7.4$ kN $= 7400$ N; $d = 32$ km $= 3200$ m; $W = ?$
$W = Fd = 7400 \times 3200 =$ **2.37×10^7 J = 23.7 MJ**

8 $F = 250$ N; $d = 20$ mm $= 0.02$ m; $W = ?$
$W = Fd = 250 \times 0.02 =$ **5.0 J**

9 $F = 500$ N; $W = 125$ J; $d = ?$

$$d = \frac{W}{F} = \frac{125}{500} = \mathbf{0.25\ m}$$

10 $F = 84$ N; $W = 6.9$ kJ $= 6900$ J; $d = ?$

$$d = \frac{W}{F} = \frac{6900}{84} = \mathbf{82.1\ m}$$

11 $E = 4.2$ kJ $= 4200$ J; $t = 24$ s; $P = ?$

$$P = \frac{E}{t} = \frac{4200}{24} = \mathbf{175\ W}$$

12 $E = 5.52$ J; $t = 0.25$ s; $P = ?$

$$P = \frac{E}{t} = \frac{5.52}{0.25} = \mathbf{22.1\ W}$$

13 $F = 50$ N; $d = 120$ m; $t = 20$ s; $P = ?$
$W = Fd = 50 \times 120 = 6000$ J

$$P = \frac{W}{t} = \frac{6000}{20} = \mathbf{300\ W}$$

14 $F = 9.3$ kN $= 9300$ N; $d = 286$ km $= 286\,000$ m;
$t = 3$ hrs $= 3 \times 60 \times 60 = 10\,800$ s; $P = ?$
$W = Fd = 9300 \times 286\,000 = 2.66 \times 10^9$ J $= 2.66$ GJ

$$P = \frac{W}{t} = \frac{2.66 \times 10^9}{10\,800} = \mathbf{2.46 \times 10^5\ W = 246\ kW}$$

15 $P = 200$ W; $t = 2$ min $= 2 \times 60 = 120$ s; $E = ?$
$E = Pt = 200 \times 120 =$ **24 000 J = 24 kJ**

16 $P = 2$ kW $= 2000$ W; $t = 160$ min $= 160 \times 60 = 9600$ s; $E = ?$
$E = Pt = 2000 \times 9600 =$ **1.92×10^7 J = 19.2 MJ**

17 $P = 3.0$ kW $= 3000$ W; $E = 1.4$ MJ $= 1.4 \times 10^6$ J; $t = ?$

$$t = \frac{E}{P} = \frac{1.4 \times 10^6}{3000} = \mathbf{467\ s}$$

18 $P = 11$ W; $E = 8.5$ kJ $= 8500$ J; $t = ?$

$$t = \frac{E}{P} = \frac{8500}{11} = \mathbf{773\ s}$$

30 Kinetic Energy and Gravitational Potential Energy

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

2 m = mass; v = velocity

3 GPE = $mg\Delta h$

4 m = mass; g = acceleration due to gravity; Δh = change in height

5 $m = 12$ kg; $g = 9.8$ ms^{-2}; $\Delta h = 84$ cm $= 0.84$ m;
GPE = $mg\Delta h = 12.0 \times 9.8 \times 0.84 =$ **98.8 J**

6 $m = 5.0 \times 10^6$ kg; $v = 11.2$ kms^{-1} $= 11.2 \times 10^3$ ms^{-1}

$KE = \frac{1}{2}mv^2 = 0.5 \times 5.0 \times 10^6 \times (11.2 \text{ x } 10^3)^2 =$ **3.14 × 10^{14} J**

7 $m = 100$ g $= 0.1$ kg; $g = 9.8$ ms^{-2}; $v = 4$ ms^{-1}; mass cancels so is not needed.

$mg\Delta h = \frac{1}{2}mv^2 \qquad \Delta h = \frac{v^2}{2g} = \frac{4^2}{2 \times 9.8} =$ **0.82 m**

8 $m = 1.2$ kg; $\Delta h = 5.2$ m; $g = 9.8$ ms^{-2}; mass cancels so is not needed.

$v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.8 \times 5.2} =$ **10 ms^{-1}**

9 The ball loses 10% of its energy after every bounce; $m = 120$ g $= 0.12$ kg; Δh = 2 m;
$g = 9.8$ m.s^{-2}

a. GPE = $mg\Delta h = 0.12 \times 9.8 \times 2 =$ **2.35 J**

b. $v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.8 \times 2} =$ **6.3 ms^{-1}**

c. 10% less GPE means 10% less height; 90% of 2 m is **1.8 m**

d. Velocity to reach height of 1.8 m $v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.8 \times 2} =$ **5.9 ms^{-1}**

10 $v = 6$ ms^{-1}; $g = 9.8$ ms^{-2}

$mg\Delta h = \frac{1}{2}mv^2 \qquad \Delta h = \frac{v^2}{2g} = \frac{6^2}{2 \times 9.8} =$ **1.84 m**

31 Waves

1 Sound, seismic P waves.

2 Two from: light, radio, microwave, infrared, ultraviolet, x-rays, gamma rays, water waves, rope waves, Mexican waves.

3 The particles oscillate at 90 degrees to the direction of motion of a transverse wave, but in the same direction of a longitudinal wave's motion.

4 a. wavelength: the length of one whole wave.
b. frequency: the number of waves passing a fixed point in one second.
c. amplitude: the maximum displacement of the wave.
d. time period: the time it takes for one complete wave.

5 Three from: reflection, refraction, diffraction, interference.

6 $\lambda = 3.2$ m; $f = 0.4$ Hz; c = ?

$c = \lambda f = 3.2 \times 0.4 =$ **1.28 ms^{-1}**

7 $\lambda = 1.29$ m; $f = 256$ Hz; $c = ?$

$c = \lambda f = 1.29 \times 256 =$ **330 ms⁻¹**

8 $c = 3 \times 10^8$ ms^{-1}; $f = 102$ MHz $= 102 \times 10^6$ Hz; $\lambda = ?$

$c = \lambda f \quad \lambda = \dfrac{c}{f} = \dfrac{3 \times 10^8}{102 \times 10^6} = \mathbf{2.94\ m}$

9 $c = 3 \times 10^8$ ms^{-1}; $\lambda = 0.05$ nm $= 0.05 \times 10^{-9}$ m; $f = ?$

$c = \lambda f \quad f = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8}{0.05 \times 10^{-9}} = \mathbf{6 \times 10^{18}\ Hz}$

10 $c = 3 \times 10^8$ ms^{-1}; $\lambda = 500$ nm $= 500 \times 10^{-9}$ m ; $T = ?$

$c = \lambda f \quad f = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8}{500 \times 10^{-9}} = 6 \times 10^{14}$ Hz

$T = \dfrac{1}{f} = \dfrac{1}{6 \times 10^{14}}\ \mathbf{1.67 \times 10^{-15}\ s}$

32 The Photon

1 a. $f = 4.5 \times 10^{15}$ Hz; $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 4.5 \times 10^{15} = \mathbf{3.0 \times 10^{-18}\ J}$

b. $f = 7.8 \times 10^{12}$Hz; $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 7.8 \times 10^{12} = \mathbf{5.1 \times 10^{-21}\ J}$

c. $f = 1.03 \times 10^7$ Hz; $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 1.03 \times 10^7 = \mathbf{6.80 \times 10^{-27}\ J}$

d. $f = 5.7 \times 10^{15}$ Hz; $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 5.7 \times 10^{15} = \mathbf{3.8 \times 10^{-18}\ J}$

2 a. $\lambda = 660$ nm $= 660 \times 10^{-9}$ m; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^8$ ms^{-1}

$E = \dfrac{hc}{\lambda} = \dfrac{6.6 \times 10^{-34} \times 3 \times 10^8}{660 \times 10^{-9}} = \mathbf{3.0 \times 10^{-19}\ J}$

b. $\lambda = 7.1 \times 10^{-9}$ m; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^8$ ms^{-1}

$E = \dfrac{hc}{\lambda} = \dfrac{6.6 \times 10^{-34} \times 3 \times 10^8}{7.1 \times 10^{-9}} = \mathbf{2.8 \times 10^{-17}\ J}$

c. $\lambda = 3.7 \times 10^{-5}$ m; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^8$ ms^{-1}

$E = \dfrac{hc}{\lambda} = \dfrac{6.6 \times 10^{-34} \times 3 \times 10^8}{3.7 \times 10^{-5}} = \mathbf{5.4 \times 10^{-21}\ J}$

d. $\lambda = 4.4 \times 10^{-15}$ m; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^8$ ms^{-1}

$E = \dfrac{hc}{\lambda} = \dfrac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.4 \times 10^{-15}} = \mathbf{4.5 \times 10^{-11}\ J}$

3 a. $E = 3.2 \times 10^{-19}$ J; $h = 6.6 \times 10^{-34}$ Js

$f = \dfrac{E}{h} = \dfrac{3.2 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{4.8 \times 10^{14}\ Hz}$

b. $E = 9.11 \times 10^{-20}$ J; $h = 6.6 \times 10^{-34}$ Js

$f = \dfrac{E}{h} = \dfrac{9.11 \times 10^{-20}}{6.6 \times 10^{-34}} = \mathbf{1.4 \times 10^{14}\ Hz}$

c. $E = 1.03 \times 10^{-18}$ J; $h = 6.6 \times 10^{-34}$ Js

$$f = \frac{E}{h} = \frac{1.03 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{1.56 \times 10^{15}\ Hz}$$

d. $E = 7.45 \times 10^{-18}$ J; $h = 6.6 \times 10^{-34}$ Js

$$f = \frac{E}{h} = \frac{7.45 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{1.13 \times 10^{16}\ Hz}$$

4 a. $E = 9.5 \times 10^{-17}$ J; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^{8}$ ms^{-1}

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{9.5 \times 10^{-17}} = \mathbf{2.1 \times 10^{-9}\ m}$$

b. $E = 4.23 \times 10^{-20}$ J; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^{8}$ ms^{-1}

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{4.23 \times 10^{-20}} = \mathbf{4.68 \times 10^{-6}\ m}$$

c. $E = 6.66 \times 10^{-18}$ J; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^{8}$ ms^{-1}

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{6.66 \times 10^{-18}} = \mathbf{2.97 \times 10^{-8}\ m}$$

d. $E = 1.07 \times 10^{-12}$ J; $h = 6.6 \times 10^{-34}$ Js; $c = 3.0 \times 10^{8}$ ms^{-1}

$$\lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1.07 \times 10^{-12}} = \mathbf{1.85 \times 10^{-13}\ m}$$

5 a. 2.1 nm is ultraviolet

b. 4.68 μm is infrared

c. 29.7 nm is ultraviolet

d. 1.85×10^{-13} m is gamma

6 $P = 0.6$ W; $\lambda = 682$ nm $= 682 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{682 \times 10^{-9}} = 2.90 \times 10^{-19}\ \text{J}$$

Number of photons per second = power / energy of photon = 0.6 / (2.9×10^{-19})
= **2.1×10^{18} photons per second**

7 $P = 24$ W; $\lambda = 512$ nm $= 512 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{512 \times 10^{-9}} = 3.87 \times 10^{-19}\ \text{J}$$

Number of photons per second = power / energy of photon = 24 / (387×10^{-19})
= **6.2×10^{17} photons per second**

8 $P = 3.8 \times 10^{26}$ W; $\lambda = 660$ nm $= 660 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{512 \times 10^{-9}} = 3.0 \times 10^{-19}\ \text{J}$$

Number of photons per second = power / energy of photon = 3.8×10^{26}/ (3.0×10^{-19})
= **1.3×10^{45} photons per second**

33 The Photoelectric Effect

1 The minimum frequency of a photon that causes an electron to be emitted from a metal surface.

2 The smallest amount of light energy, a particle of light.

3 $E = hf$

4 The minimum energy required to remove an electron from the metal surface.

5 $hf = \phi + E_{k\,max}$ where h is Planck's constant, f is frequency of light, ϕ is the work function of the metal and $E_{k\,max}$ is the maximum kinetic energy of an emitted electron.

6 $hf_0 = \phi$

7 $\phi = 3.2\text{ eV} = 3.2 \times 1.6 \times 10^{-19} = 5.12 \times 10^{-19}\text{ J}$

$$hf_0 = \phi \qquad \text{so } f_0 = \frac{\phi}{h} = \frac{5.12 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{7.8 \times 10^{14}\ Hz}$$

8 $\phi = 1.8 \times 10^{-18}\text{ J}$

$$hf_0 = \phi \qquad \text{so } f_0 = \frac{\phi}{h} = \frac{1.8 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{2.7 \times 10^{14}\ Hz}$$

9 a. $f = 4.1 \times 10^{15}$ Hz; Planck's constant $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 4.1 \times 10^{15} = \mathbf{2.7 \times 10^{-18}\ J}$

b. $\phi = 8.7\text{ eV} = 8.7 \times 1.6 \times 10^{-19} = 1.4 \times 10^{-18}\text{ J}$

$hf = \phi + E_{k\,max}$ *so* $E_{k\,max} = hf - \phi$

$= 6.6 \times 10^{-34} \times 4.1 \times 10^{15} - 1.4 \times 10^{-18} = \mathbf{1.3 \times 10^{-18}\ J}$

10 a. $f = 6.8 \times 10^{14}$ Hz; Planck's constant $h = 6.6 \times 10^{-34}$ Js

$E = hf = 6.6 \times 10^{-34} \times 6.8 \times 10^{14} = \mathbf{4.5 \times 10^{-19}\ J}$

b. $\phi = 2.5\text{ eV} = 2.5 \times 1.6 \times 10^{-19} = 4.0 \times 10^{-19}\text{ J}$

$hf = \phi + E_{k\,max}$ *so* $E_{k\,max} = hf - \phi$

$= 6.6 \times 10^{-34} \times 6.8 \times 10^{14} - 1.4 \times 10^{-18} = \mathbf{5 \times 10^{-20}\ J}$

34 Wave-particle Duality

1 Spread-out, non-localised, gradual transfer of energy without transfer of matter.

2 Lumpy, localised, sudden transfer of energy with the transfer of matter.

3 Diffraction, two-slit interference.

4 The photoelectric effect.

5 Electron diffraction, two-slit interference with electrons.

6 $v = 1.5 \times 10^{7}\text{ ms}^{-1}$; mass of electron $= 9.11 \times 10^{-31}$ kg;
Planck's constant $= 6.6 \times 10^{-34}$ Js

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.5 \times 10^{7}} = \mathbf{4.8 \times 10^{-11}\ m}$$

7 $v = 6.8 \times 10^{6}\ \text{ms}^{-1}$; mass of proton $= 1.67 \times 10^{-27}$ kg;
Planck's constant $= 6.6 \times 10^{-34}$ Js

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{1.67 \times 10^{-27} \times 6.8 \times 10^{6}} = \mathbf{5.8 \times 10^{-14}\ m}$$

8 $KE = 3.2 \times 10^{-19}$ J; mass of electron $= 9.11 \times 10^{-31}$ kg;
Planck's constant $= 6.6 \times 10^{-34}$ Js

$$KE = \tfrac{1}{2}mv^2 \text{ so } = v = \sqrt{\frac{2(KE)}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-19}}{9.11 \times 10^{-31}}} = 8.4 \times 10^{5}\ \text{ms}^{-1}$$

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 8.4 \times 10^{5}} = \mathbf{8.6 \times 10^{-10}\ m}$$

9 $KE = 2$ keV $= 2000$ eV $= 2000 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-16}$ J;
mass of electron $= 9.11 \times 10^{-31}$ kg; Planck's constant $= 6.6 \times 10^{-34}$ Js

$$KE = \tfrac{1}{2}mv^2 \text{ so } = v = \sqrt{\frac{2(KE)}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-16}}{9.11 \times 10^{-31}}} = 2.7 \times 10^{7}\ \text{ms}^{-1}$$

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 8.4 \times 10^{7}} = \mathbf{2.7 \times 10^{-11}\ m}$$

10 $KE = 20$ keV $= 20\,000$ eV $= 20\,000 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-15}$ J;
mass of proton $= 1.67 \times 10^{-27}$ kg; Planck's constant $= 6.6 \times 10^{-34}$ Js

$$KE = \tfrac{1}{2}mv^2 \text{ so } = v = \sqrt{\frac{2(KE)}{m}} = \sqrt{\frac{2 \times 3.2 \times 10^{-15}}{1.67 \times 10^{-27}}}\ 2.0 \times 10^{6}\ \text{ms}^{-1}$$

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{1.67 \times 10^{-27} \times 2.0 \times 10^{6}} = \mathbf{2.0 \times 10^{-13}\ m}$$

35 Energy Levels

1 $n = 1$

2 $n = 1$

3 They escape the atom; the atom becomes ionised.

4 a. 13.6 eV

b. 4 to 1 as this is the largest energy change and frequency is proportional to energy.

c. 4 to 3 as this is the smallest energy change and wavelength is inversely proportional to wavelength.

d. $\Delta E = E_4 - E_2 = -0.85 - -3.40 = -0.85 + 3.40 = 2.55$ eV

$\Delta E = 2.55 \times 1.6 \times 10^{-19} = \mathbf{4.08 \times 10^{-19}\ J}$

e. $n = 4$ to $n = 3$

$\Delta E = E_4 - E_3 = -0.85 - -1.51 = -0.85 + 1.51 = 0.66$ eV

$\Delta E = 0.66 \times 1.6 \times 10^{-19} = 1.06 \times 10^{-19}$ J

$$f = \frac{\Delta E}{h} = \frac{1.06 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{1.61 \times 10^{14}\ Hz}$$

f. $n = 4$ to $n = 3$

$\Delta E = E_4 - E_3 = -0.85 - -1.51 = -0.85 + 1.51 = 0.66$ eV

$\Delta E = 0.66 \times 1.6 \times 10^{-19} = 1.06 \times 10^{-19}$ J

$$\lambda = \frac{hc}{\Delta E} = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{1.06 \times 10^{-19}} = \mathbf{1.87 \times 10^{-6}\ m}$$

g. Three: $n = 3$ to $n = 1$, producing one photon; or $n = 3$ to $n = 2$ followed by $n = 2$ to $n = 1$, producing two other photons.

h. Ground state = −13.6 eV so new energy = −13.6 + 12.09 = −1.51 eV so electron reaches $n = 3$ level. Therefore two possible journeys back to the ground state, involving three different jumps: 3 to 1, or 3 to 2 and then 2 to 1

$n = 3$ to $n = 2$

$$\Delta E = E_3 - E_2 = -1.51 - -3.40 = -1.51 + 3.40 = 1.89 \text{ eV}$$

$$\Delta E = 1.89 \times 1.6 \times 10^{-19} = 3.02 \times 10^{-19} \text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{3.02 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{4.58 \times 10^{14}\ Hz}$$

$n = 3$ to $n = 1$

$$\Delta E = E_3 - E_1 = -1.51 - -13.60 = -1.51 + 13.60 = 12.09 \text{ eV}$$

$$\Delta E = 12.09 \times 1.6 \times 10^{-19} = 1.93 \times 10^{-18} \text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{1.93 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{2.92 \times 10^{15}\ Hz}$$

$n = 2$ to $n = 1$

$$\Delta E = E_2 - E_1 = -3.40 - -13.60 = -3.40 + 13.60 = 10.20 \text{ eV}$$

$$\Delta E = 10.20 \times 1.6 \times 10^{-19} = 1.63 \times 10^{-18} \text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{1.63 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{2.47 \times 10^{15}\ Hz}$$

36 The Young Modulus

1 $\textit{Stress} = \dfrac{\textit{Force}}{\textit{Cross sectional area}} = \dfrac{F}{A}$

2 Nm^{-2} or Pa

3 $\textit{Strain} = \dfrac{\textit{Change in length}}{\textit{Original length}} = \dfrac{\Delta L}{L}$

4 Strain has **no unit**.

5 $\textit{Young modulus} = \dfrac{\textit{Stress}}{\textit{Strain}} = \dfrac{FL}{\Delta LA}$

6 Nm^{-2} or Pa (same as stress).

7 Hooke's Law.

8 $F = 10$ kN $= 10 \times 10^3$ N; $d = 1.0$ cm $= 0.01$ m; stress = ?

$$\textit{Area} = \pi \frac{d^2}{4} = \frac{\pi(0.01)^2}{4} = 7.85 \times 10^{-5} \text{ m}^2$$

$$\textit{Stress} = \frac{F}{A} = \frac{10 \times 10^8}{7.85 \times 10^{-5}} = \mathbf{1.27 \times 10^8\ Pa}$$

9 $F = 25$ mN $= 25 \times 10^{-3}$ N; $d = 0.2$ mm $= 0.2 \times 10^{-3}$ m; stress = ?

$$\textit{Area} = \pi \frac{d^2}{4} = \frac{\pi(0.2 \times 10^{-3})^2}{4} = 3.14 \text{ x } 10^{-8} \text{ m}^2$$

$$\textit{Stress} = \frac{F}{A} = \frac{25 \times 10^8}{3.14 \times 10^{-8}} = \mathbf{7.96 \times 10^5\ Pa}$$

10 $L = 23$ m; $\Delta L = 3.6$ mm $= 3.6 \times 10^{-3}$ m; strain = ?

$$Strain = \frac{\Delta L}{L} = \frac{3.6 \times 10^{-5}}{23} = \mathbf{1.6 \times 10^{-4}}$$

11 $L = 23$ cm $= 0.23$ m; $\Delta L = 4.2$ mm $= 4.2 \times 10^{-3}$ m; strain = ?

$$Strain = \frac{\Delta L}{L} = \frac{4.2 \times 10^{-5}}{0.23} = \mathbf{1.8 \times 10^{-2}}$$

12 *Strain* $= 5.6 \times 10^{-3}$; *stress* $= 21$ MPa $= 21 \times 10^{6}$ Pa; *Young modulus* = ?

$$Young\ modulus = \frac{Stress}{Strain} = \frac{21 \times 10^{6}}{5.6 \times 10^{-8}} = 3.75 \times 10^{9}\ \text{Pa} = \mathbf{3.75\ GPa}$$

13 $F = 500$ N; $L = 1.5$ m; $\Delta L = 1.0$ mm $= 0.001$ m; $d = 3.0$ mm $= 3.0 \times 10^{-3}$ m; *Young modulus* = ?

$$Area = \pi\frac{d^2}{4} = \frac{\pi(3.0 \times 10^{-8})^2}{4} = 7.07 \times 10^{-6}\ \text{m}^2$$

$$Young\ modulus = \frac{FL}{\Delta LA} = \frac{500 \times 1.5}{0.001 \times 7.07 \times 10^{-6}}\ 1.06 \times 10^{11}\ \text{Pa} = \mathbf{106\ GPa}$$

14 *Young modulus* $= 0.05$ GPa $= 0.05 \times 10^{9}$ Pa; $F = 650$ N; $L = 2.4$ m; $d = 1.0$ cm $= 0.01$ m; ΔL = ?

$$Area = \pi\frac{d^2}{4} = \frac{\pi(0.01)^2}{4} = 7.85 \times 10^{-5}\ \text{m}^2$$

$$Young\ modulus = \frac{FL}{\Delta LA} = \text{so}\quad \Delta L = \frac{FL}{A(YM)} = \frac{650 \times 2.4}{7.85 \times 10^{-5} \times 0.05 \times 10^{9}} = \mathbf{0.40\ m}$$

15 *Young modulus* $= 200$ GPa $= 200 \times 10^{9}$ Pa; $L = 4.6$ m; $\Delta L = 1$ cm $= 0.01$ m; $d = 5$ mm $= 0.005$ m; F = ?

$$Area = \pi\frac{d^2}{4} = \frac{\pi(0.005)^2}{4} = 1.96 \times 10^{-5}\ \text{m}^2$$

$$Young\ modulus = \frac{FL}{\Delta LA} = \text{so}\quad F = \frac{(YM)\Delta LA}{L} = \frac{200 \times 10^{9} \times 0.01 \times 1.96 \times 10^{-5}}{4.6} = \mathbf{8500\ N}$$

Atoms and Nuclei

GCSE

You will have discussed the structure of atoms and some properties of protons, neutrons, electrons and isotopes.

A-level

You need to be able to work out the number of protons, neutrons and electrons for any isotope or ion.

You need to be able to calculate the specific charge, a property of nuclei or particles. You will need to know the meanings of terms essential for particle physics topics.

What is an atom?

An atom is the smallest particle of an element that can exist.

Atoms were thought by the ancient Greeks to be the building blocks of all matter. They were considered to be hard, indivisible spheres that came in a number of varieties.

Can the huge variety of substances and materials found in the universe have a common building block and explanation?

Yes, the Atomic theory of matter: This is a **discrete** theory of matter as opposed to a **continuous** (non-discrete) theory. It means that matter **cannot be subdivided indefinitely**; you cannot keep getting smaller bits of matter without limit.

Everything is made up of atoms of different types (elements) that combine to form billions of possible substances. (There are exceptions, such as light and subatomic particles.)

What is the nuclear model of the atom?

Ernest Rutherford's alpha particle scattering experiment showed that the atom is mainly empty space. The vast majority of the mass and all the positive charge are concentrated in a dense and tiny nucleus. Electrons were viewed as orbiting the nucleus and forming the edge of the atom.

Later experiments showed that a nucleus is itself made up of other particles. First the proton was discovered, and later the neutron. Each has approximately the same mass, with a positive charge on the proton and a neutral charge on the neutron.

What is atomic notation?

Nucleon is the name given to a particle in the nucleus, i.e. a proton or a neutron. Elements and isotopes are written as symbols, as in the periodic table.

$$^{A}_{Z}X$$

X represents the symbol for the element: eg H, C, Fe, Na etc.

Z = proton number (atomic number)

A = nucleon number (mass number or atomic mass)

Since the mass of the atom is made up of mainly protons and neutrons (electrons having only approximately 1/2000th the mass of a proton or neutron), we can calculate the number of neutrons by subtracting the proton number from the nucleon number. In a neutral atom, the number of electrons equals the number of protons.

Example

${}^{12}_{6}\mathrm{C}$ Carbon-12 has a nucleon number of 12 and a proton number of 6. The number of neutrons is 12 − 6 = 6.

${}^{7}_{3}\mathrm{Li}$ Lithium-7 has a nucleon number of 7 and a proton number of 3. The number of neutrons is 7 − 3 = 4.

What are isotopes?

Isotopes are 'versions' of elements with different masses, due to a different number of neutrons in the nucleus. The number of neutrons can change without changing the element, as the type of element depends only on the proton number.

Example

${}^{12}_{6}\mathrm{C}$ is an isotope of carbon. Carbon also has an isotope ${}^{14}_{6}\mathrm{C}$ that has 2 extra neutrons in the nucleus.

Every element has isotopes, although many are radioactive and therefore decay into other more stable isotopes.

Elements and isotopes can only have a whole number for both nucleon number and proton number. The Periodic Table shows the most common (abundant) isotope of each element.

What is specific charge?

Specific charge is not the same as charge.

Specific charge is the charge per kilogram.

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}}$$

Charge is measured in coulombs, and mass in kilograms. So unit of specific charge is coulombs per kilogram ($\mathrm{Ckg^{-1}}$)

You may be asked to calculate the specific charge of a particle, nucleus or ion.

- For a **particle**, use the given values of charge and mass.
- For a **nucleus**, the charge is the proton number times the charge on the proton ($e = 1.6 \times 10^{-19}$ C), and the mass is the nucleon number $\times\ 1.67 \times 10^{-27}$ kg (the average mass of a proton and neutron).
- For an **ion** (a charged particle), the charge is the charge on the ion times the charge on the electron (e) and the mass is the nucleon number $\times\ 1.67 \times 10^{-27}$ kg (the electron mass is too small to make much difference).

17 Atoms and Nuclei

Topic Builders

Example

What is the specific charge of a nitrogen-14 nucleus?

Nitrogen $^{14}_{7}N$ has a nucleon number of 14, so the mass is $14 \times 1.67 \times 10^{-27}$ kg

It has a proton number of 7, so the charge is $7 \times 1.6 \times 10^{-19}$ C

$$\textit{Specific Charge} = \frac{\textit{Charge}}{\textit{Mass}} = \frac{7 \times 16 \times 10^{-19}}{14 \times 1.67 \times 10^{-27}} = 4.79 \times 10^{7}\ \mathrm{Ckg^{-1}}$$

Questions

1 What is the name given to the total number of protons and neutrons in a nucleus?

2 How many protons, neutrons and electrons in a neutral atom of $^{3}_{1}H$?

3 How many protons, neutrons and electrons in a neutral atom of $^{14}_{6}C$?

4 How many protons, neutrons and electrons in a neutral atom of $^{23}_{11}Na$?

5 How many protons, neutrons and electrons in a neutral atom of $^{56}_{26}Fe$?

6 How many protons, neutrons and electrons in a neutral atom of $^{238}_{92}U$?

7 How many protons, neutrons and electrons in a neutral atom of $^{37}_{17}Cl$?

8 What is the same, and what is different between isotopes of an element?

9 Calculate the specific charge of an electron.

10 Calculate the specific charge of a proton.

11 Calculate the specific charge of a $^{4}_{2}He$ nucleus.

12 Calculate the specific charge of a $^{12}_{6}C$ nucleus.

13 Calculate the specific charge of a $^{56}_{26}Fe$ nucleus.

14 Calculate the specific charge of a $^{235}_{92}U$ nucleus.

15 Calculate the specific charge of an oxygen-16 ion with a minus 2 charge. ($^{16}_{8}O^{-2}$)

16 Calculate the specific charge of a copper-63 ion with a plus 2 charge. ($^{63}_{29}Cu^{+2}$)

Taking it Further

The ideas and notation used here are applied in particle physics as a starting point to describe particle properties. The notation is used extensively in chemistry to describe elements and isotopes.

Now use this space to make more in-depth notes about atoms and nuclei. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

- ⇒ *What is an element?*
- ⇒ *Describe the nuclear model of the atom.*
- ⇒ *What is an atom made of?*
- ⇒ *What is an isotope?*
- ⇒ *What is specific charge?*
- ⇒ *How do you calculate specific charge?*
- ⇒ *How has our understanding of the atom changed over time?*
- ⇒ *How can atoms be used to image particles?*
- ⇒ *What was Rutherford's alpha particle scattering experiment and why was it so significant?*

GCSE

You will have learnt that protons, neutrons and electrons make up atoms.

A-level

You need to know the classification of various particles and their composition in terms of quarks, using data on various properties including charge and strangeness. You will need to be familiar with the concepts of antimatter and mass-energy equivalence.

Subatomic particles are particles that are smaller than an atom; they have been discovered using particle accelerators and observations from cosmic rays. Observations and measurements of their properties have allowed the development of theories to explain their variety and interactions. This topic involves many new terms that need to be learnt.

Certain values of variables for particles, such as lepton number and strangeness, are often provided on data sheets. Check what is provided and what you need to be able to work out.

Protons, neutrons, electrons

The first of the subatomic particles to be discovered was the electron. It was relatively easy to knock them out of atoms using high-speed electrons or pull them out using high voltages. Protons required the energy of radioactive particles to knock them out of the nucleus. Neutrons, due to being neutral, were more difficult to detect and were discovered by Chadwick in 1932.

Matter and antimatter

Antimatter was predicted from the work of Paul Dirac. The first antimatter particle discovered was the **positron**. **Antiprotons** were first seen in cosmic ray experiments and later in particle accelerators. Nearly all particles have an antiparticle partner. It has the same mass but is opposite in charge, **baryon number**, **lepton numbe**r and **strangeness**.

Charge

The charge of all particles is measured in relative units of e, the charge on the electron. Particles usually have a whole number of plus or minus electron charges: +1, +2, −1, −2 etc. The only exceptions are the **quarks**, which have fractional charges.

Mass-energy equivalence

The mass of a particle can be expressed in kg, but it is often more useful to express it in the unit of energy. Since $E = mc^2$, mass and energy are interchangeable. Therefore a kilogram of mass is equivalent to 9×10^{16} joules of energy.

When dealing with such tiny particles, a joule is a very large amount of energy. An electron-volt is a much smaller unit of energy. It is also used to give values of mass for subatomic particles.

Converting electron-volts to joules
1 electron-volt = 1.6×10^{-19} joules

To convert eV to J just multiply the number of electron-volts by 1.6×10^{-19}

To convert J to eV just divide the number of joules by 1.6×10^{-19}

Particle Zoo

There are various kinds of subatomic particles. They can be classified according to their properties.

Elementary particles are not made of any smaller particles; they are fundamental.

Leptons – electrons, muons and neutrinos along with their antiparticles.

Quarks – six flavours: Up, Down, Strange, Charm, Bottom and Top, along with their antiparticles.

Composite particles are made up of bound states of quarks (quarks stuck together to make another particle).

Hadrons: Hadrons are particles containing quarks and are subject to the Strong Nuclear Force. Hadrons are made up of two groups: baryons and mesons.

> **Baryons** – combinations of three quarks (or three antiquarks in an antibaryon). Protons and neutrons are baryons. All baryons that are not protons are unstable and decay eventually, becoming protons.
> **Mesons** – combinations of quarks and antiquarks in pairs; mesons include pi mesons (pions) and K mesons (kaons). All mesons are unstable and decay into other particles.

Force carriers (bosons) are elementary particles that carry the different fundamental forces:

> photon for electromagnetism
> W^+, W^- and Z^0 for the Weak Nuclear Force
> gluons for the Strong Nuclear Force
> graviton for gravity (not observed)

These particles are the exchange particles of the force. They transmit force and energy between particles during an interaction.

Quantum numbers

These subatomic particles have other properties, in addition to the familiar charge and mass.

L – Lepton number: Leptons such as the electron and the neutrino have a lepton number of $+1$; antileptons such as the positron and the antineutrino have a lepton number of -1. A particle that is not a lepton has a lepton number of 0.

B – Baryon number: Baryons such as the proton and the neutron have a baryon number of $+1$; antibaryons such as the antiproton and the antineutron have a baryon number of -1. Quarks have a baryon number of $+\frac{1}{3}$ and antiquarks have a baryon number of $-\frac{1}{3}$. A particle that is not a baryon has a baryon number of 0.

S – Strangeness: A particle has strangeness if it contains strange quarks or strange antiquarks. A particle has a strangeness of -1 for every strange quark it contains and a strangeness of $+1$ for every strange antiquark it contains (the opposite to what you might expect!).

There are more of these ‘quantum numbers’ such as spin and isospin that are not usually covered at A-level (*you are advised to check your own exam board specification to find out which particles you will need to know about*).

Conservation laws

A particle interaction can only occur if it obeys certain conservation laws.

Charge: Conserved in all types of interaction.

Lepton number: Conserved in all types of interaction.

Baryon number: Conserved in all types of interaction.

Strangeness: Conserved in Strong Nuclear interactions, but not Weak Nuclear interactions.

For more on conservation laws in particle interactions see Topic Builder 19: Conservation Laws and Feynman Diagrams.

Questions

1 Explain the difference between elementary and composite particles.

2 The mass of an electron, in units of electron-volts, is 0.511 MeV. What is the value of this energy in joules?

3 Convert 48×10^{-19} joules into electron-volts.

4 List the six flavours of quark.

5 What type of particle is made up of three quarks?

6 What type of particle is made up of three antiquarks?

7 What type of particle is an electron?

8 What type of particle is made up of a quark and an antiquark?

9 What are the four fundamental forces?

10 What is the exchange particle of the electromagnetic force?

11 What are the two charged exchange particles for the Weak Nuclear Force?

12 What is the lepton number of a positron?

13 What is the baryon number of a proton?

14 What is the baryon number of a pion?

15 What is the lepton number of a kaon?

16 What is the lepton number of a neutrino?

17 Kaons all have a strangeness of +1 or −1. What does this tell you about their quark structure?

18 What fundamental force does not conserve strangeness?

Taking it Further

The ideas discussed and used here form part of the Standard Model of Particle Physics. This model of the way particles interact is tested using the largest particle accelerators in the world.

Now use this space to make more in-depth notes about particles. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is an elementary particle?*

⇒ *What is antimatter?*

⇒ *What is a baryon?*

⇒ *What is a lepton?*

⇒ *What is a meson?*

⇒ *What is pair production?*

⇒ *What is pair annihilation?*

⇒ *What are exchange particles?*

⇒ *What quantities are conserved in particle interactions?*

⇒ *What work is being done at CERN, Fermilab, the LEP and the LHC? And how does this refer to the knowledge you have been learning?*

Conservation Laws and Feynman Diagrams

GCSE

You will have learnt that atoms are made up of protons, neutrons and electrons and be able to describe some of their properties.

A-level

You need to be able to interpret and draw simple Feynman diagrams for various particle interactions, and use conservation laws to determine if given particle interactions are possible.

What are the fundamental forces?

There are four fundamental forces: gravity, electromagnetism, the Strong Nuclear Force and the Weak Nuclear Force. Each is carried by a particle, and particle interactions can be explained in terms of an exchange of particles that carry forces.

Exchange particles or force carriers

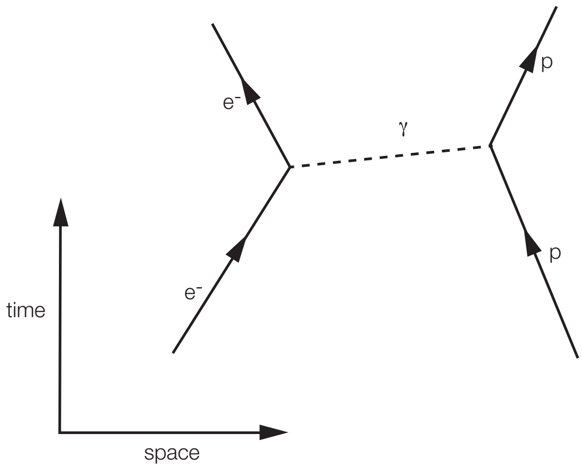
- **Photons (γ)** for electromagnetism – long range (infinite)
- **W^+, W^- and Z^0** for the Weak Nuclear Force – very short range
- **Gluons** for the Strong Nuclear Force – very short range
- **Gravitons** for gravity (not observed) – long range (infinite)

What are Feynman diagrams used for?

Particle interactions, involving the exchange of **force carriers**, can be shown diagrammatically using Feynman diagrams. Feynman diagrams show how particles interact, via each of the fundamental forces. In a Feynman diagram the axes used are *Time* on the vertical axis and *Space* on the horizontal axis (1 dimension only).

Example 1

A Feynman diagram for the interaction between an electron and a proton:



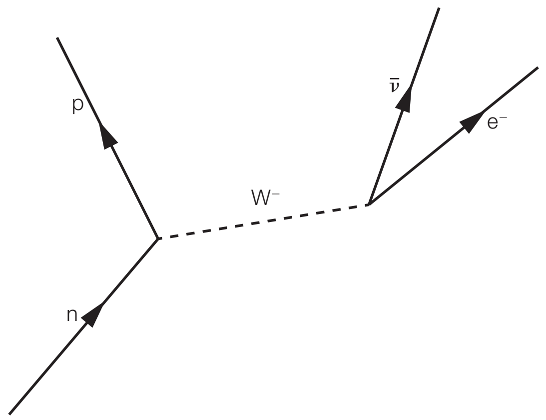
This example of a Feynman diagram shows the two particles at the bottom moving toward each other; an exchange particle is emitted on the left and received on the right. The resulting particles move apart

The equation for the diagram is: $e^- + p \rightarrow e^- + p$

Example 2

The equation for beta minus decay is: $n \rightarrow p + e^- + \bar{\nu}$

The Feynman diagram for beta minus decay would be:



This diagram shows a single neutron decaying by emitting a W minus boson and turning itself into a proton. The W minus boson decays quickly into an electron and an antineutrino; all the particles move away from each other.

This is a Weak Nuclear interaction, as the exchange particle is a W minus boson which carries the Weak Nuclear Force.

Feynman diagrams can be drawn for all fundamental forces and particle interactions. At A-level you are most likely to need to know how to draw several different examples for the Weak Nuclear Force and the electromagnetic force only (*check the requirements of your exam board specification*).

What are the conservation laws?

A particle interaction can only occur if it obeys certain conservation laws. If an interaction would break a conservation law it *does not* happen. An interaction that obeys all conservation laws may be possible (there are additional conservation laws beyond the scope of most A-level specifications). The conservation laws are as follows:

- ***Q***, charge: conserved in all types of interaction.
- ***L***, lepton number: conserved in all types of interaction. Leptons such as the electron and the neutrino have a lepton number of +1; antileptons such as the positron and the antineutrino have a lepton number of −1.
- ***B***, baryon number: conserved in all types of interaction. Baryons such as the proton and the neutron have a baryon number of +1; antibaryons such as the antiproton and antineutron have a baryon number of −1. Quarks have a baryon number of $+\frac{1}{3}$ and antiquarks have a baryon number of $-\frac{1}{3}$.
- ***S***, strangeness: conserved in Strong Nuclear interactions but not Weak Nuclear interactions. A particle has **strangeness** if it contains strange **quarks** or strange **antiquarks**. A particle has a strangeness of −1 for every strange quark it contains and a strangeness of +1 for every strange antiquark it contains (the opposite to what you might expect!).

Example of how conservation laws are applied to particle interactions

To find out whether an interaction equation breaks any of the conservation laws, simply look up each value or 'read' it from the symbol. Write each one down beneath the equation and make sure the two sides are equal. If not, then a conservation law has been broken and the interaction is not possible.

You will be provided with a table similar to the one shown below when you sit your examinations.

symbol	name	charge	baryon no.	lepton no.	strangeness
p	proton	+1	+1	0	0
n	neutron	0	+1	0	0
$\bar{p}$	antiproton	−1	−1	0	0
$\bar{n}$	antineutron	0	−1	0	0
π^+	pion +	+1	0	0	0
π^-	pion −	−1	0	0	0
π^0	pion 0	0	0	0	0
e^-	electron	−1	0	+1	0
e^+	positron	+1	0	−1	0
ν	neutrino	0	0	+1	0
$\bar{\nu}$	antineutrino	0	0	−1	0

(Kaons and muons are also required in some AS-level questions.)

These examples show how to use conservation laws to determine if the following particle reactions are possible:

a. $p + p \rightarrow \pi^+ + \pi^- + \pi^0 + e^- + e^+$

Charge Q	+1	−1	→	+1	−1	+0	−1	+1	0 = 0	✓
Baryon number B	+1	−1	→	0	+0	+0	+0	+0	0 = 0	✓
Lepton number L	0	+0	→	0	+0	+0	+1	−1	0 = 0	✓
Strangeness S	0	+0	→	0	+0	+0	+0	+0	0 = 0	✓

All of the conservation laws are obeyed, so this interaction seems possible.

b. $p + p \rightarrow e^+ + \pi^0 + e^- + n + \nu + \pi^+ + p$

Charge Q	+1	+1	→	+1	+0	−1	+0	+0	+1	+1	2 = 2	✓
Baryon number B	+1	+1	→	+0	+0	+0	+1	+0	+0	+1	2 = 2	✓
Lepton number L	+0	+0	→	−1	+0	+1	+0	+1	+0	+0	0 = +1	✗

This interaction does not follow the law of conservation of lepton number, so it is *not* possible.

The conservation laws are also applied to Feynman diagrams for possible interactions.

Questions

1 List the four fundamental forces

2 What are the exchange particles of each fundamental force?

3 What axes are used in a Feynman diagram?

4 Draw a Feynman diagram for two electrons repelling each other.

5 The equation for beta plus decay is $p \rightarrow n + e^{+} + \nu$. Draw a Feynman diagram for beta plus decay.

6 List three quantities that are conserved in all particle interactions.

7 Use the table on page 54 to determine, using conservation laws, whether the following particle interactions are possible.

a. $e^{-} + e^{+} \rightarrow \pi^{+} + \pi^{-} + \nu + n + \bar{p}$
b. $p + \bar{n} \rightarrow \pi^{+} + p + \pi^{0} + e^{-} + \bar{\nu}$
c. $e^{+} + \bar{p} \rightarrow p + \pi^{-} + \bar{n} + \bar{n} + \bar{\nu}$
d. $n + \bar{p} \rightarrow \pi^{-} + \pi^{0} + e^{-} + e^{+} + \bar{\nu}$

8 Use the conservation laws to make up some possible particle interactions, using particles in the table above. For each one show how each of the quantities is conserved.

Taking it Further

The ideas discussed and used here are essential in particle physics.

Now use this space to make more in-depth notes about conservation laws and Feynman diagrams. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What are the characteristics of the four fundamental forces?*

⇒ *What are Feynman diagrams used for?*

⇒ *How do exchange particles fit into Feynman diagrams?*

⇒ *What quantities are conserved in particle interactions?*

⇒ *How many Feynman diagrams are required to fully calculate the probability of a particle interaction happening?*

Electrical Circuits: Charge, Current and Voltage

GCSE

You will have carried out practical work and simple calculations involving current and voltage.

A-level

You need to be able to explain what current is and define potential difference. You will need to carry out calculations involving current and charge, along with calculations involving potential difference and energy in combination with these.

DC Circuits

DC stands for **direct current**. This is current that flows one way around a circuit, as with a battery.

How much current flows in a circuit depends on the **voltage** of the power supply or battery and the **resistance** of the circuit.

The words 'charge' and 'current' are often used interchangeably in normal language, but they have specific meanings in physics that you need to learn.

What is charge?

Electrical charges come in two 'flavours', positive + and negative – .

It is a property of subatomic particles such as electrons (–) and protons (+). Neutral atoms have equal numbers of positive and negative charges.

Charge *cannot* be *created* or *destroyed*. Charge is **never** 'used up' in a circuit.

When charges have difficulty moving along an insulator, charges accumulate and static electricity builds up.

In a conductor, charges do not build up, as they can easily pass along the conductor. When this happens we say a **current** is flowing in the conductor.

What is current?

A current is a flow of charge. The more charge is flowing per second, the higher the current.

Current is a measure of how quickly charge is flowing.

charge (Q) = current (I) × time (t) $\quad Q = It$

The units are as follows:

charge = coulombs (C); current = amperes (A); time = seconds (s)

And so: **1 coulomb = 1 ampere for 1 second.**

If we know the current in a circuit and how long it flows for, we can calculate the charge that passes a point in the circuit.

Conventional Current: Before it was known that electrons were the charge carriers in metals, it had been decided to describe the action of electrical currents as the flow of positive charges. This has no effect on the physics involved, as the choice of which charge to call positive and which to call negative was completely arbitrary. The result is to say that current flows from positive to negative, as it would for positive charges. This is known as conventional current, and is opposite in direction to electron flow in a circuit, which, due to the negative charge of electrons, flows from negative to positive.

Current is measured with an **ammeter**, connected in **series** with other components.

Example 1

What is the current flowing in a circuit when a charge of 12.8 C flows past a point in the circuit in 35 seconds?

$$Q = 12.8\text{ C} \qquad t = 35\text{ s} \qquad I = ?$$

$$Q = It \qquad \text{rearrange to give } I = \frac{Q}{t} = \frac{12.8}{35} = \mathbf{0.366\ A}$$

What is potential difference?

Potential is a measure of the energy per coulomb of charge.

Potential difference or voltage (pd or *V*) across a circuit is the comparison of energy content per coulomb of charge before and after passing through that circuit. Hence the **potential difference** is a measure of how much **energy per coulomb** of charge is transferred by components **out of** the circuit.

potential difference (*V*) = energy (or work) (*E* or *W*) / charge (*Q*) $\quad V = \frac{E}{Q} = \frac{W}{Q}$

The units are as follows:

potential difference = volts (V); energy or work = joules (J); charge = coulombs (C)

And so: **1 volt = 1 joule / 1 coulomb**

Potential difference between points in a circuit is measured with a **voltmeter,** connected in **parallel** between those points.

Example 2

What is the potential difference across a bulb in a circuit when it transfers 0.50 kJ for every 1.8 C of charge?

$$E = 0.50\text{ kJ} = 0.50 \times 10^3\text{ J} = 500\text{ J} \qquad Q = 1.8\text{ C} \qquad V = ?$$

$$V = \frac{E}{Q} = \frac{500}{1.8} = 2.78 \times 10^2 = \mathbf{278\ V}$$

What is electromotive force?

Electromotive force (emf or ε) is a measure of how much energy is transferred into the circuit per coulomb of charge, from the battery or supply. *So: emf transfers into a circuit, pd transfers out of a circuit*. Both emf and pd are measured in volts.

electromotive force (ε) = energy or work (*E* or *W*) / charge (*Q*) $\quad \varepsilon = \frac{E}{Q} = \frac{W}{Q}$

The units are as follows:

electromotive force = volts (V); energy or work = joules (J); charge = coulombs (C)

Electrical Circuits: Charge, Current and Voltage

So it is the energy from the supply, not the current, that gets 'used up' around the circuit. (Although of course energy never gets used up in the sense of disappearing from the universe; it simply gets transformed into other types of energy. This is due to **conservation of energy**.)

Circuit problems will require you to be able to calculate various quantities from the information given in the question. These quantities are related by the appropriate equation.

Questions

Tip: Write down what you know and put in the correct units; select the equation that relates what you know with what you want to know; rearrange if required; substitute values into the equation and solve. Make sure you include the correct units.

1 Write an equation that relates current and charge. Name all the quantities in the equation and give the unit of measurement of each.

2 Calculate the time needed for a current of 120 mA to supply 58 C of charge.

3 Calculate the time needed for a current of 13 A to supply 0.5 C of charge.

4 What charge passes a point in a circuit when a current of 50 μA flows for 10 minutes?

5 What charge passes a point in a circuit when a current of 20 mA flows for 2 hours?

6 Find the current needed for 3.80×10^3 C to pass a point in a circuit in 5 minutes.

7 Find the current needed for 2.25×10^2 C to pass a point in a circuit in 5 milliseconds.

8 42 coulombs passes an ammeter in a circuit over a 2-minute interval. What is the reading on the ammeter?

9 Write an equation that relates potential difference and charge. Name all the quantities in the equation and give the unit of measurement of each.

10 State the difference between electromotive force and potential difference.

11 Find the potential difference when 150 J of electrical energy is transferred across a bulb for every 4.2 C that flows through it.

12 Find the potential difference when 6.2k J of electrical energy is transferred across a heater for every 12.5 C that flows through it.

13 How much energy is transferred by a cell with an emf of 1.5 V when it supplies 3600 C to the circuit?

14 How much energy is transferred by a resistor with a potential difference of 32 kV when it supplies 9.6×10^6 C to the circuit?

15 What charge is required to supply 200 MJ at a potential difference of 220 kV?

16 What charge is required to supply 6.45×10^{-8} J at a potential difference of 0.05 V?

17 How much energy is transferred by a resistor when a current of 0.15 A flows for 5 minutes, with a potential difference of 12 V?

18 How much energy is transferred by a cell when a current of 125 mA flows for 30 minutes, with a potential difference of 5 V?

Taking it Further

Now use this space to make more in-depth notes about charge, current and voltage in circuits. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is charge?*

⇒ *What is current?*

⇒ *What is direct current?*

⇒ *What is alternating current?*

⇒ *What is the definition of potential difference?*

⇒ *What units are the above measured in?*

⇒ *What equation is used to calculate potential difference?*

⇒ *What is electromotive force?*

⇒ *What equation is used to calculate electromotive force?*

⇒ *How was electricity first discovered?*

⇒ *Where would you find electricity in the natural world?*

Electrical Circuits: Resistance

GCSE

You will have discussed the differences between insulators and conductors. Circuits with resistance will have been covered, along with simple resistance calculations.

A-level

You need to be able to explain what resistance is. Calculations involving resistor networks and resistors in circuits are common in all electricity problems. You need to know the characteristics of several kinds of components and how they are used in circuits.

What is resistance?

Different conductors offer different amounts of **resistance** to the passage of electrical current. They vary in the ease with which electrons can move through them. **Resistance** is a measure of the difficulty current has in passing through a material.

Resistance has the symbol ***R*** and is measured in ohms, which have the symbol Ω.

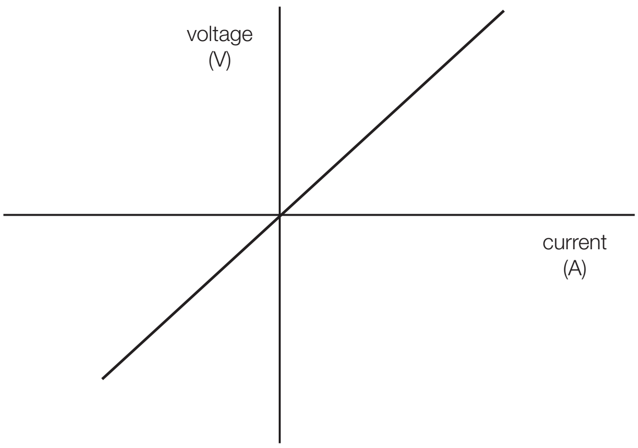
How do we measure resistance?

Whilst some multimeters do have a resistance option, an **ohm meter,** resistance is usually calculated by first measuring the potential difference (voltage) across the **resistor** and then measuring the current through the **conductor**.

Voltage current characteristics

By taking readings of voltage and current for a resistor in a circuit, we can plot a graph that shows the **voltage current characteristics**.

For a metal wire acting as a resistor, we obtain the graph shown on the right.



The graph is a straight-line graph of V (measured in volts) against I (measured in amperes). It is **linear**, and shows that the potential difference is **directly proportional** to the current: $V \propto I$. This can be written as $V = RI$ where R is the constant of proportionality, **resistance**.

The **resistance *R*** of a conductor is defined as the ratio of the potential difference V across it to the current I flowing through it.

$$\textit{Resistance (R)} = \frac{\textit{Potential Difference (V)}}{\textit{Current (I)}} \qquad R = \frac{V}{I}$$

Since the **potential difference** determines the **energy** that the current has, with which to pass through the conductor, the **voltage per unit current** is a measure of the resistance.

Experiments to measure how this ratio varies as the potential difference is increased show that a metallic conductor has a constant resistance for a given temperature.

Electrical Circuits: Resistance

What is Ohm's Law?

Ohm's Law states that the resistance of a metallic conductor does not change with potential difference, provided the temperature is constant.

Hence, voltage is directly proportional to current in an **ohmic conductor.**

An ohmic conductor is one that behaves according to Ohm's Law (a non-ohmic one doesn't)!

Example calculation:

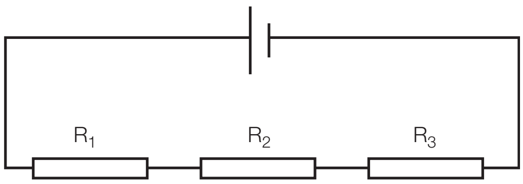
A resistor has a current of 25 mA flowing through it while a potential difference of 5 V is applied. Calculate the resistance of the resistor.

What we know: $I = 25\text{ mA} = 25 \times 10^{-3}\text{ A}$ $V = 5\text{ V}$ $R = ?$

Equation $R = \frac{V}{I}$; substituting these values in gives $R = \frac{5}{25 \times 10^{-3}} = 2.0 \times 10^2 = \mathbf{200\ \Omega}$

What happens when resistors are in series?

A series circuit simply presents one component after another. So, if a current flows through two resistors in series, it experiences the resistance of each of them in turn.



The total resistance to the flow of current across both resistors is the sum of the individual resistances.

$$R_T = R_1 + R_2 + R_3 \ldots$$

R_T is the total resistance and R_1, R_2 and R_3 (the number of '*R*s' included depends how many resistors are in the circuit) are the values of the three resistances.

Example:

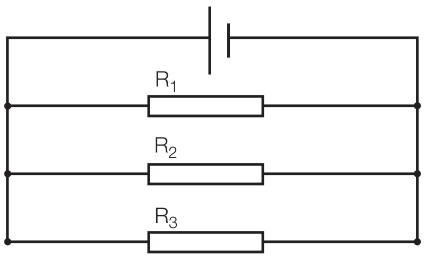
Find the total resistance when a 10 kΩ resistor is placed in series with a 500 Ω resistor and a 470 Ω resistor.

$$R_1 = 10.0\text{ k}\Omega = 10 \times 10^3\ \Omega \qquad R_2 = 500\ \Omega \qquad R_3 = 470\ \Omega \qquad R_T = ?$$

$$R_T = R_1 + R_2 + R_3 = 10 \times 10^3 + 500 + 470 = 1.097 \times 10^4 = \mathbf{10970\ \Omega}$$

What happens when resistors are in parallel?

A parallel circuit contains a junction at which current may split and flow down different possible routes. The amount of current flowing in each branch of the junction is determined by the amount of resistance in each branch. Having two identical resistors in parallel provides two routes for the current, giving an effective resistance of only half that of the individual resistors.



Electrical Circuits: Resistance

The formula to calculate the total resistance for resistors in parallel is

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

R_T is the total resistance and R_1, R_2 and R_3 are the values of the three resistances.

This formula is unusual as R_T is not the subject of the formula. The inverse of R_T, or $1 / R_T$, is the subject. Remember to **invert** your answer to obtain R_T.

Example:

Find the total resistance when a 10 kΩ resistor is placed in parallel with a 500 Ω resistor.

$R_1 = 10.0\ \text{k}\Omega = 10 \times 10^3\ \Omega$ $\quad R_2 = 500\ \Omega$ $\quad R_T = ?$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{10 \times 10^3} + \frac{1}{500} = 2.1 \times 10^{-3} \qquad R_T = \frac{1}{2.1 \times 10^{-3}} = \mathbf{476\ \Omega}$$

Notice the total resistance is lower than either of the individual resistors.

Questions

Tip: Write down what you know and put in the correct units; select an equation that relates what you know with what you want to know; rearrange if required; then substitute values into the equation and solve. Include the correct units

1 Write an equation that relates potential difference and current. Name all the quantities in the equation and give the unit of measurement of each.

2 What is the equation for finding the total resistance of resistors in series?

3 What is the equation for finding the total resistance of resistors in parallel?

4 State Ohm's Law.

5 A resistor has a current of 50 mA flowing through it while a potential difference of 1.5 V is applied. Calculate its resistance.

6 A resistor has a potential difference of 6.0 V across it when a current of 100 μA is flowing through it. Calculate its resistance and express the answer in kΩ.

7 What current flows through a 47 Ω resistor when 1.5 V is applied across it?

8 What current flows through a 470 kΩ resistor when 230 V is applied across it? Express the answer in mA.

9 Calculate the potential difference across an 11.0 MΩ resistor when a current of 74.2 mA flows through it.

10 Calculate the potential difference across a 4.7 kΩ resistor when a current of 15 μA flows through it. Express the answer in mV.

11 If $R_1 = 50\ \Omega$, $R_2 = 10\ \Omega$ and $R_3 = 200\ \Omega$ find the total resistance when each is in series.

12 If $R_1 = 1\ k\Omega$, $R_2 = 470\ \Omega$ and $R_3 = 115\ \Omega$ find the total resistance when each is in series. Through which resistor does the most current flow?

13 If $R_1 = 10\ \Omega$, $R_2 = 10\ \Omega$ and $R_3 = 10\ \Omega$ find the total resistance when each is in parallel.

14 If $R_1 = 50\ \Omega$, $R_2 = 100\ \Omega$ and $R_3 = 200\ \Omega$ find the total resistance when each is in parallel.

15 If $R_1 = 1\ k\Omega$, $R_2 = 470\ \Omega$ and $R_3 = 115\ \Omega$ find the total resistance when each is in parallel. Through which resistor does the most current flow?

16 Draw a circuit containing 2 resistors in series and 2 resistors in parallel.

a. What is the arrangement of resistors that gives the **smallest** total resistance value if you have $2 \times 500\ \Omega$ and $2 \times 100\ \Omega$ resistors (that is, which goes where in your previous circuit diagram)?

b. What is the arrangement of resistors that gives the **largest** total resistance value if you have $2 \times 500\ \Omega$ and $2 \times 100\ \Omega$ resistors (that is, which goes where in your previous circuit diagram)?

Electrical Circuits: Resistance

Taking it Further

Now use this space to make more in-depth notes about resistance in electrical circuits. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

- ⇒ *What is resistance?*
- ⇒ *How do we measure resistance?*
- ⇒ *What equation is used to calculate resistance?*
- ⇒ *What is Ohm's Law?*
- ⇒ *What is an ohmic conductor?*
- ⇒ *What is a non-ohmic conductor?*
- ⇒ *What happens to the value for resistance when resistors are in series in a circuit?*
- ⇒ *What happens to the value for resistance when resistors are in parallel?*
- ⇒ *What is a superconductor?*
- ⇒ *How is Ohm's Law used in lie detectors?*

GCSE

You will have used scalars and possibly simple vectors in a straight line. Simple trigonometry and Pythagoras' theorem will have been covered in maths.

A-level

You need to be able to explain the difference between scalars and vectors and give examples of each. Scale diagrams can be used to 'add' vectors, but trigonometry and Pythagoras' theorem are essential to solve many mechanics problems. Resolving vectors is a skill required in many other areas of physics.

Can all quantities be described by a single number?

A number can be used to give a measure of the size or magnitude of a quantity.

Henry was paid £32 for his hard work.

A quantity that can be described by just one value is called a **scalar**. A single number is all that is needed to describe it.

Some quantities that are described by scalars are: mass, energy, speed, distance.

Some quantities, however, require more than just size to completely describe them: for example, the wind speed at a point on a map. The direction of the wind as well as the speed of the wind must be included for a full description.

The wind is blowing at 50 mph in a direction 20° East of North.

A quantity that has direction as well as size is called a **vector**. It is described by two values. An arrow is a useful way to show a vector, because it has size (length of arrow) and direction (it points somewhere).

Some quantities that are described by vectors are: force, velocity, acceleration, momentum.

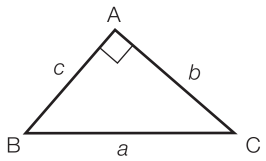
How do I add together scalars and vectors?

Combining scalars

Easy, just add them together!

Combining vectors

If two vectors are in the same direction, and you want to combine them into one vector, they can be added in the same way as scalars. If they point in different directions, however, the angle between them makes a big difference to the final result.

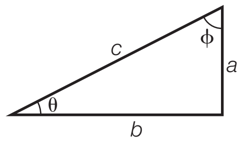


$a^2 = b^2 + c^2$

At A-level, you will need to add vectors that are at **right angles** (90°) to each other only (this makes it easier). In other words, the vectors you are adding together form the short sides of a right-angled triangle. How do you work out the long side (**hypotenuse**) when you know the other two sides? **Pythagoras' equation**!

Vectors and Scalars

To completely describe the combined vector we need to say its direction as well as its size. Since we know the two short sides of the triangle, we can use them as well as some **trigonometry** to find the angle of the hypotenuse relative to a particular side.



Since the tan function relates the lengths of the opposite and adjacent sides of a right-angled triangle to the angle, we find that

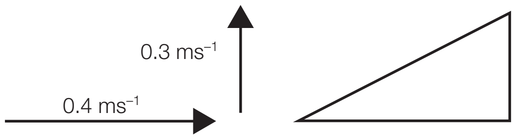
$$\tan\theta = \frac{opposite}{adjacent} \text{ and so } \theta = \tan^{-1}\frac{opposite}{adjacent} = \tan^{-1}\left(\frac{a}{b}\right)$$

Example

A toy boat points directly at the opposite bank of a river and moves forward with a speed of 0.3 ms^{-1}. If the river flows at a speed of 0.4 ms^{-1} at right angles to the direction the boat points, what is the boat's velocity as it crosses the river?

Solution

A diagram is always useful. If the river flows at a right angle to the boat, we have the arrangement shown below.



Using Pythagoras' theorem:

$c^2 = 0.3^2 + 0.4^2$

$c = \sqrt{0.25} = \mathbf{0.5\ ms^{-1}}$

To find the angle to the horizontal:

$\tan\theta = 0.3 / 0.4$

$\theta = \tan^{-1}(0.75) = \mathbf{36.9°}$

Answer: the boat moves at 0.5 ms^{-1} at 36.9° to the horizontal.

Resolving vectors

Often we need to change a vector that is at an angle to an **axis**, into its two components at right angles to each other. This is the reverse of using Pythagoras' theorem. We need to find two vectors at right angles (parallel to the x and y axes) that are the components of the original vector (so that combined they give the original vector).

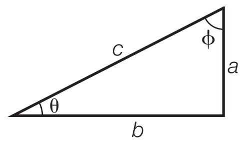
Trigonometry

Trigonometry deals with the relationships between the sides and angles of triangles. In physics we often use trigonometry with vectors, where the lengths of the sides of the triangle represent the size of the vectors, whether they are force, velocity or acceleration.

If we know an angle and a side of a right-angled triangle, we can work out the other sides and angles. For a right-angled triangle, the sine of an angle = the ratio of the length of the side opposite the angle and the length of the hypotenuse.

The mnemonic **SohCahToa** stands for: sin = opp / hyp cos = adj / hyp tan = opp / adj referring to the sides of the triangle: hypotenuse, opposite and adjacent.

For the right-angled triangle shown:



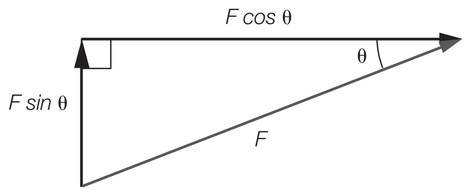
sin θ = a / c cos θ = b / c tan θ = a / b

Also sin ϕ = b / c cos ϕ = a / c tan ϕ = b / a

To resolve a vector represented by the hypotenuse (*c*) of the triangle into two components at right angles (*a*, *b*) when the vector makes an angle of θ with the *x*-axis, we rearrange the trigonometric functions.

$sin\ \theta = \frac{a}{c}$ which gives $a = c sin\ \theta$ so the side opposite the angle is the length of *c* multiplied by the sine of the angle θ.

$cos\ \theta = \frac{b}{c}$ which gives $b = c cos\ \theta$ so the side adjacent to the angle is the length of *c* multiplied by the cosine of the angle θ.



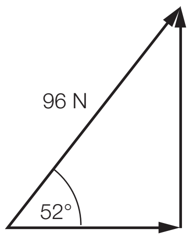
If the vector is force *F* at an angle θ to the *x*-axis and the two components of the vector are F_x along the *x*-axis and F_y along the *y*-axis, then:

$$F_x = F cos\ \theta \text{ and } F_y = F sin\ \theta$$

Example

A rope pulls on a crate at an angle of 52° to the horizontal with a force of 96 N. What are the horizontal and vertical components of the force?

Solution



Draw a quick diagram of the vector.

The horizontal component is adjacent to the angle, so we need the cosine of the angle.

$$F_x = F cos\ \theta = 96 \times \cos 52 = \mathbf{59.1\ N}$$

The vertical component is opposite to the angle, so we need the sine of the angle.

$$F_y = F sin\ \theta = 96 \times \sin 52 = \mathbf{75.6\ N}$$

In problems involving vectors, the vector may need to be resolved in directions different to *x* and *y*, such as in problems involving slopes. The directions of any pair of axes are always 90° to each other. This is because the directions are independent of each other, and hence so are the components of the original vector.

Vectors and Scalars

Questions

1 Describe the difference between a scalar and a vector.

2 List three examples of quantities that are scalars.

3 List three examples of quantities that are vectors.

4 A boy runs at 2 ms^{-1} on a train moving at 12 ms^{-1}.

a. What is his velocity when running in the same direction as the train?
b. What is his velocity when running in the opposite direction to the train?

5 A plane flies north with a speed of 56 ms^{-1} while a wind blows the plane east at a speed of 15 ms^{-1}.

a. Draw a diagram to represent the two vectors.
b. Calculate the overall speed of the plane.
c. What is the direction of the plane relative to north?

6 Two horizontal forces are applied to a box at right angles to each other.

a. If one force is 55 N and the other is 35 N what is the total force on the box?
b. Why is the answer not 90 N?

7 If a vertical rope supports a box of weight 120 N and a rope attached to the box is pulled horizontally with a force of 50 N what is the size of the tension in the originally vertical rope?

8 What does SohCahToa stand for?

9 A float on the surface of water is held by a rope at an angle of 25° to the vertical. If the tension in the rope is 2.80 kN:

a. What is the horizontal force on the float?
b. What is the vertical force on the float?

10 A cart is pulled with a horizontal rope at an angle of 60° east of north. If the tension in the rope is 40 N;

a. What component of the force is north?
b. What component of the force is east?

Taking it Further

Now use this space to make more in-depth notes about vectors and scalars. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is a vector?*

⇒ *What is a scalar?*

⇒ *Give some examples of quantities that can be described by each.*

⇒ *How can vectors be added together?*

⇒ *How can scalars be added together?*

⇒ *What is Pythagoras' equation?*

⇒ *How does this relate to vectors and scalars?*

⇒ *What diagrams may need to be used to help answer vector and scalar questions?*

⇒ *What does SohCahToa stand for?*

⇒ *How does this relate to vectors and scalars?*

Mass and Weight

GCSE

You will have used the acceleration due to gravity '*g*' to calculate weight from mass.

A-level

You need to be able to explain the difference between mass and weight. Calculations may involve different values for '*g*'. Most force problems involve weight, and examiners expect you to know how to calculate weight from mass.

The words 'weight' and 'mass' are often used interchangeably in normal language, but they have precise meanings in physics.

What is mass?

Mass is measured using a balance to compare masses

Mass is a measure of how difficult it is to change an object's motion: a measure of how much 'stuff' is present in the object. *This is true in the sense that the mass of an atom is due to the protons and neutrons in the nucleus, so mass is a measure of how many protons and neutrons an object has.*

Mass is also the property of an object on which gravitational fields act.

Mass is a scalar (see task 22) measured in kilograms, kg.

If you were to land on the moon, your mass would not have changed, since you are still in one piece. You still have the same number of protons and neutrons.

What is weight?

Weight is measured using scales with calibrated springs, such as a newton meter.

Weight is the force of gravity on an object, due to its mass. Its size depends on the mass of each of two objects being attracted, eg yourself and the Earth. If your mass, or the Earth's mass, increased, it would increase the force on you, i.e. your weight.

Weight is a vector (see task 22) measured in newtons, N.

Your weight would change on the moon due to the lower strength of its gravitational field; the moon has a smaller mass compared to the Earth. This means your mass would be attracted with less force, so your weight would be lower.

Are mass and weight connected?

Do you remember the equation $F = ma$?

Well, weight is a force, so

Weight (a **force**) = **mass** × **acceleration** (due to gravity)

$$W = mg$$

The acceleration due to gravity is given a symbol g and is a constant (its value will always be the same) on the surface of the Earth.

It is equal to the acceleration of an object falling in a vacuum. It is a measure of the strength of gravity, or how much force per kilogram is exerted by gravity.

Mass and Weight

On Earth, $g = 9.81\ ms^{-2}$. This is the acceleration an object falls at if there is no air resistance.

The acceleration due to gravity (g) has different values on different moons and planets. On our moon, $g = 1.6\ ms^{-2}$.

Often in problems where the weight of an object needs to be calculated, only the mass is provided – it is important not to forget to convert the mass in kg to a weight in N.

Questions

1 What unit is weight measured in?

2 What is the unit of mass?

3 Describe what weight is.

4 In what direction does weight act?

For the following questions you will need to know that on the surface of the Earth the acceleration due to gravity $g = 9.81\ ms^{-2}$. Assume events in questions are on the surface of the Earth unless otherwise stated.

5 Calculate the weight of a 1 kg mass.

6 Calculate the weight of a 55 kg mass.

7 Calculate the weight of a 212.6 kg mass.

8 What mass has a weight of 1 N?

9 What mass has a weight of 36 N?

10 What mass has a weight of 0.089 N?

11 What is the weight of a 1 kg mass on the moon ($g = 1.6\ ms^{-2}$)?

12 What is the weight of a 75 kg mass on the moon ($g = 1.6\ ms^{-2}$)?

13 What is the weight of a 1 kg mass on Mars ($g = 3.7\ ms^{-2}$)?

14 What is the weight of a 240 kg mass on Mars ($g = 3.7\ ms^{-2}$)?

15 What is the weight of a 62 kg mass at the surface of the sun ($g = 274\ ms^{-2}$)?

16 On an exoplanet (a planet orbiting another star) the weight of a 40 kg mass is 273 N. What is the acceleration due to gravity on this planet?

Taking it Further

Now use this space to make more in-depth notes about mass and weight. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is mass?*

⇒ *What is weight?*

⇒ *What equation connects mass and weight?*

⇒ *What is acceleration due to gravity? Does its value change?*

⇒ *What is microgravity?*

⇒ *What values for g occur on other planets?*

⇒ *How is the value for g ascertained?*

GCSE

You will have covered forces such as pushes and pulls, looking at examples of simple forces such as weight and friction.

You will recognise balanced forces on objects in simple situations.

Simple trigonometry and Pythagoras' theorem will have been covered in maths.

A-level

You will need to be able to calculate forces for objects in equilibrium.

You will need to be able to recall and apply Newton's laws of motion.

You will need to be able to add forces acting at right angles to find the resultant force, and find the components of a force using trigonometry.

Forces are **vectors**. They have size and direction. They are represented in diagrams by **arrows**.

Forces acting in the **same** direction **add** together. *Two people pulling on a rope to drag a boat out of the water produce a total force equal to the sum of their individual forces.*

Forces acting in **opposite** directions **subtract**. *In a tug-of-war, if the two teams pull with equal force in opposite directions, the overall force is zero.*

To change the motion of an object there must be an overall force acting: a **resultant** or **net** force.

Objects with **no resultant force** acting are in **equilibrium**. They continue in their state of motion whether at rest or at a constant speed in a straight line.

This is **Newton's First Law of motion**: *An object remains at rest or continues to move at a constant velocity in a straight line unless a resultant force acts.*

How do I add forces at right angles to one another?

Forces are vectors, so the same method for adding them can be used as for two vectors at right angles. Pythagoras' theorem can be used to find the length of the vector, and trigonometry can then be used to find the angle.

How do I resolve forces into components at right angles?

Given a force, F, at an angle, θ, to the horizontal: the right-angle component opposite the angle is given by $F\sin\theta$ and the right-angle component adjacent to the angle is $F\cos\theta$.

See Topic Builder 22 – Physics Topics: Vectors and Scalars for details and practice with vectors.

How should I tackle forces in equilibrium problems?

Problems will involve an object in equilibrium with a number of forces acting on it. Since the object is in equilibrium, the sum of forces in the horizontal direction will add to zero and so will the sum of forces in the vertical direction. Work through such problems by following the steps below:

- Draw a diagram of the situation given, with all forces drawn on it and labelled.
- Select an axis – usually x horizontal and y vertical.

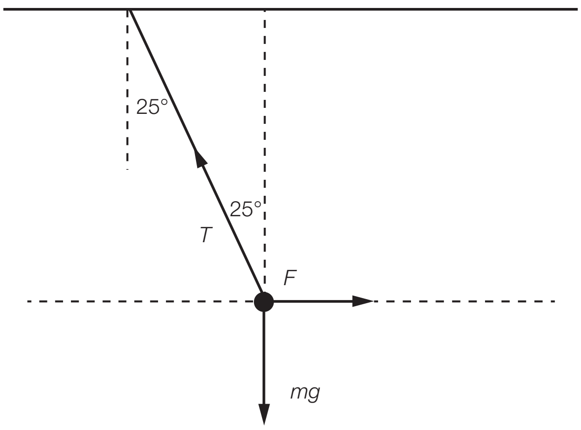
Forces in Equilibrium

- Resolve any force not parallel to one of the axes into its component vectors.
- Write an equation showing all forces in the vertical direction summing up to zero; remember + and − signs depending on direction.
- Write another equation showing all forces in the horizontal direction summing up to zero; remember + and − signs depending on direction.
- Solve for any unknown values.

Example

A light bulb with a mass of 100 g is suspended from a cable. This cable is made to make an angle of 25° with the vertical, due to a string attached to the bulb pulling it horizontally with a force *F*. Calculate the tension in the cable, *T*, and the force, *F*, pulling the bulb horizontally.

mass = 100 g = 0.1 kg;   weight = mg = 0.1 × 9.8 = 0.98 N



All forces are included and labelled. *Remember to convert mass to weight*.

The only force not parallel with the axis is *T*.

Resolving *T* into its two components gives the vertical component as $T\cos 25$ and the horizontal component as $T\sin 25$.

Vertical: $T\cos 25 - mg = 0$	*Up minus down*
$T\cos 25 - 0.98 = 0$	*We know mg = 0.98 N*
$T\cos 25 = 0.98$	
$T = 0.98 / \cos 25 =$ **1.08 N**	*Rearrange and solve*
Horizontal: $F - T\sin 25 = 0$	*Right minus left*
$F = T\sin 25 = 1.08\sin 25 =$ **0.46 N**	*Use value of T to solve*

The diagram is often the most important part of solving a problem. Ensure all forces are included, but don't add any that don't actually exist! If an object is in equilibrium, a force (or its component) should be pulling in each direction.

Questions

$g = 9.8\ \text{ms}^{-2}$

1 What is the meaning of a resultant force?

2 What can you tell about the forces on an object if it is in equilibrium?

3 If a book with a weight of 5 N rests on a table, what is the size of the reaction force of the table on the book?

4 An aircraft jet engine has a thrust of 2 kN. If a single-engine plane is in horizontal flight at a constant speed, what is the size of the drag force acting on the plane?

5 A ship is pulled by 2 tugboats with a force of 50 kN forwards. If the tugs each make an angle of 10° to the forward direction, how much tension must they each provide so that the ship is pulled with a resultant force of 50 kN?

6 A microphone with a mass of 200 g is suspended from a cable, but makes an angle of 20° to the vertical due to a horizontal force F applied by an attached string.

a. Draw a diagram of the situation with all the forces labelled.
b. Calculate the weight of the microphone.
c. Write an expression showing all vertical forces adding to zero.
d. Write an expression showing all the horizontal forces adding to zero.
e. Calculate the tension, T, in the cable.
f. Calculate the horizontal force, F.

Taking it Further

The ideas discussed and used here are essential for all mechanics topics and apply to almost all areas of physics.

Now use this space to make more in-depth notes about forces in equilibrium. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What types of forces are there?*

⇒ *What does it mean to be in equilibrium?*

⇒ *What are Newton's laws of motion?*

⇒ *How do you add forces?*

⇒ *How do you resolve forces into components?*

⇒ *What examples can you think of in which it would be essential to be able to calculate forces at equilibrium on an object?*

GCSE

You will have covered turning forces and levers at KS3, including examples of levers in action and magnification of a force.

A-level

You will need to be able to define the moment of a force and the principle of moments. You will need to be able to calculate moments of forces using various pivot points and solve problems for objects in equilibrium.

What is a centre of mass?

The **centre of mass** of an object is the point at the centre of an object's mass distribution. The weight of an object acts through the centre of mass of the object. The **balance point** of an object is directly above or below the centre of mass.

For an object of uniform **density** the centre of mass is in the centre of the volume. For example, the centre of mass of a ruler is in the middle. At A-level, the objects you will need to consider are likely to be uniform and simple 2-D shapes with forces acting only in two dimensions.

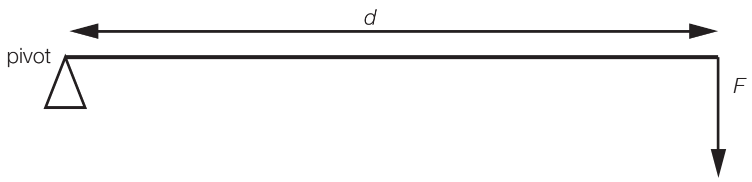
When **forces** act on an object at a **perpendicular distance** from an object's centre of mass, they cause an object to experience a turning force called the **moment** of a force (***torque*** is another term meaning the same thing).

What is the definition of a moment?

The moment of a force about a point is defined as the force multiplied by the perpendicular distance between the **pivot** and the line of action of the force.

What's the simplest machine ever invented? The lever: a stick with a thinking brain attached!

$M = Fd$ Units for moments are Nm (= Newtons × metres)



What is the principle of moments?

At equilibrium, the sum of the clockwise moments equals the sum of the anticlockwise moments.

This is the turning force equivalent to Newton's First Law of Motion.

What are couples?

A couple consists of two equal forces acting in opposite directions, equal distances from a pivot.

If a force, F, is applied in opposite directions and separated by a perpendicular distance, d (where the pivot is the midpoint between the forces), then

$$\text{moment of a couple} = \text{force} \times \text{separation} = Fd$$

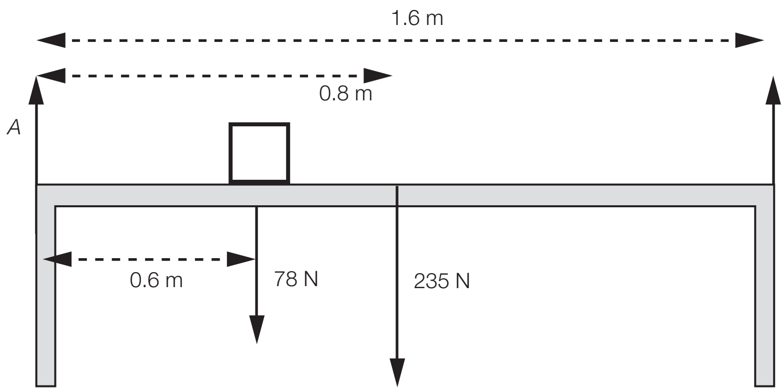
How do I solve problems involving moments?

Problems can be set where moments need to be calculated, or unknown forces found using the principle of moments. In addition to the moments in each direction being equal at equilibrium, the forces themselves must add up to zero. Follow the steps below when attempting such problems:

- Draw a diagram of the set-up, with all forces labelled and all known distances from possible pivots and forces shown. Remember that weight acts *through* the centre of mass.
- Select a suitable pivot. Sometimes there is no choice, but pick a pivot where an unknown force acts, as this eliminates it from the moment calculation.
- Sum up the moments turning clockwise and make these equal to the sum of moments turning anticlockwise.
- Solve the calculation.

Example

A uniform table top of length 1.6 m has a weight of 235 N. It is supported by legs at each end. Use moments to calculate the force on the table from each leg when a mass of 8 kg is placed 60 cm from one edge of the table. 8 kg = 8 × 9.8 = 78 N.



As you can see, such a diagram contains a lot of information that must be accurately recorded.

Select the left leg of the table as the pivot.

Sum of clockwise moments = sum of anticlockwise moments.

$$(78 \times 0.6) + (235 \times 0.8) = (B \times 1.6)$$

$$B = 147 \text{ N}$$

Total weight = 235 + 78 = 313 N
They are in equilibrium, so total weight = total upward force from the legs.

$$A + B = 313 \text{ N} \quad \text{so } A = 313 - 147 = \mathbf{166\ N}$$

Careful selection of the pivot can make problems easier. Also, remember that the sum of forces also needs to add to zero at equilibrium.

Questions

$g = 9.8\ \text{ms}^{-2}$

1 State the definition of the moment of a force.

2 State the principle of moments.

3 A force of 3.4 N acts at a perpendicular distance of 0.85 m from a pivot. Calculate the moment of the force.

4 A moment of 45 Nm is obtained using a lever with a distance between pivot and force of 0.25m. What force is required to produce the moment?

5 Two parallel, but opposite, forces of 3.2 N are placed on a dial of diameter 1.1 cm. Calculate the moment of the couple.

6 A couple produces a moment of 120 Nm using a pair of forces of 80 N each. Calculate the distance between the forces.

7 A uniform table top of length 2.4 m has a weight of 375 N. It is supported by legs at each end. Use moments to calculate the force on the table from each leg, when a box of mass 5.8 kg is placed 80 cm from one edge of the table.

8 A bridge of length 68 m has a weight of 720 kN. It is supported by concrete pillars 14 m in from each end. Use moments to calculate the force of each pillar on the bridge when a truck of mass 4200 kg is at a point 26 m from one end of the bridge.

Taking it Further

The ideas discussed and used here are essential for understanding any form of rotational motion.

Now use this space to make more in-depth notes about moments. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is a moment?*

⇒ *What is the principle of moments?*

⇒ *What is a couple?*

⇒ *What conditions are needed for an object to be in equilibrium?*

⇒ *How do moments relate to the stability of objects?*

GCSE

You will have covered motion in a straight line and drawn distance-time graphs to represent it.

A-level

You need to be able to interpret and produce displacement-time and velocity-time graphs for various types of motion in a straight line.

What is a motion graph used for?

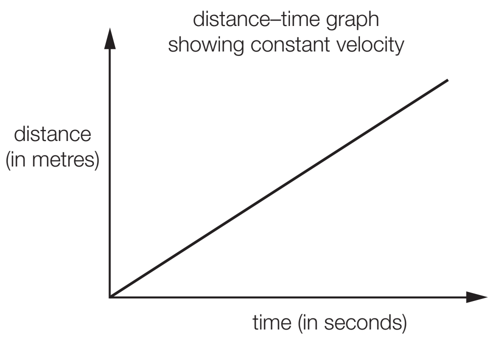
Motion graphs enable the motion of an object to be shown visually. Certain features of such a graph enable calculation of speed, acceleration and displacement at any point in the journey being represented.

At A-level, the motion graphs you will work with involve motion in a straight line.

In general, using these graphs will require two types of calculation in A-level physics: gradients and areas. As long as you know how to calculate the gradient of a line and the area under a section of a graph, you can calculate the answers to problems involving motion graphs.

What are displacement-time graphs and how can I interpret them?

These are similar to distance-time graphs but can show a negative displacement: i.e. in the opposite direction. The start point of any motion is usually considered to be at the origin of the displacement-time graph.



Gradient = distance / time = **velocity**

Positive gradient = positive velocity (away from the origin)

Negative gradient = negative velocity (towards the origin)

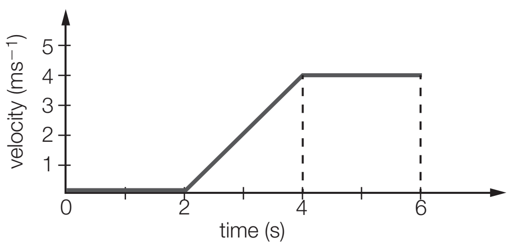
Zero gradient = zero velocity (not moving)

What are velocity-time graphs and how can I interpret them?

Velocity-time graphs can also include negative velocities for motion in the opposite direction. It is important to be sure you are working with the correct graph, so always check the axis to see if velocity or displacement is being used.

Gradient = change in velocity / change in time = **acceleration**

Positive gradient = positive acceleration (increasing velocity)



Motion Graphs

Negative gradient = negative acceleration (decreasing velocity)

Zero gradient = zero acceleration (constant velocity)

Area under the graph = displacement

The area has units of velocity (y-axis) times time (x-axis) which gives distance.

Positive area = area above $v = 0$ axis = positive displacement

Negative area = area below $v = 0$ axis = negative displacement

When calculating the area under a graph for a curve, you may need to count the squares in order to approximate the area. When doing this, it is important to also know the size of one square. Then, area = number of squares × size of one square.

Questions

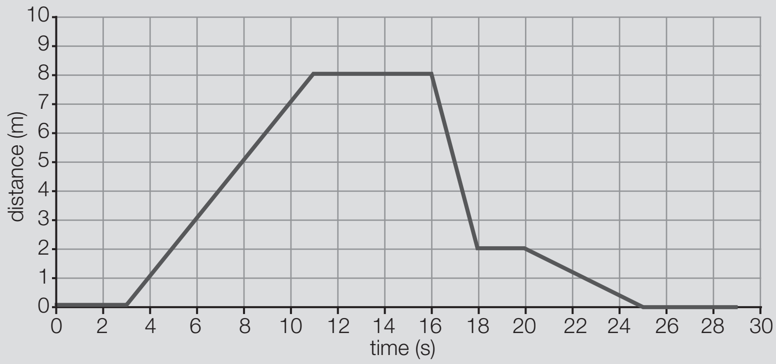
1 What does the gradient of a displacement-time graph represent?

2 What does a gradient of zero represent on a displacement-time graph?

3 What does the gradient of a velocity-time graph represent?

4 What does a gradient of zero represent on a velocity-time graph?

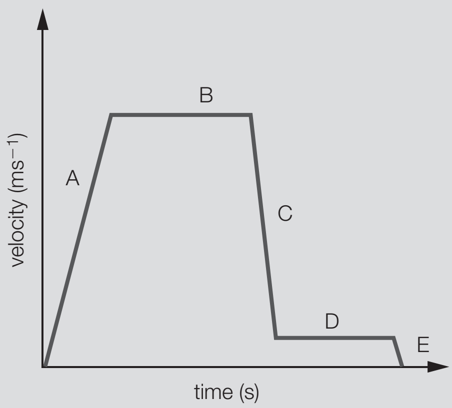
5 Using the graph shown, calculate:



a. The velocity between 3 and 11 seconds.
b. The displacement after 18 seconds.
c. The velocity at 22 seconds.
d. The time it took to return to the start point.

6 Using the graph shown, describe the motion at:

a. Region A
b. Region B
c. Region C
d. Which part of the graph shows the highest speed?
e. Which part of the graph has the largest deceleration?



Taking it Further

The ideas discussed here are useful in representing motion graphically; they underpin the equations of motion used to analyse motion. See Topic Builder 27: Equations of Motion.

Now use this space to make more in-depth notes about motion graphs. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What types of motion graphs do you need to be able to use and interpret?*

⇒ *What will be on the axis of the graphs you have just listed?*

⇒ *How do you calculate gradient on a graph?*

⇒ *How do you calculate an area under a line shown on a graph (including curves)?*

⇒ *What is the gradient equal to on a distance-time graph?*

⇒ *What is the gradient equal to on a velocity-time graph?*

⇒ *What is the area equal to on a velocity-time graph?*

⇒ *Can you make a velocity-time graph for a journey you take, labelling the key features?*

GCSE

You will have covered motion in a straight line, and calculated speed and acceleration for simple motion.

A-level

You need to be able to calculate various aspects of motion, using the equations of motion. Problems involving falling under gravity and eventually problems in two dimensions (projectiles) are likely to come up.

What is motion under constant acceleration?

Objects in motion change position over time. Motion changes due to the action of forces on an object, which produce **acceleration**. By knowing certain variables during motion, such as starting **velocity**, distance travelled and acceleration, we can use the 'equations of motion' to find values for other variables like time taken and final velocity. These equations are valid for motion in one direction at a constant acceleration.

The equations use the following variables.

a = acceleration	t = time	s = displacement (distance)
u = initial velocity	v = final velocity	

Acceleration, velocity and displacement are all vector quantities so care is needed with the signs of values used. See Topic Builder 22: Vectors and Scalars, for more information.

What are the equations of motion?

Motion in one direction at a constant acceleration can be described completely using the equations of motion. There are four equations:

$$v = u + at \qquad s = \frac{(u + v)}{2}t \qquad v^2 = u^2 + 2as \qquad s = ut + \frac{1}{2}at^2$$

These are generally provided on formula sheets in exams (check if this will be the case for your own exam board specification), but you should ensure you learn the meaning of each letter.

How do I use the equations of motion to solve problems?

To solve problems using the equations of motion, follow these steps:

- Write down what you know from the question and what you need to find out.
- Select an equation of motion that includes what you know and what you want to find out.
- Substitute all known values, in the correct units.
- Rearrange if needed and then solve.

There are a few additional things to look out for:

- An object at rest ... means the initial velocity = 0
- If an object is falling (on Earth), acceleration = g = 9.81 ms^{-2}

- Positive or negative values of velocity, acceleration and displacement: since all are vectors, a reversal of sign (from + to −) means a reversal of direction of the vector.
- If the motion involves changing direction, you need to be consistent with the use of + and − signs. Select a direction to call positive (often up). Ensure all values describing motion in the positive direction have a positive sign and all values describing motion in the negative direction have a negative sign.

Example problems

1 A car accelerates from a velocity of 12 ms^{-1} to a velocity of 20 ms^{-1} in a time of 4 seconds.

a. Calculate the acceleration of the car.
b. Calculate the distance travelled during the period of acceleration.

initial velocity $u = 12\ ms^{-1}$; final velocity $v = 20\ ms^{-1}$; time $t = 4$ s

a. acceleration a = ? You will need an equation with u, v, t and a $v = u + at$;

rearrange for a: $a = \dfrac{v - u}{t}$

$a = \dfrac{v - u}{t} = \dfrac{20 - 12}{4} = \mathbf{2\ ms^{-2}}$

b. distance s = ? You will need an equation with u, v, t and s.

$s = \dfrac{(u + v)}{2} t = \dfrac{(12 + 20)}{2} \times 4 = \mathbf{64m}$

2 A ball is thrown up in the air and gains a height of 3.2 m. Calculate:

a. The initial velocity of the ball as it leaves the hand.
b. The total time the ball is in the air, if it falls to the same point as it started.

a. Call ‘up’ positive. displacement $s = +3.2$ m acceleration $a = -9.8\ ms^{-2}$

We also know final velocity $v = 0$ at top of throw; initial velocity u = ?

Select an equation that contains s, a, v and u: $v^2 = u^2 + 2as$

$u^2 = v^2 - 2as$ so $u = \sqrt{0^2 - 2 \times (-9.8 \times 3.2)} = \mathbf{+7.9\ ms^{-1}}$

b. time t = ? To find time use initial velocity $u = +7.9\ ms^{-1}$; final velocity $v = -7.9\ ms^{-1}$

$v = u + at$ so $t = \dfrac{v - u}{a} = \dfrac{-7.9 - 7.9}{-9.8} = \mathbf{1.6\ s}$

Questions

Assume events discussed take place on Earth, unless otherwise stated, and that $g = 9.8\ ms^{-2}$. Ignore the effects of air resistance.

1 List all the letters used in the equations of motion, along with their meanings.

2 It takes a pebble 2.4 seconds to fall from a bridge. How high is the bridge?

3 A rocket motor accelerates at 75 ms^{-2} for a period of 20 seconds. If the rocket powers a sled along a horizontal track, from rest, calculate:

a. The sled's velocity after the 20-second burn period.
b. The distance needed to accelerate to that velocity.

4 A toy car accelerates from rest, down a ramp 0.8 m long, at a constant rate of 3.4 ms^{-2}. Calculate :

a. The time the car takes to reach the bottom of the ramp.
b. The car's velocity at the bottom of the ramp.

5 A flea jumps straight up, with a take-off speed of 1.5 ms^{-1}. Calculate:

a. The maximum height the flea reaches.
b. The total time the flea is in the air.

6 An Olympic diver jumps from the 10 m board, jumping up to 2.2 m above the board at the start of the dive.

a. What velocity must they leave the board with in order to reach the height of 2.2 m above the board?
b. Calculate the diver's velocity on impact with the water.
c. Calculate the time taken to complete the dive.

Taking it Further

The ideas discussed and used here are the foundations of the study of motion.

Now use this space to make more in-depth notes about the equations of motion. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is velocity?*

⇒ *What is acceleration?*

⇒ *What are the equations of motion?*

⇒ *What do each of the letters used mean?*

⇒ *How does acceleration relate to gravity?*

GCSE

You will have covered examples of forces and how unbalanced forces affect motion.

A-level

You need to be able to use Newton's Second Law of Motion to calculate acceleration.

Balanced forces

Objects with **no resultant force** acting on them are in **equilibrium**. They continue in their state of motion, whether at rest or at a constant speed in a straight line.

To change the motion of an object, there must be an overall force acting: a **resultant** or net force. It is the forces acting on an object that determine its motion.

What does Newton's First Law of Motion tell us?

A body remains at rest, or continues to move with constant velocity in a straight line, unless a resultant force acts.

In such a case, the sum of forces = zero.

What does Newton's Second Law of Motion tell us?

The acceleration of an object is directly proportional to the resultant force applied, and inversely proportional to the mass of the object.

$$F = ma$$

Units: force in newtons (N); mass in kilograms (kg); acceleration in metres per second per second (ms^{-2})

The sum of forces = mass × acceleration.

Example Problems

1 A jet engine produces a thrust of 20.0 kN. What acceleration is produced when the jet is attached to a vehicle of 2.6×10^3 kg?

$F = 20\,000$ N $\quad m = 2.6 \times 10^3$ kg $\quad a = ?$

$F = ma \quad \text{so } a = \dfrac{F}{m} = \dfrac{20\,000}{2.6 \times 10^3} = \mathbf{7.7\ ms^{-2}}$

2 How much force is experienced when a 50 kg man is subjected to 8 g of acceleration?

$m = 50$ kg $\quad a = 8 \times 9.8 = 78.4\ ms^{-2}$

$F = ma = 50 \times 78.4 = \mathbf{3920\ N}$

Weight

Weight is a force, and it is calculated by multiplying a mass by an acceleration (the acceleration due to gravity). Weight is a particular case of the Second Law of Motion.

Forces problems

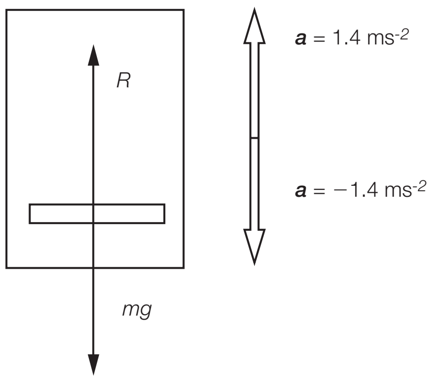
Problems involving unbalanced forces are treated the same way as problems with balanced forces except that the forces in the direction of motion now add to mass x acceleration rather than zero. Follow the steps below:

- Draw a diagram of the situation, with all forces drawn on it and labelled. Add a separate arrow for acceleration (*not* attached to object but next to it).
- Select axes – usually x horizontal and y vertical.
- Any force not parallel to one of the axes needs to be resolved into its component vectors.
- All forces in the vertical direction sum up to the mass × acceleration in that direction; remember + and − signs, depending on direction.
- All forces in the horizontal direction sum up to the mass × acceleration in that direction; remember + and − signs, depending on direction.
- Solve for any unknown values.

Example

A set of scales is placed in a lift that travels up to a weight-loss club. The lift accelerates at 1.4 ms^{-2} whether speeding up or slowing down in either direction. A person of mass 80 kg stands on the scales. Calculate:

a. The reading on the scales when the lift is stationary
b. The reading on the scales when the lift is accelerating upwards at 1.4 ms^{-2}
c. The reading on the scales when the lift is accelerating downwards at 1.4 ms^{-2}
d. The reading on the scales when the lift is travelling at a constant velocity



a. When stationary, forces sum up to zero: $R - mg = 0$
$R = mg = 80 \times 9.8 =$ **784 N**
b. Accelerating upwards so $a = +1.4$ ms^{-2}; forces sum up to ma:
$R - mg = ma$; $R = ma + mg = 80 \times 1.4 + 80 \times 9.8 =$ **896 N**
c. Accelerating downwards so $a = -1.4$ ms^{-2}; forces sum up to ma:
$R - mg = ma$;
$R = ma + mg = 80 \times (-1.4) + 80 \times 9.8 =$ **672 N**
d. When travelling at a constant velocity, forces sum up to zero:
$R - mg = 0$;
$R = mg = 80 \times 9.8 =$ **784 N**

Forces and Motion

Questions

$g = 9.8\ \text{ms}^{-2}$

1 State Newton's First Law of Motion.

2 Write an equation that represents Newton's Second Law of Motion.

3 Calculate the force required to accelerate a mass of 20 kg by 54 ms^{-2}.

4 Calculate the force required to accelerate a mass of 2 g by 890 ms^{-2}.

5 What mass accelerates at 4.7 ms^{-2} when a resultant force of 15 N is applied?

6 What mass accelerates at 205 ms^{-2} when a resultant force of 46 kN is applied?

7 What acceleration would a 50 g mass have if it were acted on by a resultant force of 80 N?

8 What acceleration would a 1000 kg mass have if it were acted on by a resultant force of 2.3 N?

9 A lift car of mass 1200 kg accelerates at 2 ms^{-2} when speeding up or slowing down. Calculate the tension in the lift cable when the lift is:

a. at rest
b. accelerating upwards
c. accelerating downwards

Taking it Further

The ideas discussed and used here are essential for understanding mechanics and motion.

Now use this space to make more in-depth notes about forces and motion. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is Newton's First Law of Motion?*

⇒ *What is Newton's Second Law of Motion?*

⇒ *How is mass related to weight?*

⇒ *How can acceleration explain weightlessness in orbit?*

⇒ *What is the value of the acceleration due to gravity on the surface of other planets?*

⇒ *How does acceleration due to gravity on the surface of a planet vary with mass and radius of the planet?*

GCSE

You will have covered different forms or types of energy. You will have calculated kinetic and gravitational potential energy. You should be able to identify energy transfers in various simple situations, describe energy resources used to produce electricity, and state what energy conservation is.

A-level

You need to be able to calculate the work done by a force moving over a distance and to solve related problems. Other calculations for energy are used throughout physics.

You need to be able to interpret power as energy per second, and solve problems involving power and energy as well as practical problems.

Energy

Energy is the currency of change. Differences in energy can cause energy to flow. If energy flows, things tend to happen. A store of chemical energy can be converted into sound, light, heat and motion, for example when a firework ignites.

Forms of energy

You may remember different types of energy from GCSE. These categories are defined in terms of equations that allow their values to be calculated. For example:

gravitational potential energy (GPE) $= mg\Delta h$

kinetic energy (KE) $= \frac{1}{2}mv^2$

Other types of energy include **chemical potential energy** and **elastic potential energy**.

These types of energy fall into two groups: energy due to motion and stored (potential) energy.

Energy is measured in **joules**. 1 joule is the energy needed to lift a 100 g mass through 1 m.

'**Work done**' is energy (mechanical energy). This is energy transferred to, or from, an object due to forces moving in the direction of the force.

We can calculate work done using the equation: $W = Fd$

work = force × distance (distance moved in direction of the force)

If a distance is travelled in the same direction as the force, the force is doing work: for example, a stone falling through a height. If a distance is travelled in the opposite direction of a force, work is done on the force: for example, a stone being lifted through a height.

If a force is at right angles to motion no work is done by the force. This is the case with planets in orbit. The force of gravity always points towards the sun, and planets move in an ellipse at 90 degrees to the line between them and the sun.

Examples of energy calculations

A cart is pulled with a horizontal force of 48 N. If the cart moves a distance of 3.52 m, how much work has been done?

Energy and Power

work = force × distance moved in direction of the force

$$W = Fd = 48 \times 3.52 = \mathbf{169\ J}$$

Conservation of energy

Energy cannot be created or destroyed, only transferred from one form to another.

If all forms of energy are considered, the sum total of energy before and after an event is the same.

Power

Power is the rate of transfer of energy. The unit of power is the **watt** (W). 1 watt = 1 joule per second.

A more powerful light bulb converts more energy per second into light than a less powerful bulb. A more powerful car engine transfers energy from the fuel, into acceleration of the car, more quickly than a less powerful one.

Bad physics joke! *What* is the unit of power? (This is said as a *question* but meant as a *statement – replace What with Watt*. For full effect simply repeat every time someone gets the answer wrong.)

Examples of power calculations

A sack weighing 400 N is lifted through a vertical distance of 7.1 m in 8 seconds by an electric motor. Calculate the average power of the motor.

Power is energy per second, so first calculate work using $W = Fd = 400 \times 7.1 = 2840$ J

$$\text{power } P = \frac{W}{t} = \frac{2840}{8} = \mathbf{355\ W}$$

Questions

Write down what you know and put in correct units; select an equation that relates what you know with what you want to know; rearrange if required; substitute values into the equation and solve. Include correct unit.

1 Write the equation for work done.

2 Write the equation for power.

3 What unit is energy measured in?

4 What is the unit of power?

5 Explain the meaning of energy conservation.

6 A force of 15 N is moved through a distance of 2.6 m. How much energy is transferred?

7 A force of 7.4 kN is moved through a distance of 32 km. How much energy is transferred?

8 A force of 250 N is moved through a distance of 20 mm. How much energy is transferred?

9 How far does a 500 N force need to move in order to do 125 J of work?

10 How far does an 84 N force need to move in order to do 6.9 kJ of work?

11 If 4.2 kJ of energy is transferred in 24 seconds by a heater, what is its power?

12 If 5.52 J of energy is transferred in 0.25 seconds by a computer chip, what is its power?

13 If a 50 N force is moved through a distance of 120 m in 20 seconds by a motor, what is the motor's power?

14 If a 9.3 kN force is moved through a distance of 286 km in 3 hours by a motor, what is the motor's power?

15 How much energy is transferred by a 200 W motor in 2 minutes?

16 How much energy is transferred by a 2 kW heater in 160 minutes?

17 How long does it take a 3.0 kW kettle to transfer 1.4 MJ of energy?

18 How long does it take an 11 W light bulb to transfer 8.5 kJ of energy?

Taking it Further

The ideas discussed and used here are applied in almost all areas of physics. Energy is a key concept in physics.

Now use this space to make more in-depth notes about energy and power. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

- ⇒ *What is energy?*
- ⇒ *How is energy calculated?*
- ⇒ *How is power calculated?*
- ⇒ *What is the meaning of energy conservation?*
- ⇒ *How is electricity produced from other sources of energy?*

You can extend your notes and understanding by trying to find answers to the following questions:

- ⇒ *Fusion: Is it a clean, limitless energy source?*
- ⇒ *How could you calculate the power output of the sun using Earth's surface-light intensity?*
- ⇒ *Concentrated energy and mass: are they 2 sides of the same coin?*
- ⇒ *What is the original 'source' of energy?*

Kinetic Energy and Gravitational Potential Energy

GCSE

You will have covered kinetic energy and gravitational potential energy.

You should have completed simple calculations involving gravitational potential energy and kinetic energy.

A-level

You need to be able to describe, and calculate, the energy transfers involved when objects move through a vertical height. Energy transfer can provide an alternative to equations of motion when solving problems.

Kinetic energy

Kinetic energy is the energy of a moving object. It takes energy to start an object moving or to stop an object moving. Energy is stored in an object's motion and depends on the object's **mass** and **velocity**.

The faster an object, the more kinetic energy it has; the more massive an object, the more kinetic energy it has.

For an object of mass m and velocity v:

$$\textit{Kinetic energy } (KE) = \frac{1}{2}mv^2$$

The unit for kinetic energy is joules (J).

Example

A stone with a mass of 0.4 kg travels at a speed of 8 ms^{-1}.

What is its kinetic energy?

$$KE = \frac{1}{2}mv^2 = 0.5 \times 0.4 \times 8^2 = \mathbf{12.8\ J}$$

Gravitational potential energy

Gravitational potential energy is the energy stored in an object due to the object's position in a **gravitational field**.

Energy is required to lift an object. That energy is then stored in the object and released as kinetic energy when the object falls. The amount of energy stored depends on the mass m of the object, the strength of the gravitational field g and the height through which the object moves Δh. *Remember this triangle 'delta' means 'change in'*.

gravitational potential energy (GPE) = $mg\Delta h$

Example

A kangaroo of mass 40 kg jumps to a height of 1.8 m.

What is its gravitational potential energy? (g = 9.8 ms^{-2})

$$\text{GPE} = mg\Delta h = 40 \times 9.8 \times 1.8 = \mathbf{706\ J}$$

The formula for gravitational potential energy is only valid near the surface of the earth (within 100 km). This is because the value of g varies with large distances from the surface of the earth.

Solving problems involving kinetic and gravitational potential energy

When an object falls, the gravitational potential energy is converted into other forms of energy. Ignoring air resistance, all of the energy is converted into kinetic energy. Knowing the gravitational potential energy on an object at the top of its fall enables calculation of the kinetic energy at the bottom of the fall, and hence velocity can be calculated. Some such problems can also be solved using the equations of motion (see Topic Builder 27: Equations of Motion).

Example 1

A roller coaster reaches a maximum height of 32 m before rolling downhill and reaching maximum speed at ground level. If all the cars' gravitational potential energy is converted into kinetic energy, calculate the maximum speed of the roller coaster.

The kinetic energy comes from the gravitational potential energy at the top.

We don't know the mass of the roller coaster cars, but we know that

GPE at start = KE at end

So $mg\Delta h = \frac{1}{2}mv^2$ in which case the mass, m, cancels and we can rearrange the equation to give

$$v = \sqrt{2g\Delta h} = \sqrt{2 \times 9.8 \times 32} = \mathbf{25\ ms^{-1}}$$

Example 2

A ball of mass 50 g is thrown vertically upwards with a velocity of 5 ms^{-1} ($g = 9.8\ ms^{-2}$).

a. Calculate the kinetic energy at the start of the throw.
b. Calculate the gravitational potential energy at the maximum height.
c. Calculate the height reached.

$m = 50\ g = 0.05\ kg$ $\quad v = 5\ ms^{-1}$ $\quad g = 9.8\ ms^{-2}$

a. $KE = \frac{1}{2}mv^2 = 0.5 \times 0.05 \times 5^2 = \mathbf{0.625\ J}$

b. At maximum height all the kinetic energy has been converted to gravitational potential energy, so GPE at the top equals kinetic energy at the bottom.
GPE = **0.625 J**

c. $\Delta h = \frac{(GPE)}{mg} = \frac{0.625}{0.05 \times 9.8} = \mathbf{1.28\ m}$

Kinetic Energy and Gravitational Potential Energy

Questions

For all questions, assume that $g = 9.8\ ms^{-2}$. You can ignore air resistance.

1 Write the equation for kinetic energy.

2 List and name the variables in the above equation.

3 Write the equation for gravitational potential energy.

4 List and name the variables in the equation.

5 A sack of potatoes with a mass of 12.0 kg is lifted through a vertical height of 84 cm. How much energy is required to lift it?

6 An asteroid with a mass of 5.0×10^6 kg has a velocity of 11.2 kms^{-1}. Calculate its kinetic energy.

7 A 100 g ball is thrown vertically into the air, with a velocity of 4 ms^{-1}. What is the maximum height it can reach? (Ignore air resistance.)

8 A roof tile with a mass of 1.2 kg falls from a height of 5.2 m. What is its velocity on impact with the ground?

9 A rubber ball loses 10% of its energy after every bounce. If its mass is 120 g and it is dropped from a height of 2 m, calculate:

a. Its initial gravitational potential energy.
b. Its velocity when it first impacts with the ground.
c. Its maximum height after the first bounce.
d. The velocity it had immediately after the first bounce.

10 To practice landing a parachute jump, trainees jump from a short height that reproduces the velocity on landing. Calculate the height needed for a landing velocity of 6 ms^{-1}.

Taking it Further

The ideas discussed and used here are useful in many mechanics problems.

Now use this space to make more in-depth notes about kinetic energy and gravitational potential energy. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is kinetic energy?*

⇒ *What is gravitational potential energy?*

⇒ *What is the equation for kinetic energy?*

⇒ *What is the equation for gravitational potential energy?*

⇒ *Why can velocity of impact from a height above the ground be found even if the mass of the object is not known?*

GCSE

You will have covered examples of transverse and longitudinal waves and be familiar with waves transferring energy and information.

A-level

You will need to be able to explain the difference between transverse and longitudinal waves.

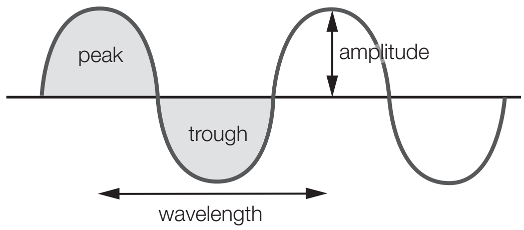
You will need to be able to calculate wavelength and frequency for various kinds of waves. Diffraction and interference will also be covered.

What is a wave?

A wave is something that transfers energy without transferring mass.

What are transverse waves?

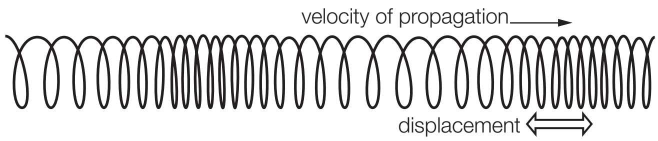
Transverse waves are the waves we all picture when thinking of a wave. Examples include: water waves, waves on a rope, and electromagnetic waves such as light and radio waves.



In transverse waves, **vibration** occurs at right angles to the direction of motion of the wave.

What are longitudinal waves?

Longitudinal waves are more difficult to picture. You may see a demonstration using a 'slinky spring': they are the compression waves in a slinky. Sound waves are longitudinal waves, as are seismic P waves.



In longitudinal waves, **vibration** occurs in the direction of the motion of the wave.

What features of waves should I know?

Differences between waves are described using various properties of waves:

Wavelength (λ): the length of one whole wave. Unit: **metre** (m).

Frequency (*f*): the number of waves passing a fixed point in one second. Unit: **hertz** (Hz).

Amplitude (*A*): the maximum **displacement** of the wave. Unit: **metre** (or, depending on the type of wave, this can be other quantities such as voltage, pressure, electric field strength etc.).

Time period (*T*): the time it takes for one complete wave. Unit: **second** (s).

Time period and frequency are related as follows $\text{Time Period} = \dfrac{1}{\text{frequency}}$ $\quad T = \dfrac{1}{f}$

This also means that 1 Hz = 1 s^{-1}.

Waves

What properties do waves have?

All waves have certain properties:

Reflection: 'bouncing' off of surfaces, mirrors for example.

Refraction: changing direction when entering materials in which the speed of the wave is different.

Diffraction: bending around objects or through gaps.

Interference: waves interfering with other waves to produce **interference** patterns.

Polarisation (only transverse waves): transverse waves can have different planes of **oscillation**, up–down or left–right or any other angle, as long as it is at 90 degrees to the direction of motion. Longitudinal waves can only oscillate in one direction.

What is the wave equation?

The speed of a wave (c) = wavelength (λ) x frequency (f) $c = \lambda f$

Units: speed ms^{-1};   wavelength m;   frequency Hz

This is known as the **wave equation**. When dealing with **electromagnetic** waves, remember that the speed is the constant in a given material and in a vacuum c = speed of light (3×10^8 ms^{-1}), but the speed of other waves will be different.

Example

What is the frequency of a light wave with wavelength 660 nm? Speed of light in a vacuum $c = 3 \times 10^8$ ms^{-1}.

$\lambda = 660$ nm $= 660 \times 10^{-9}$ m $c = 3 \times 10^8$ ms^{-1} $f = ?$

$c = \lambda f$; rearrange for f: $f = \dfrac{c}{\lambda} = \dfrac{3 \times 10^8}{660 \times 10^{-9}} = \mathbf{4.5 \times 10^{14}}$ **Hz**

Questions

$c = 3 \times 10^8\ ms^{-1}$ for speed of electromagnetic radiation in a vacuum.

1 Give an example of a longitudinal wave.

2 Give two examples of transverse waves.

3 Explain the difference between transverse waves and longitudinal waves.

4 Explain the meaning of:

a. wavelength

b. frequency

c. amplitude

d. time period

5 List three properties *all* waves have.

6 What is the speed of a water wave with a wavelength of 3.2 m and a frequency of 0.4 Hz?

7 What is the speed of a sound wave that has a frequency of 256 Hz and a wavelength of 1.29 m?

8 What is the wavelength of a radio wave that has a frequency of 102 MHz?

9 Calculate the frequency of an x-ray with a wavelength of 0.05 nm.

10 What is the time period of a light wave with a wavelength of 500 nm?

Taking it Further

The ideas discussed and used here are essential for the study of all wave phenomena.

Now use this space to make more in-depth notes about waves. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is a wave?*

⇒ *What are the two types of wave and how do they differ?*

⇒ *What properties do all waves have?*

⇒ *What is the wave equation and what does each term stand for?*

⇒ *How do different wavelengths of electromagnetic radiation give us different information about distant objects?*

32

The Photon

Topic Builders

GCSE

You will be familiar with light as a wave, and with regions of the electromagnetic spectrum.

A-level

You will need to know about light as a particle: the photon. You will calculate photon energy, frequency and wavelength. You will need to know wavelengths of regions of the electromagnetic (EM) spectrum.

What is a photon?

A photon is a **quantum** of electromagnetic energy: a packet, or lump, of electromagnetic energy. It is the smallest amount of electromagnetic radiation you can have. Experiments involving the photoelectric effect were the first to show that light can behave like a particle (a photon).

A light source gives off billions and billions of photons every second. You see light when receptors in your retina absorb a few photons and they are detected and 'seen'. Most light sources give off a range of frequencies (colours). A monochromatic source gives off only one wavelength.

Electromagnetic radiation covers all wavelengths, from radio waves with wavelengths over 1 m (with no limit!) right down to gamma rays with wavelengths below the size of a nucleus.

The wavelength boundaries of regions of the electromagnetic spectrum

region	radio	micro	infrared	visible	ultraviolet	x-rays	gamma rays
wavelength	> 0.1 m	0.1 m – 0.1 mm	0.1 mm – 700 nm	700 nm – 400 nm	400 nm – 1 nm	1 nm – 0.01 nm	< 10^{-11} m

Do all photons have the same energy?

The energy carried by these tiny packets of electromagnetic energy depends on their frequency. Some photons, such as gamma ray photons, carry relatively large energies. Radio photons carry very small amounts of energy.

The energy (E) of a photon is proportional to the frequency (f) of the photon. $E \propto f$

The constant of proportionality is **Planck's constant h = 6.6 × 10^{-34} Js**

$E = hf$

This equation describes the energy carried by a photon of electromagnetic energy. It was a founding idea of quantum theory.

Since the frequency of electromagnetic energy is related to its wavelength by the equation $c = \lambda f$,

– where c = speed of light (3×10^8 ms^{-1}), f = frequency (Hz) and λ = wavelength (m),

– we can substitute for f in the energy equation to give

$$E = \frac{hc}{\lambda}$$

Using this equation saves the additional step of calculating frequency from wavelength first.

If the energy of each photon is known and the number of photons leaving a lamp per second are known, then the power or energy per second output by the lamp can be calculated.

Total energy = photon energy × number of photons

Total power = total energy per second = photon energy × number of photons per second

Examples (use h = 6.6 × 10⁻³⁴ Js and c = 3 × 10⁸ ms⁻¹)

1 What is the energy of a photon with a frequency of 3.22×10^{15} Hz?

We know: frequency $f = 3.22 \times 10^{15}$ Hz; Planck's constant $h = 6.6 \times 10^{-34}$ J.s

We want: energy E using $E = hf$ (*no need to rearrange*)

Calculation: $E = hf = 6.6 \times 10^{-34} \times 3.22 \times 10^{15} = \mathbf{2.13 \times 10^{-18}\ J}$

2 What is the energy of a photon of wavelength 702 nm?

We know: wavelength $\lambda = 702$ nm $= 702 \times 10^{-9}$ m;
Planck's constant $h = 6.6 \times 10^{-34}$ Js; speed of light $c = 3.0 \times 10^{8}$ ms^{-1}

We want: energy E using $E = \frac{hc}{\lambda}$ (*no need to rearrange*)

Calculation: $E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{702 \times 10^{-9}} = \mathbf{2.82 \times 10^{-19}\ J}$

3 A lamp has a power output of 11 W. If the lamp only emits a single wavelength of 584 nm, how many photons per second leave the lamp?

We know: wavelength $\lambda = 584$ nm $= 584 \times 10^{-9}$ m; power $P = 11$ W = 11 joules per second

First find the energy of a photon E using $E = \frac{hc}{\lambda}$ (*no need to rearrange*)

Calculation: $E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{584 \times 10^{-9}} = \mathbf{3.39 \times 10^{-19}\ J}$

For 11 W we need 11 joules per second. So the number of photons per second = the number of photons of energy 3.39×10^{-19} J in 11 joules of energy.

$$\textit{Number of photons per second} = \frac{\textit{energy per second}}{\textit{energy of Photon}} = \frac{11}{3.39 \times 10^{-19}}$$
$$= \mathbf{3.24 \times 10^{19}\ photons\ per\ second}$$

The Photon

Questions

1 Calculate the energy of photons of the following frequency:

a. 4.5×10^{15} Hz
b. 7.8×10^{12} Hz
c. 1.03×10^{7} Hz
d. 5.7×10^{15} Hz

Write down what you know and put in the correct units; select an equation that relates what you know with what you want to know; rearrange if required; substitute into equation and solve. Include correct units.

2 Calculate the energy of photons of the following wavelength:

a. 660 nm
b. 7.1×10^{-9} m
c. 3.7×10^{-5} m
d. 4.4×10^{-15} m

3 Calculate the frequency of photons of the following energy:

a. 3.2×10^{-19} J
b. 9.11×10^{-20} J
c. 1.03×10^{-18} J
d. $7.45 \text{ x } 10^{-18}$ J

4 Calculate the wavelength of photons of the following energy:

a. 9.5×10^{-17} J
b. 4.23×10^{-20} J
c. 6.66×10^{-18} J
d. 1.07×10^{-12} J

5 Name the region of the electromagnetic spectrum each photon in Question 4 belongs to.

6 An LED has a power output of 0.60 W. If the LED only emits a single wavelength of 682 nm, how many photons per second leave the lamp?

7 A bulb has a power output of 24 W. If the bulb gives off monochromatic light of wavelength 512 nm, how many photons per second leave the lamp?

8 A star has a power output of 3.8×10^{26} W. If the average photon wavelength is 660 nm, what is the number of photons per second given off by the star?

Taking it Further

The ideas discussed and used here were part of the development of quantum theory. Quantum theory is the most accurate theory devised so far to describe the weird world of subatomic particles and atoms.

Now use this space to make more in-depth notes about photons. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What are the regions of the electromagnetic spectrum?*

⇒ *What is a photon?*

⇒ *How is photon energy related to frequency?*

⇒ *What is Planck's constant?*

⇒ *What is the speed of light? Can it be changed?*

⇒ *How do lasers work?*

⇒ *What are lasers used for?*

GCSE

You will have covered the structure of atoms and the properties of electrons.

The nature of light as a wave will also have been discussed.

A-level

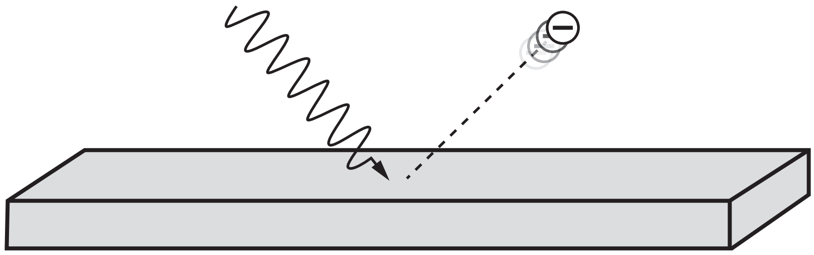
You need to be able to apply ideas of photons of light to explain the photoelectric effect.

Calculations of photon energy, electron energy and work function are required, along with discussion on the importance of evidence regarding wave-particle duality.

What is the photoelectric effect?

The photoelectric effect is the name given to the **photoemission** of electrons from the surface of a metal when the metal is **illuminated** with light of high enough frequency.

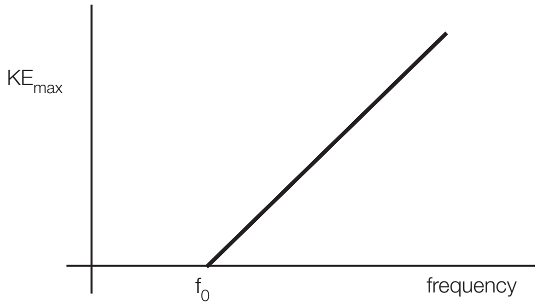
Metals have a 'sea' of free electrons. These **delocalised electrons** are able to move through the solid. If these electrons receive enough energy, they can escape the metal's surface. This can only be observed in a vacuum with a fresh metal surface (reactions of gas atoms with the surface can stop electrons escaping).



In the photoelectric effect, electromagnetic energy (light) is shone on to the metal surface to give electrons the energy required to escape.

What is threshold frequency?

The threshold frequency of a metal is the minimum frequency of light that will cause electrons to be emitted from the metal surface. Threshold frequency has the symbol f_0.



A graph of frequency of light plotted against kinetic energy of the emitted electrons gives a straight line graph, with a gradient equal to **Planck's constant**, *h*. Different metals would produce lines parallel to this (the gradient will still be equal to *h*), but with different values of threshold frequency.

What is work function?

This is an amount of energy equal to the minimum energy required to remove an electron from the metal surface. The work function is different for each metal. Work function has the symbol ϕ.

What is the maximum kinetic energy of emitted electrons?

Energy provided by a **photon** of light enables an electron to escape; the more energy this electron is given, the more kinetic energy it will have on escape.

Electrons exist on, and below, the surface of the metal. All of them can absorb energy from photons of light. Those at the surface escape if they receive **at least** the work function in energy from the photon of light. Some beneath the surface will need additional energy to get to the surface, as well as the energy needed to escape.

What is wave-particle duality?

Explaining the photoelectric effect using the 'wave model' of light generates problems. A wave of any frequency should be able to transfer enough energy to an electron to allow it to eventually escape the metal surface. However, light with a frequency below the threshold frequency, even from a brighter source, **does not** liberate electrons from the surface, no matter how long you wait. Also, the fact that there is no time delay, i.e. the energy is transferred instantly once the light hits the surface, is evidence of energy being transferred by the light in one go, as photons. Therefore, the photoelectric effect can only be fully explained if light behaves as a particle when it interacts with electrons. (See Topic Builder 34: Wave-particle Duality.)

A particle of light is called a **photon**. It is the smallest amount of energy that light of a particular frequency can have. The photon is the smallest packet or '**quantum**' of light energy.

The energy, E, of a photon of light is equal to the frequency f times Planck's constant h.

$E = hf$

(See Topic Builder 32: The Photon for more on this.)

What is the photoelectric equation?

This is really a statement of energy conservation.

photon energy (hf) = work function (ϕ) + maximum kinetic energy of emitted electrons ($E_{k\,max}$).

$hf = \phi + E_{k\,max}$

When the minimum kinetic energy is zero, the minimum photon energy equals the work function.

$hf_0 = \phi$

In problems, energy can be given in joules or electron volts (1 eV = 1.6×10^{-19} J).

Example

1 The minimum frequency of light that causes the photoemission of electrons from a metal is 2.6×10^{15} Hz.

a. What is the work function of the metal?
b. If a photon of frequency 3.6×10^{15} Hz is **incident** (i.e. the ray coming from the light source) on the metal surface, what is the maximum kinetic energy of emitted electrons?

a. Work function is equal to the energy of a photon with the threshold frequency.
$f_0 = 2.6 \times 10^{15}$ Hz
$\phi = hf_0 = 6.6 \times 10^{-34} \times 2.6 \times 10^{15} = \mathbf{1.72 \times 10^{-18}\ J}$
b. $f = 3.6 \times 10^{15}$ Hz
$hf = \phi + E_{k\,max}$ so $E_{k\,max} = hf - \phi$

$= 6.6 \times 10^{-34} \times 3.6 \times 10^{15} - 1.72 \times 10^{-18} = \mathbf{6.56 \times 10^{-19}\ J}$

The Photoelectric Effect

Questions

Planck's constant $h = 6.6 \times 10^{-34}$ Js

1 Give the meaning of threshold frequency.

2 What is a photon?

3 Write the equation for the energy of a photon.

4 Explain the meaning of the work function of a metal.

5 Write down the photoelectric equation and name all of the terms within it.

6 Write an equation relating threshold frequency to work function.

7 If a metal has a work function of 3.2 eV, calculate the minimum frequency of light that will liberate electrons from the metal surface.

8 If a metal has a work function of 1.8×10^{-19} J, calculate the threshold frequency for the metal.

9 A photon of frequency 4.1×10^{15} Hz is incident on a metal surface with work function 8.7 eV.

a. Calculate the photon energy.
b. Calculate the maximum kinetic energy of the emitted electrons.

10 A photon of frequency 6.8×10^{14} Hz is incident on a metal surface with work function 2.5 eV.

a. Calculate the photon energy.
b. Calculate the maximum kinetic energy of the emitted electrons.

Taking it Further

The ideas discussed and used here are the foundation of quantum theory.

Now use this space to make more in-depth notes about the photoelectric effect. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is a photon?*

⇒ *What is photoemission of electrons?*

⇒ *How are work function and threshold frequency related?*

⇒ *How does the energy of emitted electrons vary with frequency?*

⇒ *How does the number of emitted electrons vary with intensity of light?*

⇒ *How does the photoelectric effect show light behaving as a particle?*

⇒ *Where could the photoelectric effect have applications in everyday life?*

Wave-particle Duality

GCSE

You will have covered the structure of atoms and the properties of electrons. The nature of light as a wave will also have been discussed.

A-level

You need to be able to describe and explain the evidence of waves behaving as particles and particles behaving as waves.

You will need to use the de Broglie formula when calculating particle wavelengths.

What are waves?

Waves are ‘spread-out things’, waves occupy a region of space, waves are **non-localised**.

Waves transmit energy gradually without transmitting matter.

What are particles?

Particles are ‘lumpy things’, particles are located at a particular point in space, particles are **localised**.

Particles transmit energy in one go and involve the transmission of matter.

The properties of waves and particles appear to be very different on a very fundamental level. However, observations and experiments involving electrons and light led to the realisation that on the **quantum** scale of atoms and subatomic particles, waves, for example light, can behave as particles and particles, for example electrons, can behave as waves. This is called **wave-particle duality**.

How does light behave, and how do we know this?

Light can be shown to behave as a wave in various ‘wave’ experiments. These include **diffraction** and **interference**, which can only be produced by wave behaviour. Diffraction and interference patterns result from spread-out waves interacting with other waves and the environment they are in. It is this spread-out, non-localised feature that makes something ‘wavelike’. Light has been considered a wave for a long time, due to the observed results of ‘wave’ experiments such as the two slit experiment.

Light as a particle: the photoelectric effect

The photoelectric effect is the photoemission of electrons from metal surfaces when illuminated with light of various frequencies. This effect can only be fully explained if light behaves as a particle when it interacts with electrons. See Topic Builder 33: The Photoelectric Effect.

A particle of light is called a **photon**. It is the smallest amount of energy that light of a particular frequency can have.

How do electrons behave, and how do we know this?

Particles such as electrons and atoms are considered to be particles like small ball bearings. This simply seems the obvious (only?) way to think of small versions of big things with mass like footballs. Electrons are particles, as they have a mass and a charge, properties which have to carried by something tangible, i.e. ‘stuff’ or ‘matter’. You can easily count electrons using ammeters to measure electric current. In order to be counted they must be in a specific place: localised.

Wave behaviour of electrons: electron diffraction and electron interference

Electrons can be produced in a beam and fired at a graphite target in a vacuum chamber. A detector or screen on the other side of the target produces a pattern left by the electrons after they passed through the target. Careful observation shows a diffraction pattern of concentric rings is produced. This diffraction pattern can only be produced by 'wave' behaviour. Hence this shows electrons behaving as waves.

A two-slit experiment using electrons can be carried out. This experiment repeats the two-slit interference pattern obtained with waves, but using electrons (atoms or even molecules have also been used). This interference pattern can only be produced by 'wave' behaviour. It shows electrons behaving as waves.

What is the de Broglie equation?

The wavelength of a particle can be calculated using **de Broglie's** equation, shown below.

λ is wavelength, m is mass, v is the velocity of the particle and h is Planck's constant.

$$\lambda = \frac{h}{mv}$$

The wavelength of a particle is **inversely proportional** to mass × velocity (momentum) of the particle.

Example

Calculate the wavelength of an electron with a velocity of 2.0×10^{6} ms^{-1}.

Mass of electron = 9.11×10^{-31} kg; Planck's constant = 6.6×10^{-34} Js

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.0 \times 10^{6}} = \mathbf{3.6 \times 10^{-10}\ m}$$

This is a smaller wavelength than visible light. This is why electrons are used in electron microscopes to view objects smaller than can be seen with an optical microscope.

The more massive a particle, the smaller the wavelength of that particle. This is why we don't observe the wave behaviour of large objects.

Questions

mass of electron = 9.11×10^{-31} kg   mass of proton = 1.67×10^{-27} kg
Planck's constant = 6.6×10^{-34} Js

1 Describe wave behaviour.

2 Describe particle behaviour.

3 Give an example of an experiment that shows light behaving as a wave.

4 Give an example of an experiment that shows light behaving as a particle.

5 Give an example of an experiment that shows particles behaving as waves.

6 Calculate the wavelength of an electron with a velocity of 1.5×10^{7} ms^{-1}.

7 Calculate the wavelength of a proton with a velocity of 6.8×10^{6} ms^{-1}.

8 Calculate the wavelength of an electron with a kinetic energy of 3.2×10^{-19} J.

9 Calculate the wavelength of an electron with a kinetic energy of 2 keV.

10 Calculate the wavelength of a proton with a kinetic energy of 20 keV.

Taking it Further

The ideas discussed and used here are essential for understanding the Quantum World.

Now use this space to make more in-depth notes about wave particle duality. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What are particles?*

⇒ *What are waves?*

⇒ *What is wave-particle duality?*

⇒ *Which experiments show waves behaving as particles?*

⇒ *What experiment show particles behaving as waves?*

⇒ *What equation enables calculation of a particle's wavelength?*

⇒ *Why are wave properties of large objects not observed?*

GCSE

You will have covered the structure of atoms and the properties of electrons. Light as a wave will also have been discussed.

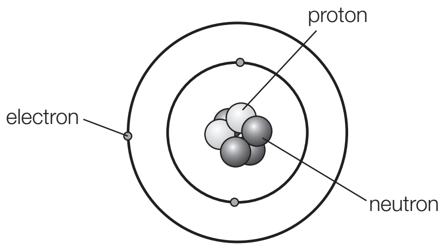
A-level

You will need to be able to interpret and draw energy level diagrams and use them to calculate energy changes.

You will need to be able to calculate the frequency and the wavelength of a photon with known energy, and vice versa.

What is the nuclear model of the atom?

This model tells us that a central dense nucleus is surrounded by orbiting electrons, in different energy levels, at different distances from the nucleus. As you learnt in chemistry, electrons can occupy different energy levels in an atom.



Electrons can only occupy certain discrete energy levels.

Only certain values of energy are allowed for the energy levels in a given atom. Evidence for these energy levels comes from the **line spectra** of glowing elements and their negatives in absorption line spectra. These spectra are unique to each element as they result from the unique arrangement of energy levels in each element.

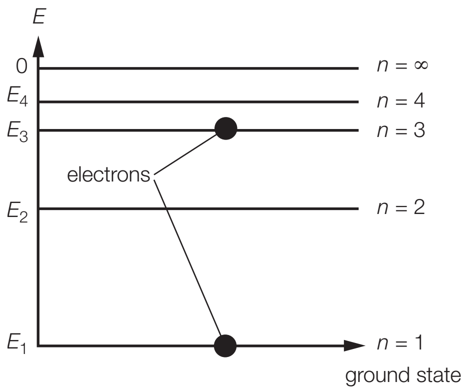
Hydrogen is the simplest atom, with only one proton and one electron. In physics we look in detail at the energy levels in a hydrogen atom and how electrons jumping between levels can produce, or absorb, a photon of light. The concepts discussed can be applied to all other elements, although the energy level diagrams become very complicated.

What is an energy level diagram?

An energy level diagram shows the relative 'position' of energy levels of electrons in atoms. Ground state: The lowest energy level is the one in which the electron is held most tightly by the force of attraction between the positive proton and the negative electron. This is the energy level nearest the nucleus. Energy levels are labelled with values of n, with $n = 1$ being the lowest energy level or **ground state**. In hydrogen, the electron will always return to the ground state as it loses energy.

An energy level diagram shows energy levels labelled from $n = 1$ to $n = \infty$ (we don't draw all of them!), where the $n = \infty$ level is the energy an electron needs to escape the atom. The energy difference between the $n = 1$ level and the $n = \infty$ level is the **ionisation energy** for a single hydrogen atom. The values of energy (E) for each level are often given as negative numbers, indicating how much energy is needed to return to zero.

Energy Levels



The spacing between levels always gets smaller as you increase the value of *n*. As there are an infinite number of energy levels closer and closer together in energy, only a few of the lower ones can be drawn.

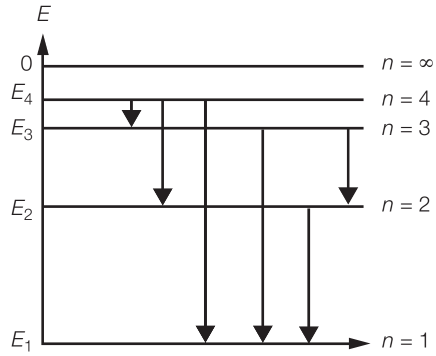
Each energy level can only hold a limited number of electrons, and electrons cannot be added to already filled energy levels.

What is a quantum jump?

Electrons jump between energy levels. This is a quantum jump, as they do not move from one level to the other; instead they disappear from one level and appear in the other.

To jump to a higher energy level (a higher value of *n*) requires energy. An electron can absorb energy equal to the energy difference between energy levels, enabling it to jump to a higher energy level. This energy can come from absorbing photons, collisions with other atoms due to heat, or collisions with other electrons due to electricity. Electrons spontaneously drop to lower energy levels if the lower levels are empty. When electrons drop to a lower energy level (a lower value of *n*), they emit energy in the form of a photon of light. The photon has energy equal to the energy difference between energy levels.

If an electron drops from $n = 2$ to $n = 1$ with a change in energy $\Delta \mathrm{E} = \mathrm{E}_2 - \mathrm{E}_1$ the photon carries away this energy, so: $\Delta E = E_2 - E_1 = hf$ where *h* is Planck's constant and *f* is frequency of the photon. In terms of wavelength, we can also write $\Delta E = E_2 - E_1 = \frac{hc}{\lambda}$ where λ is wavelength.



Electrons can drop down from high energy levels in various-sized steps, producing photons of different frequency (colour). This is how the emission spectra are formed, and since each element has a different set of allowed energy levels, emission spectra are unique to each element.

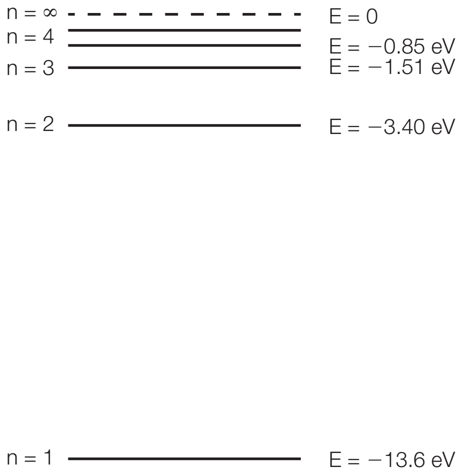
The value of energy for each level – E_1, E_2 etc. – can be given in joules or electron volts. Energy needs to be in joules for use in the formula.

To convert, use $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Example problem

A hydrogen atom's energy levels are shown in the diagram. Calculate the energy in joules of a photon emitted when an electron jumps from:

a) $n = 3$ to the ground state
b) $n = 2$ to $n = 1$
c) $n = 3$ to $n = 2$
d) calculate the frequency of each photon in a) to c)



a) ground state is $n = 1$ so $\Delta E = E_2 - E_1$

$= -1.51 - -13.6 = -1.51 + 13.6$
$= 12.09$ eV

Convert to joules: $\Delta E = 12.09 \times 1.6 \times 10^{-19}$
$= \mathbf{1.93 \times 10^{-18}\ J}$

b) $\Delta E = E_2 - E_1$

$= -3.40 - -13.6 = -3.40 + 13.6 = 10.2$ eV

Convert to joules: $\Delta E = 10.2 \times 1.6 \times 10^{-19}$
$= \mathbf{1.63 \times 10^{-18}\ J}$

c) $\Delta E = E_3 - E_2$

$= -1.51 - -3.4 = -1.51 + 3.4 = 1.89$ eV

Convert to joules: $1.89 \times 1.6 \times 10^{-19} = \mathbf{3.02 \times 10^{-19}\ J}$

d) $\Delta E = hf$ so $f = \dfrac{\Delta E}{h} = \dfrac{1.93 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{2.93 \times 10^{15}\ Hz}$ ($n = 3$ to $n = 1$)

$f = \dfrac{\Delta E}{h} = \dfrac{1.93 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{2.47 \times 10^{15}\ Hz}$ ($n = 2$ to $n = 1$)

$f = \dfrac{\Delta E}{h} = \dfrac{1.93 \times 10^{-18}}{6.6 \times 10^{-34}} = \mathbf{4.58 \times 10^{14}\ Hz}$ ($n = 3$ to $n = 2$)

Questions

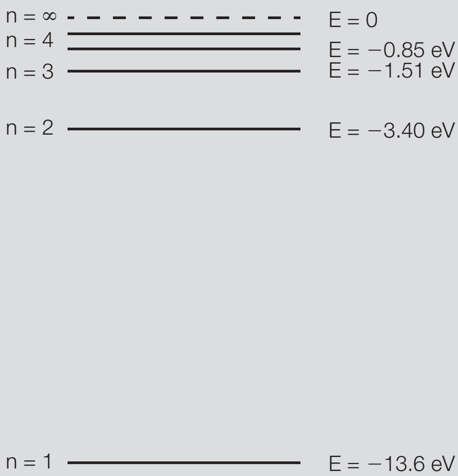
$c = 3 \times 10^8\ ms^{-1}$ $\quad h = 6.6 \times 10^{-34}$ Js $\quad 1$ eV $= 1.6 \times 10^{-19}$ J

1 Energy levels are numbered $n = 1$, $n = 2$ etc. What is the number of the energy level closest to the nucleus?

2 Which level is also called the ground state?

3 What happens to electrons given more energy than the highest energy level?

4 Use the diagram of the energy levels of hydrogen to answer the following questions:



a. What is the ionisation energy of a hydrogen atom?
b. Which transition between energy levels (1, 2, 3 and 4) gives a photon with the largest frequency?
c. Which transition between energy levels (1, 2, 3 and 4) gives a photon with the largest wavelength?
d. Calculate the energy in joules of a photon emitted when an electron jumps from $n = 4$ to $n = 2$.

e. Calculate the frequency of a photon produced when an electron jumps from $n = 4$ to $n = 3$.
f. Calculate the wavelength of a photon produced when an electron jumps from $n = 4$ to $n = 3$.
g. How many different kinds of photons might be produced by an electron in the $n = 3$ level returning to the ground state?
h. An electron in the ground state absorbs energy from a photon equal to 12.09 eV. What are the possible frequencies of the emitted photons as the electron returns to the ground state?

Taking it Further

The ideas discussed and used here are essential in understanding the interaction of light and matter.

Now use this space to make more in-depth notes about energy levels. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is the nuclear model of the atom?*

⇒ *What does the term 'discrete energy levels' mean?*

⇒ *What is an energy level diagram?*

⇒ *What is the ground state?*

⇒ *How do electrons move to higher energy levels?*

⇒ *What happens as electrons lose energy and drop to lower energy levels?*

⇒ *How do energy levels explain the observation of atomic line spectra?*

⇒ *How do absorption line spectra connect to emission spectra?*

You can extend your notes and understanding by trying to find answers to the following questions;

⇒ *How can you tell what stars are made of?*

⇒ *How does a laser work?*

The Young Modulus

GCSE

You will have covered the extension of simple springs and related this to Hooke's Law. You are likely to have carried out practical investigations into stretching springs, and to have plotted graphs to show that force is proportional to extension.

A-level

You need to be able to accurately measure the extension of a wire and analyse results, to determine the Young modulus of a material.

You need to be able to define stress and strain and relate these to the Young modulus, and solve problems involving the Young modulus.

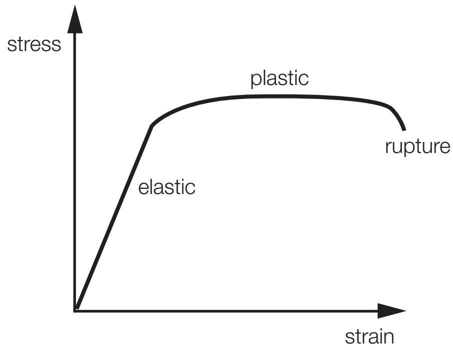
What should I recall about Hooke's Law?

The more force on a spring, the larger the extension.

This is true up to the limit of **proportionality** (*the end of the straight line*), and is where Hooke's Law holds.

$F = k\,\Delta L$

A graph of force against extension has the same shape as a graph of **stress** against **strain**. The straight-line region is where Hooke's Law applies, and the behaviour is described as **elastic deformation**.



The gradient of the elastic region on a stress-strain graph is equal to the Young modulus.

A stiff material has a steeper gradient than a more flexible material.

Stress

Stress is defined as the force per unit cross-sectional area.

$Stress = \dfrac{Force}{cross\ sectional\ area} = \dfrac{F}{A}$;   unit: $\mathrm{Nm^{-2}}$ or Pa (pascal; 1 Pa = 1 $\mathrm{Nm^{-2}}$)

The larger the cross-sectional area of a structure, the more spread out any force is, and the lower the stress.

Strain

Strain is defined as the change in length divided by the original length.

$Strain = \dfrac{change\ in\ length}{original\ length} = \dfrac{\Delta L}{L}$;   no unit (!) (m / m so cancel)

The larger the change in length (when under tension), the larger the strain.

Young modulus

The Young modulus of a material is the ratio of stress to strain.

$Young\ modulus = \dfrac{Stress}{Strain} = \dfrac{FL}{\Delta LA}$;   unit: $\mathrm{Nm^{-2}}$ or Pa (pascal; 1 Pa = 1 $\mathrm{Nm^{-2}}$)

The Young Modulus

The Young modulus of a material enables calculation of various quantities relating to stretch and the ability to take forces without breaking, for any sample of the material.

To measure the Young modulus of a wire, the diameter must be accurately measured with a **micrometer**. A known length of wire is stretched using a known force, and the change in length is measured.

A graph of **force** against **change in length** allows a gradient of $F / \Delta L$ to be determined. By combining the gradient with the measured original length, L, and the calculated cross-sectional area, A, from the measured diameter, a value for the Young modulus can be obtained.

$$\text{gradient} = \frac{FL}{\Delta L} \qquad \text{gradient} \times \frac{L}{A} = \frac{FL}{\Delta LA} = \text{Young modulus}$$

Problems involving the Young modulus of a material are usually an exercise in careful substitution of values into a few formulae. Area often needs to be worked out from a diameter, and care must be taken with units.

Questions

1 Write the equation for stress.

2 What is the unit for stress?

3 Write the equation for strain.

4 What is the unit for strain?

5 Write the equation for the Young modulus.

6 What is the unit for the Young modulus?

7 What law holds until the **limit of proportionality** when stretching a material?

8 A force of 10 kN is applied to a steel cable of diameter 1.0 cm. What is the stress in the cable?

9 A force of 25 mN is applied to a hair of diameter 0.2 mm. What is the stress in the hair?

10 A steel cable of length 23 m is extended when under tension by 3.6 mm. What is the strain in the cable?

11 A hair of length 23 cm is extended when under tension by 4.2 mm. What is the strain in the hair?

12 The strain on a nylon string is 5.6×10^{-3} and its stress is 21 MPa. What is the Young modulus of the nylon string?

13 A cable holding up a lighting rig has a diameter of 3.0 mm and length of 1.5 m. If it extends by 1.0 mm when a weight of 500 N is applied to it, what is the Young modulus of the metal used for the wire?

14 The Young modulus of a natural rubber is 0.05 GPa. What increase in length would you obtain when a 650 N force is applied to a cord of diameter 1.0 cm and length 2.4 m?

15 Steel has a Young modulus of 200 GPa. What force is needed to extend a 4.6 m length by 1 cm if it has a diameter of 5 mm?

Taking it Further

The ideas discussed and used here are essential in any study of material properties and structural engineering.

Now use this space to make more in-depth notes about the Young modulus. Some questions have been suggested to help you structure your notes effectively. You may wish to also use your course textbook to add further information to your notes.

⇒ *What is Hooke's Law?*

⇒ *What is tensile stress?*

⇒ *What is compressive stress?*

⇒ *What is strain?*

⇒ *What is the Young modulus?*

⇒ *How are the above quantities calculated?*

⇒ *What does the Young modulus of a material depend on?*

⇒ *How does the Young modulus relate to structural properties of materials?*