HAMPSTEAD SCHOOL

Learning together Achieving together

Y12 – Y13

Summer Bridging Tasks

2023

A Level Physics

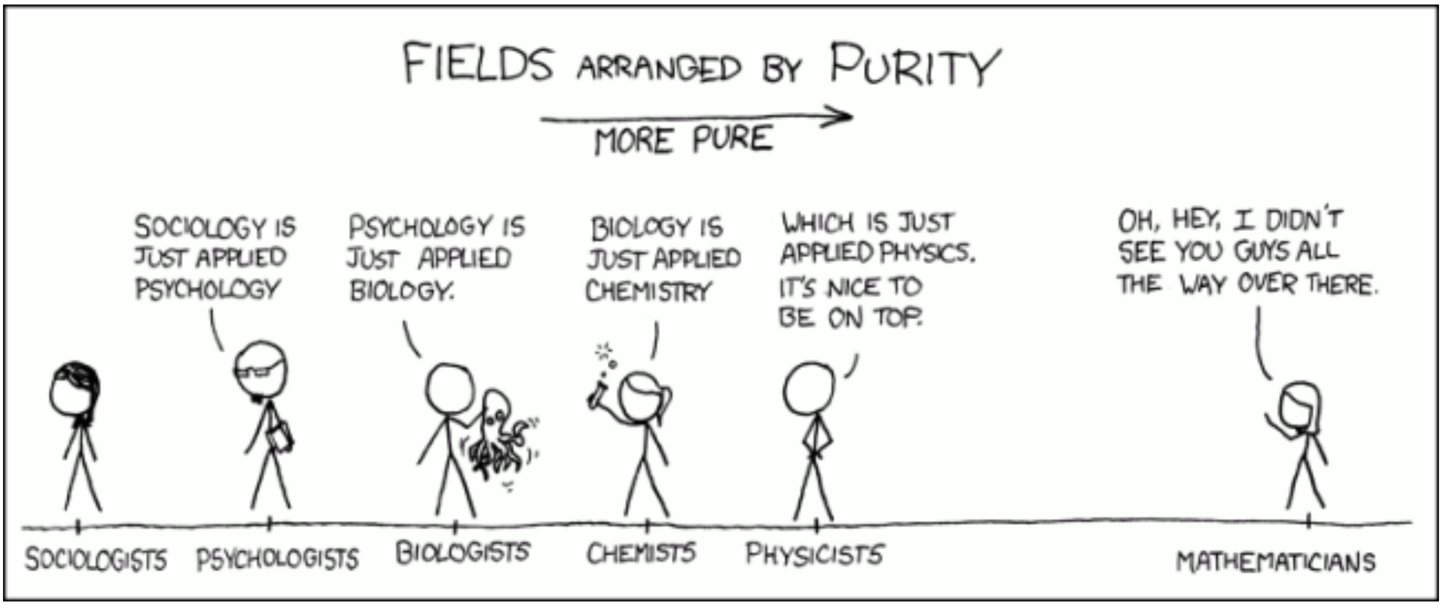
Name: ____

- You should spend some time during the summer holidays working on the activities in this booklet.
- You will be required to hand in this booklet in your first lesson at the start of Year 12 and the content will be used to form the basis of your first assessments.
- You should try your best and show commitment to your studies.

Name……………………

Physics

Bridging the Gap



Welcome to Physics!

This pack has been designed to help you bridge the gap from GCSE to AS Level to ensure that you understand what you've let yourself in for and that you are ready for your new course in September.

You will start by looking at the topics covered in Year 12 and 13 in the Physics OCR A course and give you an idea of how the course will be structured and what resources are available and when you will be doing tests, exams and practical assessments.

Then you will review what you already know and be given some work to do to make sure you're all ready to start in September to give yourself the best chance of success.

You will find this booklet and all resources described in this booklet on this website written specifically for this course.

www.jmurraysmith.wordpress.com

Requirements for studying A level Physics at Churston

You will already have been told about the minimum grades required in your GCSEs in order to keep studying Physics at A level. These grades were as follows;

- Physics (triple science) - 7
- Double science - 6,7
- Mathematics - 7

If for any reason you did not meet these requirements, don't fret, but just be aware that they have been set because Physics A level is a tough course. It is a huge jump from GCSE to A level and not only do we want you to enjoy it but we also want you to study for the two years and obtain a good grade at the end of it, that you will be happy with and will be useful to you!

The Mathematical content and difficulty is high and those students not taking A Level Maths will find the course more difficult, so please keep this in mind and be aware that you will need to keep up you Maths skills.

You must have a strong work ethic and lots of time available to study.

Benchmark Assessments

Within the first 2 weeks you will be assessed to see if you have the aptitude to carry on. The following assessments will assess your knowledge, understanding and practical skills:

1. Homework included in this booklet
2. Knowledge tests taken over the first 2 weeks
3. Practical skills test taken in lessons in the first 2 weeks

Y12 Physics – course outline

- Module 1 Development of Practical Skills
- Module 2 Foundations of Physics
- Module 3 Forces and Motion
- Module 4 Electrons, Waves and Photons

2 exam papers at the end of year 12 – can assess any content from modules 1 - 4

Y13 Physics – course outline

- Module 1 Development of Practical Skills continued
- Module 5 Newtonian World and Astrophysics
- Module 6 Particles and Medical Physics
- Modules 2,3 and 4 knowledge will be required and will essential for you to understand Modules 5 and 6.

3 exam papers at the end of year 13:

Paper 1 – modules 1, 2, 3, 5
Paper 2 – modules 1, 2, 4, 6
Paper 3 – any content modules 1 - 6

Your Physics A level grade is down to the 3 exams at the end of year 13.
The two end of year 12 exams will give you and us an idea of what you are capable of achieving and will also contribute heavily toward to UCAS predicted grade (are used when applying to university).

How hard is this physics course going to be?

Physics is one of the toughest but rewarding A Levels you could have chosen.
The students who work the hardest do the best.

Over the course you will have a little over 9 hours of lessons a fortnight that will cover all the theory and practical skills you will need.
You will be given homework questions nearly every lesson and these will be expected to be completed by the next lesson in most cases.

At A Level you are expected to be spending a minimum of 3 hours per week out of class completing homework, reviewing your work and reading around the subject.

In addition to the lessons you will receive, there is plenty of support available:

- Teachers: Your teacher is your first point of call as they are the experts – you will have 2 teachers who will always offer their time when they are available to help you in and out of lessons.
- Notes and differentiated questions: We have produced a full set of notes that accompany each lesson. These notes are targeted to the lesson objectives that we have written and have HW questions that tie into the learning outcomes. You will be expected to print these off or save them so they are easily accessible on your Chromebook, to organise these in a folder and add any extra notes that you write in or out of lessons and bring these along to lessons where we will check these periodically.

Website: The A level section of www.jmurraysmith.wordpress.com has been written specifically for the course you will be studying and has lessons, notes, questions, answers and links to other resources on the web.

Physics Clinic: The Physics clinic will run after school when needed and you are invited to come along with specific questions about physics. You will get help with homework or revision here so you aren't stuck at home for hours on something that somebody may be able to help you with in seconds. In the first term, these sessions will also specifically focus on the mathematical requirements of the course and deal with any issues regarding the practical skills assessments.

- Textbook: You will be given a textbook. It has notes, questions and revision tips and quizzes so make sure you.
- Revision Guides: We will order some revision guides in the Autumn term and we would encourage you to buy one.
- Revision Workbooks: We will order some revision workbook that coincide with the revision guide, in the Autumn term and we would encourage you to buy one of these too.
- Specification and past papers: Download the New OCR Physics A specification from: www.ocr.org.uk (H156 H556 – From 2015)

Do I need to be good at Maths?

The simple answer to this is yes.

The course includes difficult maths content and without a good grasp of this you will struggle to achieve a good grade at A Level Physics.

At A2 some more difficult maths is necessary to help explain concepts and analyse data but these skills will be developed as you study.

If you have chosen to do maths as one of your A level courses then you will have a massive advantage.

Bridging the Gap

Everything at A Level builds on your GCSE knowledge, skills and understanding and so you will first need to review everything you have done in Core and Additional GCSE.

Some of you have an advantage in that you have also done Triple science (further) Physics – it is recommended that you review this work.

For those of you that didn't do Further, it is seriously advised that you look over this content for the first time.

We will start with a 2 week Bridging Course to get everybody up to speed before we start the AS course. The course will revise some of your KS4 knowledge but it will mostly be developing new skills and understanding and culminates in an assessment that tests the content on the following pages and how quickly you pick up new information that you will be taught in these first 2 weeks.

Core Physics

Heat Transfer

Are you able…

- ❑ To evaluate ways in which heat is transferred in and out of bodies and ways in which the rates of these transfers can be reduced.

Do you understand…

- ❑ Thermal (infra red) radiation is the transfer of energy by electromagnetic waves.
- ❑ All bodies emit and absorb thermal radiation.
- ❑ The hotter a body is the more energy it radiates.
- ❑ Dark, matt surfaces are good absorbers and good emitters of radiation.
- ❑ Light, shiny surfaces are poor absorbers and poor emitters of radiation.
- ❑ The transfer of energy by conduction and convection involves particles and how this transfer takes place.
- ❑ Under similar conditions different materials transfer heat at different rates.
- ❑ The shape and dimensions of a body affect the rate at which it transfers heat.
- ❑ The bigger the temperature difference between a body and its surroundings, the faster the rate at which heat is transferred.

Energy efficiency

Are you able…

- ❑ To describe the intended energy transfers/transformations and the main energy wastages that occur with a range of devices
- ❑ To calculate the efficiency of a device using:
  $$\text{efficiency} = \frac{\text{useful energy transferred by the device}}{\text{total energy supplied to the device}}$$
- ❑ To evaluate the effectiveness and cost effectiveness of methods used to reduce energy consumption.

Do you understand…

- ❑ Energy cannot be created or destroyed. It can only be transformed from one form to another form.
- ❑ When energy is transferred and/or transformed only part of it may be usefully transferred/transformed.
- ❑ Energy which is not transferred/transformed in a useful way is wasted.
- ❑ Both wasted energy and the energy which is usefully transferred/transformed are eventually transferred to their surroundings which become warmer.
- ❑ Energy becomes increasingly spread out and becomes increasingly more difficult to use for further energy transformations.
- ❑ The greater the percentage of the energy that is usefully transformed in a device, the more efficient the device is.

Electrical energy

Are you able…

- ❑ To compare and contrast the particular advantages and disadvantages of using different electrical devices for a particular application
- ❑ To calculate the amount of energy transferred from the mains using:
  energy transferred = power × time
  (kilowatt-hour, kWh) (kilowatt, kW) (hour, h)
- ❑ To calculate the cost of energy transferred from the mains using:
  total cost = number of kilowatt-hours × cost per kilowatt-hour

Do you understand…

- ❑ Examples of energy transformations that everyday electrical devices are designed to bring about.
- ❑ Examples of everyday electrical devices designed to bring about particular energy transformations.
- ❑ The amount of electrical energy a device transforms depends on how long the appliance is switched on and the rate at which the device transforms energy.
- ❑ The power of an appliance is measured in watts (W) or kilowatts (kW).
- ❑ Energy is normally measured in joules (J).
- ❑ Electricity is transferred from power station to consumers along the National Grid.
- ❑ The uses of step-up and step-down transformers in the National Grid.
- ❑ Increasing voltage (potential difference) reduces current, and hence reduces energy losses in the cables.

Generating electricity

Are you able…

- ❑ To compare and contrast the particular advantages and disadvantages of using different energy sources to generate electricity.

Do you understand…

- ❑ In most power stations an energy source is used to heat water. The steam produced drives a turbine which is coupled to an electrical generator.
- ❑ Common energy sources include coal, oil and gas, which are burned to produce heat and uranium/ plutonium, in which nuclear fission produces heat.
- ❑ Energy from renewable energy sources can be used to drive turbines directly.
- ❑ Renewable energy sources used in this way include wind, the rise and fall of water due to waves and tides, and the falling of water in hydroelectric schemes.
- ❑ Electricity can be produced directly from the Sun's radiation using solar cells.
- ❑ In some volcanic areas hot water and steam rise to the surface. The steam can be tapped and used to drive turbines. This is known as geothermal energy.
- ❑ Using different energy resources has different effects on the environment. These effects include the release of substances into the atmosphere, noise and visual pollution, and the destruction of wildlife habitats.
- ❑ The advantages and disadvantages of using fossil fuels, nuclear fuels and renewable energy sources to generate electricity. These include the cost of building power stations, the start-up time of power stations, the reliability of the energy source, the relative cost of energy generated and the location in which the energy is needed.

Electromagnetic spectrum

Are you able…

- ❑ To evaluate the possible hazards associated with the use of different types of electromagnetic radiation
- ❑ To evaluate methods to reduce exposure to different types of electromagnetic radiation.

Do you understand…

- ❑ Electromagnetic radiation travels as waves and moves energy from one place to another.
- ❑ All types of electromagnetic waves travel at the same speed through a vacuum (space).
- ❑ The electromagnetic spectrum is continuous but the wavelengths within it can be grouped into types of increasing wavelength and decreasing frequency:
  gamma rays, X-rays, ultraviolet rays, visible light, infra red rays, microwaves and radio waves.
- ❑ Different wavelengths of electromagnetic radiation are reflected, absorbed or transmitted differently by different substances and types of surface.
- ❑ When radiation is absorbed the energy it carries makes the substance which absorbs it hotter and may create an alternating current with the same frequency as the radiation itself.
- ❑ Different wavelengths of electromagnetic radiation have different effects on living cells. Some radiations mostly pass through soft tissue without being absorbed, some produce heat, some may cause cancerous changes and some may kill cells. These effects depend on the type of radiation and the size of the dose.
- ❑ The uses and the hazards associated with the use of each type of radiation in the electromagnetic spectrum.
- ❑ Radio waves, microwaves, infra red and visible light can be used for communication.
- ❑ Microwaves can pass through the Earth's atmosphere and are used to send information to and from satellites and within mobile phone networks.
- ❑ Infra red and visible light can be used to send signals along optical fibres and so travel in curved paths.
- ❑ Communication signals may be analogue (continuously varying) or digital (discrete values only, generally on and off). Digital signals are less prone to interference than analogue and can be easily processed by computers.
- ❑ Electromagnetic waves obey the wave formula:
  wave speed = frequency × wavelength
  (metre/second, m/s) (hertz, Hz) (metre, m)

Radioactivity

Are you able…

- ❑ To evaluate the possible hazards associated with the use of different types of nuclear radiation
- ❑ To evaluate measures that can be taken to reduce exposure to nuclear radiations
- ❑ To evaluate the appropriateness of radioactive sources for particular uses, including as tracers, in terms of the type(s) of radiation emitted and their half-lives.

Do you understand…

- ❑ The basic structure of an atom is a small central nucleus composed of protons and neutrons surrounded by electrons.

- ❑ The atoms of an element always have the same number of protons, but have a different number of neutrons for each isotope.
- ❑ Some substances give out radiation from the nuclei of their atoms all the time, whatever is done to them. These substances are said to be radioactive.
- ❑ Identification of an alpha particle as a helium nucleus, a beta particle as an electron from the nucleus and gamma radiation as electromagnetic radiation.
- ❑ Properties of the alpha, beta and gamma radiations limited to their relative ionising power, their penetration through materials and their range in air.
- ❑ Alpha and beta radiations are deflected by both electric and magnetic fields but gamma radiation is not.
- ❑ The uses of and the dangers associated with each type of nuclear radiation.
- ❑ The half-life of a radioactive isotope is defined as the time it takes for the number of nuclei of the isotope in a sample to halve or the time it takes for the count rate from a sample containing the isotope to fall to half its initial level.

<u>Origins of the universe</u>

Are you able…

- ❑ To compare and contrast the particular advantages and disadvantages of using different types of telescope on Earth and in space to make observations on and deductions about the universe.

Do you understand…

- ❑ If a wave source is moving relative to an observer there will be a change in the observed wavelength and frequency.
- ❑ There is a red-shift in light observed from most distant galaxies.
- ❑ The further away galaxies are the bigger the red-shift.
- ❑ How the observed red-shift provides evidence that the universe is expanding and supports the big bang theory (that the universe began from a very small initial point).
- ❑ Observations of the solar system and the galaxies in the universe can be carried out on the Earth or from space.
- ❑ Observations are made with telescopes that may detect visible light or other electromagnetic radiations such as radio waves or X-rays

Additional Physics

Describing Movement

Are you able:

- ❑ To construct distance-time graphs for a body moving in a straight line when the body is stationary or moving with a constant speed
- ❑ To construct velocity-time graphs for a body moving with a constant velocity or a constant acceleration
- ❑ *To calculate the speed of a body from the slope of a distance-time graph*
- ❑ *To calculate the acceleration of a body from the slope of a velocity-time graph*
- ❑ *To calculate the distance travelled by a body from a velocity-time graph*

Do you understand that:

- ❑ The slope of a distance-time graph represents speed
- ❑ The velocity of a body is its speed in a given direction
- ❑ The acceleration of a body is given by:
  acceleration = change in velocity (metre/second, m/s)
  (metre/second^2 m/s^2) time taken for change (second, s)
- ❑ The slope of a velocity-time graph represents acceleration.
- ❑ The area under a velocity-time graph represents distance travelled.

Force and acceleration

Are you able:

- ❑ to draw and interpret velocity-time graphs for bodies that reach terminal velocity, including a consideration of the forces acting on the body
- ❑ to calculate the weight of a body using:
  weight = mass × gravitational field strength
  (newton, N) (kilogram, kg) (newton/kilogram, N/kg)

Do you understand that:

- ❑ Whenever two bodies interact, the forces they exert on each other are equal and opposite
- ❑ A number of forces acting on a body may be replaced by a single force which has the same effect on the body as the original forces all acting together. The force is called the resultant force
- ❑ If the resultant force acting on a stationary body is zero the body will remain stationary
- ❑ If the resultant force acting on a stationary body is not zero the body will accelerate in the direction of the resultant force
- ❑ If the resultant force acting on a moving body is zero the body will continue to move at the same speed and in the same direction
- ❑ If the resultant force acting on a moving body is not zero the body will accelerate in the direction of the resultant force
- ❑ Force, mass and acceleration are related by the equation:
  resultant force = mass × acceleration
  (newton, N) (kilogram, kg) (metre/second^2, m/s^2)

- ❑ When a vehicle travels at a steady speed the frictional forces balance the driving force
- ❑ The greater the speed of a vehicle the greater the braking force needed to stop it in a certain distance
- ❑ The stopping distance of a vehicle depends on the distance the vehicle travels during the driver's reaction time and the distance it travels under the braking force
- ❑ A driver's reaction time can be affected by tiredness, drugs and alcohol
- ❑ A vehicle's braking distance can be affected by adverse road and weather conditions and poor condition of the vehicle
- ❑ The faster a body moves through a fluid the greater the frictional force which acts on it
- ❑ A body falling through a fluid will initially accelerate due to the force of gravity. Eventually the resultant force on the body will be zero and it will fall at its terminal velocity.

Work and energy

Are you able:

- ❑ to discuss the transformation of kinetic energy to other forms of energy in particular situations.

Do you understand that:

- ❑ When a force causes a body to move through a distance, energy is transferred and work is done
- ❑ Work done = energy transferred
- ❑ The amount of work done, force and distance are related by the equation:
  work done = force applied × distance moved in direction of force
  (joule, J) (newton, N) (metre, m)
- ❑ Work done against frictional forces is mainly transformed into heat
- ❑ For an object that is able to recover its original shape, elastic potential is the energy stored in the object when work is done on the object to change its shape
- ❑ The kinetic energy of a body depends on its mass and its speed
- ❑ *Calculate the kinetic energy of a body using the equation:*
  kinetic energy = ½ × mass × speed^2
  (joule, J) (kilogram, kg) ((metre/second)^2, (m/s)^2)

Momentum

Are you able:

- ❑ to use the conservation of momentum (in one dimension) to calculate the mass, velocity or momentum of a body involved in a collision or explosion
- ❑ to use the ideas of momentum to explain safety features.

Do you understand that:

- ❑ Momentum, mass and velocity are related by the equation:
  momentum = mass × velocity
  (kilogram metre/second, kg m/s) (kilogram, kg) (metre/second, m/s)
- ❑ Momentum has both magnitude and direction
- ❑ When a force acts on a body that is moving, or able to move, a change in momentum occurs
- ❑ Momentum is conserved in any collision/explosion provided no external forces act on the colliding/exploding bodies

- ❑ *Force, change in momentum and time taken for the change are related by the equation:*

$$\text{force (newton, N)} = \frac{\text{change in momentum (kilogram metre/second, kg(m/s))}}{\text{time taken for the change (second, s)}}$$

<u>Static electricity</u>

Are you able:

- ❑ to explain why static electricity is dangerous in some situations and how precautions can be taken to ensure that the electrostatic charge is discharged safely
- ❑ to explain how static electricity can be useful.

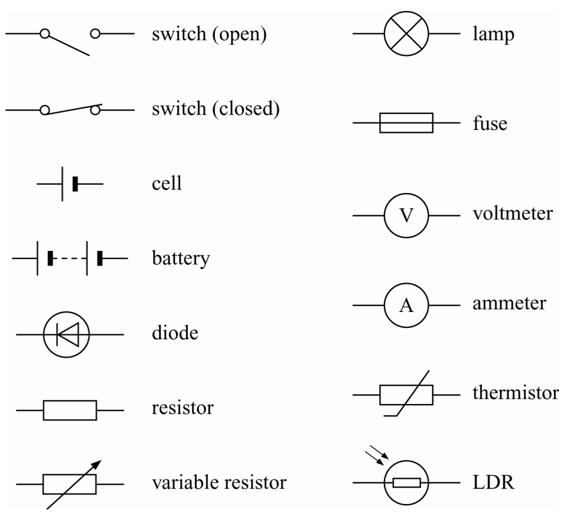
Do you understand that:

- ❑ When certain insulating materials are rubbed against each other they become electrically charged. Negatively charged electrons are rubbed off one material onto the other
- ❑ The material that gains electrons becomes negatively charged. The material that loses electrons is left with an equal positive charge
- ❑ When two electrically charged bodies are brought together they exert a force on each other
- ❑ Two bodies that carry the same type of charge repel. Two bodies that carry different types of charge attract
- ❑ Electrical charges can move easily through some substances, eg metals
- ❑ The rate of flow of electrical charge is called the current
- ❑ A charged body can be discharged by connecting it to earth with a conductor. Charge then flows through the conductor
- ❑ *The greater the charge on an isolated body the greater the potential difference between the body and earth. If the potential difference becomes high enough a spark may jump across the gap between the body and any earthed conductor which is brought near it*
- ❑ Electrostatic charges can be useful, for example in photocopiers and smoke precipitators and the basic operation of these devices

<u>Current electricity</u>

Are you able:

- ❑ to interpret and draw circuit diagrams using standard symbols. The following standard symbols should be known:

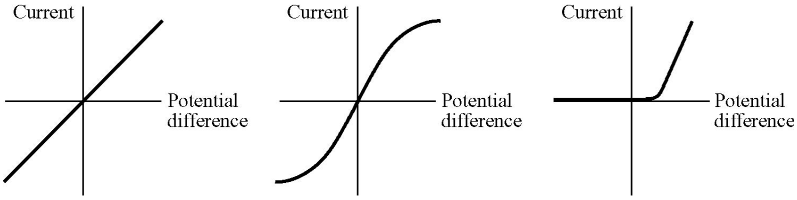


- ❑ to apply the principles of basic electrical circuits to practical situations.

Do you understand that:

- ❑ Current-potential difference graphs are used to show how the current through a component varies with the potential difference across it.

A resistor at constant temperature | A filament lamp | A diode



- ❑ The current through a resistor (at a constant temperature) is directly proportional to the potential difference across the resistor

- ❑ Potential difference, current and resistance are related by the equation:
  potential difference = current × resistance
  (volt, V) (ampere, A) (ohm, Ω)

- ❑ The resistance of a component can be found by measuring the current through, and potential difference across, the component

- ❑ The resistance of a filament lamp increases as the temperature of the filament increases

- ❑ The current through a diode flows in one direction only. The diode has a very high resistance in the reverse direction

- ❑ The resistance of a light-dependent resistor (LDR) decreases as light intensity increases

- ❑ The resistance of a thermistor decreases as the temperature increases (ie knowledge of negative temperature coefficient thermistor only is required)

- ❑ The current through a component depends on its resistance. The greater the resistance the smaller the current for a given potential difference across the component

- ❑ The potential difference provided by cells connected in series is the sum of the potential difference of each cell (depending on the direction in which they are connected).

- ❑ For components connected in series:
  - the total resistance is the sum of the resistance of each component
  - there is the same current through each component
  - the total potential difference of the supply is shared between the components.

- ❑ For components connected in parallel:
  - the potential difference across each component is the same
  - the total current through the whole circuit is the sum of the currents through the separate components.

<u>Mains electricity</u>

Are you able:

- ❑ to recognise errors in the wiring of a three-pin plug

- ❑ to recognise dangerous practice in the use of mains electricity

- ❑ to compare potential differences of d.c. supplies and the peak potential differences of a.c. supplies from diagrams of oscilloscope traces

- ❑ *to determine the period and hence the frequency of a supply from diagrams of oscilloscope traces.*

Do you understand that:

- ❑ Cells and batteries supply current which always passes in the same direction. This is called direct current (d.c.)
- ❑ An alternating current (a.c.) is one which is constantly changing direction. Mains electricity is an a.c. supply. In the UK it has a frequency of 50 cycles per second (50 hertz)
- ❑ UK mains supply is about 230 volts
- ❑ Most electrical appliances are connected to the mains using cable and a three-pin plug
- ❑ The structure of electrical cable
- ❑ The structure of a three-pin plug
- ❑ Correct wiring of a three-pin plug
- ❑ If an electrical fault causes too great a current the circuit should be switched off by a fuse or a circuit breaker
- ❑ When the current in a fuse wire exceeds the rating of the fuse it will melt, breaking the circuit
- ❑ Appliances with metal cases are usually earthed
- ❑ The earth wire and fuse together protect the appliance and the user.
- ❑ *The live terminal of the mains supply alternates between positive and negative potential with respect to the neutral terminal*
- ❑ *The neutral terminal stays at a potential close to zero with respect to earth*

<u>Electrical energy and power</u>

Are you able:

- ❑ to calculate the current through an appliance from its power and the potential difference of the supply and from this determine the size of fuse needed.

Do you understand that:

- ❑ Electric current is the rate of flow of charge
- ❑ When an electrical charge flows through a resistor, electrical energy is transformed into heat energy
- ❑ The rate at which energy is transformed in a device is called the power

$$\underset{\text{(watt, W)}}{\text{power}} = \frac{\text{energy transformed (joule, J)}}{\text{time } \textit{(second, s)}}$$

- ❑ Power, potential difference and current are related by the equation:

$$\underset{\text{(watt, W)}}{\text{power}} = \underset{\text{(ampere, A)}}{\text{current}} \times \underset{\text{(volt, V)}}{\text{potential difference}}$$

- ❑ *Energy transformed, potential difference and charge are related by the equation:*

$$\underset{\textit{(joule, J)}}{\textit{energy transformed}} = \underset{\textit{(volt, V)}}{\textit{potential difference}} \times \underset{\textit{(coulomb, C)}}{\textit{charge}}$$

- ❑ *The amount of electrical charge that flows is related to current and time by the equation:*

$$\underset{\textit{(coulomb, C)}}{\textit{charge}} = \underset{\textit{(ampere, A)}}{\textit{current}} \times \underset{\textit{(second, s)}}{\textit{time}}$$

Nuclear decay

Are you able:

- ❑ *to explain how the Rutherford and Marsden scattering experiment led to the plum pudding model of the atom being replaced by the nuclear model.*

Do you understand that:

- ❑ The relative masses and relative electric charges of protons, neutrons and electrons.
- ❑ In an atom the number of electrons is equal to the number of protons in the nucleus. The atom has no net electrical charge.
- ❑ Atoms may lose or gain electrons to form charged particles called ions.
- ❑ All atoms of a particular element have the same number of protons.
- ❑ Atoms of different elements have different numbers of protons.
- ❑ Atoms of the same element which have different numbers of neutrons are called isotopes.
- ❑ The total number of protons in an atom is called its atomic number.
- ❑ The total number of protons and neutrons in an atom is called its mass number.
- ❑ The effect of alpha and beta decay on radioactive nuclei.
- ❑ The origins of background radiation.

Nuclear fission and nuclear fusion

Are you able:

- ❑ to sketch a labelled diagram to illustrate how a chain reaction may occur.

Do you understand that:

- ❑ There are two fissionable substances in common use in nuclear reactors, uranium 235 and plutonium 239.
- ❑ Nuclear fission is the splitting of an atomic nucleus.
- ❑ For fission to occur the uranium 235 or plutonium 239 nucleus must first absorb a neutron
- ❑ The nucleus undergoing fission splits into two smaller nuclei and 2 or 3 neutrons and energy is released.
- ❑ The neutrons may go on to start a chain reaction.
- ❑ Nuclear fusion is the joining of two atomic nuclei to form a larger one.
- ❑ Nuclear fusion is the process by which energy is released in stars.

Further

Title	Objectives	
Moments	The turning effect of a force is called the moment. The size of the moment is given by the equation: moment = force x perpendicular distance from the line of action of the force to the axis of rotation. **HT** to calculate the size of a force, or its distance from an axis of rotation, acting on a body that is balanced.	
Principle of moments	**HT** If a body is not turning, the total clockwise moment must be exactly balanced by the total anticlockwise moment about any axis.	
Centre of mass	to describe how to find the centre of mass of a thin sheet of a material The centre of mass of a body is that point at which the mass of the body may be thought to be concentrated. If suspended, a body will come to rest with its centre of mass directly below the point of suspension. The centre of mass of a symmetrical body is along the axis of symmetry.	
Stability	**HT** to analyse the stability of bodies by considering their tendency to topple. **HT** Recognise the factors that affect the stability of a body. **HT** If the line of action of the weight of a body lies outside the base of the body there will be a resultant moment and the body will tend to topple.	
Circular Motion	to identify which force(s) provide(s) the centripetal force in a given situation When a body moves in a circle it continuously accelerates towards the centre of the circle. This acceleration changes the direction of motion of the body, not its speed. The resultant force causing this acceleration is called the centripetal force. The direction of the centripetal force is always towards the centre of the circle.	
Circular motion analysis	to interpret data on bodies moving in circular paths. The centripetal force needed to make a body perform circular motion increases as: - the mass of the body increases; - the speed of the body increases; - the radius of the circle decreases.	
Gravitational Attraction	Gravitational force provides the centripetal force that allows planets and satellites to maintain their circular orbits. The further away an orbiting body is the longer it takes to make a complete orbit. To stay in orbit at a particular distance, smaller bodies, including planets and satellites, must move at a particular speed around larger bodies. The bigger the masses of the bodies the bigger the force of gravity between them. As the distance between two bodies increases the force of gravity between them decreases.	
Satellites	Communications satellites are usually put into a geostationary orbit above the equator. Monitoring satellites are usually put into a low polar orbit.	
Reflection (from plane mirrors)	The normal is a construction-line perpendicular to the reflecting/refracting surface at the point of incidence. The angle of incidence is equal to the angle of reflection. The nature of an image is defined by its size relative to the object,	
Reflection	to construct ray diagrams to show the formation of images by plane, convex and concave mirrors.	
Reflection (concave mirrors)	The nature of the image produced by a convex mirror. The nature of the image produced by a concave mirror for an object placed at different distances from the mirror. to construct ray diagrams to show the formation of images by plane, convex and concave mirrors to calculate the magnification produced by a lens or mirror using the formula: $\text{magnification} = \frac{\text{image height}}{\text{object height}}$	
Refraction	Refraction at an interface.	
Refraction by a prism	Refraction by a prism.	
Diverging Lenses	The nature of the image produced by a diverging lens. to construct ray diagrams to show the formation of images by diverging lenses and converging lenses	

Converging lenses	The nature of the image produced by a converging lens for an object placed at different distances from the lens. The use of a converging lens in a camera to produce an image of an object on a detecting device (eg film). to calculate the magnification produced by a lens or mirror using the formula: $\text{magnification} = \frac{\text{image height}}{\text{object height}}$	
Sound	Sound is caused by mechanical vibrations and travels as a wave. Sound cannot travel through a vacuum.	
Looking at sound	The quality of a note depends upon the waveform. Sound waves can be reflected and refracted. The pitch of a note increases as the frequency increases. The loudness of a note increases as the amplitude of the wave increases. to compare the amplitudes and frequencies of sounds from diagrams of oscilloscope traces.	
Ultrasound	Sounds in the range 20-20 000 Hz can be detected by the human ear. Electronic systems can be used to produce ultrasound waves which have a frequency higher than the upper limit of hearing for humans. Ultrasound waves are partially reflected when they meet a boundary between two different media. The time taken for the reflections to reach a detector is a measure of how far away such a boundary is. Ultrasound waves can be used in industry for cleaning and quality control. Ultrasound waves can be used in medicine for pre-natal scanning. to determine the distance between interfaces in various media from diagrams of oscilloscope traces. to compare the amplitudes and frequencies of ultrasounds from diagrams of oscilloscope traces. **HT** to determine the distance between interfaces in various media from diagrams of oscilloscope traces.	
Motor effect	When a conductor carrying an electric current is placed in a magnetic field, it may experience a force. The size of the force can be increased by: - increasing the strength of the magnetic field - increasing the size of the current. The conductor will not experience a force if it is parallel to the magnetic field. The direction of the force is reversed if either the direction of the current or the direction of the magnetic field is reversed.	
Making motors	to explain how the motor effect is used in simple devices.	
Generator Effect	If an electrical conductor 'cuts' through magnetic field lines, an electrical potential difference is induced across the ends of the conductor. If a magnet is moved into a coil of wire, an electrical potential difference is induced across the ends of the coil. If the wire is part of a complete circuit, a current is induced in the wire. If the direction of motion, or the polarity of the magnet, is reversed, the direction of the induced potential difference and the induced current is reversed. The generator effect also occurs if the magnetic field is stationary and the coil is moved. The size of the induced potential difference increases when: - the speed of the movement increases - the strength of the magnetic field increases - the number of turns on the coil increases - the area of the coil is greater.	
AC Generators	**HT** to explain from a diagram how an a.c. generator works, including the purpose of the slip rings and brushes.	
Transformers	The basic structure of the transformer. An alternating current in the primary coil produces a changing magnetic field in the iron core and hence in the secondary coil. This induces an alternating potential difference across the ends of the secondary coil.	
Uses of transformers	to determine which type of transformer should be used for a particular application. **HT** The potential difference (p.d.) across the primary and secondary coils of a transformer are related by the equation: $\frac{\text{p.d. across primary}}{\text{p.d. across secondary}} = \frac{\text{number of turns on primary}}{\text{number of turns on secondary}}$ In a step-up transformer the potential difference across the secondary coil is greater than the potential difference across the primary coil. In a step-down transformer the potential difference across the secondary coil is less than the potential difference across the primary coil. The uses of step-up and step-down transformers in the National Grid.	

Stars, Galaxies and the Universe	Our Sun is one of the many billions of stars in the Milky Way galaxy. The Universe is made up of billions of galaxies. Stars form when enough dust and gas from space is pulled together by gravitational attraction. Smaller masses may also form and be attracted by a larger mass to become planets. Gravitational forces balance radiation pressure to make a star stable.	
Lifecycle of a star	A star goes through a life cycle (limited to the life cycle of stars of similar size to the Sun and stars much larger than the Sun). Fusion processes in stars produce all naturally occurring elements. These elements may be distributed throughout the Universe by the explosion of a star (supernova) at the end of its life.	
Making elements	to explain how stars are able to maintain their energy output for millions of years to explain why the early Universe contained only hydrogen but now contains a large variety of different elements.	

Practice Test

Energy and energy resources

1 Thermal energy can be transferred in different ways.

Match the words in the list with the numbers **1** to **4** in the sentences.

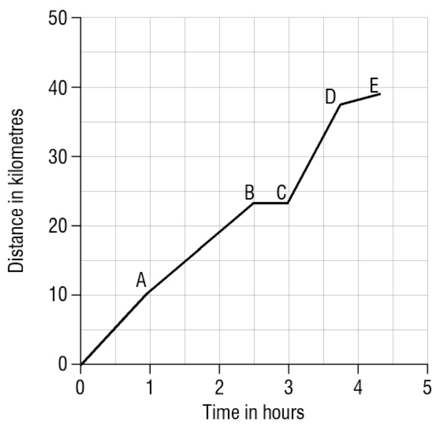
A electrons ....   **B** liquids ....

C particles ....   **D** solids ....

Conduction occurs mainly in ……**1**…… All metals are good conductors because they have a lot of free ……**2**……. Convection occurs in gases and ……**3**…… Radiation does not involve ……**4**…… *(4 marks)*

Motion

2 The graph shows how far a marathon runner travels during a race.



(a) What was the distance of the race? (1)

(b) How long did it take the runner to complete the race? (1)

(c) What distance did the runner travel during the first 2 hours of the race? (1)

(d) For how long did the runner rest during the race? (1)

(e) Ignoring the time for which the runner was resting, between which two points was

- the runner moving the slowest?
- Give a reason for your answer. (2)

Speeding up Slowing down

3. a) When two objects interact, they exert ………………. and ………………. forces on each other.

   b) The unit of force is the ………………. (symbol …..).

   c) A moving object acted on by a resultant force:

      i) in the same direction as the direction of its motion ………………………..,

      ii) in the opposite direction to its direction of motion ……………………….. .

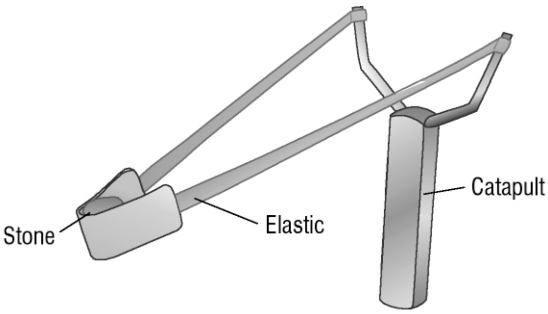
   d) Resultant force = …………………………………….. × ……………………………………………..

   (in ………) (in kg) (in ………)

(11)

Work energy and momentum

4 The picture shows a catapult.



(a) When a force is applied to the stone, work is done in stretching the elastic and the stone moves backwards.

(i) Write down the equation you could use to calculate the work done. (1)

(ii) The average force applied to the stone is 20 N. This moves it backwards 0.15 m. Calculate the work done and give its unit.

....

(3)

(b) The work done is stored as energy.

(i) What type of energy is stored in the stretched elastic?

(1)

(ii) What type of energy does the stone have when it is released?

……………………………………………………………………………………... (1)

Turning forces

5 There are many satellites orbiting the Earth in circular paths.

(a) (i) What force provides the centripetal force that allows satellites to maintain their circular orbits?

....

(1)

(ii) A satellite moving at a steady speed in a circular orbit is continuously accelerating.

Explain why.

....

....

(2)

(b) Some satellites are in *geostationary orbits*.

(i) What is meant by a *geostationary orbit*?

....

(1)

(ii) What is the time period of a geostationary orbit?

....

(1)

(iii) What type of satellite is usually put into a geostationary orbit?

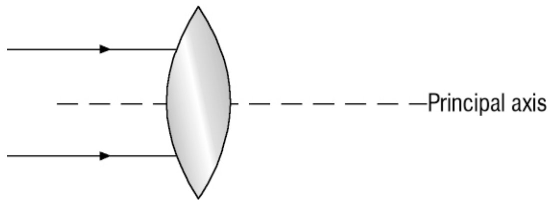
....

(1)

Light and sound

6 (a) (i) Complete the diagram below to show what happens to the two rays of light after they enter the lens.

(2)



(ii) Put an **F** on the diagram to label the principal focus of the lens.

(1)

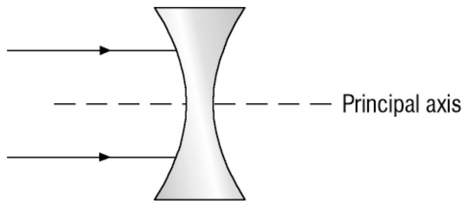
(iii) What word can be used to describe this type of lens?

....

(1)

(b) (i) Complete the diagram below to show what happens to the two rays of light after they enter the lens.

(2)



(ii) Put an **F** on the diagram to label the principal focus of the lens.

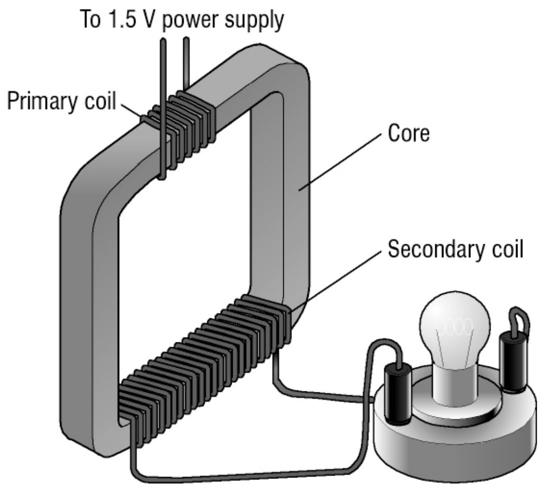
(1)

(iii) What word can be used to describe this type of lens?

(1)

Electromagnetism

7 The diagram shows a transformer.



(a) Explain how an alternating current in the primary coil produces an alternating current through the lamp.

....

(4)

(b) The potential difference across the primary coil is 1.5 V. There are 6 turns on the primary coil and 24 turns on the secondary coil.

Calculate the potential difference across the lamp.

....

....

(4)

Stars and space

8 The sentences below describe the life cycle of a star such as the Sun.

A The star contracts to form a white dwarf.

B The star is in a stable state.

C The star expands to form a red giant.

D Gravitational forces pull dust and gas together and the star is formed.

(a) Put the sentences in the correct order.

	→		→		→	

(3)

(b) At which stage in its life is the Sun, **A**, **B**, **C** or **D**?

....

(1)

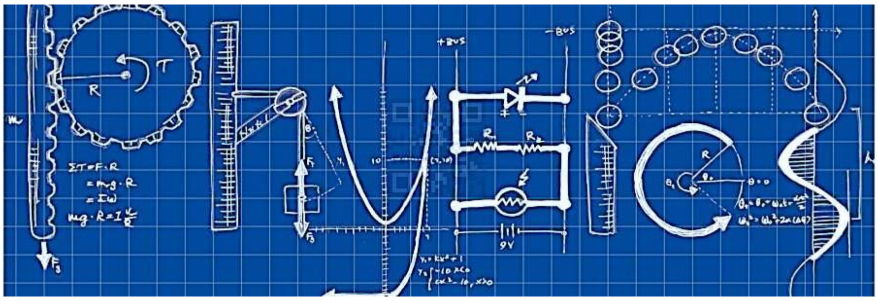
(c) What balances the gravitational forces to make a star stable?

....

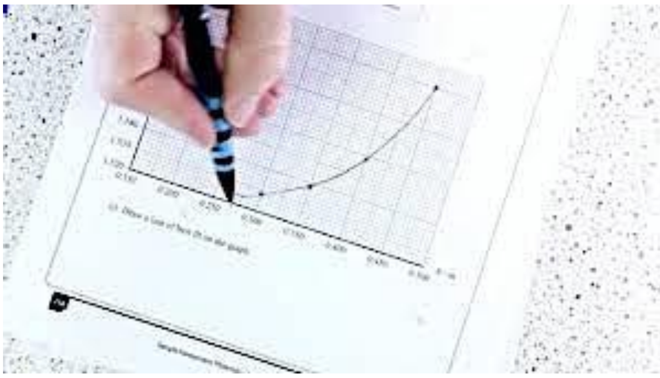
....

....

(2)



AS Physics at Hampstead School



Transition Booklet from GCSE Physics to AS Physics

Introduction

This booklet will assist you in getting better prepared to study AS Physics at Hampstead School. You must work through the booklet and self assess to identify the topics/areas for improvement. Write a brief comment on your progress in the comments box as you complete each topic. This help will inform you with what you must revise prior to beginning the AS Physics course. Bring your copy of the completed booklet to your first AS Physics lesson.

AS Physics
Skills

Contents

Topic	Title	Completed (date)	Comments. Do you need more practice? Are you confident with this area? What areas of weakness have you identified?
1	Prefixes and units		
2	Significant Figures		
3	Converting Length, Area and Volume		
4	Rearranging Equations		
5	Variables		
6	Constructing Tables		
7	Drawing Lines of Best Fit		
8	Constructing Graphs		
9	Calculating Gradients – Straight Lines		
10	Calculating Gradients – Curved Lines		
11	Calculating Areas – Straight Line Graphs		
12	Calculating Areas – Curved Line Graphs		
13	Interpreting Graphs		
14	Accuracy vs Precision		
15	Identifying Errors		
16	Improving Experiments – Accuracy, Precision and Reliability		
17	Describing Experiments		
18	Appendix 1 Solutions. Appendix 2 It's all Greek		

AS Physics	# 1. Prefixes and units
Skills	

In Physics we have to deal with quantities from the very large to the very small. A prefix is something that goes in front of a unit and acts as a multiplier. This sheet will give you practice at converting figures between prefixes.

Symbol	**Name**	**What it means**		**How to convert**	
P	peta	10^{15}	1000000000000000		↓ x1000
T	tera	10^{12}	1000000000000	↑ ÷ 1000	↓ x1000
G	giga	10^{9}	1000000000	↑ ÷ 1000	↓ x1000
M	mega	10^{6}	1000000	↑ ÷ 1000	↓ x1000
k	kilo	10^{3}	1000	↑ ÷ 1000	↓ x1000
			1	↑ ÷ 1000	↓ x1000
m	milli	10^{-3}	0.001	↑ ÷ 1000	↓ x1000
µ	micro	10^{-6}	0.000001	↑ ÷ 1000	↓ x1000
n	nano	10^{-9}	0.000000001	↑ ÷ 1000	↓ x1000
p	pico	10^{-12}	0.000000000001	↑ ÷ 1000	↓ x1000
f	femto	10^{-15}	0.000000000000001	↑ ÷ 1000	

Convert the figures into the units required.

6 km	=	6 x 10^{3}	m
54 MN	=		N
0.086 µV	=		V
753 GPa	=		Pa
23.87 mm/s	=		m/s

Convert these figures to suitable prefixed units.

640	GV	=	640 x 10^{9}	V
		=	0.5 x 10^{-6}	A
		=	93.09 x 10^{9}	m
	kN	=	32 x 10^{5}	N
	nm	=	0.024 x 10^{-7}	m

Convert the figures into the prefixes required.

s	**ms**	**µs**	**ns**	**ps**
0.00045	0.45	450	450 000 or 450 x10^{3}	450 x 10^{6}
0.000000789				
0.000 000 000 64				

mm	**m**	**km**	**µm**	**Mm**
1287360				
295				

The equation for wave speed is:

$$wave\ speed = frequency\ \times wavelength$$

$$(m/s) \qquad (Hz) \qquad (m)$$

Whenever this equation is used, the quantities must be in the units stated above. At GCSE we accepted m/s but at AS/A Level we use the index notation. m/s becomes m s^{-1} and m/s^2 becomes m s^{-2}.

By convention we should also leave one space between values and units. 10m should be 10 m.

We also leave a space between different units but no space between a prefix and units.

This is to remove ambiguity when reading values.

Example ms^{-1} means 1/millisecond because the ms means millisecond, 10^{-3} s

but m s^{-1} means metre per second the SI unit for speed.

or mms^{-1} could mean mm s^{-1} compared with m ms^{-1}

millimeters per second compared with meters per millisecond - quite a difference!!!

Calculate the following quantities using the above equation, giving answers in the required units.

1) Calculate the speed in m s^{-1} of a wave with a frequency of 75 THz and a wavelength 4.0 µm.

$$v = f\,\lambda = 75 \times 10^{12} \times 4.0 \times 10^{-6} = 3.0 \times 10^{8}\ m\ s^{-1}\ (300\ Mm\ s^{-1})$$

2) Calculate the speed of a wave in m s^{-1} which has a wavelength of 5.6 mm and frequency of 0.25 MHz.

3) Calculate the wavelength in metres of a wave travelling at 0.33 km s^{-1} with a frequency of 3.0 GHz.

4) Calculate the frequency in Hz of a wave travelling at 300 x 10^3 km s^{-1} with a wavelength of 0.050 mm.

5) Calculate the frequency in GHz of a wave travelling at 300 Mm s^{-1} that has a wavelength of 6.0 cm.

AS Physics	# 2. Significant Figures
Skills	

1. **All non-zero numbers ARE significant.** The number 33.2 has THREE significant figures because all of the digits present are non-zero.

2. **Zeros between two non-zero digits ARE significant.** 2051 has FOUR significant figures. The zero is between 2 and 5

3. **Leading zeros are NOT significant.** They're nothing more than "place holders." The number 0.54 has only TWO significant figures. 0.0032 also has TWO significant figures. All of the zeros are leading.

4. **Trailing zeros when a decimal is shown ARE significant.** There are FOUR significant figures in 92.00 and there are FOUR significant figures in 230.0.

5. **Trailing zeros in a whole number with no decimal shown are NOT significant.** Writing just "540" indicates that the zero is NOT significant, and there are only TWO significant figures in this value.

(THIS CAN CAUSE PROBLEMS!!! WE SHOULD USE POINT 8 FOR CLARITY, BUT OFTEN DON'T - 2/3 significant figures is accepted in IAL final answers - eg 500/260 = 1.9 to 2 sf. Better 5.0 x 10^2 / 2.6 x 10^2 = 1.9)

8. **For a number in scientific notation: N x 10^x, all digits comprising N ARE significant by the first 5 rules; "10" and "x" are NOT significant.** 5.02 x 10^4 has THREE significant figures.

For each value state how many significant figures it is stated to.

Value	Sig Figs	Value	Sig Figs	Value	Sig Figs	Value	Sig Figs
2		1066		1800.45		0.070	
2.0		82.42		2.483 x 10^4		69324.8	
500		750000		0.0006		0.0063	
0.136		310		5906.4291		9.81 x 10^4	
0.0300		3.10 x 10^4		200000		40000.00	
54.1		3.1 x 10^2		12.711		0.0004 x 10^4	

When adding or subtracting numbers

Round the final answer to the **least precise** number of decimal places in the original values.

Eg. 0.88 + 10.2 – 5.776 (= 5.304) = **5.3** (to 1d.p. , since 10.2 only contains 1 decimal place)

(Khan Academy- Addition/ subtraction with sig fig excellent video- make sure you watch .)

Add the values below then write the answer to the appropriate number of significant figures

Value 1	Value 2	Value 3	Total Value	Total to correct sig figs
51.4	1.67	3.23		
7146	–32.54	12.8		
20.8	18.72	0.851		
1.4693	10.18	–1.062		
9.07	0.56	3.14		
739762	26017	2.058		
8.15	0.002	106		
152	0.8	0.55		

When multiplying or dividing numbers

Round the final answer to the **least** number of significant figures found in the initial values.

E.g. 4.02 x 3.1 | 0.114 = (109.315…) = **110** (to 2s.f. as 3.1 only has 2 significant figures.

Multiply the values below then write the answer to the appropriate number of significant figures

Value 1	Value 2	Total Value	Total to correct sig figs
0.91	1.23		
8.764	7.63		
2.6	31.7		
937	40.01		
0.722	634.23		

Divide value 1 by value 2 then write the answer to the appropriate number of significant figures

Value 1	Value 2	Total Value	Total to correct sig figs
5.3	748		
3781	6.50		
91×10^{2}	180		
5.56	22×10^{-3}		
3.142	8.314		

When calculating a mean

1) Remove any **obvious** anomalies (circle these in the table)
2) Calculate the mean with the remaining values, and record this to the **least** number of decimal places in the included values

E.g. Average 8.0, 10.00 and 145.60:

1) Remove 145.60

2) The average of 8.0 and 10.00 is **9.0** (to 1 d.p.)

Calculate the mean of the values below then write the answer to the appropriate number of significant figures

Value 1	Value 2	Value 3	Mean Value	Mean to correct sig figs
1	1	2		
435	299	437		
5.00	6.0	29.50		
5.038	4.925	4.900		
720.00	728.0	725		
0.00040	0.00039	0.000380		
31	30.314	29.7		

AS Physics Skills	3. Converting length, area and volume

Whenever substituting quantities into an equation, you must always do this in SI units – such as time in seconds, mass in kilograms, distance in metres…

If the question doesn't give you the quantity in the correct units, you should always convert the units **first**, rather than at the end. Sometimes the question may give you an area in mm^2 or a volume in cm^3, and you will need to convert these into m^2 and m^3 respectively before using an equation.

To do this, you first need to know your length conversions:

1m = 100 cm = 1000 mm (1 cm = 10 mm)

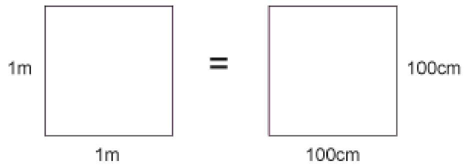
m → cm	x 100	cm → m	÷ 100
m → mm	x 1000	m → mm	÷ 1000

Always think –

"Should my number be getting larger or smaller?" This will make it easier to decide whether to multiply or divide.

Converting Areas

A 1m x 1m square is equivalent to a 100 cm x 100 cm square.



Therefore, $1\ m^2 = 10\ 000\ cm^2$

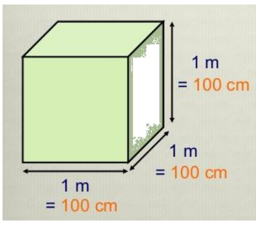
Similarly, this is equivalent to a 1000 mm x 1000 mm square;

So, $1\ m^2 = 1\ 000\ 000\ mm^2$

m^2 → cm^2	x 10 000	cm^2 → m^2	÷ 10 000
m^2 → mm^2	x 1 000 000	m^2 → mm^2	÷ 1 000 000

Converting Volumes

A 1m x 1m x 1m cube is equivalent to a 100 cm x 100 cm x 100 cm cube.



Therefore, $1\ m^3 = 1\ 000\ 000\ cm^3$

Similarly, this is equivalent to a 1000 mm x 1000 mm x 1000 mm cube;

So, $1\ m^3 = 10^9\ mm^3$

m^3 → cm^3	x 1 000 000	cm^3 → m^3	÷ 1 000 000
m^3 → mm^3	x 10^9	m^3 → mm^3	÷ 10^9

6 m^2	=	cm^2
0.002 m^2	=	mm^2
24 000 cm^2	=	m^2
46 000 000 mm^3	=	m^3
0.56 m^3	=	cm^3

750 mm^2	=	m^2
5 x 10^{-4} cm^3	=	m^3
8.3 x 10^{-6} m^3	=	mm^3
3.5 x 10^2 m^2	=	cm^2
152000 mm^2	=	m^2

Now use the technique shown on the previous page to work out the following conversions:

31 x 10^8 m^2	=	km^2
59 cm^2	=	mm^2
24 dm^3	=	cm^3
4 500 mm^2	=	cm^2
5 x 10^{-4} km^3	=	m^3

(*Hint: There are 10 cm in 1 dm)*

A 2.0 m long solid copper cylinder has a cross-sectional area of 3.0 x10^2 mm^2. What is its volume in cm^3?

Volume = _____ cm^3

For the following, think about whether you should be writing a smaller or a larger number down to help decide whether you multiply or divide.

Eg. *To convert 5 m ms^{-1} into m s^{-1} – you will travel more metres in 1 second than in 1 millisecond, therefore you should multiply by 1000 to get 5000 m s^{-1}.*

5 N cm^{-2}	=	N m^{-2}
1150 kg m^{-3}	=	g cm^{-3}
3.0 m s^{-1}	=	km h^{-1}
65 kN cm^{-2}	=	N mm^{-2}
7.86 g cm^{-3}	=	kg m^{-3}

AS Physics	# 4. Rearranging Equations
Skills	

Rearrange each equation into the subject shown in the middle column.

Equation		Rearrange Equation
$V = IR$	R	
$I = \frac{Q}{t}$	t	
$\rho = \frac{RA}{l}$	A	
$\varepsilon = V + Ir$	r	
$s = \frac{(u+v)}{2}t$	u	

Equation		Rearrange Equation
$hf = \phi + E_K$	f	
$E_P = mgh$	g	
$E = \frac{1}{2}Fe$	F	
$v^2 = u^2 + 2as$	u	
$T = 2\pi\sqrt{\frac{m}{k}}$	m	

AS Physics	# 5. Variables
Skills	

A variable is a quantity that takes place in an experiment. There are three types of variables:

Independent variable – *this is the quantity that you* ***change***

Dependent variable – *this is the quantity that you* ***measure***

Control variable – *this is a quantity that you* ***keep the same*** *so that it does not affect the results*

You can only have one independent variable and one dependent variable, but the more control variables you have the more accurate your results will be.

Further to these, you can also split the independent variable category – this can be continuous or discrete.

A continuous variable can take *any* numerical value, including decimals. You will construct line graphs for continuous variables.

A discrete variable can only take *specific* values or labels (eg. integers or categories). You will construct bar charts for discrete variables.

For each case study below, state the independent variable, dependent variable, and any control variables described. ***Add further control variables****, and state what type the independent variable is and what type of graph you will present the results with (if required).*

Case study 1 – *Measuring the effect of gravity*

The aim of this experiment is to find out how fast objects of different masses take to fall from height. To conduct this experiment we used a number of spheres of the same diameter, which had different masses. Each sphere had its mass measured on electronic scales, before being dropped from a marker exactly 2.000 m from the floor. The time the sphere took to drop was timed on a stopwatch, and repeated 3 times for each sphere to gain an average time.

Independent variable: ____

Dependent variable: ____

Control variables: ____

____

Type of independent variable: ____

Graph: ____

Case study 2 – *The number of children involved in different after school activities.*

The aim of this study is to discover which activities are most popular so the correct resources can be supplied to the correct member of staff. On a certain day after school the number of children were recorded for the different activities they took.

Independent variable: ____________________

Dependent variable: ____________________

Control variables: ____________________

Type of independent variable: ____________________

Graph: ____________________

Case study 3 – *How far does the spring stretch?*

The aim of this experiment is to find how far different masses stretch a spring. A spring was hung from a clamp stand, and its length end to end measured. A 10g mass was then added and the length of the spring measured and recorded. This was repeated adding 10g between 0g and 100g.

Independent variable: ____________________

Dependent variable: ____________________

Control variables: ____________________

Type of independent variable: ____________________

Graph: ____________________

Case study 4 - *What is the best design for a turbine?*

A wind turbine is connected to a voltmeter and is placed 1.0 m from a desk fan. The potential difference produced for different number of blades attached to the turbine is measured. The aim is to see what design produces the largest potential difference.

Independent variable: ____________________

Dependent variable: ____________________

Control variables: ____________________

____

Type of independent variable: ____________________

Graph: ____________________

AS Physics	# 6. Constructing tables
Skills	

The **left hand column** is for your **independent variable**.

The **right hand column** is for your **dependent variable**. You may split this up into further columns if repeats are carried out, and make sure you include an average column. Each sub column must come under the main heading (including the average column).

Place results in the table in order of independent variable, usually starting with the smallest value first.

Ensure each column contains a heading with units in brackets. No units should be placed in the table.

All measured values in one column should be to the same decimal place – don't forget to add zeros if necessary!

Any averages should be given to the same number of decimal places as the measured values. Remember to remove any anomalies by circling the results and do not include them in calculating your average.

Any calculated values should be given to a suitable number of significant figures/ precision.

At AS/A Level we don't use brackets to separate the quantity heading from the units but use a / .

Example: **mass (kg)** should be written as **mass / kg.**

speed of car (m/s) should be written as **speed of car / m s^{-1}**

Independent Variable Heading /unit	Dependent Variable Heading /unit			
	1	2	3	Average

A student forgot his exercise book when doing a practical on electrical resistance for a resistor. Below are his readings in the practical. He measured the current in the circuit three times for five different voltages. He has made many errors.

V : 0.11A, 0.1A, 0.12A
2.0V : 0.21A, 0.18A, 0.24

5V : 0.5, 5.1, 0.48   4.0V : 0.35A, 0.40A, 0.45

3.0V: 0.33A, 0.6
0.30

Construct a suitable table for his results.

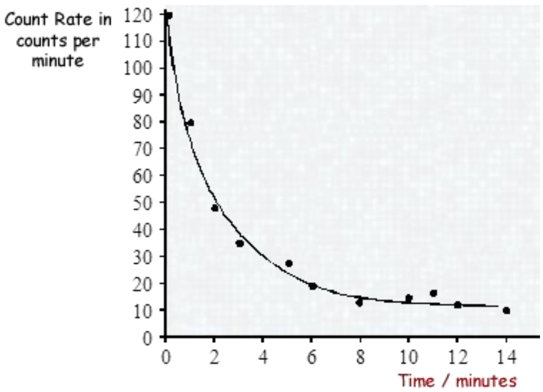
AS Physics	# 7. Drawing Lines of Best Fit
Skills	

When drawing lines of best fit, draw a *smooth* straight or curved line that passes through the majority of the points. If you can, try to have an even number of points above and below the line if it can't go through all points.

When describing the trend, use the phrase….

"As 'X' increases, 'Y' *increases/decreases* in a *linear/non-linear* fashion."

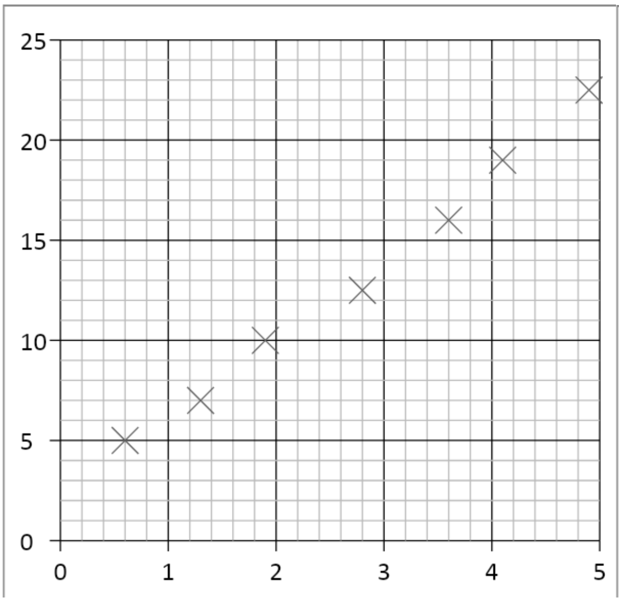
Substitute the quantities into X and Y, and choose either of the two options to describe the graph.

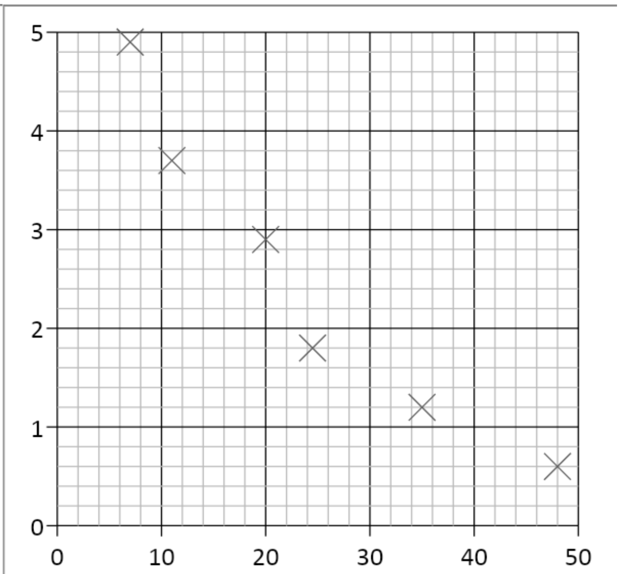


Eg.

As time increases, the count rate decreases in a non-linear fashion.

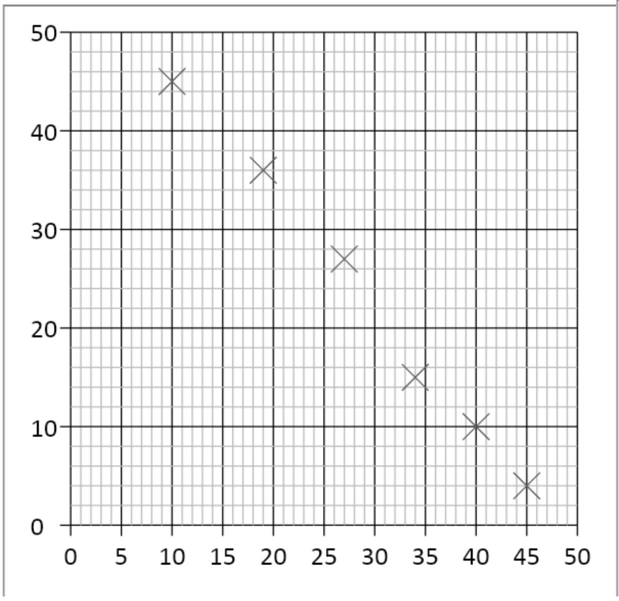
Draw a line of best fit for each of the graphs and describe the trend shown by each (call the quantities X and Y).

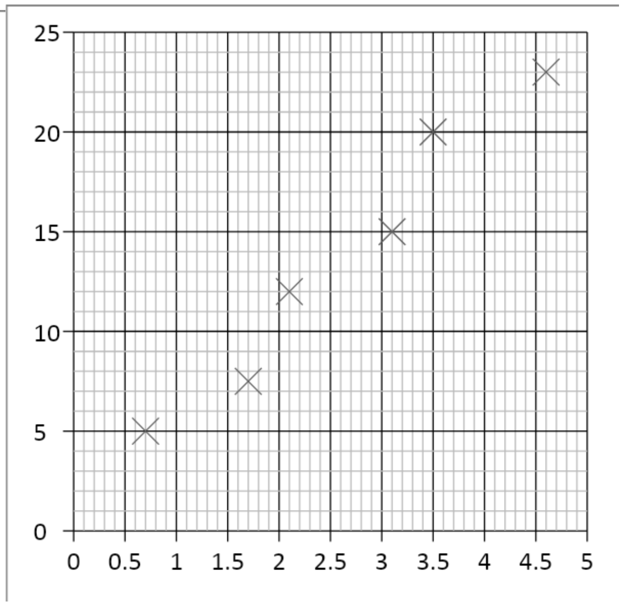




1.

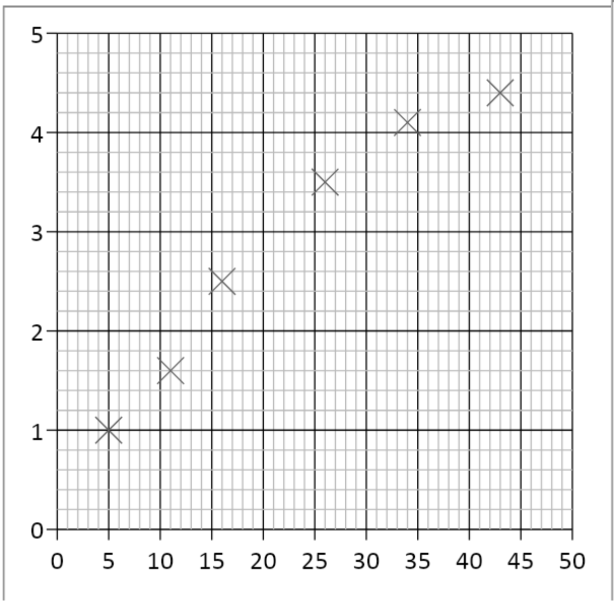
2.

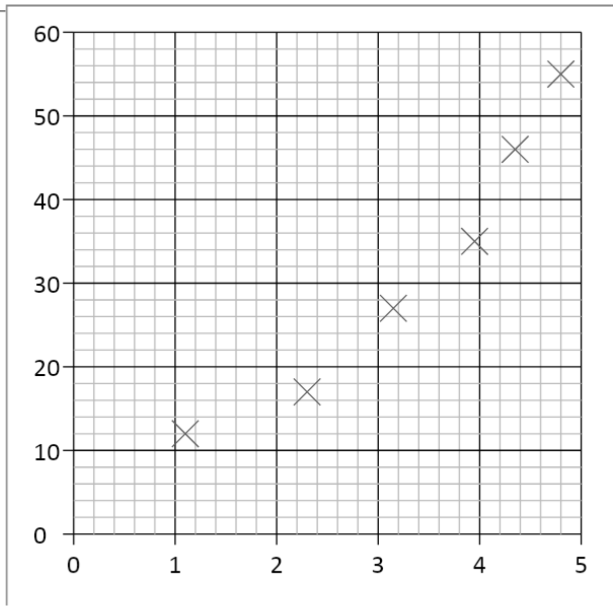

50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50


25
20
15
10
5
0
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

3.

4.


5
4
3
2
1
0
0 5 10 15 20 25 30 35 40 45 50


60
50
40
30
20
10
0
0 1 2 3 4 5

5.

6.

AS Physics	# 8. Constructing Graphs
Skills	

When drawing graphs, you will be marked on the following criteria:

1) Axes – Your independent variable is on the x axis, and your dependent variable is on the y axis. Both axes need to be labelled.
2) Units – Add units to your axes when labelling.
3) Scale – Make your scale as large as possible so that your data fills most of the page. **You don't have to start your axes at the origin**. *Make sure you have a regular scale that goes up in nice numbers – 1, 2, 5, 10 etc…*
4) Points – mark each point with a cross using a sharp pencil. Don't use circles or dots as points.
5) Line of best fit – draw a smooth line of best fit – straight or curved depending on what pattern your data follows.

An easy way to remember these points is….. **S** cale

L ine

A xes

P oints

U nits

Plot graphs for the following sets of data, including a line of best fit for each.

Surface area of pendulum / cm²	**Time taken for pendulum to stop/ s**
5.0	170
6.2	127
7.4	99
8.0	86
8.8	70
9.9	56
Current / A	**Voltage / V**
0.07	1.46
0.14	1.44
0.21	1.42
0.30	1.40
0.41	1.38
0.57	1.33
0.81	1.29

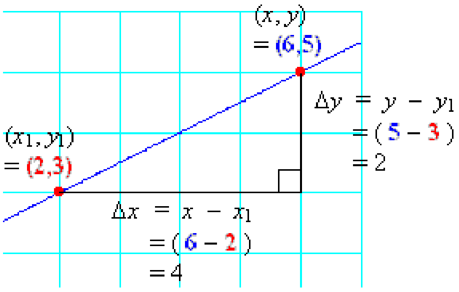
AS Physics	# 9. Calculating Gradients – Straight Lines
Skills	

Gradients are a useful tool that show how fast or slow quantities change – eg speed tells us how fast distance is changing, or how quickly energy is being lost over time.

To calculate the gradient, pick any two points on the line as far away as possible and draw a large triangle between them.
The gradient is given by:

$$gradient = \frac{diffference\ in\ y\ values}{difference\ in\ x\ values}$$

But make sure the you subtract the values in the same order! Remember – if the line slopes up, the gradient should be positive; if the line slopes down, then the gradient should be negative.

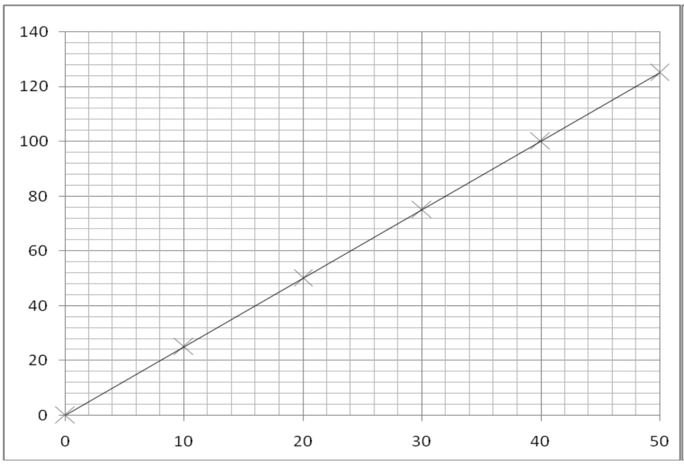


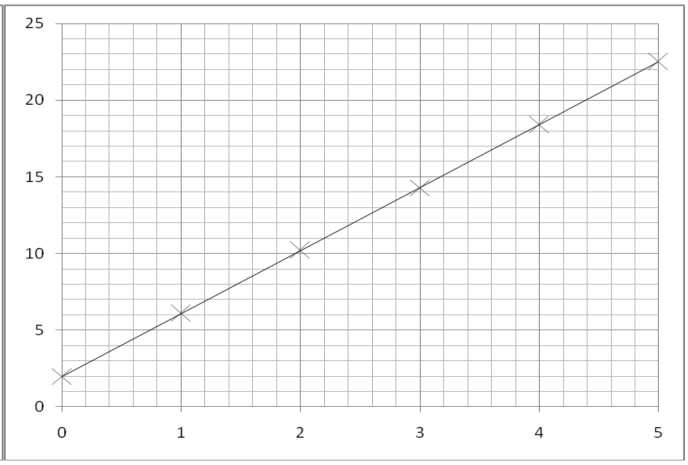
$$\text{Gradient} = \frac{difference\ in\ y}{difference\ in\ x}$$

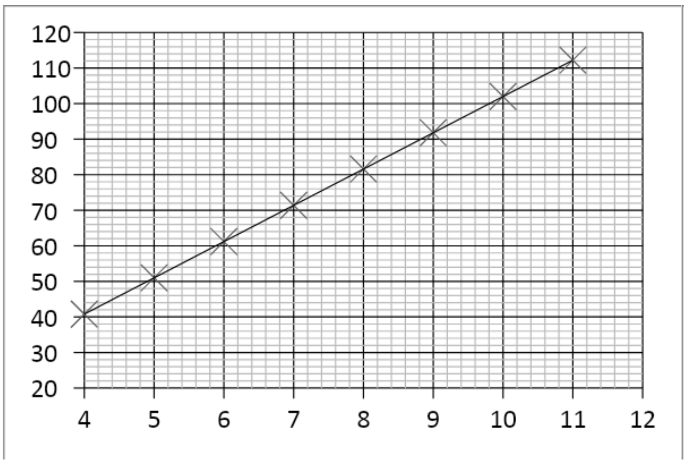
$$= \frac{2}{4}$$

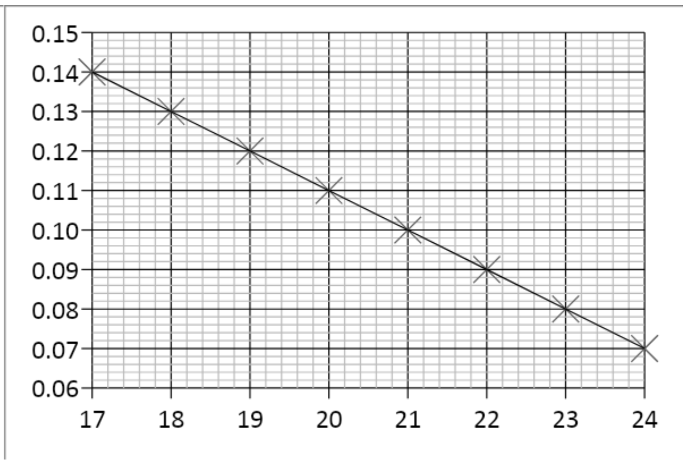
$$\underline{\boldsymbol{= 0.5}}$$

Calculate the gradients of the graphs below









AS Physics

Skills

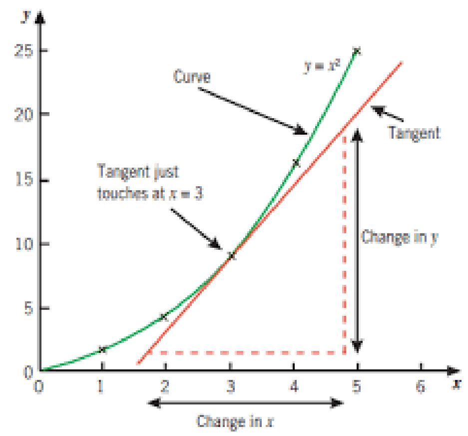
10. Calculating Gradients – Curved Lines

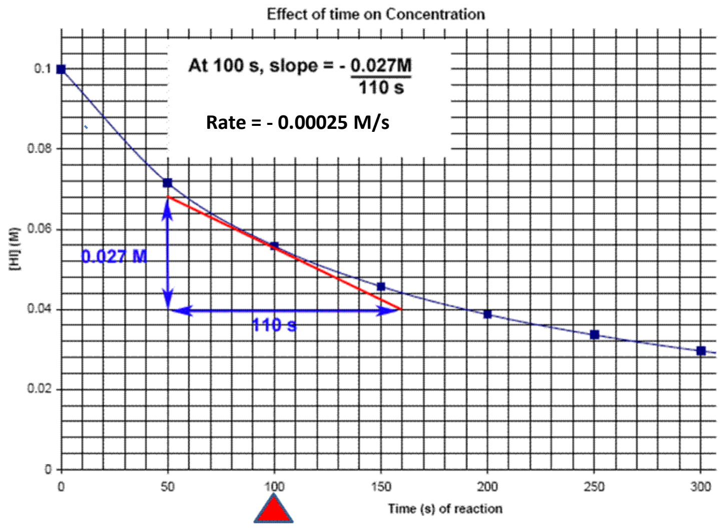
Most graphs in real life are not straight lines, but curves; however it is still useful to know how the quantity changes over time, hence we still need to calculate gradients.

If we want to know the gradient at a particular point, firstly we need to draw a *tangent* to the curve at that point. A tangent is a straight line that follows the gradient at the required point. Once we have drawn the straight line tangent, its gradient can be calculated in exactly the same way as the previous page showed.

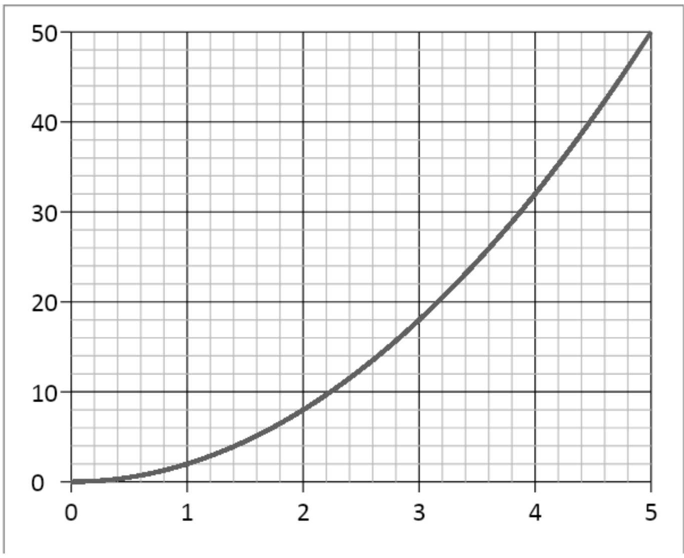
Tip – make sure your tangents and gradient triangles are as big as possible to be as accurate as you can!

Examples of drawing tangents and calculating the gradient of a tangent:

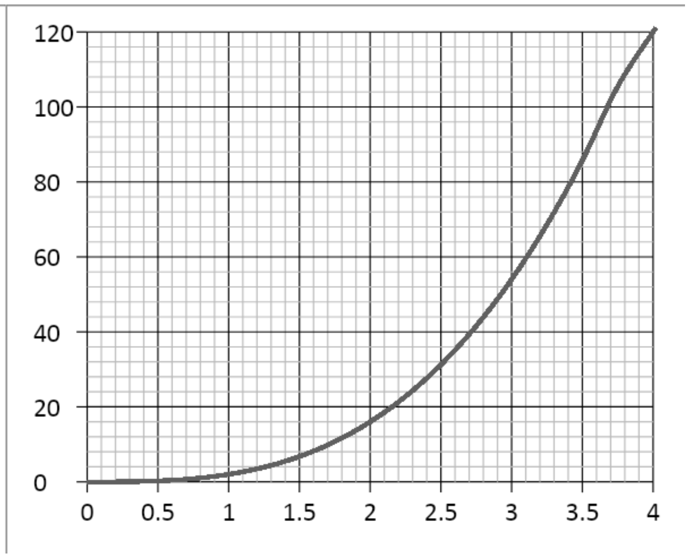




Draw a tangent to the line and calculate its gradient at the following x-axis values:



2.0 and 4.0



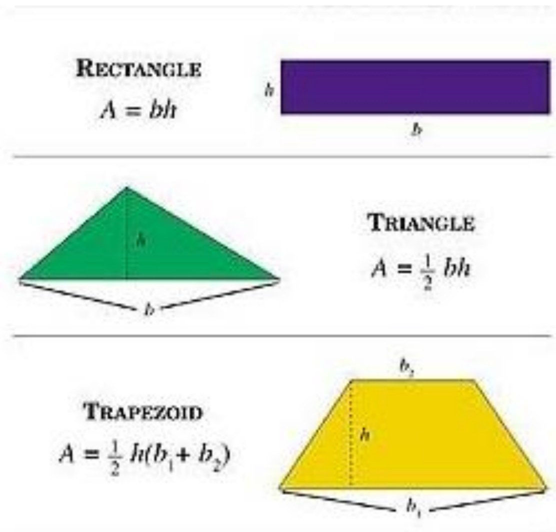
1.5 and 3.5

(Note - gradients in Physics often have units, this is something we will consider as we progress in the course)

AS Physics	11. Calculating Areas – Straight line Graphs
Skills	

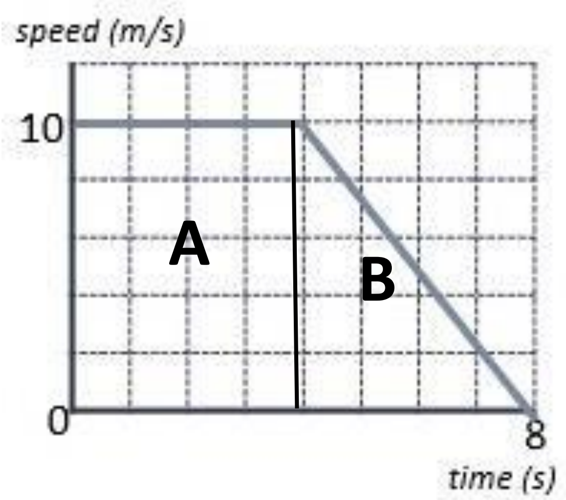
Often other quantities can be found by multiplying the two quantities represented on a graph together (for example, multiplying velocity and time gives distance travelled). The exact quantity can be found by calculating the area under the graph.

If the graph is made of straight lines, the total area can be found by splitting the graph into segments of rectangles and triangles (or into a trapezium) and adding those areas together.



Important – the heights that you use should always be the perpendicular height from the base.

Calculate the distance travelled by determining the area under the graph:



Area A = 10 x 4 = 40 m

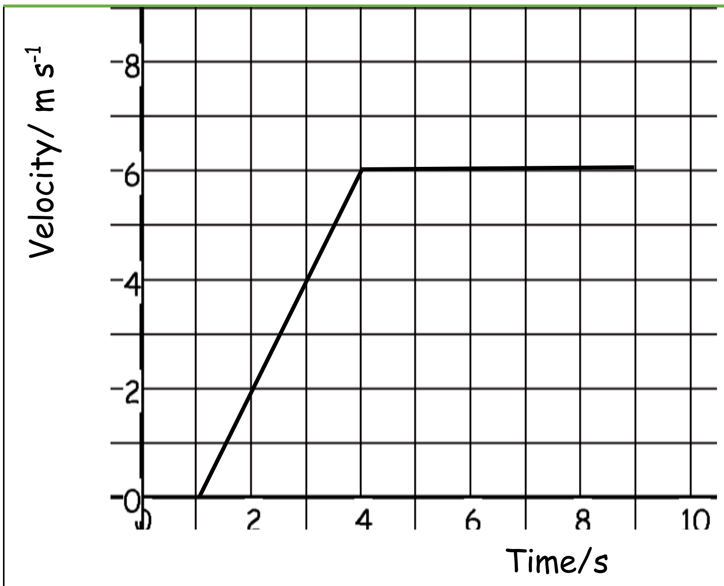
Area B = ½ x 4 x 10 = 20 m

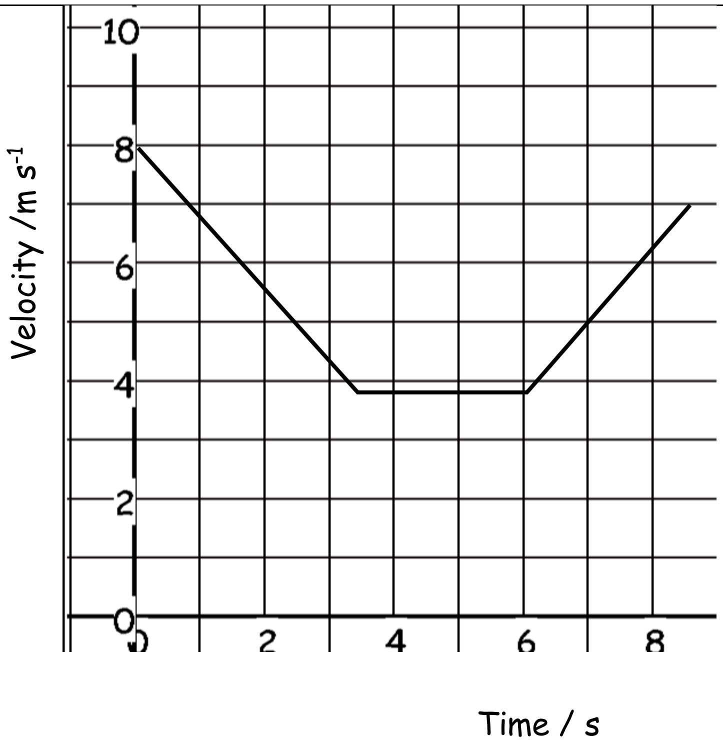
Total Area = A + B = 40 + 20 = **60 m**

Or

Area of trapezium = ½ (4 + 8) x 10 = **60 m**

Calculate the area of the below graphs and the correct unit for that area.



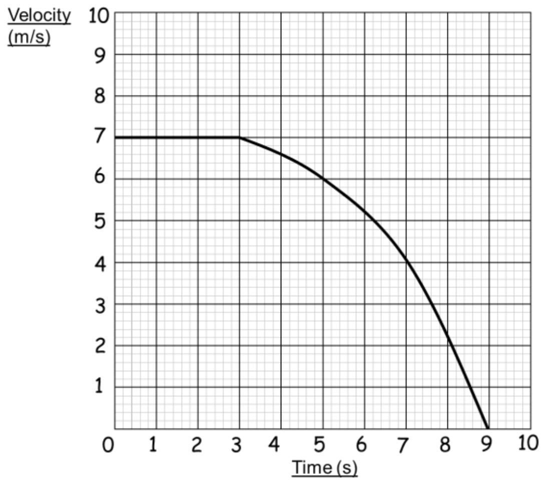


AS Physics	12. Calculating Areas – Curved line Graphs
Skills	

When graphs have curved lines we use a simple process of counting squares and estimating.

1) Calculate the area of 1 small (but the not smallest!) square on the graph
2) Count the number of whole squares under the line
3) Estimate the whole number of squares that have been segmented by the line.
4) Multiply the total number of squares by the area of one square to estimate the area.

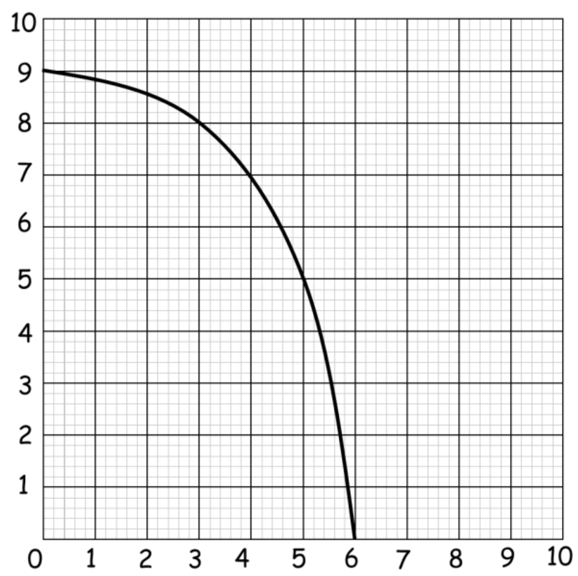
Eg. Work out the distance travelled by calculating the area under the graph.



1) 1 square = 1 m s^{-1} x 1 s = 1 m
2) Whole Squares = 44
3) Segmented squares = 4
4) 48 squares x 1 m = **<u>48 m</u>**

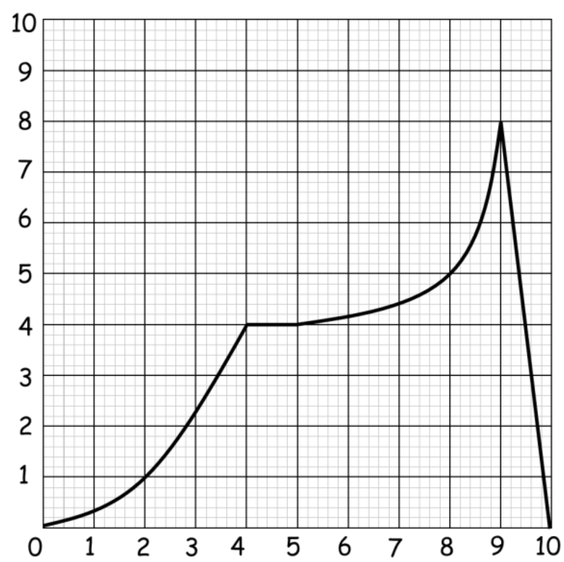
Calculate the area under the following graphs.

velocity/m s^{-1}



time /s

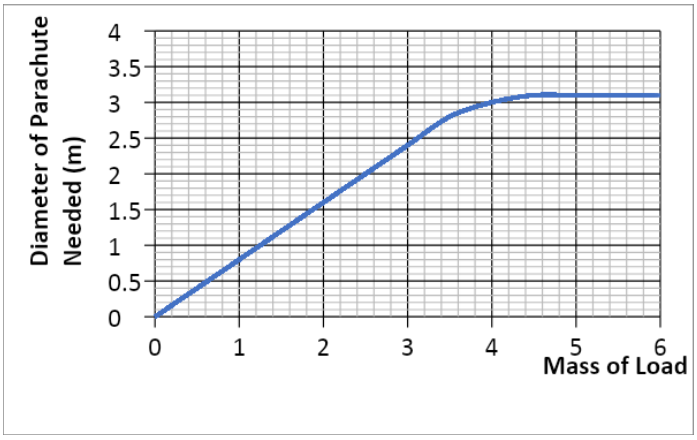
velocity/ km s^{-1}



time /min

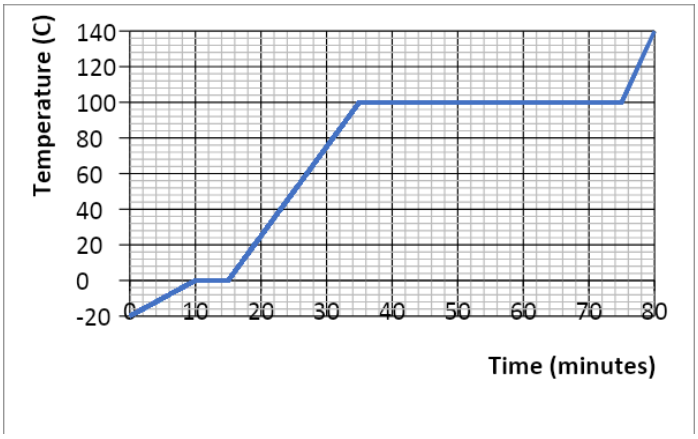
When interpreting graphs that are worth more than 2 marks, you need to go into more detail describing how the gradient changes over time and pick specific values to help support your answer.

Tips:
Use the quantities on the axes to support your answer.
Are there any points where the y value doesn't change? What is this value? When does this happen on the x axis?
Are there any maximum or minimum values? What are they? When do they occur?
The gradient increases/decreases at a constant/increasing/decreasing rate….
Does the gradient represent anything (eg. velocity or acceleration)?
Are there multiple gradients? Are some steeper than others?



As the mass of the load increases, the diameter of the parachute needed also increases at a constant rate. This occurs to a mass of 3.4kg (which gives a diameter of 2.8m), where the gradient increases at a decreasing rate until the diameter remains constant at 3.1m for any load beyond 4.4kg.

Describe in detail each graph. Write your answer at the side of each graph. Include the points mentioned under 'tips' in your answers.



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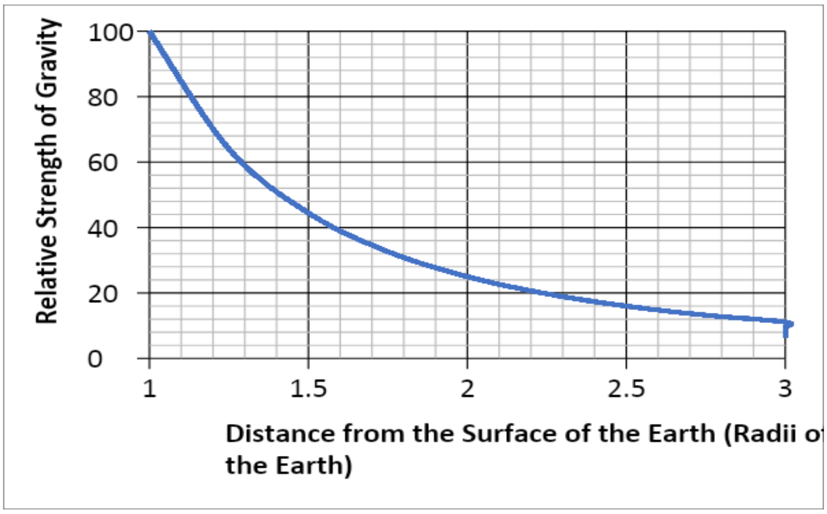
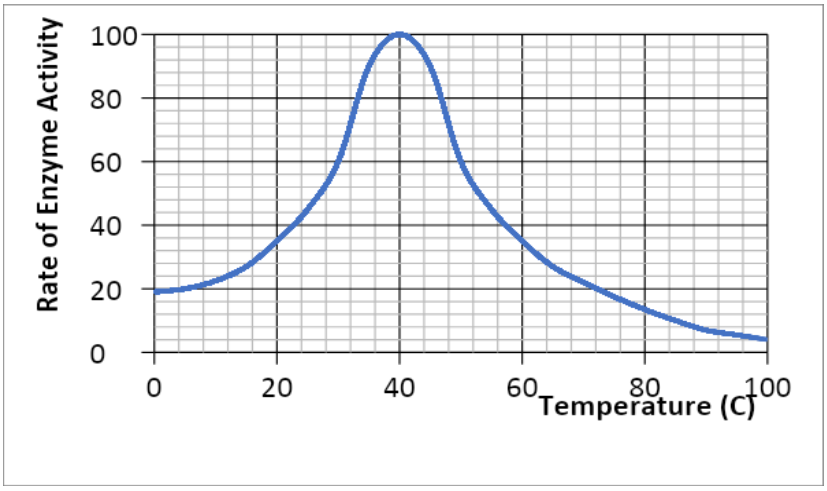
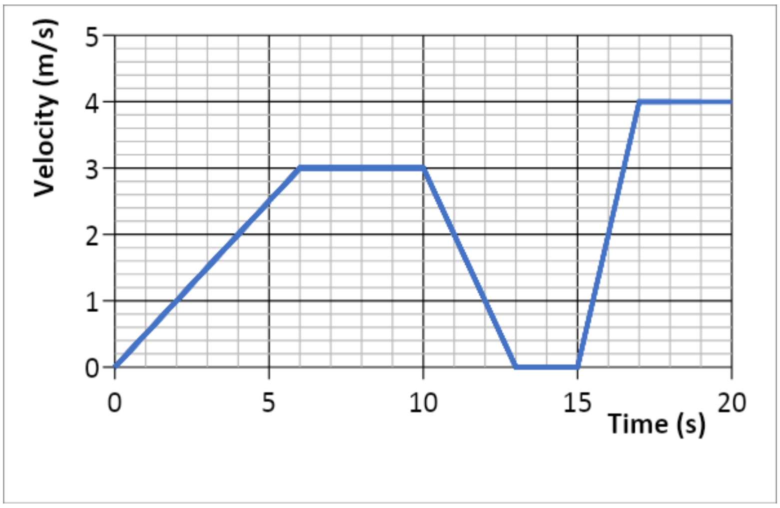


Relative Strength of Gravity
100
80
60
40
20
0
1
1.5
2
2.5
3
Distance from the Surface of the Earth (Radii of the Earth)



Rate of Enzyme Activity
100
80
60
40
20
0
0
20
40
60
80
100
Temperature (C)



Velocity (m/s)
5
4
3
2
1
0
0
5
10
15
20
Time (s)

14. Accuracy, Precision, Resolution

An ***accurate*** result is one that is judged to be close to the true value. It is influenced by random and systematic errors.

The true value is the value that would be obtained in an ideal measurement.

A ***precise*** measurement is described when the values 'cluster' close together. We describe measurements as precise when repeated values are close together (consistent). It is influenced by random effects.

Resolution is the smallest change in the quantity being measured that causes a perceptible change in the output of the measuring device. This is usually the smallest measuring interval. It does not mean a value is accurate.

Uncertainty is variation in measured data and is due to random and systematic effects. We usually assume the uncertainty is the same as the resolution of the measuring instrument.
example ruler, resolution +/- 1 mm so uncertainty is also +/- 1 mm
Stop watch used by a pupil, resolution +/- 0.01 s but uncertainty estimated as +/- 0.2 s due to human reaction time.
For our exam we estimate uncertainty and as long as you have a sensible justification your answer will be ok.

Eg. The true temperature of the room is 22.4 ℃. One thermometer gives a reading of 22 ℃ and another gives a reading of 23.4 ℃ . Which is most accurate and estimate its uncertainty?

23.4 ℃ has the best resolution but is not close to the correct value.
22 ℃ has less resolution but is more accurate as it is closer to the correct result.
The uncertainty in this reading is 22 +/– 1 ℃

Example
Isabelle is finding the mass of an insect, but the insect moves while on the electronic balance.

She records a set of readings as 5.00 mg , 5.01 mg, 4.98 mg, 5.02 mg.
The true value of the insect's mass is 4.5 mg.
Calculate an average value with estimated uncertainty for her results and compare this value with the true value using the terms above.

15. Identifying Errors

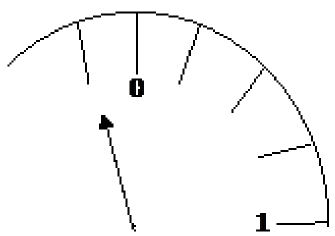
There are two main types of error in Science:

1) Random error
2) Systematic error

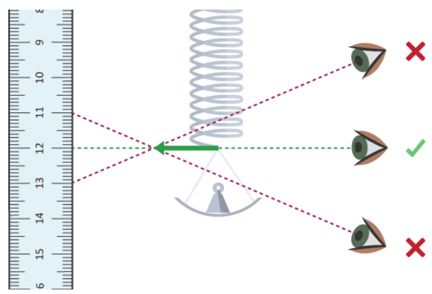
Random errors can be caused by changes in the environment that causes readings to alter slightly, measurements to be in between divisions on a scale or observations being perceived differently by other observers. These errors can vary in size and can give readings both smaller and larger than the true value.
The best way to reduce random error is to use as large values as possible (eg. Large distances) and repeat and average readings, as well as taking precaution when carrying out the experiment.

Systematic errors have occurred when all readings are shifted by the same amount away from the true value.
The two main types of systematic error are:

i) *Zero error* – this is where the instrument does not read zero initially and therefore will always produce a shifted result (eg. A mass balance that reads 0.01g before an object is placed on it). Always check instruments are zeroed before using.
ii) *Parallax error* – this is where a measurement is not observed from eye level so the measurement is always read at an angle producing an incorrect reading. Always read from eye level to avoid parallax.



Zero Error



Parallax Error

Repeat and averaging experiments will not reduce systematic errors as correct experimental procedure is not being followed.

There are occasions where readings are just measured incorrectly or an odd result is far away from other readings – these results are called **anomalies**. Anomalies should be removed and repeated before used in any averaging.

For each of the measurements listed below identify the most likely source of error what type of error this is and one method of reducing it.

Measurement	Source of error	Type of error
A range of values are obtained for the length of a copper wire		
The reading for the current through a wire is 0.74 A higher for one group in the class		
A range of values are obtained for the rebound height of a ball dropped from the same start point onto the same surface.		
A few groups obtain different graphs of resistance vs light intensity for an LDR. A light bulb placed at different distances from the LDR was used to vary the light intensity.		
The time period (time of one oscillation) of a pendulum showing a range of values		

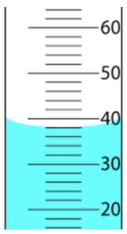
AS Physics	# 16. Improving Experiments – Accuracy, Resolution and Reliability
Skills	

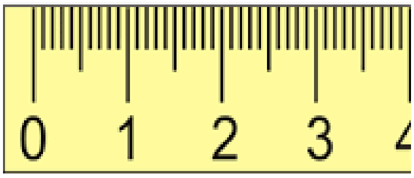
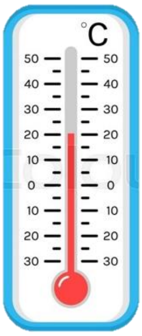
When improving **accuracy**, you must describe how to make sure your *method* obtains the best results possible. You should also try to *use as large quantities as possible as this reduces the percentage error in your results*. Also make your range as large as possible, with small intervals between each reading.

Resolution refers to the smallest scale division provided by your measuring instrument, or what is the smallest non-zero reading you can obtain from that instrument.

Reliability refers to how 'trustworthy' your results are. You can improve reliability by repeating and averaging your experiment, as well as removing anomalies.

Complete the table below to state how to use the measuring instruments as accurately as possible, as well as stating the precision (smallest scale division) of each instrument.

Measuring Instrument	**Accuracy** What procedures should you use to ensure you gain accurate results?	**Resolution** State the resolution of the instruments shown in the diagram.
Measuring Cylinder  		
Top Pan Electronic (Mass) Balance  		

Measuring Instrument	**Accuracy** What procedures should you use to ensure you gain accurate results?	**Precision** State the precision of the instruments shown in the diagram.
Ruler 		
Thermometer 		

Research and describe a method to determine the thickness of one sheet of A4 paper accurately. You may only use a mm ruler. You should also refer to the precision and reliability of your result.

AS Physics	# 17. Describing Experiments
Skills	

Variables *– Which variables will you keep the same and which will you change?*
Instruments *– What measuring instruments will you use and how will you take the measurements?*
Range *– Give specific values for the range and intervals you will use. Make sure your range is large with small intervals.*
Analyse *– State any equations you will use and what graph you will plot including the axes.*
Accuracy *– State ways you are being accurate with your measuring instruments.*
Reliability *– State "Repeat and average" to improve reliability*

Using the steps above, describe how to carry out the following experiments below:

e.g.
Water is placed in a plastic tray, one end it raised, dropped and the speed of the water wave is measured. A student suggests that the speed of the wave depends on the height of the water in the tray. How could you prove this?

Change the depth of water by filling the tray to different heights. The height of the water will be measured by placing a ruler into the tray. Depths from 1.0 to 5.0 cm, at 1.0 cm intervals should be used.
The tray should be lifted to the same height each time and dropped without pushing it down. The height the tray is lifted to should also be measured with a ruler that is vertical using a set square.
When the tray hits the table, the time should be measured for the wave to pass end to end 4 times, then divided by 4 to make the reading more accurate to reduce reaction time. The time should be measured using a stopwatch.
The length of the tray should be measured using a ruler, overhead and measured at eye level for accuracy.
The equation speed = distance / time should be used to calculate the speed of the wave.
Repeat each height and average to improve reliability.
Plot a graph of speed (y axis) vs depth of water (x axis) to see if there is a relationship between the two variables.

Question. A student suggests that if an egg was dropped from different heights the area of splatter would increase as the height increases but only until a certain point. How could you investigate this?

AS Physics	# 18. Appendix 1- Solutions
Skills	

Topic 1

54×10^6 0.086×10^{-6} 753×10^9 23.87×10^{-3}

0.5 μm 93.09 Gm 3 200 kN 2.4 nm

s	ms	µs	ns	ps
0.00045	0.45	450	450 000 or 450×10^3	450×10^6
0.000000789	0.000789	0.789	789	789×10^3
0.000 000 000 64	0.000 000 64	0.000 64	0.64	640

mm	m	km	µm	Mm
1287360	1 287.360	1.28 7360	1 287 360 000	0. 001 287 360
295	0.295	0.000 295	295 000	0 .000 000 295

2. $v = f\lambda = 0.25 \times 10^6 \times 5.6 \times 10^{-6} = 1400$ m s^{-1}

3. $\lambda = v/f = 330 / 3.0 \times 10^9 = 1.1 \times 10^{-7}$ m

4. $f = v/\lambda = 300 \times 10^6 / 0.050 \times 10^{-3} = 6.0 \times 10^{12}$ Hz = 6.0 THz

5. $f = v/\lambda = 300 \times 10^6 / 6.0 \times 10^{-2} = 5.0 \times 10^9$ Hz = 5.0 GHz

Topic 2

Value	Sig Figs	Value	Sig Figs	Value	Sig Figs	Value	Sig Figs
2	1	1066	4	1800.45	7	0.070	2
2.0	2	82.42	4	2.483×10^4	4	69324.8	6
500	1	750000	2	0.0006	1	0.0063	2
0.136	3	310	2	5906.4291	8	9.81×10^4	3
0.0300	3	3.10×10^4	3	200000	1	40000.00	7
54.1	3	3.1×10^2	2	12.711	5	0.0004×10^4	1

Value 1	Value 2	Value 3	Total Value	Total to correct sig figs
51.4	1.67	3.23	56.3	56.3
7146	–32.54	12.8	7126.26	7126
20.8	18.72	0.851	40.371	40.4
1.4693	10.18	–1.062	10.5873	10.59
9.07	0.56	3.14	12.77	12.77
739762	26017	2.058	765781.058	765781
8.15	0.002	106	114.152	114
152	0.8	0.55	153.35	153

Value 1	Value 2	Total Value	Total to correct sig figs
0.91	1.23	1.1193	1.1
8.764	7.63	66.86932	66.9
2.6	31.7	82.42	82
937	40.01	37489.37	37 500
0.722	634.23	457.91406	458

Value 1	Value 2	Total Value	Total to correct sig figs
5.3	748	7.085561×10^{-3}	7.1×10^{-3}
3781	6.50	581.6923077	582
91×10^{2}	180	50.55555555556	51
5.56	22×10^{-3}	252.727272727	250
3.142	8.314	0.37791677	0.3779

Value 1	Value 2	Value 3	Mean Value	Mean to correct sig figs
1	1	2	1.3333	1
435	299	437	436	436
5.00	6.0	29.50	5.50	5.5
5.038	4.925	4.900	4.9543333333	4.954
720.00	728.0	725	724.3333333333	724
0.00040	0.00039	0.000380	0.000380	0.00038
31	30.314	29.7	30.338	30

Topic 3

6 m^2	=	60 000 cm^2
0.002 m^2	=	2000 mm^2
24 000 cm^2	=	2.4 m^2
46 000 000 mm^3	=	0.046 m^3
0.56 m^3	=	560 000 cm^3

750 mm^2	=	0.00075 m^2
5×10^{-4} cm^3	=	5.0×10^{-10} m^3
8.3×10^{-6} m^3	=	8300 mm^3
3.5×10^2 m^2	=	3.5×10^6 cm^2
152000 mm^2	=	0.152 m^2

31×10^8 m^2	=	3100 km^2
59 cm^2	=	5900 mm^2
24 dm^3	=	24000 cm^3
4 500 mm^2	=	45 cm^2
5×10^{-4} km^3	=	500 000 m^3

A 2.0 m long solid copper cylinder has a cross-sectional area of 3.0×10^2 mm^2. What is its volume in cm^3?

h= 2.0 m = 2.0×10^2 cm csa = 3.0 cm^2

V = cross-section area x height = $2.0 \times 10^2 \times 3.0$= 600

Volume = ______600 cm^3

5 N cm^{-2}	=	50 000 N m^{-2}
1150 kg m^{-3}	=	(1150 x1000 / 100x100x100) = 1.15 g cm^{-3}
3.0 m s^{-1}	=	(3.0 /1000) x (60x60) = 10.8 km h^{-1}
65 kN cm^{-2}	=	650 N mm^{-2}
7.86 g cm^{-3}	=	7860 kg m^{-3}

Topic 4

$R = V/I$ $t = Q/I$ $A = \rho L/A$ $r = (\varepsilon - V)/I$

$u = 2s/t - v$ $f = (\Phi + E_K)/h$ $g = E_{P,}/ mh$ $F = 2E/e$

$u = \sqrt{(v^2 - 2as)}$ $m = T^2 k/ 4\pi^2$

Topic 5

Case study 1

IV Mass of sphere DV time to fall a set distance CV drop distance, diameter of sphere

IV continuous graph - line graph

Case Study 2

IV types of activities DV number of children CV time of day and day of the week

IV categoric / discrete graph bar chart

Case study 3

IV Value of mass (g) DV length of spring CV same spring, spring stationary when measured

IV continuous graph line

Case study 4

IV number of blades DV output potential difference

CV same dist from fan, constant fan output, same blade design

IV discrete graph bar chart

Topic 6.

Pd across resistor/V	Current through the resistor/A			
	I_1	I_2	I_3	$I_{average}$
1.0	0.11	0.10	0.12	0.11
2.0	0.21	0.18	0.24	0.21
3.0	0.33	0.60	0.30	0.32
4.0	0.35	0.40	0.45	0.40
5.0	0.50	5.10	0.48	0.49

Topic 7

1. Straight line positive gradient , constant
2. Curve, negative gradient, steep then getting shallower
3. Straight line, negative gradient, constant
4. Straight line positive gradient, constant
5. Curve , positive gradient, decreasing
6. Curve, positive gradient, increasing.

Topic 8

Use S L A P U (5 mark) criteria. Graphs will be reviewed in the new term.

Topic 9

Show construction lines on your graphs.

1. m = 124-0/50-0 = 2.5
2. m = 22.5 -2.0/5.0-0 = 4.1
3. m= 112 - 42/11-4 = 10
4. m = 0.07-0.14/24-17 = -0.01

Topic 10.

Construction lInes need to be drawn on graphs for the full method.

1. Gradient at point 2.0 m= 22-0/4-0 = 5.5 gradient at point 4.0 m= 46-0/5.0-1.8 = 14.4
2. Gradient at point 1.5 m= 424-0/4-1 = 14.7 gradient at point 3.5 m= 116-0/4-2 = 58

Topic 11- always show a full method with your solutions.

Top graph area = 39 m Bottom graph area = 33 +/- 1 m (to 2 sig fig)

Topic 12. All values approximate, your estimate should be within quoted error.
Left hand graph- 41 squares each square 1 m s^{-1} x 1 s = 1 m area = 41 m +/- 1 m

Right hand graph 31 squares each square 1 km s^{-1} x 60 s = 60 km area = 1860 km +/- 60 km

Topic 13.

Graph 1- 0-10 minutes temperature rises at a constant rate from -20 ^{0}C to 0 ^{0}C of 2 ^{0}C min^{-1}.
Ice gaining thermal energy.
10-15 minutes temp is constant at 0 ^{0}C as a change of state occurs; solid to liquid.
15- 35 minutes temp rises at 5 ^{0}C min^{-1}, constant rate because gradient is constant.
35-75 minutes temp constant at 100 ^{0}C, change of state ; liquid to gas.
75-80 minutes rapid increase in temp, gradient steepest 8 ^{0} min^{-1}, gas phase.
(values are expected from the graph as is suitable theory; you are expected to recognise graphs).

Graph 2.
As the distance increases from Earth the (relative) value of g decreases. Large decrease initially seen by steep gradient with gradient decreasing as distance increases.
Taking values from graph:
relative dist 1.0, relative g =100 relative dist 2.0, relative g =25, double d , g drops by 4
relative dist 1.5, relative g = 44 relative dist 3.0, relative g =11, double d, g drops by 4
We are always looking for patterns in data, gradients, areas or values such as above.

In this case doubling the distance drops g by a factor of 4; called the inverse square law.
This is a very important law in Physics

Graph 3.
Section 1 At 0 ^{0}C activity low at 20 units (no units given so we use **units** as a term) rising to a max activity of 100 units at 40 ^{0}C.

Section 2 From peak at 40 ^{0}C activity rapidly drops to a low of 4 units at 100 ^{0}C.

Optimum activity is at 40 +/- 4 ^{0}C

Graph 4. 6- sections (only 2 described you need to write a description for all sections)

Section 1 - Constant acceleration of 3/6=0.5 m s^{-2} for 6 seconds, covering a displacement from the start point of (3 x 6)/2 = 9m
Section 2 - constant velocity of 3 m s^{-1} for 4 seconds covering a displacement of 3 x 4 = 12m

<u>Topic 14.</u>

Average mass = 20.01/4 = 5.00 +/- 0.01g (uncertainty is +/- the resolution of instrument)

Recorded values are precise as the repeat readings are close together but they are not accurate because the average value does not equal the true value. Do not confuse resolution with precise.

There is possibly a zero error on the balance as all the recorded values are above the true value by a similar amount.

Topic 15

Measurement	Source of error	Type of error
A range of values are obtained for the length of a copper wire	RULER measuring length of wire	RANDOM
Reduce this error by ensuring the wire is laid out straight, place the rules directly next to the wire, take repeat readings, remove anomalous readings and calculate an average length for the wire		
The reading for the current through a wire is 0.74 A higher for one group in the class	Ammeter	SYSTEMATIC
Zero error in the ammeter. Check reading before any current flows in the circuit. Subtract zero error reading from each value or calibrate/adjust ammeter to read zero.		
A range of values are obtained for the rebound height of a ball dropped from the same start point onto the same surface.	Ruler / person measuring rebound height	RANDOM SYSTEMATIC
RANDOM because person recording the height looks at the rule from different positions and or doesn't use same part of ball to record max height. SYSTEMATIC because rule might have a zero error. Solution- put graph paper scale on a screen behind the ball. Drop the ball close to the screen and record the fall in slo-mo using a camera (smart phone). Analyse the play back to get accurate values.		
A few groups obtain different graphs of resistance vs light intensity for an LDR. A light bulb placed at different distances from the LDR was used to vary the light intensity.	Additional light sources in the room	SYSTEMATIC
Some groups may be near a window which will allow extra light onto the measuring equipment beyond that from the light bulb used in the initial experiment. Reduce error by using proper black out curtains and switch off additional light sources while taking readings or cover the apparatus with blackout material.		
The time period (time of one oscillation) of a pendulum showing a range of values	Timing the oscillation	Random
Time 20 oscillations and divide by 20. Use a fiducial mark (pin as a point of reference) to help determine the point of one complete oscillation while counting the 20 oscillations. Release the pendulum at the same amplitude- should be a small angle of about 15^0 from vertical.		

Topic 16

Measuring cylinder - Read the volume of water from the bottom of the meniscus and perpendicular to the scale to reduce parallax error. resolution/error +/- 2 ml

Top pan electronic balance - Ensure balance is zeroed before any reading are taken.
Make sure paper is not touch surfaces either side of the active top pan measuring surface.

Ensure no breeze or external forces are acting on the top pan.

resolution/error +/- 0.01g

Ruler - Place the ruler adjacent to the object being measured to reduce parallax error.
Make sure zero is placed at the start of the object being measured.

Ensure ruler is parallel to the measured surface.

resolution/error +/- 1 mm

Thermometer - Read the top of the active liquid and perpendicular to the scale to reduce parallax error.
resolution/error +/- 2^0C (estimate, we should be better than +/- 5^0C increments shown on the scale) .

Topic 17.

Some pointers.
Produce an equipment list; think of key/essential equipment .
IV height egg dropped from, m
DV diameter of splatter, m (area, m^2 , calculated from this value, we don't calculate the area directly)
CV size of egg, type of surface the egg is dropped onto.
Range of IV 0.50 to 4.00 m in 0.50 m increments.
Give a suitable table with heading /units
Graph plotted of height egg dropped (m) on x-axis v area of splatter (m^2)
Add more detail to your method and hand in with the rest of the notes.
Your method should be detailed enough to be followed and the experiment carried out.

You are expected to know most of these letters.
The letters we will not use at A level are zeta, chi, psi, iota, kappa, xi, omicron.

Greek alphabet list

Upper Case Letter	Lower Case Letter	Greek Letter Name	Upper Case Letter	Lower Case Letter	Greek Letter Name	Upper Case Letter	Lower Case Letter	Greek Letter Name
Α	α	Alpha	Ρ	ρ	Rho	Ι	ι	Iota
Β	β	Beta	Σ	σ,ς *	Sigma	Κ	κ	Kappa
Γ	γ	Gamma	Τ	τ	Tau	Λ	λ	Lambda
Δ	δ	Delta	Υ	υ	Upsilon	Μ	μ	Mu
Ε	ε	Epsilon	Φ	φ	Phi	Ν	ν	Nu
Ζ	ζ	Zeta	Χ	χ	Chi	Ξ	ξ	Xi
Η	η	Eta	Ψ	ψ	Psi	Ο	ο	Omicron
Θ	θ	Theta	Ω	ω	Omega	Π	π	Pi
						Ρ	ρ	Rho

<u>Note.</u>

The second lower case symbol for sigma is used at the end of Greek words and not in our equations.

<u>TASK.</u> Write out the Greek letters that you have used in physics and mathematics.
Can you find other letter you have not used yet? If so write them out.
We often use the upper and lower case letters so learn both.

Using SI units

Specification references

- *3.1.1 Use of SI units and their prefixes*
- *M0.1 Recognise and make use of appropriate units in calculations*

Maths Skills for Physics references

- *1.1 Units and dimensions*

Learning objectives

After completing the worksheet you should be able to:

- show knowledge and understanding of base and derived SI units
- use equations to work out derived units
- use base units to check homogeneity of equations.

Introduction

Base quantities are measured in base units. These are units that are not based on other units. For example, mass is measured in kilograms and length is measured in metres. Other quantities have units which are derived from the base quantities. For example, the unit of density ($kg\,m^{-3}$) is derived from the kilogram and the metre.

The first example shows you how to use an equation to work out the unit of a derived quantity. The second example shows you how to check that an equation is homogeneous or, in other words, that its units are balanced.

Worked example

Question

What is the SI unit of speed?

Answer

Step 1

Identify the equation to use.

Speed is defined as: $\dfrac{\text{distance travelled}}{\text{time taken}}$

Step 2

Write the equation in terms of units.

The SI unit of speed is defined as: $\dfrac{\text{unit of distance travelled}}{\text{unit of time taken}}$

Step 3

Select the appropriate SI base units.

SI unit of distance = metre (m)

SI unit of time = second (s)

Step 4

Insert the SI base units into the equation.

SI unit of speed = $\frac{\text{metre (m)}}{\text{time taken (s)}}$ = metre per second = m s^{-1}

Question

1 Work out the missing units, unit symbols and names, equations, and quantities in this table. (*1 mark* for each correct answer)

Physical quantity	Equation used	Unit	Derived unit symbol and name
frequency	$\frac{1}{\text{time period}}$	**a**	Hz hertz
volume	length^3	**b**	–
acceleration	$\frac{\text{velocity}}{\text{time}}$	**c**	–
force	mass × acceleration	kg m s^{-2}	**d**
work and energy	force × distance	**e**	J joule
potential difference	$\frac{\text{energy}}{\text{electric charge}}$	J C^{-1}	**f**
electrical resistance	**g**	V A^{-1}	**h**
momentum	mass × velocity	**i**	–
impulse	force × time	**j**	–
k	$\frac{\text{force}}{\text{area}}$	**l**	Pa pascal
m	**n**	kg m^{-3}	–

Worked example

Question

Check that the equation: kinetic energy = $\frac{1}{2} m v^2$ is homogeneous.

Answer

Make sure you always state which side of the equation you are working on, left-hand side (LHS) or right-hand side (RHS).

Step 1

Start with the LHS. The unit of kinetic energy is the joule. Change this to base units.

LHS: $\mathrm{J = N\,m = kg\,m\,s^{-2} \times m = kg\,m^2\,s^{-2}}$

Step 2

Repeat Step 1 for the RHS.

RHS: units of $\frac{1}{2} m v^2$ are $\mathrm{kg \times (m\,s^{-1})^2 = kg\,m^2\,s^{-2}}$

(The constant, $\frac{1}{2}$, is a number with no units.)

Step 3

Don't forget to write your conclusion.

LHS = RHS so the equation is homogeneous.

We can't tell that there is a $\frac{1}{2}$ in the equation, so we cannot say that the equation is correct, only that it is homogeneous.

Questions

2 Use base units to show the equation $Q = I\,t$ for electric charge passing a point in time t, when the electric current is I, is homogeneous. (*1 mark*)

3 Use base units to show that the equation $P = I\,V$ is homogeneous, where I is electric current, V is voltage, and P is power measured in watts (W). (Hint: $\mathrm{1\,W = 1\,J\,s^{-1}}$) (*2 marks*)

4 The Earth's gravitational field strength, $g = 9.81\,\mathrm{N\,kg^{-1}}$, is also sometimes given as the acceleration due to gravity, $g = 9.81\,\mathrm{m\,s^{-2}}$. Show that these units are equivalent. (*1 mark*)

Maths skills links to other areas

You may also need to check equations are homogeneous wherever they are used in the specification – examples can be found in Chapter 7 *On the move*, and Topic 11.1 *Density*.

You can also use this method to help you decide whether you have remembered an equation correctly.

Answers

1 **a** s^{-1} (*1 mark*)

b m^3 (*1 mark*)

c $m\,s^{-2}$ (*1 mark*)

d N newton (*1 mark*)

e $kg\,m^2\,s^{-2}$ (allow N m, remind students that this is a derived unit) (*1 mark*)

f V volt (*1 mark*)

g $\frac{\text{voltage}}{\text{current}}$ (*1 mark*)

h Ω ohm (*1 mark*)

i $kg\,m\,s^{-1}$ (*1 mark*)

j N s (*1 mark*)

k pressure (*1 mark*)

l $N\,m^{-2}$ (*1 mark*)

m density (*1 mark*)

n $\frac{\text{mass}}{\text{volume}}$ (*1 mark*)

2 LHS: C = A s

RHS: A s

LHS = RHS (*1 mark*)

3 LHS: $W = J\,s^{-1} = kg\,m^2\,s^{-3}$ (*1 mark*)

RHS: $A \times V = A \times J\,C^{-1} = A \times kg\,m^2\,s^{-2} \times (A\,s)^{-1} = A \times kg\,m^2\,s^{-2} \times A^{-1} \times s^{-1} = kg\,m^2\,s^{-3}$ (*1 mark*)

LHS = RHS

4 $N\,kg^{-1} = kg\,m\,s^{-2} \times kg^{-1} = m\,s^{-2}$ (*1 mark*)

Linear motion

Specification references

- *3.4.1.3*
- *M2.2 Change the subject of an equation, including non-linear equations*
- *M2.4 Solve algebraic equations, including quadratic equations*
- *M3.3 Understand that $y = mx + c$ represents a linear relationship*

Maths Skills for Physics references

- *3.3 Motion 3*

Learning outcomes

After completing the worksheet you should be able to:

- demonstrate an understanding of, and select and apply, the following equations:
  - $s = \frac{1}{2}(u + v)t$
  - $v = u + at$
  - $s = ut + \frac{1}{2}at^2$
  - $v^2 = u^2 + 2as$

  where s = displacement, u = initial velocity, v = final velocity, a = acceleration, and t = time
- understand that in free fall under gravity, objects fall with a constant acceleration, g, when air resistance is negligible.

Introduction

You do not have to memorise the equations of motion, sometimes referred to as the *suvat* equations. It is useful to know them, but always check the data sheet if you are not sure. The acceleration of free fall, g, will be provided on the data sheet so you should always use the value provided ($g = 9.81\ \mathrm{m\ s^{-2}}$) unless the question tells you otherwise. You will lose marks for approximating it to $10\ \mathrm{m\ s^{-2}}$.

When you are solving a problem:

- write down the values you know and the ones you want to calculate
- choose the equation and substitute all the values into it
- rearrange the equation and calculate the answer.

Worked example

Question

A student throws a ball vertically upwards at $5\ \mathrm{m\,s^{-1}}$. When it comes down, the student catches it at the same point.

a Calculate the height the ball reaches.

b Calculate the length of time the ball is airborne.

Answer

a *Step 1*

Write down the values of u, s, v, a, and t that you know and those that you want to find.

You know $v = 0$ because as the ball rises it will slow down, until it comes to a stop and then it will start falling downwards. So when $v = 0$, the ball is at its maximum height.

Values are: $u = 5.0\ \mathrm{m\,s^{-1}}$, $s = ?$, $v = 0$, $a = g = -9.81\ \mathrm{m\,s^{-2}}$

Step 2

Use what you have written to choose the equation with just these variables.

In this case there is no t, so choose:

$$v^2 = u^2 + 2as$$

Step 3

Substitute the values, taking care to check the units (for example, in case distance is in km rather than m).

$0^2 = 5.0^2 + 2 \times -9.81 \times s$

$0 = 25 - 2 \times 9.81 \times s$

$0 = 25 - 19.62 \times s$

Step 4

Rearrange the equation so you can find s.

$19.62s = 25$

$s = \dfrac{25}{19.62} = 1.27\ \mathrm{m} = 1.3\ \mathrm{m}$ (2 significant figures)

b *Step 5*

At the starting point, $t = 0$ and $s = 0$. The ball travels upwards so that s increases to the maximum, then it starts falling and s decreases until $s = 0$ (because the ball has returned to its starting point). You want to find the time, t, at this point.

Write down the values of u, s, v, a, and t that you know and those that you want to find.

$u = 5.0\ \text{m s}^{-1}$, $s = 0\ \text{m}$, $a = g = -9.81\ \text{m s}^{-2}$, $t = ?$

Step 6

Use what you have written to choose the equation with just these variables.

In this case there is no v, so choose:

$$s = ut + \frac{1}{2}at^2$$

Step 7

Substitute the values, taking care with the units.

$$0 = (5.0\,t) + \frac{1}{2}(-9.81)\,t^2$$

$$0 = 5.0\,t - \frac{1}{2}(9.81)\,t^2$$

$$0 = t\,(5.0 - 0.4905\,t)$$

(Notice that one solution is $t = 0$, because at the start when $t = 0$ the ball is at the starting point, $s = 0$. The other solution for t is at the end when the ball returns to the starting point, $s = 0$.)

The other solution, at the end, is given by:

$$5.0 = 0.4905\,t$$

Step 8

Calculate t.

$$t = \frac{5.0}{0.4905} = 1.02\ \text{s} = 1.0\ \text{s (2 significant figures)}$$

Questions

1 A racing car travelling at $13\ \text{m s}^{-1}$ accelerates at $4.0\ \text{m s}^{-2}$ for 9.0 s. What is its final speed? (*2 marks*)

2 A car travelling at $28\ \text{m s}^{-1}$ slows down and stops in 75 m. Calculate the acceleration, assuming it is constant. (*2 marks*)

3 A stone is dropped down a dry well. It is heard to hit the bottom after 2.9 s. How deep is the well? (*2 marks*)

4 A rollercoaster accelerates from 0 to 27 m s^{-1} in 2.8 s. Calculate:

- **a** the acceleration (*2 marks*)
- **b** the distance travelled while accelerating. (*2 marks*)

5 A stone is dropped over the edge of a cliff and at the same time a small ball is fired vertically up in the air from the same height, with velocity 10 m s^{-1}, so that it falls and hits the beach next to the stone. The cliff is 100 m high. Calculate:

- **a** the time for the ball to reach its maximum height (*2 marks*)
- **b** the maximum height above the cliff reached by the ball (*2 marks*)
- **c** the time for the ball to fall from this height to the beach (*2 marks*)
- **d** the time for the stone to fall to the beach (*2 marks*)
- **e** the time interval between the stone and the ball hitting the beach. (*2 marks*)

Maths skills links to other areas

You may also need to change the subject of an equation, solve algebraic equations, and understand that $y = mx + c$ represents a linear relationship, when plotting and interpreting suitable graphs from experimental results.

Answers

1 $v = u + a\,t$

$v = (13\text{ m s}^{-1}) + (4.0\text{ m s}^{-2})(9.0\text{ s})$ (*1 mark*)

$v = 49\text{ m s}^{-1}$ (*1 mark*)

2 $v^2 = u^2 + 2\,a\,s$

$0 = (28\text{ m s}^{-1})^2 + 2\,a\,(75\text{ m})$ (*1 mark*)

$a = -\dfrac{784}{150}\text{ m s}^{-2} = -5.2\text{ m s}^{-2}$ (*1 mark*)

3 $s = u\,t + \dfrac{1}{2}a\,t^2$

Taking upwards as positive, $s = (0)(2.9\text{ s}) + \dfrac{1}{2}(-9.81\text{ m s}^{-2})(2.9\text{ s})^2$ (*1 mark*)

$s = -41$ m (41 m downwards) (*1 mark*)

Allow: taking down as positive: $s = (0)(2.9\text{ s}) + \dfrac{1}{2}(9.81\text{ m s}^{-2})(2.9\text{ s})^2$ and $s = 41$ m

4 **a** $v = u + a\,t$

$27\text{ m s}^{-1} = 0 + a\,(2.8\text{ s})$ (*1 mark*)

$a = \dfrac{27}{2.8}\text{ m s}^{-2} = 9.6\text{ m s}^{-2}$ (*1 mark*)

b $s = \dfrac{1}{2}(u + v)\,t$

$s = \dfrac{1}{2}(0 + 27) \times 2.8$ (*1 mark*)

$s = 37.8\text{ m s}^{-1} = 38\text{ m s}^{-1}$ (2 significant figures) (*1 mark*)

5 **a** Taking upwards as positive, ball thrown up:
$t = ?$, $u = 10.0\text{ m s}^{-1}$, $v = 0$, $a = -g = -9.81\text{ m s}^{-2}$

$v = u + a\,t$

$0 = 10 - 9.81\,t$ (*1 mark*)

$t = \dfrac{10}{9.81} = 1.01\text{ s} = 1.0\text{ s}$ (2 significant figures) (*1 mark*)

b $s = ?$, $a = -g = -9.81\text{ m s}^{-2}$, $u = 10\text{ m s}^{-1}$, $v = 0$

$v^2 = u^2 + 2\,a\,s$

$0 = (10)^2 - 2\,(9.81)\,s$ (*1 mark*)

$s = \dfrac{2 \times 105.1}{9.81} = 5.096\text{ m} = 5.1\text{ m}$ (2 significant figures) (*1 mark*)

c Total distance fallen = 100 m + 5.1 m so s = –105.1 m

$a = -g = -9.81\ \text{m s}^{-2}$, $u = 0$, $t = ?$

$$s = ut + \frac{1}{2}at^2$$

$$-105.1 = (0)t - \frac{1}{2}(9.81)t^2$$ (*1 mark*)

$$t^2 = \frac{2 \times 105.1}{9.81}$$

$t = 4.63$ s = 4.6 s (2 significant figures) (*1 mark*)

Allow: taking downwards as positive if it is clear.

d Stone dropped: $u = 0$, final $s = -100$ m, $a = -g = -9.81\ \text{m s}^{-2}$

$$s = ut + \frac{1}{2}at^2$$

$$-100 = (0)t + \frac{1}{2}(-9.81)t^2$$ (*1 mark*)

$$t^2 = \frac{200}{9.81}$$

$t = 4.52$ s = 4.5 s (2 significant figures) (*1 mark*)

Allow: taking downwards as positive if it is clear.

e Time for stone to reach beach from part **d** = 4.5 s

Time for ball to reach beach = time to reach maximum height + time to fall

= answer from part **a** + answer from part **c**

= 1.0 s + 4.6 s = 5.6 s (2 significant figures) (*1 mark*)

Time interval = 5.6 – 4.5 s = 1.1 s (*1 mark*)

The photon model

Specification references

- *3.2.1.3 Particles, antiparticles and photons*
- *3.5.1.2 Basics of electricity*
- *M0.2 Recognise and use expressions in decimal and standard form*
- *M2.4 Solve algebraic equations*

Maths Skills for Physics references

- *6.1 The photoelectric effect*

Learning objectives

After completing the worksheet you should be able to:

- calculate the energy of a photon in joules or in electronvolts given its frequency or wavelength
- calculate the frequency and wavelength of photons with energy given in joules or in electronvolts
- convert energies from joules to electronvolts, and vice versa.

Introduction

In some situations, electromagnetic radiation behaves as discrete packets of energy called photons. The energy of a photon, E, is directly proportional to its frequency.

$E = h\,f$

where f is the frequency of the electromagnetic radiation in Hz and $h = 6.63 \times 10^{-34}$ J s (the Planck constant).

You know that the wave equation is $c = f\lambda$.

Substituting $f = \dfrac{c}{\lambda}$ into the wave equation gives:

$$E = \frac{hc}{\lambda}$$

The energy of an individual photon or electron is very small, so the electronvolt (eV) is often used as a unit instead of the joule.

When an electron is accelerated though a potential difference (pd) of 1 V, it has an energy of 1 eV. Its energy in joules is calculated using the equation for the work done on the electron.

$W = Q\,V$, where Q is the charge on the electron e.

$\therefore W = e\,V$, where $e = 1.60 \times 10^{-19}$ C and $V = 1$ V

$W = (1.60 \times 10^{-19}\text{C}) \times (1\text{ V}) = 1.60 \times 10^{-19}$ J

So 1 electronvolt = 1.60×10^{-19} J, a very small amount of energy. (You can find this in your data sheet.)

If an electron is accelerated through 1000 V, its energy is 1000 eV = $1000 \times 1.6 \times 10^{-19}$ J = 1.6×10^{-16} J.

Worked example

Question

Electrons are accelerated in an X-ray tube by a pd of 25 kV.

a State the kinetic energy gained by the electrons in eV.

b Calculate the kinetic energy gained by the electrons in joules.

Answer

a *Step 1*

Use the definition of the eV (an electron accelerated through 1 V has energy 1 eV) to deduce the kinetic energy of an electron when accelerated through 25 kV.

V = 25 kV so E = 25 keV

b *Step 2*

Convert your answer to part **a** from eV to J. (Remember the joule is much bigger than the eV so your answer will be a much smaller number.)

$$25\,\text{keV} = 25\,\text{keV} \times (1.6 \times 10^{-19}\,\text{J per eV})$$
$$= 25 \times 10^{3} \times 1.6 \times 10^{-19}\,\text{J}$$
$$= 4.0 \times 10^{-15}\,\text{J}$$

Questions

1 Electrons are accelerated in a discharge tube by a pd of 12 kV.

- **a** State the kinetic energy gained by the electrons in eV. (*1 mark*)
- **b** Calculate the kinetic energy gained by the electrons in joules. (*1 mark*)

2 The electrons hitting a screen have been accelerated through a vacuum tube and have each gained a kinetic energy of 6.4 keV. Calculate:

- **a** the accelerating pd (*1 mark*)
- **b** the kinetic energy gained by the electrons in joules. (*1 mark*)

3 A scientist requires a beam of electrons with energy 5.0×10^{-16} J. Calculate the accelerating pd required. (*1 mark*)

Worked example

Question

A visible light source has wavelength 488 nm.

a Calculate the frequency of the light.

b Calculate the energy of a photon in:

i joules

ii electronvolts.

Answer

a *Step 1*

Write down your known values, and substitute them into $c = f\lambda$.

$\lambda = 4.88 \times 10^{-7}$ m, $c = 3.0 \times 10^{8}$ m s^{-1}

$c = f\lambda$

$3.0 \times 10^{8}\ \text{m s}^{-1} = f\,(4.88 \times 10^{-7}\ \text{m})$

Step 2

Rearrange the equation to calculate *f*.

$$f = \frac{3.0 \times 10^{8}\ \text{m s}^{-1}}{4.88 \times 10^{-7}\ \text{m}}$$

$$= 6.15 \times 10^{-14}\ \text{Hz}$$

b i *Step 3*

Substitute your value for *f* (from part **a**) into the equation $E = hf$ to calculate *E*.
$h = 6.63 \times 10^{-34}$ J s

$E = (6.63 \times 10^{-34}\ \text{J s}) \times (6.15 \times 10^{-14}\ \text{Hz})$

$= 4.08 \times 10^{-19}$ J

ii *Step 4*

Convert your answer from part **b i** to eV using 1 eV = 1.6×10^{-19} J, so $1\ \text{J} = \frac{1}{1.6 \times 10^{-19}\ \text{J}}$ eV. (Remember your answer will be a bigger number than the number of joules because eVs are small.)

$$4.08 \times 10^{-19}\ \text{J} = \frac{4.08 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= 2.55\ \text{eV}$$

Questions

4 Calculate the energy of a photon of red light with frequency 4.3×10^{14} Hz in:

a joules (*1 mark*)

b electronvolts. (*1 mark*)

5 Calculate the energy of a photon of violet light with wavelength 3.5×10^{-7} m in:

a joules (*1 mark*)

b electronvolts. (*1 mark*)

6 Calculate the energy of a photon of yellow light of wavelength 590 nm in:

a J (*1 mark*)

b eV (*1 mark*)

Worked example

Question

To ionise a hydrogen atom, a photon requires energy of 13.6 eV.

Calculate the wavelength of the electromagnetic radiation with this photon energy.

Answer

Step 1

Write down the equation and values you are using to calculate λ.

If you do not know which equation to use, start by writing out the variables you know, in this case *E*, *c*, and *h*, and then look to see which equation uses these variables.

$E = 13.6$ eV, $c = 3.0 \times 10^{8}$ m s^{-1}, $h = 6.63 \times 10^{-34}$ J s

$$E = \frac{hc}{\lambda}$$

Step 2

Change the energy in eV to an energy in J.

$E = 13.6 \text{ eV} = 13.6 \times 1.6 \times 10^{-19}$ J

$E = 2.18 \times 10^{-18}$ J

Step 3

Substitute the values into the equation.

$$2.18 \times 10^{-18}\ \text{J} = \frac{(6.63 \times 10^{-34}\ \text{J s})(3.0 \times 10^{8}\ \text{m s}^{-1})}{\lambda}$$

Step 4

Rearrange the equation to make λ the subject.

$$\lambda = \frac{(6.63 \times 10^{-34}\,\mathrm{J\,s})(3.0 \times 10^{8}\,\mathrm{m\,s^{-1}})}{2.18 \times 10^{-18}\,\mathrm{J}}$$

Step 5

Calculate λ.

$\lambda = 9.1 \times 10^{-8}$ m or 91 nm

Questions

7 A photon has energy 4.6×10^{-19} J. Calculate:

a its frequency (*1 mark*)

b its wavelength. (*1 mark*)

8 A photon has energy 10.21 eV. Calculate:

a its frequency (*2 marks*)

b its wavelength. (*1 mark*)

9 In a blue LED, a photon is emitted when an electron fills a positive hole (a gap left by a missing electron). The wavelength of the photon is 470 nm. Calculate the energy, in eV, transferred from the electron to the photon. (*2 marks*)

10 An electron is accelerated through a pd of 15 kV and strikes a metal target. If all the energy is transferred to a photon of electromagnetic radiation, deduce the wavelength of the photon emitted. (*2 marks*)

11 X-rays are required with a wavelength of 0.10 nm. Calculate the accelerating pd required for an X-ray tube to produce rays with a minimum wavelength of 0.10 nm. (*2 marks*)

Maths skills links to other areas

You will also need to calculate photon energy, and convert between joules and electronvolts in Topic 3.3 *Collisions of electrons with atoms*. You will need to be able to recognise and use expressions in decimal and standard form throughout the course.

Answers

1 **a** $V = 12\ \text{kV}$ so $E = 12\ \text{keV}$ (*1 mark*)

b $E = 12\ \text{keV} \times (1.6 \times 10^{-19}\ \text{J per eV})$

$E = 12 \times 10^{3} \times 1.6 \times 10^{-19}\ \text{J}$

$= 1.9 \times 10^{-15}\ \text{J}$ (*1 mark*)

2 **a** $E = 6.4\ \text{keV}$ so $V = 6.4\ \text{kV}$ (*1 mark*)

b $E = 6.4\ \text{keV} \times (1.6 \times 10^{-19}\ \text{J per eV})$

$E = 6.4 \times 10^{3} \times 1.6 \times 10^{-19}\ \text{J} = 1.0 \times 10^{-15}\ \text{J}$ (*1 mark*)

3 $E = 5.0 \times 10^{-16}\ \text{J}$ so $E = \dfrac{5.0 \times 10^{-16}\ \text{J}}{1.6 \times 10^{-19}\ \text{J per eV}} = 3.1 \times 10^{3}\ \text{eV}$

So $V = 3.1 \times 10^{3}\ \text{V} = 3.1\ \text{kV}$ (*1 mark*)

OR $V = \dfrac{E}{e}$

$= \dfrac{5.0 \times 10^{-16}\ \text{J}}{1.6 \times 10^{-19}\ \text{C}}$

$= 3.1 \times 10^{3}\ \text{V} = 3.1\ \text{kV}$ (*1 mark*)

4 **a** $E = (6.63 \times 10^{-34}\ \text{J s}) \times (4.3 \times 10^{14}\ \text{Hz}) = 2.9 \times 10^{-19}\ \text{J}$ (*1 mark*)

b $E = \dfrac{2.9 \times 10^{-19}\ \text{J}}{1.6 \times 10^{-19}\ \text{J per eV}} = 1.8\ \text{eV}$ (*1 mark*)

5 **a** $E = \dfrac{(6.63 \times 10^{-34}\ \text{J s}) \times (3.00 \times 10^{8}\ \text{m s}^{-1})}{3.5 \times 10^{-7}\ \text{m}} = 5.7 \times 10^{-19}\ \text{J}$ (*1 mark*)

b $E = \dfrac{5.7 \times 10^{-19}\ \text{J}}{1.6 \times 10^{-19}\ \text{J per eV}} = 3.6\ \text{eV}$ (*1 mark*)

6 **a** $E = \dfrac{(6.63 \times 10^{-34}\ \text{J s}) \times (3.00 \times 10^{8}\ \text{m s}^{-1})}{590 \times 10^{-9}\ \text{m}} = 3.4 \times 10^{-19}\ \text{J}$ (*1 mark*)

b $E = \dfrac{3.4 \times 10^{-19}\ \text{J}}{1.6 \times 10^{-19}\ \text{J per eV}} = 2.1\ \text{eV}$ (*1 mark*)

7 **a** $f = \dfrac{E}{h} = \dfrac{4.6 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 6.9 \times 10^{14}\ \text{Hz}$ (*1 mark*)

b $\lambda = \dfrac{c}{f} = \dfrac{3.00 \times 10^{8}\ \text{m s}^{-1}}{6.9 \times 10^{-14}\ \text{Hz}} = 4.3 \times 10^{-7}\ \text{m}$ (*1 mark*)

OR $\lambda = \dfrac{hc}{E} = \dfrac{(6.63 \times 10^{-34}\ \text{J s})(3.00 \times 10^{8}\ \text{m s}^{-1})}{4.6 \times 10^{-19}\ \text{J}} = 4.3 \times 10^{-7}\ \text{m}$ (*1 mark*)

8 **a** $10.21\ \text{eV} = 10.21 \times 1.6 \times 10^{-19}\ \text{J} = 1.63 \times 10^{-18}\ \text{J}$ (*1 mark*)

$f = \dfrac{E}{h} = \dfrac{1.63 \times 10^{-18}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 2.5 \times 10^{15}\ \text{Hz}$ (*1 mark*)

b $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\,\mathrm{m\,s^{-1}}}{2.5\times10^{15}\,\mathrm{Hz}} = 1.2\times10^{-7}\,\mathrm{m}$ (*1 mark*)

9 $E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\,\mathrm{J\,s})(3.00\times10^{8}\,\mathrm{m\,s^{-1}})}{470\times10^{-9}\,\mathrm{m}} = 4.23\times10^{-19}\,\mathrm{J}$ (*1 mark*)

$E = \frac{4.23\times10^{-19}\,\mathrm{J}}{1.6\times10^{-19}\,\mathrm{J\ per\ eV}} = 2.6\ \mathrm{eV}$ (*1 mark*)

10 $V = 15\,\mathrm{kV}$ so $E = 15\times10^{3}\times1.6\times10^{-19}\,\mathrm{J} = 2.4\times10^{-15}\,\mathrm{J}$ (*1 mark*)

$\lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34}\,\mathrm{J\,s})(3.00\times10^{8}\,\mathrm{m\,s^{-1}})}{2.4\times10^{-15}\,\mathrm{J}} = 8.3\times10^{-11}\,\mathrm{m}$ (*1 mark*)

11 $\lambda = 0.1\,\mathrm{nm} = 0.1\times10^{-9}\,\mathrm{m}$

$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\,\mathrm{J\,s})(3.00\times10^{8}\,\mathrm{m\,s^{-1}})}{0.1\times10^{-9}\,\mathrm{m}} = 1.99\times10^{-15}\,\mathrm{J}$ (*1 mark*)

$E = \frac{1.99\times10^{-15}\,\mathrm{J}}{1.6\times10^{-19}\,\mathrm{J\ per\ eV}} = 1.2\ \mathrm{x}\ 10^{4}\,\mathrm{eV}$ so $V = 1.2\ \mathrm{x}\ 10^{4}\,\mathrm{V} = 12\,\mathrm{kV}$ (*1 mark*)

OR use $W = QV$ so $E = eV$

$(1.99\times10^{-15}\,\mathrm{J}) = (1.6\times10^{-19}\,\mathrm{C})\,V$ (*1 mark*)

$V = \frac{1.99\times10^{-15}\,\mathrm{J}}{1.6\times10^{-19}\,\mathrm{C}} = 1.2\times10^{4}\,\mathrm{V} = 12\,\mathrm{kV}$ (*1 mark*)

Wave motion

Specification reference

- *3.3.1.1 Progressive waves*
- *3.3.1.2 Longitudinal and transverse waves*
- *M0.2 recognise and use expressions in decimal and standard form*
- *M1.1 use an appropriate number of significant figures*
- *M2.2 change the subject of an equation*

Maths Skills for Physics references

- *2.1 Graphs of waves*

Learning objectives

After completing the worksheet you should be able to:

- demonstrate and apply knowledge and understanding of the terms used to describe waves: displacement, amplitude, wavelength, period, frequency, and speed of a wave
- use the equation $f = \frac{1}{T}$
- use the equation $c = f\lambda$
- interpret an oscilloscope trace.

Introduction

A wave is produced when a vibrating source periodically disturbs nearby particles of a medium. This disturbance is passed from one particle to the next and this creates a wave pattern that travels through the medium.

Transverse waves have vibrations perpendicular (at 90°) to the direction of travel (the direction of propagation) of the wave.

Longitudinal waves have vibrations along the direction of (parallel to) the direction of propagation.

The **frequency**, *f,* at which each individual particle vibrates is equal to the frequency at which the source vibrates. Frequency is measured in hertz (Hz): 1 Hz = 1 complete oscillation per second.

The **period of vibration**, *T,* is measured in seconds and is the time taken for one complete oscillation, or the time for a wave to move one whole wavelength past a given point.

$$f = \frac{1}{T}$$

Amplitude, A, is the maximum displacement of a particle from its equilibrium position.

Wavelength, λ, is the shortest distance between two adjacent particles in the medium that have the same displacement and are moving in the same direction.

Wave speed, c, is the speed at which the wave travels through the medium.

The wave equation can be derived from the above definitions: $c = f\lambda$.

An oscilloscope can be used to determine the time period T of a wave. An oscilloscope shows a graph of potential difference against time. If each square on the time axis is 1 cm horizontally and the time base is set to 1 s cm^{-1} then each square represents a time interval of 1 s. The distance, in cm, of one complete wave on the time axis = time base setting × distance on time axis.

Worked example

Question

A transverse wave has amplitude 0.5 cm, a wavelength of 4.0 cm, and time period of 80.0 s. The displacement, s, is 0 cm at time $t = 0$ s, and distance travelled, $d = 0$ cm.

a Sketch a graph of:

- **i** displacement against distance travelled
- **ii** displacement against time.

b Calculate:

- **i** the frequency of the wave
- **ii** the wave speed of the wave.

Answer

a i *Step 1*

Draw a y-axis that extends from an amplitude of –0.5 cm to +0.5 cm, and an x-axis that allows for more than one wavelength – so it is longer than 4.0 cm.

Label your axes.

Step 2

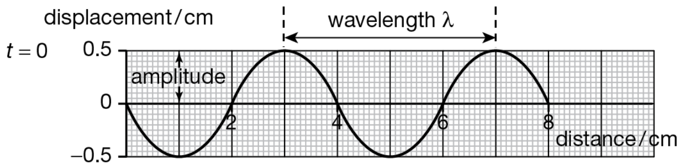
Plot points at the maximum (both positive and negative) and zero displacement for about two wavelengths.

Step 3

Draw a smooth curve through the points.

Step 4

Label the amplitude and the wavelength on the graph.



ii *Step 5*

Draw a *y*-axis that extends from an amplitude of –0.5 cm to +0.5 cm and an *x*-axis that allows for more than one time period – so it is longer than 80.0 s.

Label your axes.

Step 6

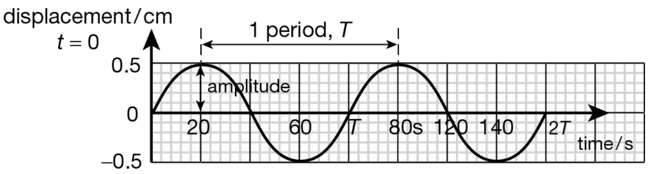
Plot points at the maximum (both positive and negative) and zero displacement for about two periods.

Step 7

Draw a smooth curve through the points.

Step 8

Label the amplitude and the period on the graph.



b i *Step 9*

Use the equation $f = \dfrac{1}{T}$ to calculate the frequency of the wave.

$$f = \frac{1}{T}$$

$$f = \frac{1}{80.0\,\text{s}}$$

$f = 0.0125\,\text{Hz}$

$= 0.013\,\text{Hz}$ (two significant figures)

ii *Step 10*

Substitute the wavelength and your value for *f* into the equation $v = f\lambda$.

$c = f\lambda$

$v = (0.0125\,\text{Hz})\,(4.0 \times 10^{-2}\,\text{m})$

Step 11

Calculate the wave speed, *c*.

$c = 5.0 \times 10^{-4}\,\text{m s}^{-1}$ **or** $5.0 \times 10^{-2}\,\text{cm s}^{-1}$

Questions

1 A wave has amplitude 8.0 mm, wavelength 1.5 m, and frequency 50 Hz.

a Sketch:

i a displacement–distance graph (*2 marks*)

ii a displacement–time graph. (*2 marks*)

b Calculate the wave speed. (*1 mark*)

2 A sound wave travels through a solid with a wavelength of 2.1 m and a frequency of 300 Hz. Calculate its speed. (*1 mark*)

3 A sound wave with frequency 250 Hz travels through a liquid with a wavelength of 5.7 m. Calculate its speed. (*1 mark*)

4 A musical note has frequency 512 Hz. Calculate its wavelength.

Speed of sound in air is 330 m s^{-1}. (*1 mark*)

5 A sound wave travels through a liquid with a wavelength of 1.5 m and a speed of 450 m s^{-1}.

Calculate:

a its frequency (*1 mark*)

b its period. (*1 mark*)

Worked example

Question

An electromagnetic wave travelling through the atmosphere has a wavelength of 1.5 km. Calculate its frequency.

Answer

Step 1

Remember that all electromagnetic waves travel with speed $c = 3.00 \times 10^8$ m s^{-1} in free space, and the difference in speed in the atmosphere is negligible.

Step 2

Substitute the values into the equation $c = f\lambda$.

$c = f\lambda$

$(3.0 \times 10^8 \text{ m s}^{-1}) = f(1.5 \times 10^3 \text{ m})$

Step 3

Rearrange the equation to make f the subject.

$$f = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{1.5 \times 10^3 \text{ m}}$$

Step 4

Calculate f.

$f = 2.0 \times 10^5$ Hz

or $f = 200$ kHz

Questions

6 Calculate the frequency of light with wavelength 580 nm. (*1 mark*)

7 The hydrogen spectrum has a red line at 656 nm and the helium spectrum has a red line at 668 nm. Calculate the frequency of each line and hence find the difference in the frequencies. (*3 marks*)

8 In magnetic resonance imaging, the resonant or Larmor frequency of hydrogen nuclei in a magnetic field is about 64 MHz. What is the wavelength of the radio signal that gives this frequency? (*1 mark*)

Worked example

Question

Figure 1 shows a trace displayed on an oscilloscope. The time base is set to 2.0 ms cm^{-1}.

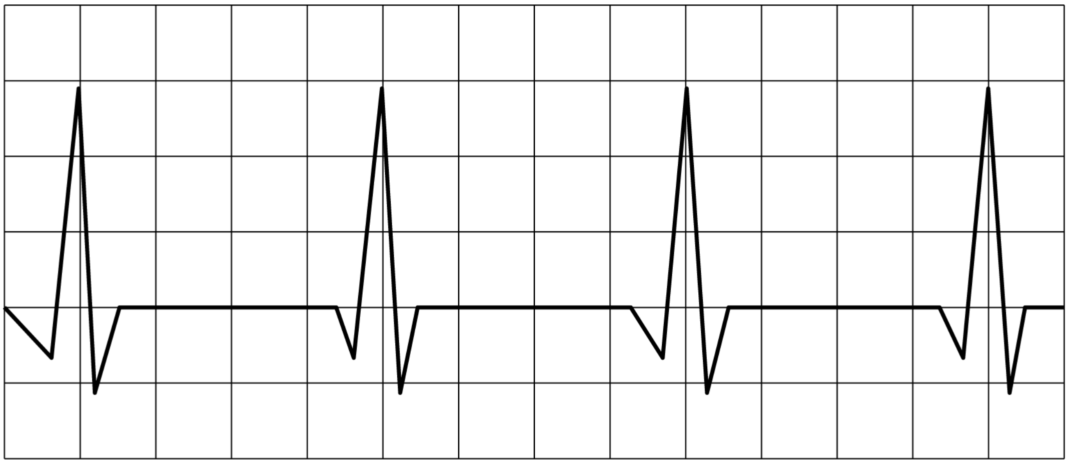


Figure 1

a Deduce the period of the wave.

b Calculate the frequency of the wave.

Answer

a *Step 1*

If the peaks line up with the grid lines, you can read the distance on the time axis easily. If not, use a ruler and measure the horizontal peak-to-peak distance on the paper to the nearest mm.

Horizontal peak-to-peak distance = 4.0 cm

Step 2

Set the ruler against the time axis with zero on the ruler lined up with a grid line on the time base, and read off the value corresponding to the length measured in Step 1.

4.0 cm is equivalent to 4.0 cm.

Step 3

Use the time base setting and the distance on the time axis to calculate the period.

$T = (2\ \text{ms cm}^{-1}) \times (4.0\ \text{cm})$

$\quad = 8.0\ \text{ms}$

b *Step 4*

Calculate f from $f = \dfrac{1}{T}$.

$f = \dfrac{1}{T} = \dfrac{1}{8.0\ \text{ms}}$

$= 125\ \text{Hz}$

$= 130\ \text{Hz}$ (two significant figures)

Questions

9 Calculate the frequency of the wave in Figure 2 if the time base is set to:

- **a** $5.0\ \text{ms cm}^{-1}$ (*2 marks*)
- **b** $2.0\ \mu\text{s cm}^{-1}$ (*2 marks*)
- **c** $100\ \text{ns cm}^{-1}$ (*2 marks*)

Each square represents 1 cm.

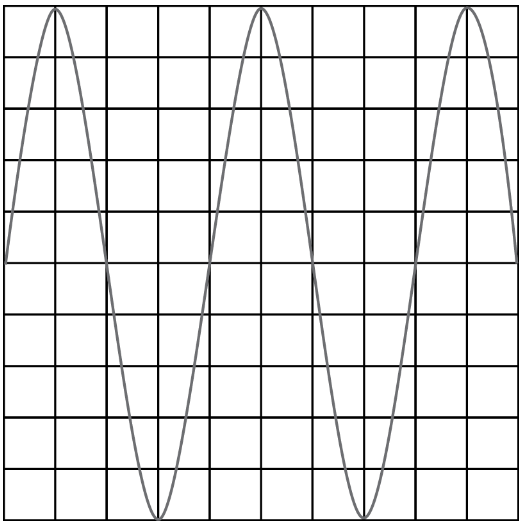
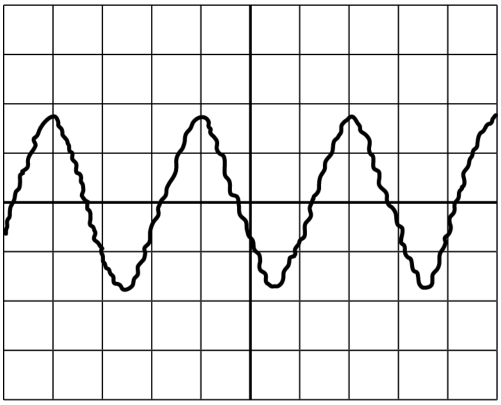


Figure 2

10 An electromagnetic wave is picked up by a detector, which produces an electrical signal. This signal is amplified and displayed on an oscilloscope screen.
Each square represents 1 cm.



a The scale on the *y*-axis is 2.0 V cm^{-1}. Determine the amplitude of the electrical signal. (*1 mark*)

b The time base is set to 25 ns cm^{-1}. Determine the frequency of the signal and hence the wavelength of the electromagnetic wave. (*5 marks*)

c What type of electromagnetic wave is being detected? (*1 mark*)

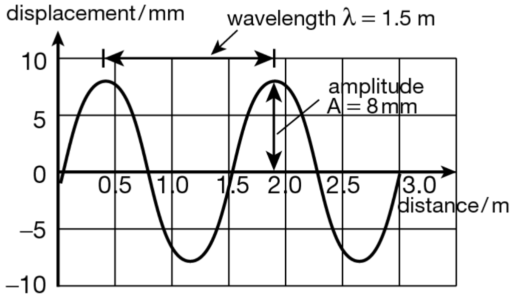
Maths skills links to other areas

It is important to always quote your final answers to an appropriate number of significant figures. During calculations you should always carry values to one more significant figure than your answer requires.

You will also need to recognise and use expressions in decimal and standard form throughout the course, including Topic 11.1 *Density*.

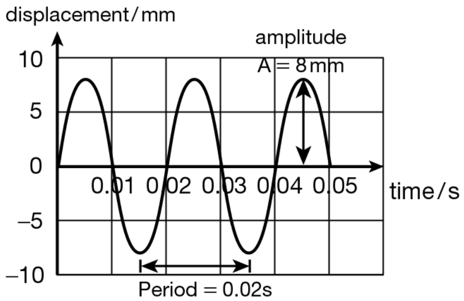
Answers

1 a i



(*1 mark correct amplitude, 1 mark correct wavelength*)

ii



1 mark for the correct amplitude and *1 mark* for the correct period

($T = \frac{1}{f}$, $T = \frac{1}{50\,\text{Hz}} = 0.02\,\text{s}$)

b $c = f\lambda$

$c = (50\,\text{Hz}) \times (1.5\,\text{m})$

$= 75\,\text{m s}^{-1}$ (*1 mark*)

2 $c = f\lambda$

$c = (300\,\text{Hz}) \times (2.1\,\text{m})$

$= 630\,\text{m s}^{-1}$ (*1 mark*)

3 $c = f\lambda$

$c = (250\,\text{Hz}) \times (5.7\,\text{m})$

$= 1425\,\text{m s}^{-1}$

$= 1400\,\text{m s}^{-1}$ (two significant figures) (*1 mark*)

4 $\lambda = \frac{v}{f}$

$\lambda = \frac{330\,\text{m s}^{-1}}{512\,\text{Hz}}$

$= 0.64\,\text{m}$ **or** $64\,\text{cm}$ (two significant figures) (*1 mark*)

5 a $f = \frac{c}{\lambda}$

$f = \frac{450\,\text{m s}^{-1}}{1.5\,\text{m}}$

$= 300\,\text{Hz}$ (*1 mark*)

b $T = \frac{1}{f}$

$T = \frac{1}{300\,\text{Hz}}$

$= 3.33 \times 10^{-3}\,\text{s}$

$= 3.3 \times 10^{-3}\,\text{s}$ or 3.3 ms (two significant figures) (*1 mark*)

6 $c = f\lambda$

$(3.00 \times 10^{8}\,\text{m s}^{-1}) = f\,(580 \times 10^{-9}\,\text{m})$

$f = \frac{3.00 \times 10^{8}\,\text{m s}^{-1}}{580 \times 10^{-9}\,\text{m}}$

$= 5.2 \times 10^{14}\,\text{Hz}$ (*1 mark*)

7 Hydrogen

$c = f\lambda$

$(3.00 \times 10^{8}\,\text{m s}^{-1}) = f\,(656 \times 10^{-9}\,\text{m})$

$f = \frac{3.00 \times 10^{8}\,\text{m s}^{-1}}{656 \times 10^{-9}\,\text{m}}$

$= 4.573 \times 10^{14}\,\text{Hz}$ (*1 mark*)

Helium

$c = f\lambda$

$(3.00 \times 10^{8}\,\text{m s}^{-1}) = f\,(668 \times 10^{-9}\,\text{m})$

$f = \frac{3.00 \times 10^{8}\,\text{m s}^{-1}}{668 \times 10^{-9}\,\text{m}}$

$= 4.491 \times 10^{14}\,\text{Hz}$ (*1 mark*)

Difference $= 4.573 \times 10^{14}\,\text{Hz} - 4.491 \times 10^{14}\,\text{Hz}$

$= 0.0820 \times 10^{14}\,\text{Hz}$

$= 8.20 \times 10^{12}\,\text{Hz}$ (three significant figures) (*1 mark*)

(Note that finding the difference in wavelength will not give the difference in frequency if substituted in the wave equation.)

8 $c = f\lambda$

$(3.00 \times 10^{8}\,\text{m s}^{-1}) = (64 \times 10^{6}\,\text{Hz})\,\lambda$

$\lambda = \frac{3.00 \times 10^{8}\,\text{m s}^{-1}}{64 \times 10^{6}\,\text{Hz}} = 4.7\,\text{m}$ (*1 mark*)

9 One wave is 4 cm on the screen.

a $T = 5.0\,\text{ms cm}^{-1} \times 4\,\text{cm}$

$= 20\,\text{ms}$ (*1 mark*)

$f = \frac{1}{20} \times 10^{-3}$

$= 50\,\text{Hz}$ (*1 mark*)

b $T = 2.0\ \mu s\ cm^{-1} \times 4\ cm$

$= 8\ \mu s$ (*1 mark*)

$f = \frac{1}{8} \times 10^{-6}$

$= 1.25 \times 10^{5}$ Hz

$= 130$ kHz (two significant figures) (*1 mark*)

c $T = 100\ ns\ cm^{-1} \times 4\ cm$

$= 400$ ns (*1 mark*)

$f = \frac{1}{400} \times 10^{-9}$

$= 2.5 \times 10^{6}$ Hz

$= 2.5$ MHz (*1 mark*)

10 a amplitude $= 1.8\ cm \times 2.0\ V\ cm^{-1}$

$= 3.6$ V (*1 mark*)

b $T = 25\ ns\ cm^{-1} \times 3.0\ cm$ (*1 mark*)

$= 7.5 \times 10^{-8}$ s (*1 mark*)

$f = \frac{1}{7.5 \times 10^{-8} s}$

$= 1.33 \times 10^{7}$ Hz

$= 1.3 \times 10^{7}$ Hz **or** 13 MHz (two significant figures) (*1 mark*)

$\lambda = \frac{c}{f}$

$\lambda = \frac{3 \times 10^{8}\ m\ s^{-1}}{1.33 \times 10^{7}\ Hz}$ (*1 mark*)

$= 22.6$ m

$= 23$ m (two significant figures) (*1 mark*)

c 23 m is in the radio frequency range – so the wave is a radio wave.
(Allow e.c.f. for wavelength.) (*1 mark*)

Determining uncertainty

Specification references

- *3.1.2 Limitation of physical measurements*
- *M0.3 Use ratios, fractions, and percentages*
- *M1.5 Identify uncertainties in measurements and use simple techniques to determine uncertainty when data are combined by addition, subtraction, multiplication, division, and raising to powers*

Maths Skills for Physics references

- *1.2 Uncertainties and significant figures*

Learning objectives

After completing the worksheet you should be able to:

- demonstrate knowledge and understanding of percentage errors and uncertainties
- evaluate absolute and percentage uncertainties
- determine uncertainty when data are combined by addition, subtraction, multiplication, division, and raising to powers.

Percentage uncertainties

Introduction

When something is measured there will always be a small difference between the measured value and the true value. There are several possible reasons for uncertainty in measurements, including the difficulty of taking the measurement, the precision of the measuring instrument (for example, due to the size of the scale divisions), and the natural variation of the quantity being measured. The word 'uncertainty' is generally used in preference to 'error', because 'error' implies something that is wrong – mistakes in making measurements should be avoided, and are not included in the uncertainty.

A measurement of 2.8 g is measured on a scale with divisions of 0.1 g. The true value could be anything from 2.85 g up to (but not including) 2.95 g, but the precision of the scale used does not allow us to measure the value to two decimal places. So we write the value as 2.8 (± 0.1) g. Here, 0.1 g is called the absolute uncertainty.

The percentage uncertainty in a measured value is calculated as shown below.

$$\text{percentage uncertainty} = \frac{\text{(absolute) uncertainty}}{\text{measured value}} \times 100\%$$

Worked example

Question

a The distance from **A** to **B** is carefully measured by stretching a 10-metre tape measure across the two points, taking a reading at both ends, and subtracting the larger value from the smaller value. The tape measure is marked in millimetre increments. The measured value is 7.500 m.

i Deduce the absolute uncertainty in the measurement.

ii Determine the percentage uncertainty in the measurement.

b The distance from **B** to **C** is measured as 6.5 m using a measuring wheel that gives measurements every 0.5 m. The wheel was reset to 0 and started rolling at point **B**.

i Deduce the absolute uncertainty in the measurement.

ii Determine the percentage uncertainty in the measurement.

c Calculate the absolute uncertainty in the total distance from **A** to **B** to **C**.

d Calculate the percentage uncertainty in the total distance from **A** to **B** to **C**.

Answer

a i *Step 1*

Consider the start point (**A**) and end point (**B**) of the measurement, and the scale division size. Due to the method used (a measurement was taken at both ends), there will be an uncertainty in the measurement both at the start point (**A**) and the end point (**B**).

The uncertainty in the measurement 1 mm at each end, giving a total uncertainty of 2 mm or 0.002 m.

Step 2

Write out the measurement with its absolute uncertainty. The uncertainty has the same unit as the measurement.

The distance **AB** is 7.500 ($\pm$ 0.002) m.

ii *Step 3*

Calculate the percentage uncertainty using the equation:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{measured value}} \times 100\%$$

$$\text{percentage uncertainty} = \frac{0.002}{7.500} \times 100\% = 0.027\% \text{ (to 2 significant figures)}$$

b i *Step 4*

This time there will be no uncertainty in the measurement at the start point (**B**), as the wheel was reset and no measurement was made at the start. The uncertainty and the end point (**C**) will be 0.5 m, as this is the precision of the measuring wheel.

Step 5

Write out the measurement with its absolute uncertainty.

The distance **BC** is 6.5 (± 0.5) m.

Step 6

The percentage uncertainty $= \frac{0.5}{6.5} \times 100\%$

$= 7.7\%$ (to 2 significant figures)

c *Step 7*

For the distance **ABC** the two measurements are added. The overall absolute uncertainty will be the sum of the individual absolute uncertainties.

uncertainty in **ABC** = uncertainty in **AB** + uncertainty in **BC**

$= 0.002\text{ m} + 0.5\text{ m}$

$= 0.502\text{ m}$ (note, the 0.002 is fairly insignificant here)

d *Step 8*

To find the percentage uncertainty, first calculate the measured value of **ABC**.

ABC $= 7.500 + 6.5 = 14\text{ m}$

Step 9

Calculate the percentage uncertainty using the equation:

percentage uncertainty $= \frac{\text{uncertainty}}{\text{calculated value}} \times 100\%$

percentage uncertainty $= \frac{0.502}{14} \times 100\%$

$= 3.6\%$ (to 2 significant figures)

Questions

1 Write down these measurements with their absolute uncertainty.

- **a** 6.0 cm length measured with a ruler marked in mm (*1 mark*)
- **b** 0.642 mm diameter measured with a digital micrometer (*1 mark*)
- **c** 36.9 °C temperature measured with a thermometer which has a quoted accuracy of: '± 0.1 °C (34 to 42 °C), rest of range ± 0.2 °C'. (*1 mark*)

2 Calculate the percentage uncertainty in these measurements.

a 5.7 ± 0.1 cm (*1 mark*)

b 2.0 ± 0.1 A (*1 mark*)

c 450 ± 2 kg (*1 mark*)

d 10.60 ± 0.05 s (*1 mark*)

e 47.5 ± 0.5 mV (*1 mark*)

f 366 000 ± 1000 J (*1 mark*)

3 Calculate the absolute uncertainty in these measurements.

a 1200 W ± 10% (*1 mark*)

b 34.1 m ± 1% (*1 mark*)

c 330 000 Ω ± 0.5% (*1 mark*)

d 0.008 00 m ± 1% (*1 mark*)

4 Calculate the absolute and percentage uncertainty in the total mass of suitcases of masses *x*, *y*, and *z*.

$x = 23.3\ (\pm\ 0.1)$ kg, $y = 18\ (\pm\ 1)$ kg, $z = 14.7\ (\pm\ 0.5)$ kg (*2 marks*)

Combining uncertainties

Introduction

In a calculation, if several of the quantities have uncertainties then these will all contribute to the uncertainty in the answer. The following rules will help you calculate the uncertainty in your final answers.

- When quantities are added, the uncertainty is the sum of the *absolute* uncertainties.
- When quantities are subtracted, the uncertainty is also the sum of the *absolute* uncertainties.
- When quantities are multiplied, the *total percentage* uncertainty is the sum of the *percentage* uncertainties.
- When quantities are divided, the *total percentage* uncertainty is also the sum of the *percentage* uncertainties.
- When a quantity is raised to the power *n*, the *total percentage* uncertainty is *n* multiplied by the *percentage* uncertainty – for example, for a quantity x^2, total percentage uncertainty = 2 × percentage uncertainty in *x*.

Worked example

Question

A current of 2.8 (± 0.1) A passes through a kettle element. The mains power supply is 230 (± 12) V.

Calculate the power transferred, including its uncertainty.

Answer

Step 1

Calculate the power.

$P = IV$

$P = (2.8\ \text{A}) \times (230\ \text{V}) = 644\ \text{W}$

Step 2

Calculate the percentage uncertainties.

The percentage uncertainty in current $= \dfrac{0.1}{2.8} \times 100\% = 3.57\%$

The percentage uncertainty in voltage $= \dfrac{12}{230} \times 100\% = 5.22\%$

The percentage uncertainty in power $= 3.57\% + 5.22\% = 8.79\% = 9\%$ (to nearest %)

Step 3

Calculate the absolute uncertainty in the power.

The absolute uncertainty $= \dfrac{8.79}{100} \times 644\ \text{W} = 57\ \text{W}$

Step 4

State the answer with units.

Power = 644 (± 57) W

Questions

5 A piece of string 1.000 (± 0.002) m is cut from a ball of string of length 100.000 (± 0.002) m. Calculate the length of the remaining string and the uncertainty in this length. (*2 marks*)

6 A runner completes 100.0 (± 0.1) m in 18.6 (± 0.2) s. Calculate his average speed and the uncertainty in this value. (*2 marks*)

7 A car accelerates, with constant acceleration, from 24 (± 1) m s^{-1} to 31 (± 2) m s^{-1} in 9.5 (± 0.1) s. Calculate the acceleration. State your answer with its absolute uncertainty. (*3 marks*)

8 A cube has a mass of 7.870 (± 0.001) kg and sides of length 10.0 (± 0.1) cm. Give the value of the density of the cube. (*2 marks*)

9 In a Young's slits experiment, two slits that are very close together are illuminated, and on a distant screen an interference pattern of light and dark fringes is seen. The separation of the fringes can be used to calculate the wavelength of the light. In a demonstration of this experiment:

- the double slit separation, $s = 0.20\ (\pm\ 0.01)$ mm
- the distance from the slits to the screen, $D = 4.07\ (\pm\ 0.01)$ m
- the distance between two adjacent bright fringes $w = 12.0\ (\pm\ 0.05)$ mm.

The equation for calculating wavelength is $\lambda = \frac{ws}{D}$.

a Calculate:

i the wavelength, λ, of the light (*1 mark*)

ii the absolute uncertainty in the wavelength. (*2 marks*)

b The distance between 11 fringes (10 spaces) = 120.0 (± 0.05) mm. Using this value, calculate the new absolute uncertainty in the wavelength. (*2 marks*)

c Comment on whether the uncertainty in the wavelength could be significantly reduced by increasing the number of fringes measured to, for example, 20 or more. (*1 mark*)

Maths skills links to other areas

You may also need to calculate uncertainties when considering precision and accuracy of measurements and data, including margins of error, percentage errors, and uncertainties in apparatus.

Answers

1 **a** 6.0 (± 0.1) cm (*1 mark*)
b 0.642 (± 0.001) mm (*1 mark*)
c 36.9 (± 0.1) °C (*1 mark*)

2 **a** ± 1.8% (*1 mark*)
b ± 5% (*1 mark*)
c ± 0.44% (*1 mark*)
d ± 0.47% (*1 mark*)
e ± 1.1% (*1 mark*)
f ± 0.27% (*1 mark*)

3 **a** ± 120 W (*1 mark*)
b ± 0.3 m (*1 mark*)
c ± 2000 (or 1650) Ω (*1 mark*)
d ± 0.000 08 m (*1 mark*)

4 Absolute uncertainty is ± 1.6 kg (*1 mark*)

Percentage uncertainty is $\pm \frac{1.6}{56} \times 100\% = \pm 2.9\%$ (to 2 significant figures) (*1 mark*)

5 99.000 (*1 mark*) ± 0.004 m (*1 mark*)

6 Average speed = 5.376 m s^{-1} (*1 mark*)

Percentage uncertainty is 0.1% + 1.08% = 1.18%

Absolute uncertainty is ± 0.063 m s^{-1} (*1 mark*) (accept percentage or absolute uncertainty)

7 Change in speed = 7 (± 3) m s^{-1}

Acceleration = $\frac{7}{9.5}$ = 0.737 m s^{-2} (*1 mark*)

Percentage uncertainty = $\frac{3}{7} \times 100\% + \frac{0.1}{9.5} \times 100\%$

= 42.8% + 1.1%

= 43.9% (*1 mark*)

Absolute uncertainty = $\frac{43.9}{100} \times 7 = 3$

Acceleration with absolute uncertainty = 0.7 (± 0.3) m s^{-2} (*1 mark*)

8 Density = 7870 kg m^{-3} (1 mark)

Percentage uncertainty = $\frac{0.001}{7.870} \times 100\% + 3 \times \left(\frac{0.001}{0.1} \times 100\%\right)$

= 0.01% + 3%

= 3% to the nearest %

Density = 7900 (± 3% or ± 200) kg m^{-3} (*1 mark*) (accept percentage or absolute uncertainty)

9 a i $\lambda = \frac{ws}{D}$

$= \frac{(0.20 \times 10^{-3}\ \text{m}) \times (12.0 \times 10^{-3}\ \text{m})}{4.07\ \text{m}}$

$= 5.896 \times 10^{-7}$ m

$= 5.9 \times 10^{-7}$ m (2 significant figures) (*1 mark*)

ii % uncertainty in $\lambda = \frac{0.01 \times 100\%}{0.2} + \frac{0.05 \times 100\%}{12.0} + \frac{0.01 \times 100\%}{4.07}$

$= 5\% + 0.4\% + 0.2\%$

$= 5.6\%$

$= 6\%$ (to nearest %) (*1 mark*)

Absolute uncertainty $= 6\%$ of 5.9×10^{-7} m

$= 3.54 \times 10^{-8}$ m

$= 0.4 \times 10^{-7}$ m (1 significant figure) (*1 mark*)

b New % uncertainty $= 5\% + \frac{0.05 \times 100\%}{120.0} + 0.2\%$

$= 5\% + 0.04\% + 0.2\%$

$= 5\%$ to nearest % (*1 mark*)

Absolute uncertainty $= 5\%$ of 5.9×10^{-7} m

$= 2.95 \times 10^{-8}$ m

$= 0.3 \times 10^{-7}$ m (1 significant figure) (*1 mark*)

c The 5% uncertainty is due to the uncertainty in the slit separation *s*, so a further reduction in the uncertainty in *x* would not reduce the total uncertainty. (*1 mark*)

Allow errors carried forward from results in parts **a** and **b**.

Using scalars and vectors

Specification references

- *3.4.1.1*
- *M0.6 Use calculators to handle sin x, cos x, and tan x when x is expressed in degrees or radians*
- *M4.2 Visualise and represent 2D and 3D forms*
- *M4.4 Use Pythagoras' theorem and the angle sum of a triangle*
- *M4.5 Use sin, cos, and tan in physical problems*

Maths Skills for Physics references

- *3.1 Motion 1*
- *3.4 Forces*
- *3.5 Resolving forces*

Learning outcomes

After completing the worksheet you should be able to:

- show and apply knowledge and understanding of scalar and vector quantities
- solve problems involving vector addition and subtraction
- use a vector triangle to determine the resultant of any two coplanar vectors.

Introduction

Scalar quantities have magnitude but no direction. For example, speed, distance, and time are all scalar quantities.

Vector quantities have magnitude and direction. Velocity is a vector quantity: it is speed in a certain direction. When we calculate velocity, v, we need to know the displacement, s. Displacement is also a vector: it is the distance travelled in a certain direction. The direction of a vector is sometimes indicated by giving an angle to a reference direction, for example, north. Sometimes a vector has a positive direction and a negative direction, in this case, the negative direction is opposite to the positive direction.

Acceleration is the rate of change of velocity, not of speed. This means that it is a vector. Consider an object moving in a circle at constant speed. Its direction is constantly changing, which means its velocity is changing. Therefore, it is accelerating.

When you add or subtract vectors, you must take the direction into account. Figure 1 shows that walking 3 m from **A** to **B**, and then turning through 30° and walking 2 m to **C**, has the same effect as walking directly from **A** to **C**. $\overrightarrow{AB}$ and $\overrightarrow{BC}$ are vectors and are shown by a single arrowhead on a vector diagram. $\overrightarrow{AC}$ is the resultant vector, shown by the double arrowhead.

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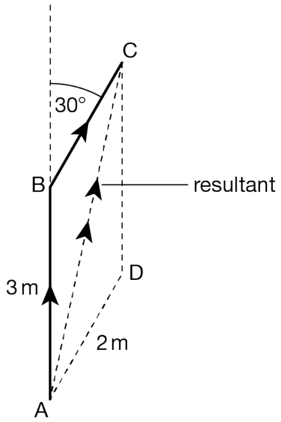
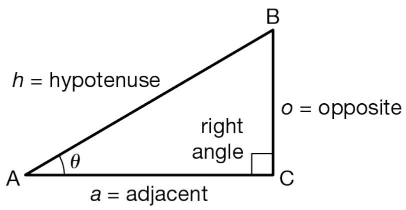


Figure 1

To combine any two vectors, we can draw a triangle like **ABC** in Figure 1, where the lengths of the sides represent the magnitude of the vector (for example, forces of 30 N and 20 N). The third side of the triangle shows us the magnitude and direction of the resultant force. Careful drawing of a scale diagram allows us to measure these.

Notice that if the vectors are combined by drawing them in the opposite order (**AD** and **DC** in Figure 1) these are the other two sides of a parallelogram and give the same resultant. If you draw both vectors so they start from point **A**, their resultant will be the diagonal of the parallelogram.

In solving problems with triangles, remember the angles in a triangle add up to 180°. In a right-angled triangle this means the other two angles add up to 90°.



For a right-angled triangle as shown, Pythagoras' theorem says:

$h^2 = o^2 + a^2$

Also:

$\sin\theta = \frac{o}{h}$, $\cos\theta = \frac{a}{h}$, $\tan\theta = \frac{o}{a}$ (some people remember: soh cah toa)

Worked example

Question

A sub-atomic particle experiences two forces at right angles, one of 2.0×10^{-15} N the other 3.0×10^{-15} N. Calculate the resultant force on the particle.

Answer

Step 1

Draw a diagram showing the two forces on the particle.

You can either draw the two forces acting on the particle at the same point, with the resultant as the diagonal of the rectangle formed, or consider the forces acting one after the other with the resultant as the third side of the triangle. Figure 2 shows both of these diagrams. In each the resultant is represented by F.

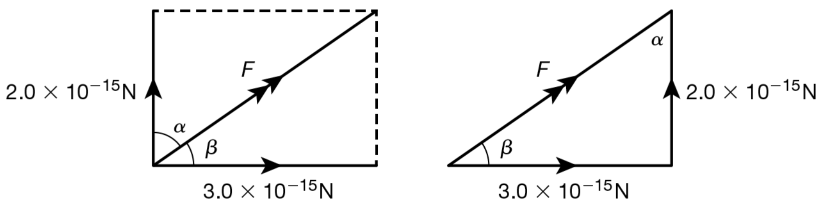


Figure 2

Step 2

Use Pythagoras' theorem to calculate the magnitude of the resultant, F.

$$F^2 = (2.0 \times 10^{-15}\ \text{N})^2 + (3.0 \times 10^{-15}\ \text{N})^2$$

$$= (4.0 \times 10^{-30} + 9.0 \times 10^{-30})\ \text{N}^2$$

Step 3

Don't forget to take the square root of your answer.

$$F = \sqrt{13 \times 10^{-30}}\ \text{N}$$

Step 4

Write your answer to the same number of significant figures as the question and with the correct units.

$$F = 3.6 \times 10^{-15}\ \text{N}$$

Step 5

Either calculate the angle to the vertical using tan α, or calculate the angle to the horizontal using tan β.

$$\tan\alpha = \frac{3.0 \times 10^{-15}\ \text{N}}{2.0 \times 10^{-15}\ \text{N}} = 1.5$$

Use your calculator to find α.

$$\alpha = \tan^{-1} 1.5 = 56°$$

Or:

$$\tan\beta = \frac{2.0 \times 10^{-15}\ \text{N}}{3.0 \times 10^{-15}\ \text{N}} = 0.67$$

Use your calculator to find β.

$\beta = \tan^{-1} 0.67 = 34°$

Step 6

Don't forget to write out your final answer.

If you used angle α:

Resultant force = 3.6×10^{-15} N at 56° to the 2.0×10^{-15} N force

Or, if you used angle β:

Resultant force = 3.6×10^{-15} N at 34° to the 3.0×10^{-15} N force

Questions

1 Divide these quantities into vectors and scalars. (*3 marks*)

density
electric charge
electrical resistance
energy
field strength
force
friction
frequency
mass
momentum
power
voltage
volume
weight
work done

2 Divide these data into vectors and scalars. (*2 marks*)

3 m s^{-1}

$+20 \text{ m s}^{-1}$

100 m NE

50 km

–5 cm

10 km S30°W

3 **a** Sketch a vector triangle showing a force of 3.0 N and a force of 4.0 N acting at right angles, and the resultant of the two vectors. (*2 marks*)

b Determine the magnitude and direction of the resultant force. (*2 marks*)

4 Find the resultant force of a 5.0 N and 12.0 N force acting at right angles. (*2 marks*)

5 A ship is cruising at $9.4\ \mathrm{m\ s^{-1}}$ and a boy runs across the deck, at right angles to the direction of the ship, at $3.0\ \mathrm{m\ s^{-1}}$. Calculate his resultant velocity. (*2 marks*)

6 An aircraft flies east at a speed of $53\ \mathrm{m\ s^{-1}}$. The wind is blowing from the north at a constant $16\ \mathrm{m\ s^{-1}}$. What is the resultant velocity of the aircraft? (*2 marks*)

7 Two tugboats are towing a ship in a straight line. Tug A is pulling with a force of 50 kN at 60° to the direction in which the ship is moving. Tug B is pulling at 30° to the direction in which the ship is moving. Draw a sketch and then calculate the magnitude of:

a the resultant force on the ship (*1 mark*)

b the force from tug B. (*1 mark*)

Maths skills links to other areas

You may need to do similar calculations and draw vector diagrams in Topic 7.7 *Projectile motion 1*, and Topic 7.8 *Projectile motion 2*.

Answers

1 Scalars: density, electric charge, electrical resistance, energy, frequency, mass, power, voltage, volume, work done

Vectors: field strength, force, friction, momentum, weight

Award *3 marks* for all correct, *2 marks* for one wrong, *1 mark* for two wrong, and *0 marks*
for three or more wrong.

2 Scalars: 3 m s^{-1}, 50 km

Vectors: +20 m s^{-1}, 100 m NE, –5 cm, 10 km S30°W

Award *2 marks* for all correct, *1 mark* for one wrong, and *0 marks* for two or more wrong.

3 **a** The two sides representing 3.0 N and 4.0 N meet at right angles. One has an arrowhead towards the right angle and the other has an arrowhead away from the right angle. (*1 mark*)

The resultant is the hypotenuse (opposite side to the right angle) and has a double arrow. The direction is such that it is an equivalent alternative route – see Figure 1
on the student sheet. (*1 mark*)

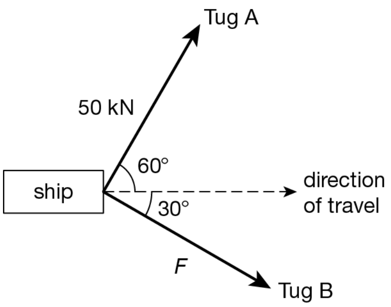
b $R = \sqrt{[(5.0\ \text{N})^2 + (12.0\ \text{N})^2]}$ = 5.0 N (*1 mark*) at an angle tan^{-1} (3.0 / 4.0) = 37° to the 4.0 N force (*1 mark*)

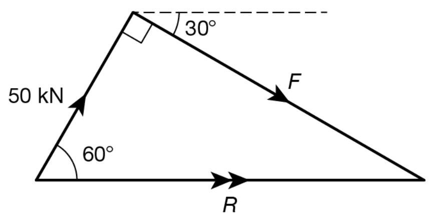
4 $R = \sqrt{[(5.0\ \text{N})^2 + (12.0\ \text{N})^2]}$ = 13 N (*1 mark*) at an angle tan^{-1} (5.0 / 12.0) = 23° to the 12.0 N force (*1 mark*)

5 $v_R = \sqrt{[(9.4\ \text{m s}^{-1})^2 + (3.0\ \text{m s}^{-1})^2]}$ = 9.9 m s^{-1} (*1 mark*) at an angle tan^{-1} (3.0 / 9.4) = 18° to
the direction of the ship (*1 mark*)

6 $v_R = \sqrt{[(53\ \text{m s}^{-1})^2 + (16\ \text{m s}^{-1})^2]}$ = 55 m s^{-1} (*1 mark*) at an angle tan^{-1} (16 / 53) = 17° south
of east (*1 mark*)

7





a $R = \dfrac{50\ \text{kN}}{\cos 60°} = 100\ \text{kN}$ (*1 mark*)

b $F = (100\ \text{kN}) \cos 30° = 87\ \text{kN}$ (*1 mark*)

Triangles of forces

Specification references

- *3.4.1.1*
- *3.4.1.2*
- *M4.1 Use angles in regular 2D and 3D structures*
- *M4.2 Visualise and represent 2D and 3D forms including 2D representations of 3D objects*
- *M4.4 Use Pythagoras' theorem and the angle sum of a triangle*

Maths Skills for Physics references

- *3.4 Forces*
- *3.5 Resolving forces*

Learning outcomes

After completing the worksheet you should be able to:

- demonstrate knowledge and understanding of the conditions for equilibrium under the action of forces
- sketch a triangle of forces for an object in equilibrium
- make a scale drawing of a triangle of forces and apply this to deduce the magnitude and direction of a force
- use a triangle of forces to calculate the magnitude and direction of a force.

Conditions for equilibrium

Introduction

An object is in equilibrium when the resultant force on it is zero.

The pendulum bob in Figure 1 will not stay in its current position if you remove your finger, because the tension, **T**, and weight, **W**, have a resultant force, **R**, that will return the string to a vertical position. (You can find more about resultant forces in '6.1 Calculation sheet: Using scalars and vectors'.) When the force from the finger, **F**, is equal and opposite to the resultant, **R**, then the bob is in equilibrium and the three forces, **T**, **F**, and **W**, form a triangle of forces.

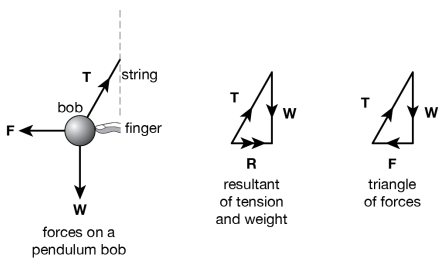
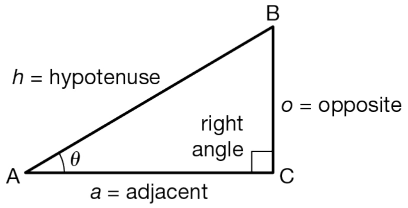


Figure 1

If three forces are acting on an object and it is in equilibrium, then the forces will always form a closed triangle of forces. By drawing the triangle of forces, you can find the magnitude and direction of one of the forces if you know the other two. In solving problems with triangles, remember the angles in a triangle add up to 180°. In a right-angled triangle this means the other two angles add up to 90°.



For a right-angled triangle as shown, Pythagoras' theorem says:

$h^2 = o^2 + a^2$

Also:

$\sin\theta = \frac{o}{h}$, $\cos\theta = \frac{a}{h}$, $\tan\theta = \frac{o}{a}$ (some people remember: soh cah toa)

Worked example

Question

A box weighing 100 N is on a slope with angle 30° to the horizontal. Friction prevents the box sliding down the slope.

a Sketch a triangle of forces for the forces acting on the box.

b Draw a scale diagram and deduce the magnitude of the friction force.

Answer

a *Step 1*

First sketch the situation: the box on the slope of 30° to the horizontal, the weight of the box, the normal contact force perpendicular to the slope, and the friction parallel to and up the slope.

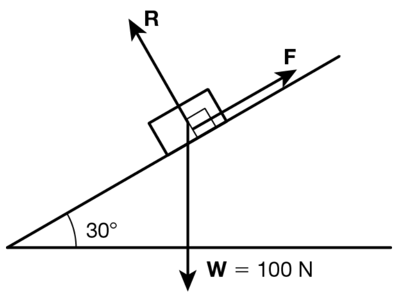


Figure 2 *Sketch of the situation*

Step 2

Decide how to draw the triangle of forces. The three forces must be in the directions shown in Figure 2, and you must put them together in an order so that they all follow round, in a clockwise, or an anticlockwise, direction. You cannot have one going in the opposite direction.

Sketch the triangle, and mark the angle, or angles, you know – remember that angles in a triangle add to 180°.

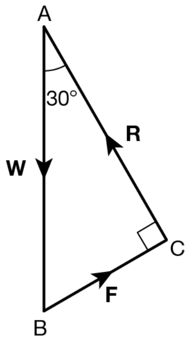


Figure 3 *Sketch of the triangle of forces*

b *Step 3*

Decide on a scale – make your diagram as big as you can, because it will be more accurate. Make sure you have a sharp pencil, a straight ruler – transparent ones are best as you can see what you are covering – and a protractor.

For example: Scale: 1 cm = 10 N

Step 4

Draw a vertical line and mark **AB**, which is 10 cm, representing the weight of 100 N.

Step 5

Use the protractor to draw a line that starts at **A** and is at 30° to **AB**. Make sure it is long enough (use your sketch, Figure 3, to guide you).

Step 6

Use the protractor to draw a line that starts at **B** and is at 60° to **AB**. Make sure it crosses your line from step 5. The point at which they cross is point **C**. You can check you have drawn it accurately because the angle at **C** should be 90°.

Step 7

Label the lines and add arrowheads to show the directions of the forces.

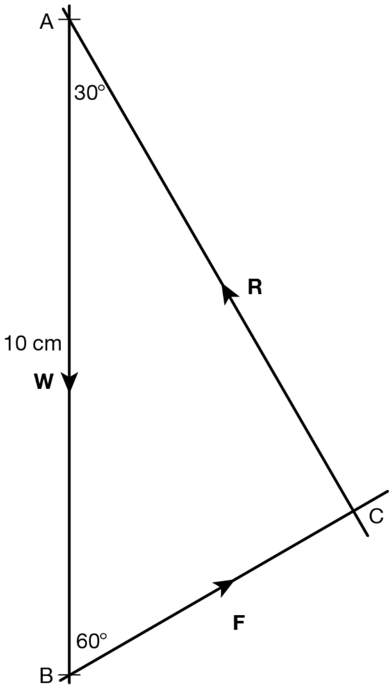


Figure 4 *Scale diagram of the triangle of forces*

Step 8

Measure the length of **BC**.

BC = 5.0 cm

Step 9

Use your scale to work out the magnitude of the friction.

Friction = 5.0 cm × 10 N per cm = 50 N

Questions

1 There are three forces on the jib of a tower crane. These are the tension in the cable **T**, the weight **W**, and a third force **F** which acts at the point **X**. See Figure 5.

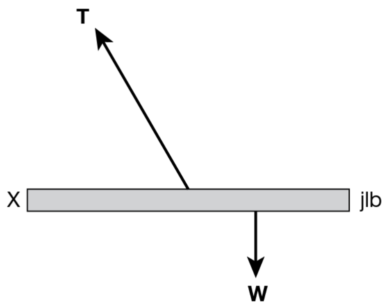


Figure 5

The crane is in equilibrium. Sketch the triangle of forces. (*1 mark*)

2 Two forces of 5 kN are towing a boat, as shown in Figure 6.

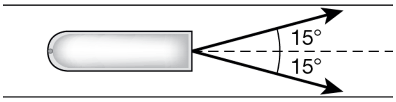


Figure 6

The boat is travelling at constant speed. Sketch a triangle of forces showing the towing forces and the drag force acting on the boat. (*1 mark*)

3 The three forces in Figure 7 are in equilibrium.

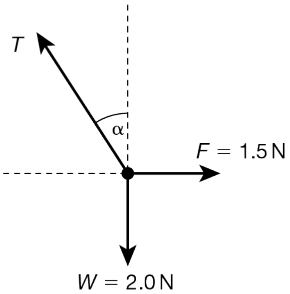


Figure 7

a Sketch a triangle of forces. (*1 mark*)

b Draw a scale diagram and deduce the magnitude of **T** and the angle α. (*3 marks*)

4 A climber of weight 600 N is walking down a vertical cliff face using a rope which makes an angle of 20° to the cliff.

a Sketch the free-body diagram when one leg is in contact with the cliff and is horizontal. (*1 mark*)

b Draw the triangle of forces. (*1 mark*)

c Find the magnitude of the tension in the rope by scale drawing. (*1 mark*)

Strings and cables

Introduction

Strings or cables are often used to exert a force to keep an object in position.

Remember that a string or cable can be in tension, but not in compression. If it is in tension, the force pulls on the objects it is attached to.

You should know that the tension is the same at every point in the cable, because otherwise the cable would break, so it is always the same at both ends.

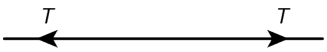


Figure 8 *A cable in tension*

Worked example

Question

1 A lamp hangs from three cables that are tied as shown in Figure 9.

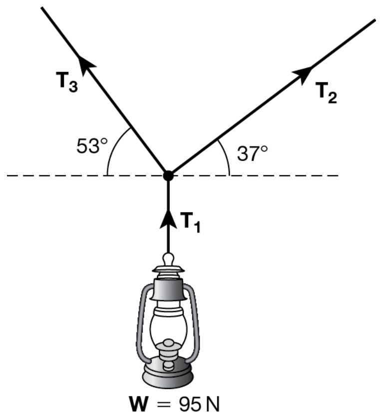


Figure 9

The lamp and the knot in the cable are both in equilibrium.

a Draw free-body diagrams for the lamp and the knot in the cable.

b Deduce the magnitude of the tension $\mathbf{T_1}$.

c Sketch a triangle of forces for the knot in the cable.

d Calculate the magnitudes of the tensions $\mathbf{T_2}$ and $\mathbf{T_3}$.

Answer

a *Step 1*

Sketch the free-body diagram for the lamp, showing all the forces on the lamp – the weight and the tension in the cable $\mathbf{T_1}$.

Step 2

Sketch the free-body diagram for the knot in the cable, showing the tensions in the three cables.

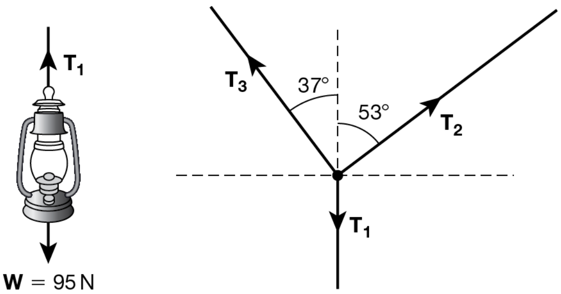


Figure 10 *The free-body force diagrams*

b *Step 3*

If the lamp is in equilibrium, the two forces on it must be equal and opposite.

For the lamp: magnitude of $\mathbf{T_1}$ = magnitude of $\mathbf{W}$ = 95 N

c *Step 4*

Sketch the triangle of forces for the three tension forces. Remember to keep their directions as they are in the free-body diagram (Figure 10), and draw them in order so that they all follow round in an anti-clockwise direction.

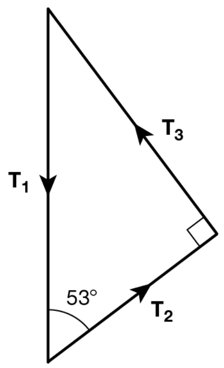


Figure 11 *The triangle of forces for the knot*

Step 5

Calculate the third angle and mark it on the diagram.

Third angle = 180° – (90° + 52°) = 37°

$\mathbf{T_1}$ is downwards, $\mathbf{T_2}$ is at 53° to $\mathbf{T_1}$, and $\mathbf{T_3}$ is at (37° + 53°) to $\mathbf{T_2}$.
Notice (37° + 53°) = 90°.

d *Step 6*

The triangle of forces is a right-angled triangle. Use cos 53° or sin 37° to calculate the magnitude of $\mathbf{T_2}$.

Magnitude of $\mathbf{T_2}$ = (95 N) cos 53° = 57 N (2 significant figures)

Or:

Magnitude of $\mathbf{T_2}$ = (95 N) sin 37° = 57 N (2 significant figures)

Step 7

Use cos 37° or sin 53° to calculate the magnitude of $\mathbf{T_3}$.

Magnitude of $\mathbf{T_3}$ = (95 N) cos 37° = 76 N (2 significant figures)

Or:

Magnitude of $\mathbf{T_3}$ = (95 N) sin 53° = 76 N (2 significant figures)

Questions

5 The three strings in Figure 12 are in tension and in equilibrium.

a Sketch a triangle of forces. (*1 mark*)

b Calculate the tension in each string. (*2 marks*)

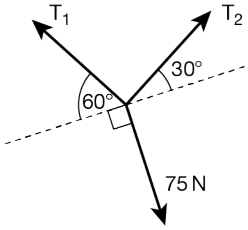


Figure 12

6 A sign of mass 50 kg is supported by a wire and a rod as shown in Figure 13.

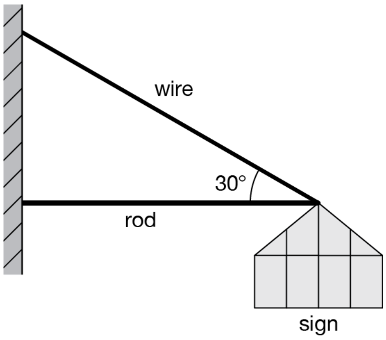


Figure 13

a Sketch the free-body diagram for the sign. (*1 mark*)

b Sketch the triangle of forces for the sign. (*1 mark*)

c Calculate the tension in the wire. (*3 marks*)

7 Figure 14 shows a ball of weight 200 N which is held in place by two cables **AB** and **BC**.

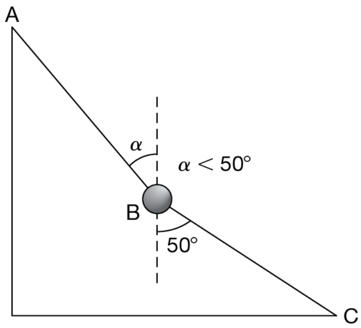


Figure 14

a Draw a free-body diagram. Label the tension in cable **AB** as $\mathbf{T_1}$ and the tension in cable **BC** as $\mathbf{T_2}$. (*1 mark*)

b Determine the magnitudes of $\mathbf{T_2}$ and $\mathbf{T_1}$ when $\alpha = 25°$, by drawing a scale diagram of the triangle of forces, or by calculation. (*3 marks*)

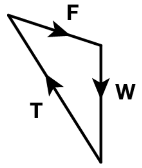
c Explain why the ball cannot be in equilibrium if $\alpha = 50°$ and **BC** stays at 50° to the vertical. (*1 mark*)

Maths skills links to other areas

For more information on triangles of forces, see Chapter 6 *Forces in equilibrium*.

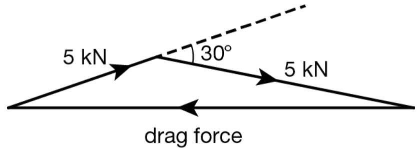
Answers

1



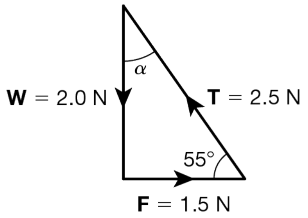
(*1 mark*)

2



(*1 mark*)

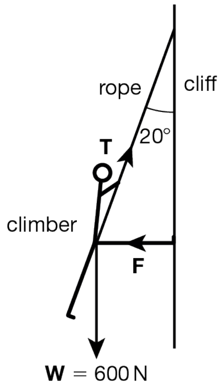
3 **a**



(*1 mark*)

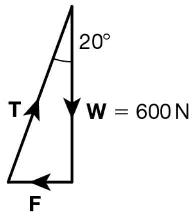
b Magnitude of **T** = 2.5 N, $\alpha = 35°$. (*1 mark* for a scale drawing, e.c.f. wrong triangle, *1 mark* for correct **T**, and *1 mark* for correct α. No marks for **T** and α if found by calculation.)

4 **a** Students should draw the three forces at the midpoint of the person, as shown.



(*1 mark*)

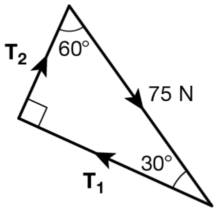
b



(*1 mark*)

c Magnitude of **T** = 640 N (*1 mark*)

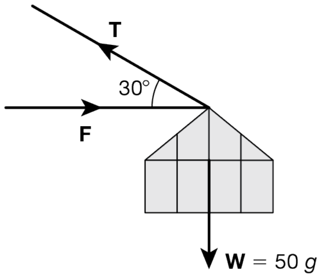
5 a



(*1 mark*)

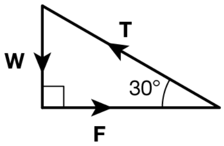
b Tensions are 75 N (given), $\mathbf{T_1}$ = 75 cos 30° = 65 N (*1 mark*), $\mathbf{T_2}$ = 75 sin 30° = 38 N (*1 mark*).

6 a



(*1 mark*)

b

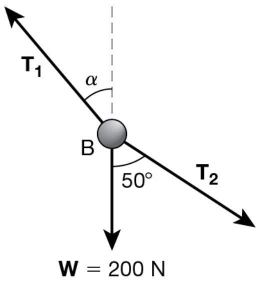


(*1 mark*)

c Magnitude of **W**: $W = 50g = 50\text{ kg} \times 9.81\text{ m s}^{-2} = 490.5\text{ N}$ (*1 mark*)

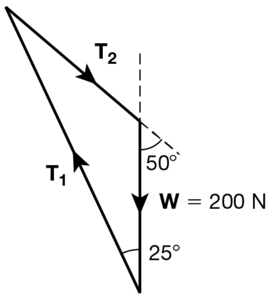
Magnitude of **T**: $T = \dfrac{W}{\sin 30°}$ (*1 mark*) $= \dfrac{490.5}{0.5} = 981\text{ N} = 980\text{ N}$ (2 significant figures) (*1 mark*)

7 a



(*1 mark*)

b The sketch of the triangle of forces (*1 mark*) shows that it has two angles of 25° so it is isosceles and the magnitude of $\mathbf{T_2}$ = magnitude of **W** = 200 N (*1 mark*).



By drawing a perpendicular line and dividing the triangle into two right-angled triangles, T_1, the magnitude of $\mathbf{T_1}$, is given by:

$$\cos 25° = \frac{0.5T_1}{200\,\text{N}}$$

$T_1 = (400\,\text{N})\cos 25° = 363\,\text{N} = 360\,\text{N}$ (2 significant figures) (*1 mark*)

Alternatively solve by scale diagram:

Choose scale, e.g. 1 cm = 40 N.

Draw vertical line 5 cm long to represent **W**.

Draw line from bottom of this line at 25° to represent $\mathbf{T_1}$.

Draw line from top of vertical line at (180° – 50°) = 130° to represent $\mathbf{T_2}$. (*1 mark*)

Measure length of $\mathbf{T_1}$: 9.1 cm, so $\mathbf{T_1} = 40 \times 9.1 = 364\,\text{N} = 360\,\text{N}$ (2 significant figures). (*1 mark*)

Measure length of $\mathbf{T_2}$: 5 cm, so $\mathbf{T_2} = 200\,\text{N}$. (*1 mark*)

c If $\alpha = 50^\circ$ and **BC** stays at 50° to the vertical, this means, looking at the triangle of forces, the direction of $\mathbf{T_1}$ and $\mathbf{T_2}$ are the same – they are parallel and will not meet to form a triangle. As the three forces $\mathbf{T_1}$, $\mathbf{T_2}$, and **W** do not form a triangle of forces, they are not in equilibrium.

Using velocity–time graphs

Specification references

- *3.4.1.3*
- *M3.5 Calculate a rate of change from a graph showing a linear relationship*
- *M3.6 Draw and use the slope of a tangent to a curve as a measure of rate of change*
- *M4.3 Calculate areas of triangles*

Maths Skills for Physics references

- *3.1 Motion 1*
- *3.2 Motion 2*

Learning outcomes

After completing the worksheet you should be able to:

- demonstrate and apply knowledge and understanding of the appearance of a velocity–time graph for an object
- use a velocity–time graph to calculate uniform and non-uniform acceleration
- use a velocity–time graph to calculate the distance travelled in a given time.

Introduction

You should always check carefully whether a graph is a displacement–time graph or a velocity–time graph. Remember the following points for a velocity–time graph:

- A horizontal line means the object is travelling at constant velocity. In Figure 1 in the worked example, the object has a constant velocity of 8 m s^{-1} between points **Q** and **R**.
- The object is stationary when it has a velocity of 0 m s^{-1}. In Figure 1, this happens at points **O** and **S**.
- If the graph has a linear slope, the object is accelerating at a constant rate. In Figure 1, the object has constant acceleration between **O** and **P**, and between **P** and **Q**. The steeper slope between **P** and **Q** shows the acceleration is greater than between **O** and **P**.
- If the slope is non-linear, the acceleration is not constant. In Figure 1, between **R** and **S** the object is slowing down – it has a non-uniform negative acceleration.
- The area under the curve of a velocity–time graph is equal to the distance travelled.
- You can calculate the area under the linear parts of the graph using the formulae for the area of a rectangle and of a triangle, and by counting the squares under a curve.

Worked example 1

Question

Figure 1 shows the motion of an object over 8 s. Use the graph to calculate:

a the acceleration between **P** and **Q**

b the acceleration at time 6.0 s.

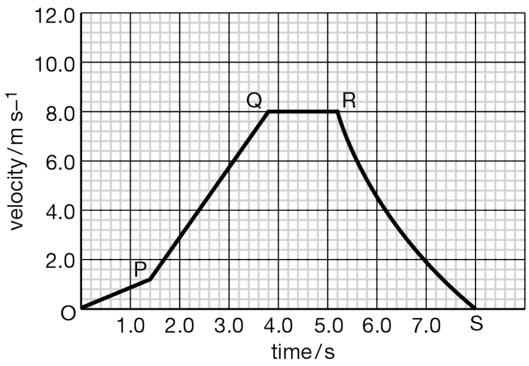


Figure 1

Answer

a *Step 1*

The acceleration between **P** and **Q** can be found from the gradient of the line between points **P** and **Q**.

If the line is very short then you can extend it so the change in velocity and the change in time are large – see Figure 2 where this has been done. This will give a more accurate value. You can use any two points on the straight line that passes through **P** and **Q**. You should make the triangle for calculating a gradient as large as will fit on the graph paper.

Acceleration = gradient of line between **P** and **Q**

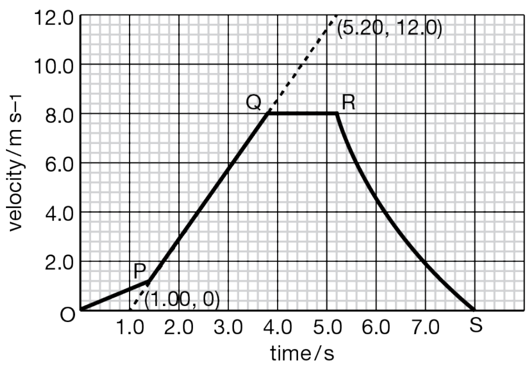


Figure 2

Step 2

Calculate the gradient between points (1.00, 0.0) and (5.20, 12.0).

For a graph of x against y, gradient = $\dfrac{\text{change in } y}{\text{change in } x}$

Gradient = $\dfrac{(12.0 - 0.0)\ \text{m s}^{-1}}{(5.20 - 1.00)\ \text{s}} = 2.86\ \text{m s}^{-2}$

Step 3

Remember to state the acceleration with correct units.

Acceleration between **P** and **Q** = $2.86\ \text{m s}^{-2}$

b *Step 4*

The acceleration between **R** and **S** is not constant. At any time the acceleration is equal to the gradient of the curve at that time. To find the acceleration at time $t = 6.0$ s, you need to draw a tangent to the curve at the point where $t = 6.0$ s and find the gradient of the tangent. The tangent is the line that just touches the curve at that point.

At $t = 6.0$ s, the acceleration = gradient of the tangent when $t = 6.0$ s.

Step 5

Draw the tangent to the curve as shown in Figure 3. Use a transparent ruler and a sharp pencil. Ensure the ruler touches the curve only at the point where the tangent is to be drawn – the ruler should not cross the curve. Extend the tangent far enough to get an accurate value.

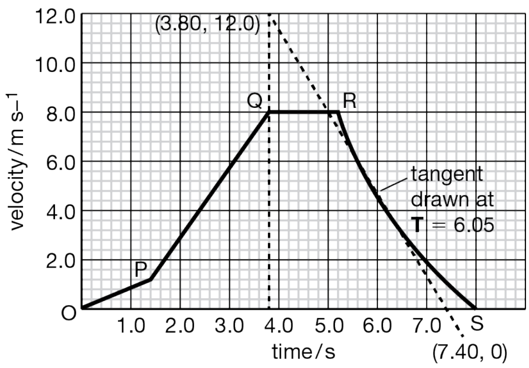


Figure 3

Step 6

Calculate the gradient between points (3.80, 12.0) and (7.40, 0.00). Notice that the gradient is negative because the object is slowing down (decelerating).

Gradient = $\dfrac{(0 - 12.0)\ \text{m s}^{-1}}{(7.40 - 3.80)\ \text{s}} = -3.33\ \text{m s}^{-2}$

Step 7

Remember to state the acceleration with correct units and to say that it is negative. Alternatively, state it as a deceleration and leave the value positive.

Acceleration at $t = 6.0$ s = -3.33 m s^{-2}

Deceleration at $t = 6.0$ s = 3.33 m s^{-2}

Question

1 For the velocity–time graph in Figure 1:

- **a** state the velocity after the object has been moving for 3.4 s (*1 mark*)
- **b** state the velocity after the object has been moving for 5.6 s (*1 mark*)
- **c** calculate the acceleration between **O** and **P** (*1 mark*)
- **d** calculate the acceleration at $t = 7.0$ s. (*1 mark*)

Worked example 2

Question

Figure 4 shows the motion of a toy car. Calculate how far it has it travelled after 5.2 s.

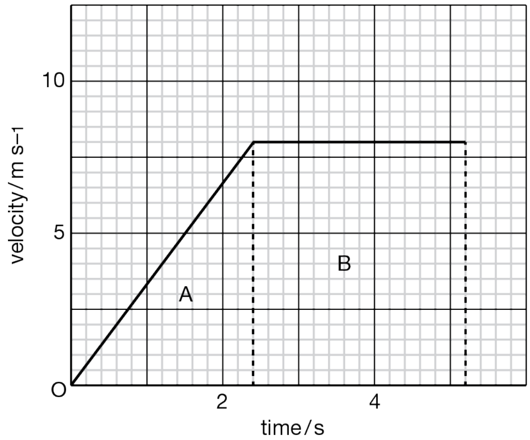


Figure 4

Answer

Step 1

The distance travelled is represented by the area under the graph. Separate the area into rectangles and triangles. If you make a mistake later on, then this step may still be worth some marks.

Distance travelled = area under curve = area A + area B

Step 2

Calculate the area of triangle A using the formula:

area of triangle = $\frac{1}{2}$ base × perpendicular height.

Notice that this area represents distance, which has the unit metre. See ‘2 Calculation sheet: Using S.I. units’ for more information on units.

Base = $(2.4 - 0)\ \mathrm{m\,s^{-1}} = 2.4\ \mathrm{m\,s^{-1}}$

Height = $(8.0 - 0)\ \mathrm{m\,s^{-1}} = 8.0\ \mathrm{m\,s^{-1}}$

Area of A = $0.5 \times 2.40\ \mathrm{s} \times 8.0\ \mathrm{m\,s^{-1}}$

Area A = 9.6 m

Step 3

Calculate the area of rectangle B using the formula:
area of rectangle = base × height.

Base = $(5.2 - 2.4)\ \mathrm{m\,s^{-1}} = 2.8\ \mathrm{m\,s^{-1}}$

Height = $(8.0 - 0)\ \mathrm{m\,s^{-1}} = 8.0\ \mathrm{m\,s^{-1}}$

Area of B = $2.80\ \mathrm{s} \times 8.0\ \mathrm{m\,s^{-1}}$

Area B = 22.4 m

Step 4

Add the distances to get the total.

Distance travelled = 9.6 m + 22.4 m

Distance travelled = 32.0 m

Question

2 Calculate the distance travelled during the journey shown in Figure 5. (*2 marks*)

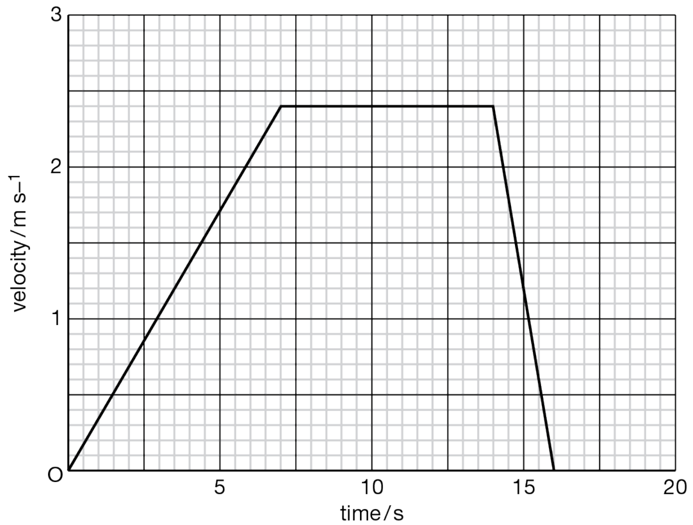


Figure 5

Worked example 3

Question

Calculate the distance travelled in the car journey shown in Figure 6.

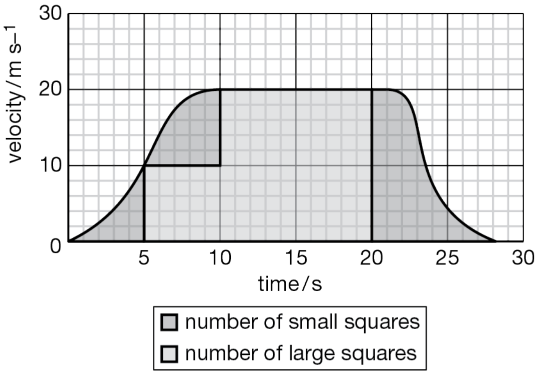


Figure 6

Answer

Step 1

Write down that the distance travelled is equal to the area under the curve:

Distance travelled = area under the curve

Step 2

Count the complete large squares under the graph, crossing them off as you go.

Number of large squares = 5

Step 3

Count the remaining complete small squares under the graph, crossing them off as you go. Count all the squares of which are half or more under the curve, leave out those where less than half is under the curve.

Number of small squares ≈ 69

Step 4

Calculate the distance represented by a small square and a large square. Take care that you have read the scales for the horizontal and vertical axes correctly.

1 small square: area represents $1.0\,\mathrm{s} \times 2.0\,\mathrm{m\,s^{-1}} = 2.0\,\mathrm{m}$.

1 large square (25 small squares): area represents $5\,\mathrm{s} \times 10\,\mathrm{m\,s^{-1}} = 50\,\mathrm{m}$.

Step 5

Calculate the area under graph.

Area under graph = (number of large squares × distance represented by one large square) + (number of small squares × distance represented by one small square).

Distance travelled ≈ (5 × 50 m) + (69 × 2.0 m)

≈ 200 m + 138 m

≈ 338 m

≈ 340 m (2 significant figures)

Questions

3 Estimate the distance travelled in Figure 1 on this sheet. (*3 marks*)

4 Figure 7 is a velocity–time graph showing the motion of two cars, P and Q, which are at the same place at $t = 0$ s.

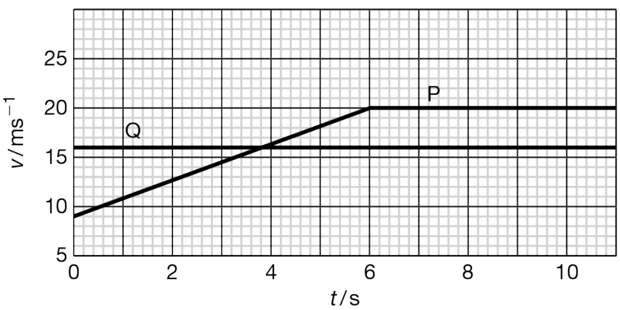


Figure 7

a Describe the motion of P from 0 to 10 s. (*2 marks*)

b Calculate the distance travelled by P in the first 6 s. (*3 marks*)

c Use the graph to identify the time at which both cars have the same velocity. (*1 mark*)

d Determine the time at which car P overtakes car Q. (*4 marks*)

Maths skills links to other areas

You may also need to determine the area under a graph in Topic 11.4 *More about stress and strain*, and Topic 9.2 *Impact forces*.

Answers

1 **a** $6.8\ \text{m s}^{-1}$ (*1 mark*)

b $-6.0\ \text{m s}^{-1}$ (*1 mark*)

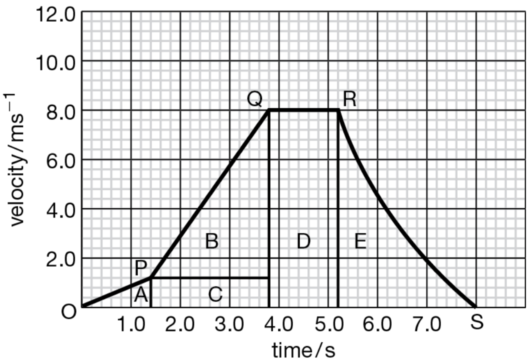
c $\frac{(7.6-0.0)\ \text{m s}^{-1}}{(8.2-0.0)\ \text{s}} = 0.9\ \text{m s}^{-2}$ (*1 mark*)

d $\frac{(0.0-12.0)\ \text{m s}^{-1}}{(7.8-2.7)\ \text{s}} = -2.4\ \text{m s}^{-2}$ (*1 mark*)

2 Area = $[\frac{1}{2} \times (7.0\ \text{s}) \times (2.4\ \text{m s}^{-1})] + [(14.0\ \text{s} - 7.0\ \text{s}) \times (2.4\ \text{m s}^{-1})] + [\frac{1}{2} \times (2.0\ \text{s}) \times (2.4\ \text{m s}^{-1})]$ (*1 mark*)

Area = 8.4 m +16.8 m + 2.4 m = 27.6 m = 28 m (2 significant figures) (*1 mark*)

3 Award *1 mark* for using the area under the curve, *1 mark* for counting squares or using triangles, and *1 mark* for the correct answer.



One possible method: area = triangle A + triangle B + rectangle C + rectangle D + counting squares under curve E

This gives: $(0.5 \times 1.4\ \text{s} \times 1.2\ \text{m s}^{-1}) + 0.5 \times (3.8 - 1.4)\ \text{s} \times (8.0 - 1.2)\ \text{m s}^{-1} + (3.8 - 1.4)\ \text{s} \times 1.2\ \text{m s}^{-1} + (8.0\ \text{m s}^{-1} \times 1.4\ \text{s}) + 120 \times (0.4\ \text{m s}^{-1} \times 0.2\ \text{s})$

= 0.84 m + 8.16 m + 2.88 m + 9.6 m = 21.48 m = 21 m (2 significant figures)

4 **a** At the start P has a uniform acceleration and accelerates from $9\ \text{m s}^{-1}$ to $20\ \text{m s}^{-1}$ in 6 s. (*1 mark*)

It then continues at a constant speed of $20\ \text{m s}^{-1}$. (*1 mark*)

b Distance travelled in first 6 s = area under graph (1

$= (9\ \text{m s}^{-1} \times 6\ \text{s}) + 0.5 \times (20 - 9)\ \text{m s}^{-1} \times 6\ \text{s}$ (*1 mark*)

= 87 m (*1 mark*)

c Both have same *v* when graphs go through same point: after 4.0 s. (*1 mark*)

d P overtakes Q when both have travelled the same distance: after time *X* where Q has travelled 16*X* and P has travelled [distance in part **b** + 20(*X* – 6) = 84 + 20(*X* – 6)].

16*X* = 84 + 20(*X* – 6) gives 36 = 4*X* so *X* = 9 s. (*4 marks*)

Elastic and inelastic collisions

Specification references

- *3.4.1.8 Conservation of momentum*
- *3.4.1.6 Momentum*
- *M0.5 Use calculators to find and use power functions*
- *M2.2 Change the subject of an equation, including non-linear equations*
- *M2.3 Substitute numerical values into algebraic equations using appropriate units for physical quantities*
- *M2.4 Solve algebraic equations, including quadratic equations*

Maths Skills for Physics references

- 3.11 Momentum and energy

Learning objectives

After completing the worksheet you should be able to:

- understand and apply the knowledge that in a perfectly elastic collision kinetic energy is conserved
- use the principle of conservation of momentum and the conservation of kinetic energy to solve problems involving perfectly elastic collisions
- understand that both momentum and energy are conserved in all collisions.

Introduction

Two important principles in physics are the conservation of energy and the conservation of momentum.

Energy and momentum are very different quantities:

- momentum is calculated using mass × velocity and is measured in kilogram metres per second ($kg\,m\,s^{-1}$) or newton seconds (N s)
- energy is measured in joules (J) and kinetic energy, for example, is calculated using $\frac{1}{2}$ mass × velocity^2 $\left(\frac{1}{2}mv^2\right)$.

The principle of conservation of energy states that energy is always conserved. (In nuclear reactions, we must take into account the conversion of energy to mass and mass to energy.) When a collision occurs between two objects, the total energy is conserved. But it is difficult to say by how much the thermal energy of the colliding objects and their surroundings increases.

The principle of conservation of momentum states that momentum is always conserved in a collision, as long as no external force is acting on the system. You can use this law to calculate the velocities of colliding objects.

Collisions can be elastic or inelastic. In a perfectly elastic collision, kinetic energy is conserved, whereas in an inelastic collision, kinetic energy is not conserved. To determine if a collision is elastic, you use the principle of conservation of momentum to find the velocities of the objects after the collision, and then calculate the kinetic energy before and after the collision to see if it is conserved. The steps for this are shown below:

- principle of conservation of momentum:
  momentum before collision = momentum after collision
- $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$
- kinetic energy before $= \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$
- kinetic energy after $= \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$
- change in kinetic energy, $\Delta E_k = \frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 - \left(\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2\right)$
- if the change in kinetic energy $\Delta E_k = 0$, then the collision is elastic.

Almost all real collisions are inelastic. The most extreme inelastic collision occurs when the colliding objects stick together. Perfectly elastic collisions occur between atoms and sub-atomic particles.

Worked example

Question

A neutron collides head-on with a stationary nucleus with a mass twice that of the neutron. The initial velocity of the neutron is 1.2×10^7 m s^{-1}. After the collision it rebounds with velocity 0.40×10^7 m s^{-1}.

Show whether the collision is elastic.

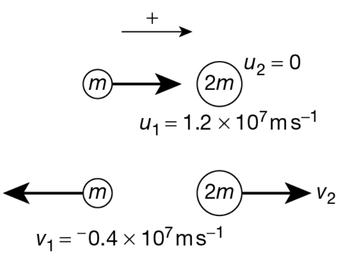
Answer

Step 1: Find the final velocity of the nucleus by using the principle of conservation of momentum. Do not forget to state that you are using this principle.

total momentum before = total momentum after

Step 2: Draw a diagram, showing which direction you are taking as positive, the values of mass and velocity you know, and the one you are calculating.

In this case, name the mass of the neutron *m*, so then the mass of the nucleus is 2*m*.



Step 3: Substitute the values into the equation: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

m_1 = mass of neutron (m)

m_2 = mass of nucleus ($2m$)

u_1 = initial velocity of neutron

u_2 = initial velocity of nucleus

v_1 = final velocity of neutron

v_2 = final velocity of nucleus

$m\,(1.2 \times 10^7\ \text{m s}^{-1}) + 0 = m\,(-0.40 \times 10^7\ \text{m s}^{-1}) + 2m\,v_2$

Step 4: Divide everything by m to remove it from your equation – you can do this as long as m is not zero, and it is not.

$(1.2 \times 10^7) = (-0.40 \times 10^7) + 2v_2$

Step 5: Rearrange the equation to find v_2.

$2v_2 = (1.2 \times 10^7) + (0.40 \times 10^7)$

Step 6: Calculate v_2

$$v_2 = \frac{1}{2}\,(1.6 \times 10^7)$$

$v_2 = 0.80 \times 10^7\ \text{m s}^{-1}$

Step 7: Use the equation $E_K = \frac{1}{2}m\,v^2$ to find the kinetic energy before the collision.

Before: $E_K = \frac{1}{2}m_1\,u_1^{\,2} + \frac{1}{2}m_2\,u_2^{\,2}$

$$E_K = \frac{1}{2}m\,(1.2 \times 10^7)^2$$

You can leave this expression for E_K or simplify it further:

$$E_K = \frac{1}{2}m\,(1.44 \times 10^{14})$$

$E_K = (0.72 \times 10^{14})\,m$

Step 8: Repeat Step 7 for the kinetic energy after the collision.

After: $E_K = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$

$E_K = \frac{1}{2} m\,(0.40 \times 10^7)^2 + \frac{1}{2}\,2\,m\,(0.80 \times 10^7)^2$

Step 9: Simplify the equation from Step 8 (kinetic energy after the collision) by taking the $\frac{1}{2} m$ outside the brackets. Take care with the squared numbers.

$E_K = \frac{1}{2} m\,[0.40^2 + 2 \times 0.80^2] \times (10^7)^2$

Step 10: Simplify the calculation inside the square brackets. You are aiming to get the same expression as for the E_K before the collision (which you found in Step 7) – this will only work if E_K is conserved.

$E_K = \frac{1}{2} m\,(0.16 \times 10^7 + 2 \times 0.64 \times 10^7)^2$

$E_K = \frac{1}{2} m\,[0.16 + 2 \times 0.64] \times (10^7)^2$

$E_K = \frac{1}{2} m\,[1.44] \times (10^{14})$

$E_K = (0.72 \times 10^{14})\,m$

or

$E_K = \frac{1}{2} m\,(1.2 \times 10^7)^2$ (if this is how you left the expression in Step 7)

Step 11: Remember to answer the question by stating whether the collision is elastic, and how you know.

kinetic energy before the collision = kinetic energy after the collision

Therefore, the collision is perfectly elastic.

Questions

1 Two snooker balls, A and B, with the same mass move towards each other and collide. The initial velocity for A is $+0.3\,\mathrm{m\,s^{-1}}$, for and B is $-0.2\,\mathrm{m\,s^{-1}}$. The final velocity of A is $-0.2\,\mathrm{m\,s^{-1}}$.

a Determine the final velocity of B. (*1 mark*)

b Show whether the collision is elastic. (*2 marks*)

2 A mass of 5.00 kg moving with velocity $20.0\,\mathrm{m\,s^{-1}}$ to the right collides with a stationary mass of 10.0 kg. The final velocity of the 5.00 kg mass is $6.67\,\mathrm{m\,s^{-1}}$ to the left.

a Calculate the final velocity of the 10.0 kg mass. (*2 marks*)

b Is the collision elastic? (*2 marks*)

3 A 1.0 kg mass with initial velocity $5.0\,\mathrm{m\,s^{-1}}$ collides with, and sticks to, a stationary 6.0 kg mass. The combined mass collides with, and sticks to, a stationary 3.0 kg mass. The collisions are all head-on.

Calculate:

a the final velocity (*2 marks*)

b the kinetic energy lost. (*3 marks*)

4 An alpha particle of mass 4.0 u with a velocity of $1.0 \times 10^{6}\,\mathrm{m\,s^{-1}}$ to the right collides with a stationary proton of mass 1.0 u. After the collision, the alpha particle moves with velocity $0.60 \times 10^{6}\,\mathrm{m\,s^{-1}}$ to the right.

a Calculate the velocity of the proton. (*2 marks*)

b Show that the collision is elastic. (*3 marks*)

Maths skills links to other areas

You may need to use similar calculations, and apply the principle of the conservation of energy and the conservation of momentum in other areas of the course. For example, in Topic 9.3 *Conservation of momentum* and Topic 10.1 *Work and energy.*

Answers

1 a By conservation of momentum: $m\,(0.3\text{ m s}^{-1}) + m\,(-0.2\text{ m s}^{-1}) = m\,(-0.2\text{ m s}^{-1}) + mv_2$

$v_2 = +0.3\text{ m s}^{-1}$ (*1 mark*)

b Use $\frac{1}{2}mv^2$ to show total KE before = total KE after.

Before: $\frac{1}{2}m\,(0.3\text{ m s}^{-1})^2 + \frac{1}{2}m\,(-0.2\text{ m s}^{-1})^2$ (*1 mark*)

After: $\frac{1}{2}m\,(-0.2\text{ m s}^{-1})^2 + \frac{1}{2}m\,(0.3\text{ m s}^{-1})^2$

These are equal therefore the collision is elastic.(*1 mark* for KE after correct calculation and correct st

2 a $(5.0\text{ kg})\,(20.0\text{ m s}^{-1}) + (0) = (5.0\text{ kg})\,(-6.67\text{ m s}^{-1}) + (10.0\text{ kg})\,v_2$ (*1 mark*)

$v_2 = 13.35\text{ m s}^{-1} = 13.3\text{ m s}^{-1}$ (three significant figures) (*1 mark*)

b E_K before $= \frac{1}{2}\,(5.0\text{ kg})\,(20.0\text{ m s}^{-1})^2 = 1000\text{ J}$

E_K after $= \frac{1}{2}\,(5.0\text{ kg})\,(6.67\text{ m s}^{-1})^2 + \frac{1}{2}\,(10.0\text{ kg})\,(13.35\text{ m s}^{-1})^2 = 1002\text{ J} = 1000\text{ J}$
(three significant figures)

Therefore, the collision is elastic to three significant figures.

Award *1 mark* for correct calculation of KE before **or** after, award *2 marks* for correct calculation of KE before **and** after, and correct statement.

3 a By conservation of momentum: $(1.0\text{ kg})\,(5.0\text{ m s}^{-1}) = (7.0\text{ kg})\,v_1$

$v_1 = \frac{5.0}{7.0}\text{ m s}^{-1}$ (*1 mark*)

By conservation of momentum: $(7.0\text{ kg})\,\frac{5.0}{7.0}\text{ m s}^{-1} = (10.0\text{ kg})\,v_2$

$v_2 = \frac{5.0}{10.0}\text{ m s}^{-1} = 0.5\text{ m s}^{-1}$ (*1 mark*)

b E_K before: $\frac{1}{2}\,(1.0\text{ kg})\,(5.0\text{ m s}^{-1})^2 = 12.5\text{ J}$ (*1 mark*)

E_K after: $\frac{1}{2}\,(10.0\text{ kg})\,(0.50\text{ m s}^{-1})^2 = 1.25\text{ J}$ (*1 mark*)

E_K lost: $12.5\text{ J} - 1.25\text{ J} = 11.25\text{ J}$ (*1 mark*)

4 a By conservation of momentum:

$(4\text{u})\,(1.0 \times 10^6\text{ m s}^{-1}) + (0) = (4\text{u})\,(0.60 \times 10^6\text{ m s}^{-1}) + (1\text{u})\,v_2$ (*1 mark*)

$v_2 = 1.6 \times 10^6\text{ m s}^{-1}$ (*1 mark*)

b E_K before $= \frac{1}{2}\,(4\text{u})\,(1.0 \times 10^6\text{ m s}^{-})^2$ (*1 mark*)

E_K after $= \frac{1}{2}$ (4u)(0.60 × 10^6 m $s^{-1})^2$ + $\frac{1}{2}$ (1u) (1.6 × 10^6 m $s^{-1})^2$ = $\frac{1}{2}$ (4u)(1.0 × 10^6 m $s^{-})^2$ (*1 mark*)

E_K before = E_K after, therefore the collision is elastic. (*1 mark*)

Students may try to convert from u to kg – you may wish to explain that this is unnecessary in this case, but if done correctly they would still gain full marks.

Understanding Hooke's law

Specification references

- *3.4.2.1 Bulk properties of solids*
- *M2.1 Understands and use the symbols:* $=$, $\propto$
- *M3.2 Plot two variables from experimental or other data*
- *M3.4 Determine the slope and intercept of a linear graph*
- *M3.1 Translate information between graphical, numerical and algebraic forms*

Maths skills for Physics references

- *4.1 Elasticity 1*

Learning objectives

After completing the worksheet you should be able to:

- demonstrate knowledge and understanding of Hooke's law
- plot and interpret graphs of force against extension (or compression) for springs and wires
- apply knowledge and understanding of extension and compression to springs, wires, and samples of other materials.

Introduction

If you stretch a solid it is in *tension*. The forces applied are tensile forces and there is an *extension* – an increase in length.

If you compress a solid it is in *compression*. The forces applied are compressive forces and there is a *decrease in length*.

When a material obeys Hooke's law the extension, ΔL, is directly proportional to the force applied, F, as long as the limit of proportionality is not exceeded.

$F \propto L$ or $F = k\,\Delta L$, where k is the stiffness constant for the wire or spring. Units of k are $\mathrm{N\,m^{-1}}$.

$$k = \frac{F}{x}$$

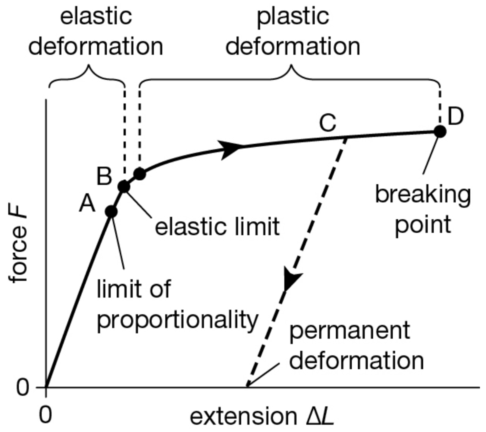


Figure 1

Figure 1 is a force–extension graph for a metal. OA is the region where Hooke's law is obeyed. Other metals, and other materials, will have different graphs depending on their properties. Notice the following two points.

- The elastic limit (B) is the point after which the material no longer returns to its original length. This is not always the same as the limit of proportionality (A).
- When a material starts to experience plastic deformation, there is a much bigger *increase* in extension for an *increase* in force. (It is always true that there is a bigger extension for a bigger force, so be careful how you explain the change.)

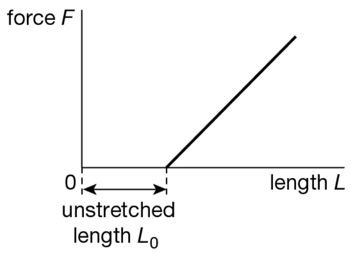


Figure 2

Figure 2 is a force–length graph for the same metal as Figure 1. Notice that whilst the force is directly proportional to extension (see Figure 1) it is incorrect to say that force is directly proportional to the length, L, of the wire. A graph of F against ΔL goes through the origin (0,0), but a graph of F against L goes through the point where
$F = 0$ and L is the unstretched length (or natural length) of the wire, L_0. This is a linear relationship: $F = k(L - L_0)$.

Worked example

Question

Figure 3 is a graph of force against extension for a wire.

a Deduce the applied force and the length of the wire when it reaches the limit of proportionality.

b Calculate the stiffness constant for the wire.

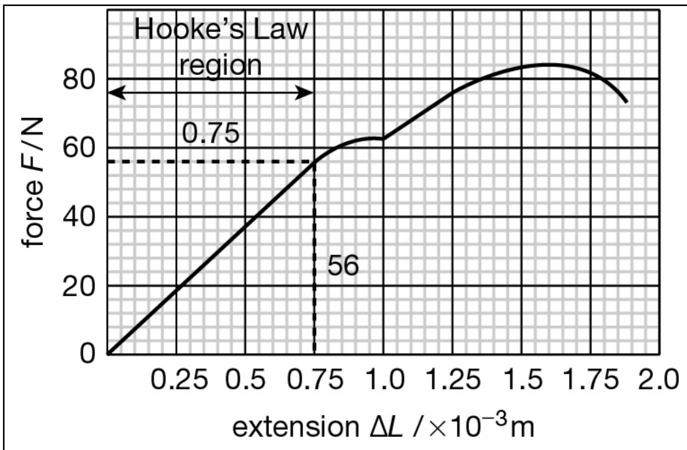


Figure 3

Answer

a *Step 1*

Mark, on the graph, the point at the end of the straight-line section of the graph.

Step 2

Use a transparent ruler to line the point up with the force axis and read off the force, taking care with the scale of the graph. Note down the answer.

Force, $F = 56\ldots$

Step 3

Check the axis for the unit and any scale factor, and multiply your answer by these.

Force, $F = 56\,\text{N}$

Step 4

Repeat Steps 1 to 3 for the extension axis.

Extension, $\Delta L = 0.75\ldots$

Extension, $\Delta L = 0.75 \times 10^{-3}\,\text{m}$

b *Step 5*

State that the stiffness constant is equal to the gradient of the graph, and show the gradient is the change in force divided by the change in extension over a long straight part of the graph.

The stiffness constant, k, is equal to the gradient of the graph:

$$k = \frac{56\,\text{N}}{0.75 \times 10^{-3}\,\text{m}}.$$

Step 6

Use you calculator to calculate the value, and do not forget the units.

$k = 75\,000\,\text{N m}^{-1}$ (two significant figures)

Questions

1 A force of 160 N extends a copper wire by 2.7 cm. Calculate the stiffness constant of the wire. (*1 mark*)

2 A 12 N weight is hung on a spring 5.0 cm long with spring constant 8500 N m^{-1}. Calculate:

a the extension (*1 mark*)

b the new length of the spring. (*1 mark*)

3 A horizontal plank is supported at each end. A child of mass 55 kg stands on the centre of the plank, which bends, so the centre moves down 4.0 mm.

Calculate the stiffness constant of the plank. (*1 mark*)

4 A student has two identical springs with spring constant 240 N m^{-1} and natural length 210 mm. The weight of the springs is negligible. Calculate the length of each of the springs when:

a they are joined vertically and stretched with a weight of 8.0 N (*2 marks*)

b they are joined in parallel and stretched with a weight of 8.0 N. (*2 marks*)

5 Force is applied to a spring and this data is collected:

Force / N	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
Length / cm	2.6	2.8	3.0	3.2	3.4	3.6	3.9	4.3

a Plot a force–extension graph for the spring. (*5 marks*)

b Explain the shape of the graph. (*3 marks*)

c Calculate the spring constant. (*2 marks*)

d Suggest and explain your choice for:

i a material that would give a similarly shaped graph (*1 mark*)

ii a material that would not give a similarly shaped graph. (*2 marks*)

Maths skills links to other areas

You will need to be able to plot and interpret graphs throughout the AS Level course, both from data provided and from your own experimental results; for example, when investigating distance–time graphs in Topic 7.1 *Speed and velocity*.

Answers

6 $k = \frac{F}{\Delta L} = \frac{160\,\text{N}}{2.7 \times 10^{-2}\,\text{m}} = 5900\,\text{N m}^{-1}$ (*1 mark*)

7 a $\Delta L = \frac{F}{k} = 1\frac{12\,\text{N}}{8500\,\text{N m}^{-1}} = 1.41 \times 10^{-3}\,\text{m} = 1.4\,\text{mm}$ (*1 mark*)

b $L = 5.0\,\text{cm} + 1.41\,\text{mm} = 5.141\,\text{cm} = 5.1\,\text{cm}$ (two significant figures) (*1 mark*)

8 $F = (55\,\text{kg}) \times (9.81\,\text{m s}^{-2})$; $\Delta L = 4.0\,\text{mm}$

$k = \frac{(155\text{kg}) \times (9.81\text{ms}^{-2})}{(4.0 \times 10^{-3}\text{m})} = 1.3 \times 10^5\,\text{N m}^{-1}$ (*1 mark*)

9 a Vertically the force on both springs is 8.0 N (imagine each spring in turn removed or replaced with an inextensible wire). For each spring:

$\Delta L = \frac{F}{k} = \frac{8.0\,\text{N}}{240\,\text{N m}^{-1}}$

$= 0.0333\,\text{m} = 33\,\text{mm}$ (two significant figures) (*1 mark*)

Length of each spring $= 210\,\text{mm} + 33\,\text{mm}$

$= 243\,\text{mm} = 240\,\text{mm}$ (two significant figures) (*1 mark*)

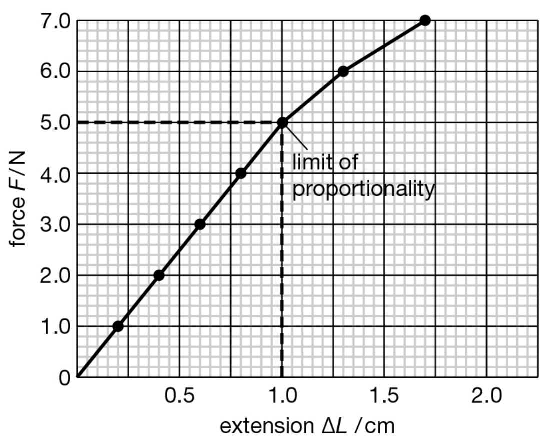
b Connected in parallel the two springs take the weight, so the force on each spring $= \frac{F}{2}$

$= 4.0\,\text{N}$

$\Delta L = \frac{F}{k} = \frac{4.0\,\text{N}}{240\,\text{N m}^{-1}} = 0.0167\,\text{m} = 17\,\text{mm}$ (two significant figures) (*1 mark*)

Length of each spring $= 210\,\text{mm} + 17\,\text{mm} = 227\,\text{mm} = 230\,\text{mm}$ (two significant figures) (*1 mark*)

10 a



Note that extensions are found by subtracting the length at $F = 0$ (2.6 cm) from all the lengths.

Award up to *5 marks* from the following points.

- Force on vertical axis labelled force **or** F; extension on horizontal axis labelled extension **or** ΔL. (*1 mark*)
- Units of /N **and** /cm or / $\times 10^{-2}$ m shown on axes. (*1 mark*)
- Extensions correctly calculated. (*1 mark*)
- Points correctly plotted to within half a small square (e.c.f. calculated extensions). (*1 mark*)
- Straight line drawn through points and origin where these are straight, then curves as shown. (*1 mark*)

b The answer should include the following points.

- The limit of proportionality is marked on the graph (or state coordinates (5.0, 1.0)). (*1 mark*)
- Force is directly proportional to extension from 0 to 5 N so graph goes through origin and is a straight line. In this region the spring obeys Hooke's law. (*1 mark*)
- The limit of proportionality is reached at, or just beyond, 5 N as the graph then curves. An increase in force then produces a greater increase in extension since the material is undergoing plastic deformation. (*1 mark*)

c Students should calculate the gradient of the graph before the limit of proportionality is reached. (*1 mark*)

$$k = \frac{F}{\Delta L} = \frac{5.0\,\text{N}}{1.0 \times 10^{-2}\,\text{m}} = 500\,\text{N}\,\text{m}^{-1}$$ (*1 mark*)

d i Allow any correct answer. For example, a metal such as copper would show this behaviour. (Also, brass, aluminium, or cast iron, but not steel, which has a yield point, glass, which is brittle, or rubber, which does not obey Hooke's law.) Copper obeys Hooke's law up to a certain force and then it is ductile and has a region where it deforms plastically. (*1 mark*)

ii Allow any correct answer. For example, glass is brittle. It obeys Hooke's law up to a certain force, but then it snaps without any plastic deformation. (*1 mark* for a material and *1 mark* for an explanation)

Elastic energy

Specification references

- *3.4.2.1 Bulk properties of solids*
- *M0.5 Use calculators to find and use power functions*
- *M3.1 Translate information between graphical, numerical, and algebraic forms*
- *M3.8 Understand the possible physical significance of the area between a curve and the x-axis and be able to calculate it, or estimate it by graphical methods as appropriate*
- *M3.12 Sketch relationships which are modelled by* $y = k\Delta L$, *and* $y = k\Delta L^2$

Maths Skills for Physics references

- *4.1 Elasticity 1*

Learning objectives

After completing the worksheet you should be able to:

- understand that the work done in stretching (or compressing) a material is equal to the area under a force–extension (or compression) graph
- deduce the work done in stretching (or compressing) a material from a graph of force–extension (or compression)
- calculate elastic potential energy when a material is stretched or compressed, using $E = \frac{1}{2}F\Delta L$ or $E = \frac{1}{2}k\Delta L^2$

Introduction

When you stretch or compress a material, work is done by the force you exert on the material. If the material is elastic then it gains elastic potential energy, E, which is released when it returns to its original shape. When plastic deformation occurs, the force deforms the material permanently and energy is transferred by heating.

The work done by any force can be found using a force–distance graph. When a constant force, F, acts over a distance, ΔL, the work done can be calculated from the formula $W = F\Delta L$. On a force–distance graph, this would be the area of the rectangle between the horizontal line and the x-axis (see Figure 1a). If the force is changing, the work done is the area between the line or curve of the graph and the x-axis (see Figure 1b).

In the case of a force *stretching* a material, as the stretching force (or the tension) increases the extension increases.

In the linear region of a force–extension graph, the area under the line can be calculated using the formula for the area of a triangle.

The elastic potential energy, E, equals the work done on the material by the stretching force.

$E = \frac{1}{2} F \Delta L$ and $F = k \Delta L^2$

Therefore, $E = \frac{1}{2} k \Delta L^2$

Out of the linear region, the work done can be found by counting the squares under the curve.

Worked example

Question

Figure 1a shows the force–extension graph for a material that stretches by obeying Hooke's law but does not go back to its original length.

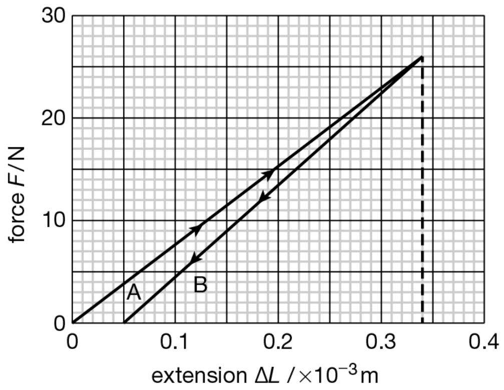


Figure 1a

Calculate:

a the work done in stretching the wire

b the energy recovered when the force is removed

c the energy dissipated in heating the wire as the wire is stretched by the force.

Answer

a *Step 1*

Identify the area that represents the work done on the wire. This is the area of the large triangle, made up of triangles A and B.

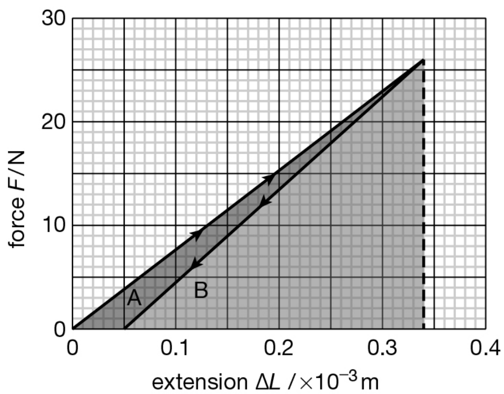


Figure 1b

Work done loading (stretching): W_L = area of triangle (A + B)

Step 2

Use the formula: triangle area = $\frac{1}{2}$ base × height, and substitute values for the base and perpendicular height.

$$W_L = \frac{1}{2}(0.34 \times 10^{-3}\ \text{m}) \times (26\ \text{N})$$

Step 3

State the answer, with units, to two significant figures.

$W_L = 4.42 \times 10^{-3}$ J

$= 4.4 \times 10^{-3}$ J (two significant figures)

b *Step 4*

Identify the area that represents the energy recovered by the wire when the force is removed.

The area of triangle B represents the energy recovered by the wire when the force is removed. It is the potential energy stored in the wire when it is stretched. This energy is recovered when the force on the wire is removed and it returns to its original length. This is the work done *by* the wire as it is unloaded and its extension decreases.

The potential energy, E_P, equals the energy transferred when the wire is unloaded, which equals the area of triangle B.

Step 5

Use the formula: triangle area = $\frac{1}{2}$ base × height, and substitute values for the base and perpendicular height.

$$E_P = \frac{1}{2}[(0.34 \times 10^{-3}\ \text{m}) - (0.05 \times 10^{-3}\ \text{m})] \times (26\ \text{N})$$

Step 6

State the answer, with units, to two significant figures.

$E_P = 3.77 \times 10^{-3}$ J

$= 3.8 \times 10^{-3}$ J (two significant figures)

c *Step 7*

Explain that the energy dissipated in heating the wire is the difference between the work done by the force stretching the wire and the potential energy stored in the stretched wire (the energy recovered in unloading).

Energy transferred as heat: $W_L - E_P = 4.42 \times 10^{-3}\ \text{J} - 3.77 \times 10^{-3}\ \text{J}$

Step 8

State the answer, with units, to two significant figures.

Energy transferred as heat: 6.5×10^{-4} J (two significant figures)

Questions

1 When a wire is stretched by a weight of 8.0 N it extends by 1.2 mm. The wire obeys Hooke's law and when the load is removed it reverts back to its original length.

Calculate the potential energy stored in the wire when the extension is 1.2 mm. (*1 mark*)

2 A wire has a force constant of 7000 N m^{-1}. The wire stretches 3.0 mm within the linear region of the graph.

Calculate the elastic potential energy stored in the wire when it is stretched by 3.0 mm. (*1 mark*)

3 Figure 2 shows three graphs of a wire being stretched with a force F_L (different in each case). For each wire, **a**, **b**, and **c**, calculate:

i the work done by the stretching force, F_L (*1 mark for each wire*)

ii the potential energy stored (*1 mark for each wire*)

iii the energy dissipated in heating the wire and its surroundings when the wire is loaded with F_L. (*1 mark for each wire*)

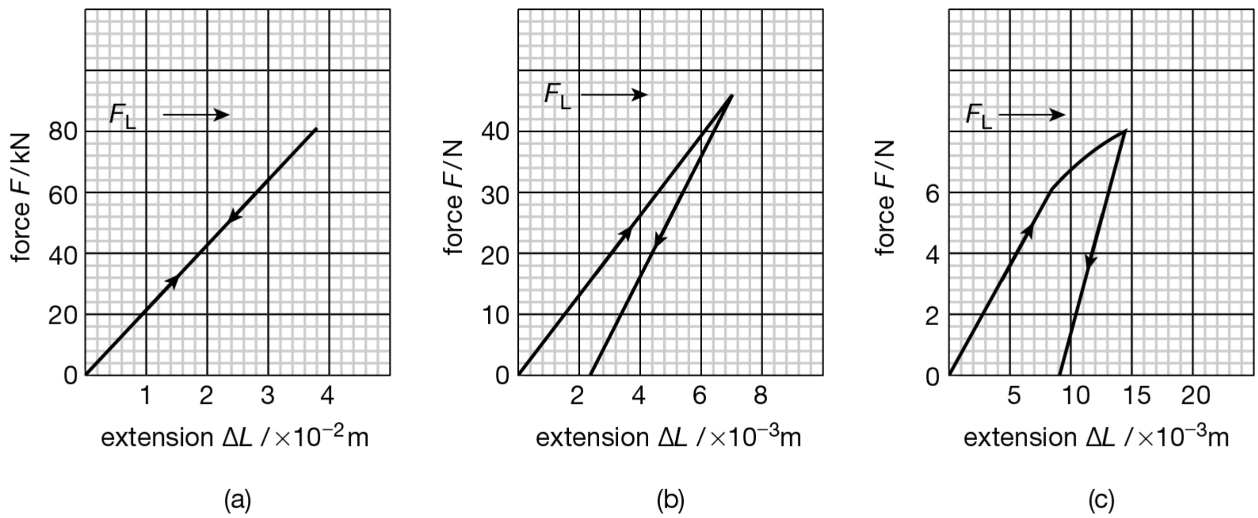


Figure 2

Hint: For graph **c** you will need to break the area up into rectangles and triangles.

Worked example

Question

Figure 3 shows a force–extension graph for a rubber band when masses were added one by one to a hanger suspended from the rubber band, and then removed one by one.

Calculate the energy dissipated in heating the rubber band during the loading.

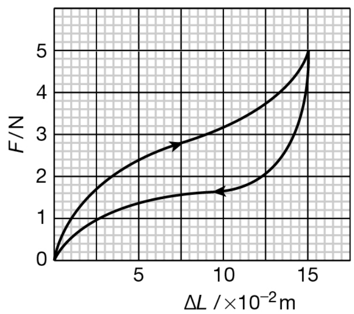


Figure 3

Answer

Step 1

Explain that the energy dissipated in heating is represented by the area between the loading graph and the unloading graph.

The energy dissipated in heating equals the area between the loading and unloading lines on the force–extension graph.

Step 2

Count the squares – including all those that are half a square or more, and omitting all those less than half a square.

(Try to be as accurate as you can. There will be a range of acceptable answers that are $\pm$ a few small squares. It is a good idea to make a small mark in each square as you count it to help you to keep count.)

There are 168 small squares.

Step 3

Explain how to convert this answer to energy using the scale on each axis.

Each small square $= (0.20\ \mathrm{N}) \times (0.50 \times 10^{-2}\ \mathrm{m})$

$= 1 \times 10^{-3}\ \mathrm{J}$

Step 4

Calculate the energy and state the answer to two significant figures.

$E = 168 \times 1 \times 10^{-3}\ \mathrm{J}$

$= 0.168\ \mathrm{J}$

$= 0.17\ \mathrm{J}$ (two significant figures)

Questions

4 A piece of elastic 12.0 cm long that is stretched to a length of 23.6 cm and released produces the force–extension graph shown in Figure 4. Use the graph to deduce the energy dissipated in heating the band when the band is stretched to this length, and then released. (*2 marks*)

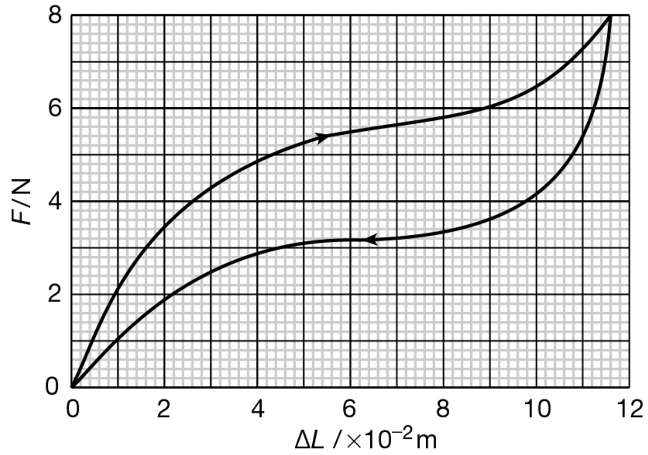


Figure 4

5 The graph in Figure 5 shows the extension of a spring when a tensile force is applied.

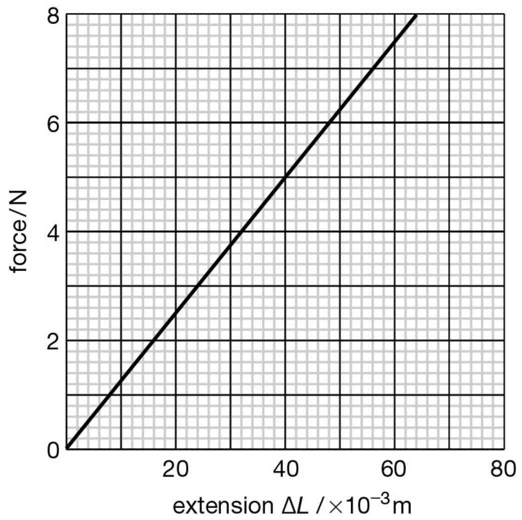


Figure 5

a Use the graph to determine:

i the force constant of the spring (*2 marks*)

ii the work done when a tensile force of 4.0 N is applied to the unstretched spring. (*1 mark*)

b **i** Calculate the potential energy stored in the spring when the unstretched spring is stretched by 82 mm. (*1 mark*)

ii Write down one assumption that you made in calculating your answer to **i**. (*1 mark*)

c The energy stored in the spring is used to launch a small sphere of mass 10 g horizontally.

Assuming all the energy is transferred to the sphere, calculate its initial velocity. (*2 marks*)

Maths skills links to other areas

You will need to be able to plot and interpret graphs throughout the AS Level course, both from data provided and from your own experimental results; for example, when investigating *I–V* characteristics of ohmic and non-ohmic components in Topic 12.4 *Components and their characteristics*. You will also be expected to understand the possible physical significance of the gradient and area under a graph in the graphs you plot.

Answers

1 $E_P = \frac{1}{2}\Delta L$

$= \frac{1}{2}(8.0\text{ N}) \times (1.2 \times 10^{-3}\text{ m})$

$= 4.8 \times 10^{-3}\text{ J}$ (*1 mark*)

2 $E_P = \frac{1}{2}\Delta L^2 = \frac{1}{2}(7000\text{ N m}^{-1}) \times (3.0 \times 10^{-3}\text{ m})^2 = 0.0315\text{ J} = 0.032\text{ J}$ (two significant figures) (*1 mark*)

3 a i W = area of triangle with base (0 to 3.8×10^{-2} m) and height F_L = (80 kN)

$W = \frac{1}{2}(80\text{ kN}) \times (3.8 \times 10^{-2}\text{ m}) = 1520\text{ J}$ (*1 mark*)

ii All this energy is transferred as potential energy, because it is all recovered when the wire is unloaded. $E_P = 1520$ J (*1 mark*)

iii Energy transferred as heat = 0 because all energy is transferred as potential energy (*1 mark*)

b i W = area of triangle with base (0 to 7.2×10^{-3} m) and height F_L = (46.0 N)

$W = \frac{1}{2}(46.0\text{ N}) \times (7.2 \times 10^{-3}\text{ m}) = 0.1656\text{ J} = 0.17\text{ J}$ (two significant figures) (*1 mark*)

ii E_P = work done under unloading curve. This is what was stored and is now released.

W = area of triangle with base (2.4×10^{-3} m to 7.2×10^{-3} m) and height F_L = (46.0 N)

$W = \frac{1}{2}(46.0\text{ N}) \times [(7.2 - 2.4) \times 10^{-3}\text{ m}] = 0.1104\text{ J} = 0.11\text{ J}$ (two significant figures) (*1 mark*)

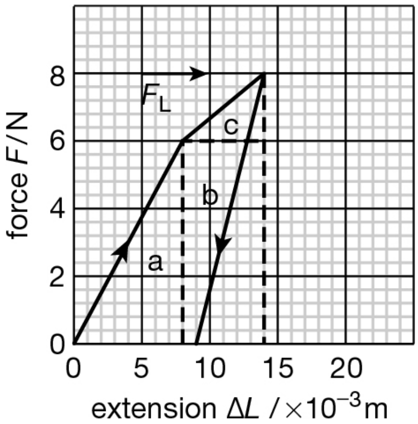
iii Energy transferred as heat = difference between **i** and **ii** = 0.1656 – 0.1104 = 0.0552 J = 0.055 J

or use the area of the triangle formed by the unloading and loading curves:

$E = \frac{1}{2}(46.0\text{ N}) \times (2.4 \times 10^{-3}\text{ m}) = 0.0552\text{ J} = 0.055\text{ J}$ (two significant figures) (*1 mark*)

c i W = area under curve with base (0 to 14.0×10^{-3} m) and height F_L = (8.0 N)

Divide it into areas a, b, and c (a shape can sometimes be approximated to a triangle). You can then use the formulae for areas of rectangles and triangles (or trapeziums if you prefer).



W = area a + area b + area c

$W = \frac{1}{2}$ (6.0 N) × (8.0 × 10^{-3} m) + (6.0 N) × [(14.0 – 8.0) × 10^{-3} m] + $\frac{1}{2}$ (8.0 N) [(14.0 – 8.0) × 10^{-3} m]

= 24.0 × 10^{-3} J + 36.0 × 10^{-3} J + 24 × 10^{-3} J = 84.0 × 10^{-3} J

= 8.4 × 10^{-2} J (two significant figures) (*1 mark*)

ii E_P = work done under unloading curve. This is what was stored and is now released.

W = area under curve with base (9.0 to 14.0 × 10^{-3} m) and height F_L = (8.0 N)

$W = \frac{1}{2}$ (8.0 N) × [(14.0 – 9.0) × 10^{-3} m]

= 20.0 × 10^{-3} J

= 2.0 × 10^{-2} J (two significant figures) (*1 mark*)

iii Energy transferred as heat = difference between **i** and **ii**

= 8.4 × 10^{-2} J – 2.0 × 10^{-2} J = 6.4 × 10^{-2} J (two significant figures) (*1 mark*)

4 This question gives lengths rather than extensions. The extension is 23.6 cm – 12 cm = 11.6 cm. Looking at the graph you can see that it is a graph of a material stretched to an extension of 11.6 cm and released. The energy transferred as heat is the energy inside the shape formed by the loading and unloading curves.

By counting squares, there are 140 ± 5 small squares. (*1 mark*)

Each square represents (0.40 N) × (0.40 × 10^{-2} m) = 1.60 × 10^{-3} J

E = 140 × 1.60 × 10^{-3} J = 0.224 J (*1 mark*)

(135 squares gives 0.216 J and 145 squares gives 0.232 J so your answer should be in this range.)

5 a i k = gradient of graph

$= \frac{(8.00)\text{ N}}{(64-0)\times 10^{-3}\text{ m}}$ (*1 mark*)

= 125 Nm^{-1} = 130 N m^{-1} (two significant figures) (*1 mark*)

ii When F = 4.0 N, x = 38 × 10^{-3} m

$W = \frac{1}{2} F \, \Delta L$

$= \frac{1}{2} (4.0\,\text{N}) \times (32 \times 10^{-3}\,\text{m})$

$= 0.064\,\text{J}$ (*1 mark*)

b **i** $E_P = \frac{1}{2} k \, \Delta L^2$

$= \frac{1}{2} (125\,\text{N m}^{-1}) \times (82 \times 10^{-3}\,\text{m})^2$

$= 0.420\,\text{J} = 0.42\,\text{J}$ (two significant figures) (*1 mark*)

ii The limit of proportionality has not been exceeded **or** the extension is still proportional to the applied force when $\Delta L = 82$ mm. (*1 mark*)

c $E_P = 0.420$ J all transferred to 10 g sphere ($= 10 \times 10^{-3}$ kg), which then has $E_K = \frac{1}{2} m v^2$

$\frac{1}{2} m v^2 = 0.420\,\text{J}$ (*1 mark*)

$v = \sqrt{\frac{2 \times 0.420}{10 \times 10^{-3}\,\text{kg}}} = 9.2\,\text{m s}^{-1}$ (*1 mark*)

Transition from GCSE to A Level

Moving from GCSE Science to A Level can be a daunting leap. You'll be expected to remember a lot more facts, equations, and definitions, and you will need to learn new maths skills and develop confidence in applying what you already know to unfamiliar situations.

This worksheet aims to give you a head start by helping you:

- to pre-learn some useful knowledge from the first chapters of your A Level course
- understand and practise of some of the maths skills you'll need.

Learning objectives

After completing the worksheet you should be able to:

- define practical science key terms
- recall the answers to the retrieval questions
- perform maths skills including:
  - unit conversions
  - uncertainties
  - using standard form and significant figures
  - resolving vectors
  - rearranging equations
  - equations of work, power, and efficiency.

Retrieval questions

You need to be confident about the definitions of terms that describe measurements and results in A Level Physics.

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

Practical science key terms

When is a measurement valid?	when it measures what it is supposed to be measuring
When is a result accurate?	when it is close to the true value
What are precise results?	when repeat measurements are consistent/agree closely with each other
What is repeatability?	how precise repeated measurements are when they are taken by the *same* person, using the *same* equipment, under the *same* conditions
What is reproducibility?	how precise repeated measurements are when they are taken by *different* people, using *different* equipment
What is the uncertainty of a measurement?	the interval within which the true value is expected to lie
Define measurement error	the difference between a measured value and the true value
What type of error is caused by results varying around the true value in an unpredictable way?	random error
What is a systematic error?	a consistent difference between the measured values and true values
What does zero error mean?	a measuring instrument gives a false reading when the true value should be zero
Which variable is changed or selected by the investigator?	independent variable
What is a dependent variable?	a variable that is measured every time the independent variable is changed
Define a fair test	a test in which only the independent variable is allowed to affect the dependent variable
What are control variables?	variables that should be kept constant to avoid them affecting the dependent variable

Foundations of Physics

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

What is a physical quantity?	a property of an object or of a phenomenon that can be measured
What are the S.I. units of mass, length, and time?	kilogram (kg), metre (m), second (s)
What base quantities do the S.I. units A, K, and mol represent?	current, temperature, amount of substance
List the prefixes, their symbols and their multiplication factors from pico to tera (in order of increasing magnitude)	pico (p) 10^{-12}, nano (n) 10^{-9}, micro (μ) 10^{-6}, milli (m) 10^{-3}, centi (c) 10^{-2}, deci (d) 10^{-1}, kilo (k) 10^{3}, mega (M) 10^{6}, giga (G) 10^{9}, tera (T) 10^{12}
What is a scalar quantity?	a quantity that has magnitude (size) but *no* direction
What is a vector quantity?	a quantity that has magnitude (size) *and* direction
What are the equations to resolve a force, F, into two perpendicular components, F_x and F_y?	$F_x = F\cos\theta$ $F_y = F\sin\theta$
What is the difference between distance and displacement?	distance is a scalar quantity displacement is a vector quantity
What does the Greek capital letter Δ (delta) mean?	'change in'
What is the equation for average speed in algebraic form?	$v = \frac{\Delta x}{\Delta t}$
What is instantaneous speed?	the speed of an object over a very short period of time
What does the gradient of a displacement–time graph tell you?	velocity
How can you calculate acceleration and displacement from a velocity–time graph?	acceleration is the gradient displacement is the area under the graph
Write the equation for acceleration in algebraic form	$a = \frac{\Delta v}{\Delta t}$
What do the letters *suvat* stand for in the equations of motion?	s = displacement, u = initial velocity, v = final velocity, a = acceleration, t = time taken
Write the four *suvat* equations.	$v = u + at$ $\quad s = ut + \frac{1}{2}at^2$ $s = \frac{1}{2}(u+v)t$ $\quad v^2 = u^2 + 2as$
Define *stopping distance*	the total distance travelled from when the driver first sees a reason to stop, to when the vehicle stops
Define *thinking distance*	the distance travelled between the moment when you first see a reason to stop to the moment when you use the brake
Define *braking distance*	the distance travelled from the time the brake is applied until the vehicle stops
What does *free fall* mean?	when an object is accelerating under gravity with no other force acting on it

Matter and radiation

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

What is an atom made up of?	a positively charged nucleus containing protons and neutrons, surrounded by electrons
Define a *nucleon*	a proton or a neutron in the nucleus
What are the absolute charges of protons, neutrons, and electrons?	$+1.60\times10^{-19}$, 0, and -1.60×10^{-19} coulombs (C) respectively
What are the relative charges of protons, neutrons, and electrons?	1, 0, and – 1 respectively (charge relative to proton)
What is the mass, in kilograms, of a proton, a neutron, and an electron?	1.67×10^{-27}, 1.67×10^{-27}, and 9.11×10^{-31} kg respectively
What are the relative masses of protons, neutrons, and electrons?	1, 1, and 0.0005 respectively (mass relative to proton)
What is the atomic number of an element?	the number of protons
Define an isotope	isotopes are atoms with the same number of protons and different numbers of neutrons
Write what *A*, *Z* and X stand for in isotope notation ($^{A}_{Z}X$)?	*A*: the number of nucleons (protons + neutrons) *Z*: the number of protons X: the chemical symbol
Which term is used for each type of nucleus?	nuclide
How do you calculate specific charge?	charge divided by mass (for a charged particle)
What is the specific charge of a proton and an electron?	9.58×10^{7} and 1.76×10^{11} C kg^{-1} respectively
Name the force that holds nuclei together	strong nuclear force
What is the range of the strong nuclear force?	from 0.5 to 3–4 femtometres (fm)
Name the three kinds of radiation	alpha, beta, and gamma
What particle is released in alpha radiation?	an alpha particle, which comprises two protons and two neutrons
Write the symbol of an alpha particle	$^{4}_{2}\alpha$
What particle is released in beta radiation?	a fast-moving electron (a beta particle)
Write the symbol for a beta particle	$^{0}_{-1}\beta$
Define *gamma radiation*	electromagnetic radiation emitted by an unstable nucleus
What particles make up everything in the universe?	matter and antimatter
Name the antimatter particles for electrons, protons, neutrons, and neutrinos	positron, antiproton, antineutron, and antineutrino respectively
What happens when corresponding matter and antimatter particles meet?	they annihilate (destroy each other)
List the seven main parts of the electromagnetic spectrum from longest wavelength to shortest	radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays
Write the equation for calculating the wavelength of electromagnetic radiation	wavelength $(\lambda) = \dfrac{\text{speed of light } (c)}{\text{frequency } (f)}$
Define a *photon*	a packet of electromagnetic waves
What is the speed of light?	3.00×10^{8} m s^{-1}
Write the equation for calculating photon energy	photon energy (*E*) = Planck constant (*h*) × frequency (*f*)
Name the four fundamental interactions	gravity, electromagnetic, weak nuclear, strong nuclear

Maths skills

1 Measurements

1.1 Base and derived SI units

Units are defined so that, for example, every scientist who measures a mass in kilograms uses the same size for the kilogram and gets the same value for the mass. Scientific measurement depends on standard units – most are *Système International* (SI) units. Every measurement must give the unit to have any meaning. You should know the correct unit for physical quantities.

Base units

Physical quantity	Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s

Physical quantity	Unit	Symbol
electric current	ampere	A
temperature difference	Kelvin	K
amount of substance	mole	mol

Derived units

Example:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

If a car travels 2 metres in 2 seconds:

$$\text{speed} = \frac{2\,\text{metres}}{2\,\text{seconds}} = 1\frac{\text{m}}{\text{s}} = 1\,\text{m/s}$$

This defines the SI unit of speed to be 1 metre per second (m/s), or 1 m s^{-1} ($s^{-1} = \frac{1}{s}$).

Practice questions

1 Complete this table by filling in the missing units and symbols.

Physical quantity	Equation used to derive unit	Unit	Symbol and name (if there is one)
frequency	period^{-1}	s^{-1}	Hz, hertz
volume	length^3		–
density	mass ÷ volume		–
acceleration	velocity ÷ time		–
force	mass × acceleration		
work and energy	force × distance		

1.2 Significant figures

When you use a calculator to work out a numerical answer, you know that this often results in a large number of decimal places and, in most cases, the final few digits are 'not significant'. It is important to record your data and your answers to calculations to a reasonable number of significant figures. Too many and your answer is claiming an accuracy that it does not have, too few and you are not showing the precision and care required in scientific analysis.

Numbers to 3 significant figures (3 s.f.):

3.62 25.4 271 0.0147 0.245 39 400

(notice that the zeros before the figures and after the figures are *not* significant – they just show you how large the number is by the position of the decimal point).

Numbers to 3 significant figures where the zeros *are* significant:

207 4050 1.01 (any zeros between the other significant figures *are* significant).

Standard form numbers with 3 significant figures:

9.42×10^{-5} 1.56×10^{8}

If the value you wanted to write to 3.s.f. was 590, then to show the zero was significant you would have to write:

590 (to 3.s.f.) or 5.90×10^{2}

Practice questions

2 Give these measurements to 2 significant figures:

a 19.47 m **b** 21.0 s **c** 1.673×10^{-27} kg **d** 5 s

3 Use the equation:

$$\text{resistance} = \frac{\text{potential difference}}{\text{current}}$$

to calculate the resistance of a circuit when the potential difference is 12 V and the current is 1.8 mA. Write your answer in kΩ to 3 s.f.

1.3 Uncertainties

When a physical quantity is measured there will always be a small difference between the measured value and the true value. How important the difference is depends on the size of the measurement and the size of the uncertainty, so it is important to know this information when using data.

There are several possible reasons for uncertainty in measurements, including the difficulty of taking the measurement and the resolution of the measuring instrument (i.e. the size of the scale divisions).

For example, a length of 6.5 m measured with great care using a 10 m tape measure marked in mm would have an uncertainty of 2 mm and would be recorded as 6.500 ± 0.002 m.

It is useful to quote these uncertainties as percentages.

For the above length, for example,

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{measurement}} \times 100$$

$$\text{percentage uncertainty} = \frac{0.002}{6.500} \times 100\% = 0.03\%.$$ The measurement is 6.500 m ± 0.03%.

Values may also be quoted with absolute error rather than percentage uncertainty, for example, if the 6.5 m length is measured with a 5% error,

the absolute error = 5/100 × 6.5 m = ±0.325 m.

Practice questions

4 Give these measurements with the uncertainty shown as a percentage (to 1 significant figure):

a 5.7 ± 0.1 cm **b** 450 ± 2 kg **c** 10.60 ± 0.05 s **d** 366 000 ± 1000 J

5 Give these measurements with the error shown as an absolute value:

a 1200 W ± 10% **b** 330 000 Ω ± 0.5%

6 Identify the measurement with the smallest percentage error. Show your working.

A 9 ± 5 mm **B** 26 ± 5 mm **C** 516 ± 5 mm **D** 1400 ± 5 mm

2 Standard form and prefixes

When describing the structure of the Universe you have to use very large numbers. There are billions of galaxies and their average separation is about a million light years (ly). The Big Bang theory says that the Universe began expanding about 14 billion years ago. The Sun formed about 5 billion years ago. These numbers and larger numbers can be expressed in standard form and by using prefixes.

2.1 Standard form for large numbers

In standard form, the number is written with one digit in front of the decimal point and multiplied by the appropriate power of 10. For example:

- The diameter of the Earth, for example, is 13 000 km.
  13 000 km = 1.3 × 10 000 km = 1.3×10^4 km.
- The distance to the Andromeda galaxy is 2 200 000 light years = 2.2 × 1 000 000 ly = 2.2×10^6 ly.

2.2 Prefixes for large numbers

Prefixes are used with SI units (see Topic 1.1) when the value is very large or very small. They can be used instead of writing the number in standard form. For example:

- A kilowatt (1 kW) is a thousand watts, that is 1000 W or 10^3 W.
- A megawatt (1 MW) is a million watts, that is 1 000 000 W or 10^6 W.
- A gigawatt (1 GW) is a billion watts, that is 1 000 000 000 W or 10^9 W.

Prefix	Symbol	Value
kilo	k	10^3
mega	M	10^6

Prefix	Symbol	Value
giga	G	10^9
tera	T	10^{12}

For example, Gansu Wind Farm in China has an output of 6.8×10^{9} W. This can be written as 6800 MW or 6.8 GW.

Practice questions

1 Give these measurements in standard form:

a 1350 W **b** 130 000 Pa **c** 696×10^{6} s **d** 0.176×10^{12} C kg^{-1}

2 The latent heat of vaporisation of water is 2 260 000 J/kg. Write this in:

a J/g **b** kJ/kg **c** MJ/kg

2.3 Standard form and prefixes for small numbers

At the other end of the scale, the diameter of an atom is about a tenth of a billionth of a metre. The particles that make up an atomic nucleus are much smaller. These measurements are represented using negative powers of ten and more prefixes. For example:

- The charge on an electron = 1.6×10^{-19} C.
- The mass of a neutron = $0.016\,75 \times 10^{-25}$ kg = 1.675×10^{-27} kg (the decimal point has moved 2 places to the right).
- There are a billion nanometres in a metre, that is 1 000 000 000 nm = 1 m.
- There are a million micrometres in a metre, that is 1 000 000 μm = 1 m.

Prefix	Symbol	Value
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}

Prefix	Symbol	Value
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Practice questions

3 Give these measurements in standard form:

a 0.0025 m **b** 160×10^{-17} m **c** 0.01×10^{-6} J **d** 0.005×10^{6} m **e** 0.00062×10^{3} N

4 Write the measurements for question 3a, c, and d above using suitable prefixes.

5 Write the following measurements using suitable prefixes.

a a microwave wavelength = 0.009 m

b a wavelength of infrared = 1×10^{-5} m

c a wavelength of blue light = 4.7×10^{-7} m

2.4 Powers of ten

When multiplying powers of ten, you must *add* the indices.

So 100 × 1000 = 100 000 is the same as $10^{2} \times 10^{3} = 10^{2+3} = 10^{5}$

When dividing powers of ten, you must *subtract* the indices.

So $\frac{100}{1000} = \frac{1}{10} = 10^{-1}$ is the same as $\frac{10^{2}}{10^{3}} = 10^{2-3} = 10^{-1}$

But you can only do this when the numbers with the indices are the same.

So $10^{2} \times 2^{3} = 100 \times 8 = 800$

And you can't do this when adding or subtracting.

$10^2 + 10^3 = 100 + 1000 = 1100$

$10^2 - 10^3 = 100 - 1000 = -900$

Remember: You can only add and subtract the indices when you are multiplying or dividing the numbers, not adding or subtracting them.

Practice questions

6 Calculate the following values – read the questions very carefully!

a $20^6 + 10^{-3}$

b $10^2 - 10^{-2}$

c $2^3 \times 10^2$

d $10^5 \div 10^2$

7 The speed of light is 3.0×10^8 m s^{-1}. Use the equation $v = f\lambda$ (where λ is wavelength) to calculate the frequency of:

a ultraviolet, wavelength 3.0×10^{-7} m

b radio waves, wavelength 1000 m

c X-rays, wavelength 1.0×10^{-10} m.

3 Resolving vectors

3.1 Vectors and scalars

Vectors have a magnitude (size) and a direction. Directions can be given as points of the compass, angles or words such as forwards, left or right. For example, 30 mph east and 50 km/h north-west are velocities.

Scalars have a magnitude, but no direction. For example, 10 m/s is a speed.

Practice questions

1 State whether each of these terms is a vector quantity or a scalar quantity: density, temperature, electrical resistance, energy, field strength, force, friction, frequency, mass, momentum, power, voltage, volume, weight, work done.

2 For the following data, state whether each is a vector or a scalar: 3 ms^{-1}, +20 ms^{-1}, 100 m NE, 50 km, −5 cm, 10 km S 30° W, 3×10^8 ms^{-1} upwards, 273 °C, 50 kg, 3 A.

3.2 Drawing vectors

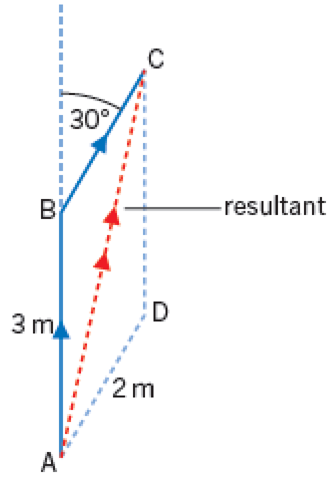
Vectors are shown on drawings by a straight arrow. The arrow starts from the point where the vector is acting and shows its direction. The length of the vector represents the magnitude.

When you add vectors, for example two velocities or three forces, you must take the direction into account.

The combined effect of the vectors is called the resultant.

This diagram shows that walking 3 m from A to B and then turning through 30° and walking 2 m to C has the same effect as walking directly from A to C. AC is the resultant vector, denoted by the double arrowhead.

A careful drawing of a scale diagram allows us to measure these. Notice that if the vectors are combined by drawing them in the opposite order, AD and DC, these are the other two sides of the parallelogram and give the same resultant.



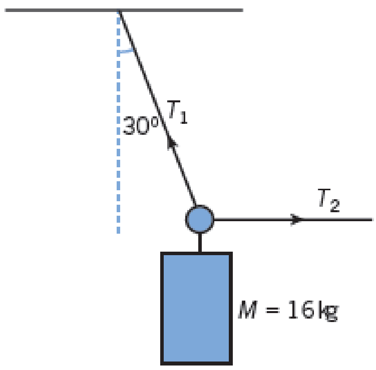
Practice questions

3 Two tractors are pulling a log across a field. Tractor 1 is pulling north with force 1 = 5 kN and tractor 2 is pulling east with force 2 = 12 kN. By scale drawing, determine the resultant force.

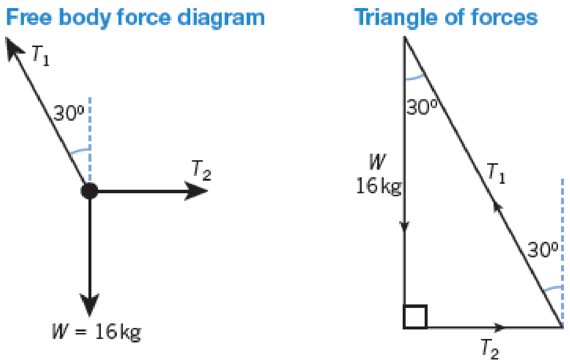
3.3 Free body force diagrams

To combine forces, you can draw a similar diagram to the one above, where the lengths of the sides represent the magnitude of the force (e.g., 30 N and 20 N). The third side of the triangle shows us the magnitude and direction of the resultant force.

When solving problems, start by drawing a free body force diagram. The object is a small dot and the forces are shown as arrows that start on the dot and are drawn in the direction of the force. They don't have to be to scale, but it helps if the larger forces are shown to be larger. Look at this example.



A 16 kg mass is suspended from a hook in the ceiling and pulled to one side with a rope, as shown on the right. Sketch a free body force diagram for the mass and draw a triangle of forces.



Notice that each force starts from where the previous one ended and they join up to form a triangle with no resultant because the mass is in equilibrium (balanced).

Practice questions

4 Sketch a free body force diagram for the lamp (**Figure 1**, below) and draw a triangle of forces.

5 There are three forces on the jib of a tower crane (**Figure 2**, below). The tension in the cable T, the weight W, and a third force P acting at X.

The crane is in equilibrium. Sketch the triangle of forces.

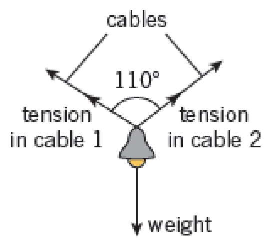


Figure 1

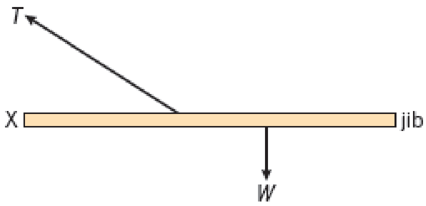


Figure 2

3.4 Calculating resultants

When two forces are acting at right angles, the resultant can be calculated using Pythagoras's theorem and the trig functions: sine, cosine, and tangent.

For a right-angled triangle as shown:

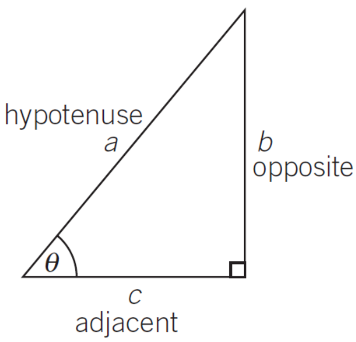
$h^2 = o^2 + a^2$

$\sin \theta = \frac{o}{h}$

$\cos \theta = \frac{a}{h}$

$\tan \theta = \frac{o}{a}$

(soh-cah-toa).



Practice questions

6 **Figure 3** shows three forces in equilibrium.
Draw a triangle of forces to find T and α.

7 Find the resultant force for the following pairs of forces at right angles to each other:
a 3.0 N and 4.0 N **b** 5.0 N and 12.0 N

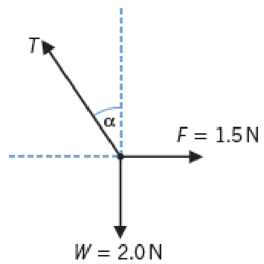


Figure 3

4 Rearranging equations

Sometimes you will need to rearrange an equation to calculate the answer to a question. For example, if you want to calculate the resistance R, the equation:

potential difference (V) = current (A) × resistance (Ω) or $V = I R$

must be rearranged to make R the subject of the equation:

$$R = \frac{V}{I}$$

When you are solving a problem:

- Write down the values you know and the ones you want to calculate.
- you can rearrange the equation first, and then substitute the values

  or
- substitute the values and then rearrange the equation

4.1 Substitute and rearrange

A student throws a ball vertically upwards at 5 m s^{-1}. When it comes down, she catches it at the same point. Calculate how high it goes.

Step 1: Known values are:

- initial velocity u = 5.0 m s^{-1}
- final velocity v = 0 (you know this because as it rises it will slow down, until it comes to a stop, and then it will start falling downwards)
- acceleration $a = g = -9.81$ m s^{-2}
- distance s = ?

Step 2: Equation:

(final velocity)^2 − (initial velocity)^2 = 2 × acceleration × distance

or $v^2 - u^2 = 2 \times g \times s$

Substituting: $(0)^2 - (5.0 \text{ m s}^{-1})^2 = 2 \times -9.81 \text{ m s}^{-2} \times s$

$0 - 25 = 2 \times -9.81 \times s$

Step 3: Rearranging:

$-19.62\, s = -25$

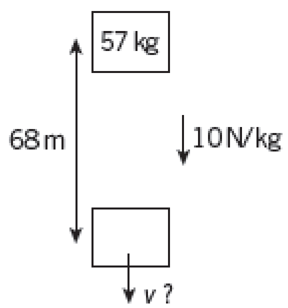
$s = \dfrac{-25}{-19.62}$ = 1.27 m = 1.3 m (2 s.f.)

Practice questions

1. The potential difference across a resistor is 12 V and the current through it is 0.25 A. Calculate its resistance.
2. Red light has a wavelength of 650 nm. Calculate its frequency. Write your answer in standard form.
   (Speed of light = 3.0 × 10^8 m s^{-1})

4.2 Rearrange and substitute

A 57 kg block falls from a height of 68 m. By considering the energy transferred, calculate its speed when it reaches the ground.



(Gravitational field strength = 10 N kg^{-1})

Step 1: m = 57 kg h = 68 m g = 10 N kg^{-1} v = ?

Step 2: There are three equations:

PE = $m\,g\,h$ KE gained = PE lost KE = 0.5 $m\,v^2$

Step 3: Rearrange the equations before substituting into it.

As KE gained = PE lost, $m\,g\,h = 0.5\,m\,v^2$

You want to find v. Divide both sides of the equation by 0.5 m:

$$\frac{mgh}{0.5m} = \frac{0.5mv^2}{0.5m}$$

$2\,g\,h = v^2$

To get v, take the square root of both sides: $v = \sqrt{2gh}$

Step 4: Substitute into the equation:

$v = \sqrt{2 \times 10 \times 68}$

$v = \sqrt{1360} = 37\ \text{m s}^{-1}$

Practice questions

3 Calculate the specific latent heat of fusion for water from this data:
4.03×10^4 J of energy melted 120 g of ice.
Use the equation:
thermal energy for a change in state (J) = mass (kg) × specific latent heat (J kg^{-1})
Give your answer in J kg^{-1} in standard form.

5 Work done, power, and efficiency

5.1 Work done

Work is done when energy is transferred. Work is done when a force makes something move. If work is done *by* an object its energy decreases and if work is done *on* an object its energy increases.

work done = energy transferred = force × distance

Work and energy are measured in joules (J) and are scalar quantities (see Topic 3.1).

Practice questions

1 Calculate the work done when the resultant force on a car is 22 kN and it travels 2.0 km.

2 Calculate the distance travelled when 62.5 kJ of work is done applying a force of 500 N to an object.

5.2 Power

Power is the rate of work done.

It is measured in watts (W) where 1 watt = 1 joule per second.

$$\text{power} = \frac{\text{energy transferred}}{\text{time taken}} \quad \textit{or} \ \text{power} = \frac{\text{work done}}{\text{time taken}}$$

$P = \Delta W / \Delta t$ *Δ is the symbol 'delta' and is used to mean a 'change in'*

Look at this worked example, which uses the equation for potential energy gained.

A motor lifts a mass m of 12 kg through a height Δh of 25 m in 6.0 s.

Gravitational potential energy gained:

$\Delta PE = mg\Delta h = (12\ \text{kg}) \times (9.81\ \text{m s}^{-2}) \times (25\ \text{m}) = 2943\ \text{J}$

$$\text{Power} = \frac{2943\ \text{J}}{6.0\ \text{s}} = 490\ \text{W (2 s.f.)}$$

Practice questions

3 Calculate the power of a crane motor that lifts a weight of 260 000 N through 25 m in 48 s.

4 A motor rated at 8.0 kW lifts a 2500 N load 15 m in 5.0 s. Calculate the output power.

5.3 Efficiency

Whenever work is done, energy is transferred and some energy is transferred to other forms, for example, heat or sound. The efficiency is a measure of how much of the energy is transferred usefully.

Efficiency is a ratio and is given as a decimal fraction between 0 (all the energy is wasted) and 1 (all the energy is usefully transferred) or as a percentage between 0 and 100%. It is not possible for anything to be 100% efficient: some energy is always lost to the surroundings.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \text{ or Efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

(multiply by 100% for a percentage)

Look at this worked example.

A thermal power station uses 11 600 kWh of energy from fuel to generate electricity. A total of 4500 kWh of energy is output as electricity. Calculate the percentage of energy 'wasted' (dissipated in heating the surroundings).

You must calculate the energy wasted using the value for useful energy output:

$$\text{percentage energy wasted} = \frac{(\text{total energy input - energy output as electricity})}{\text{total energy input}} \times 100$$

$$\text{percentage energy wasted} = \frac{(11600 - 4500)}{11600} \times 100 = 61.2\% = 61\% \text{ (2 s.f.)}$$

Practice questions

5 Calculate the percentage efficiency of a motor that does 8400 J of work to lift a load.
The electrical energy supplied is 11 200 J.

6 An 850 W microwave oven has a power consumption of 1.2 kW.
Calculate the efficiency, as a percentage.

7 Use your answer to question 4 above to calculate the percentage efficiency of the motor. (The motor, rated at 8.0 kW, lifts a 2500 N load 15 m in 5.0 s.)

8 Determine the time it takes for a 92% efficient 55 W electric motor take to lift a 15 N weight 2.5 m.

 http://www.oxfordsecondary.co.uk/acknowledgements

Answers to maths skills practice questions

1 Measurements

1

Physical quantity	Equation used to derive unit	Unit	Symbol and name (if there is one)
frequency	period^{-1}	s^{-1}	Hz, hertz
volume	length^3	m^3	–
density	mass ÷ volume	kg m^{-3}	–
acceleration	velocity ÷ time	m s^{-2}	–
force	mass × acceleration	kg m s^{-2}	N newton
work and energy	force × distance	N m (or kg m^2 s^{-2})	J joule

2 **a** 19 m **b** 21 s
c 1.7×10^{-27} kg **d** 5.0 s

3 Resistance $= \dfrac{12\text{ V}}{1.8\text{ mA}} = \dfrac{12\text{ V}}{0.0018\text{ A}} = 6666.666...\Omega = 6.66666...\text{k}\Omega = 6.67\Omega$

4 **a** 5.7 cm ± 2% **b** 450 kg ± 0.4%
c 10.6 s ± 0.5% **d** 366 000 J ± 0.3%

5 **a** 1200 ± 120 W **b** 330 000 ± 1650 Ω

6 **D** 1400 ± 5 mm (Did you calculate them all? The same absolute error means the percentage error will be smallest in the largest measurement, so no need to calculate.)

2 Standard form and prefixes

1 **a** 1.35×10^3 W (or 1.350×10^3 W to 4 s.f.) **b** 1.3×10^5 Pa
c 6.96×10^8 s **d** 1.76×10^{11} C kg^{-1}

2 **a** 2 260 000 J in 1 kg, so there will be 1000 times fewer J in 1 g: $\dfrac{2\,260\,000}{1000} = 2260$ J/g

b 1 kJ = 1000 J, $2\,260\,000\text{ J/kg} = \dfrac{2\,260\,000}{1000}\text{kJ/kg} = 2260\text{ kJ/kg}$

c 1 MJ = 1000 kJ, so $2260\text{ kJ/kg} = \dfrac{2260}{1000}\text{MJ/kg} = 2.26\text{ MJ/kg}$

3 **a** 2.5×10^{-3} m **b** 1.60×10^{-15} m
c 1×10^{-8} J **d** 5×10^3 m
e 6.2×10^{-1} N

4 **a** 2.5 µm **b** 1.60 f m
c 10 nJ **or** 0.01 µJ **d** 5 km
e 0.62 N **or** 62 cN

5 **a** 0.009 m = 9×10^{-3} m = 9 mm
b 1×10^{-5} m = $1 \times 10 \times 10^{-6}$ m = 10×10^{-6} m = 10 µm
c 4.7×10^{-7} m = $4.7 \times 100 \times 10^{-9}$ m = 470×10^{-9} m = 470 nm

6 **a** 64000000 **or** 6.4×10^7 **b** 99.99

c 800 d 10^3

7 a 3.0×10^8 m s^{-1} ÷ 3.03×10^{-7} m = 1.0×10^{15} Hz

b 3.0×10^8 m s^{-1} ÷ 1000 m = 3.0×10^5 Hz

c 3.0×10^8 m s^{-1} ÷ 1.0×10^{-10} m = 3.0×10^{18} Hz

3 Resolving vectors

1 **Scalars:** density, electric charge, electrical resistance, energy, frequency, mass, power, temperature, voltage, volume, work done

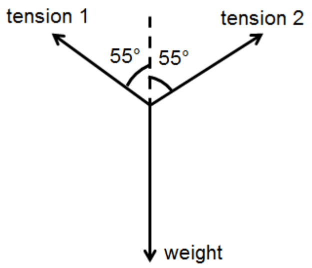
Vectors: field strength, force, friction, momentum, weight

2 **Scalars:** 3 ms^{-1}, 50 km, 273 °C, 50 kg, 3 A

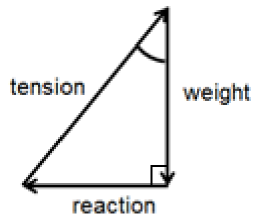
Vectors: +20 ms^{-1}, 100 m NE, −5 cm, 10 km S 30°W, 3 × 10^8 m/s upwards

3 13 kN

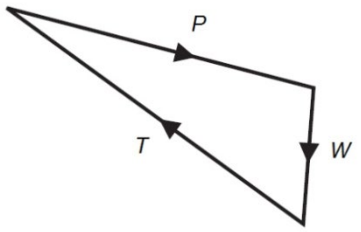
4 **Free body force diagram:**



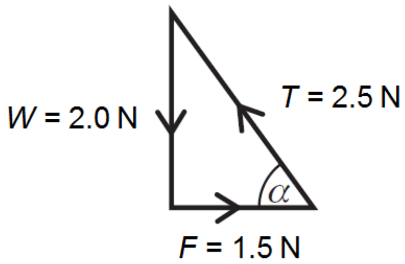
Triangle of forces:



5



6



7 a 5.0 N at 37° to the 4.0 N force b 13 N at 23° to the 12.0 N force

4 Rearranging equations

1 $V = 12$ V and $I = 0.25$ A

$V = IR$ so $12 = 0.25 \times R$

$$R = \frac{V}{I} = \frac{12}{0.25} = 48\ \Omega$$

2 $\lambda = 650$ nm $= 650\times10^{-9}$ m and $v = 3.0\times10^8$ m/s

$v = f\lambda$ so $3.0\times10^{8} = f \times 650\times10^{-9}$

$f = \frac{v}{\lambda} = \frac{3.0\times10^{8}}{650\times10^{-9}} = 0.00462\times10^{17} = 4.62\times10^{14}$ Hz

3 $E = 4.01\times10^{4}$ J and $m = 0.120$ g $= 0.120$ kg

$E = mL$ so $4.01\times10^{4} = 0.120 \times L$

$L = \frac{E}{m} = \frac{4.01\times10^{4}}{0.120} = 334\,166$ J/kg $= 3.34\times10^{5}$ J/kg in standard form

5 Work done, power, and efficiency

1 22×10^{3} N $\times$ 2×10^{3} m = 44 000 000 J = 44 MJ

2 $\frac{62.5\times10^{3}\text{ J}}{500\text{ N}} = 125$ m

3 $\frac{260\,000\text{ N}\times25\text{ m}}{48\text{ s}} = 13\,541.6$ W = 14 000 W or 14 kW (2 s.f.)

4 $\frac{2500\text{ N}\times15\text{ m}}{5\text{ s}} = 7500$ W = 7.5 kW

5 $\frac{8400}{11200}\times100 = 75\%$

6 $\frac{850}{1.2\times10^{3}}\times100 = 71\%$

7 $\frac{7.5}{8.0}\times100 = 94\%$

8 0.74 s

Transition Pack for A Level Physics

Get ready for A-level!

A guide to help you get ready for A-level Physics, including everything from topic guides to days out and online learning courses.

Commissioned by The PiXL Club Ltd. February 2016

Please note: these resources are non-board specific. Please direct your students to the specifics of where this knowledge and skills most apply.

So you are considering A Level Physics?

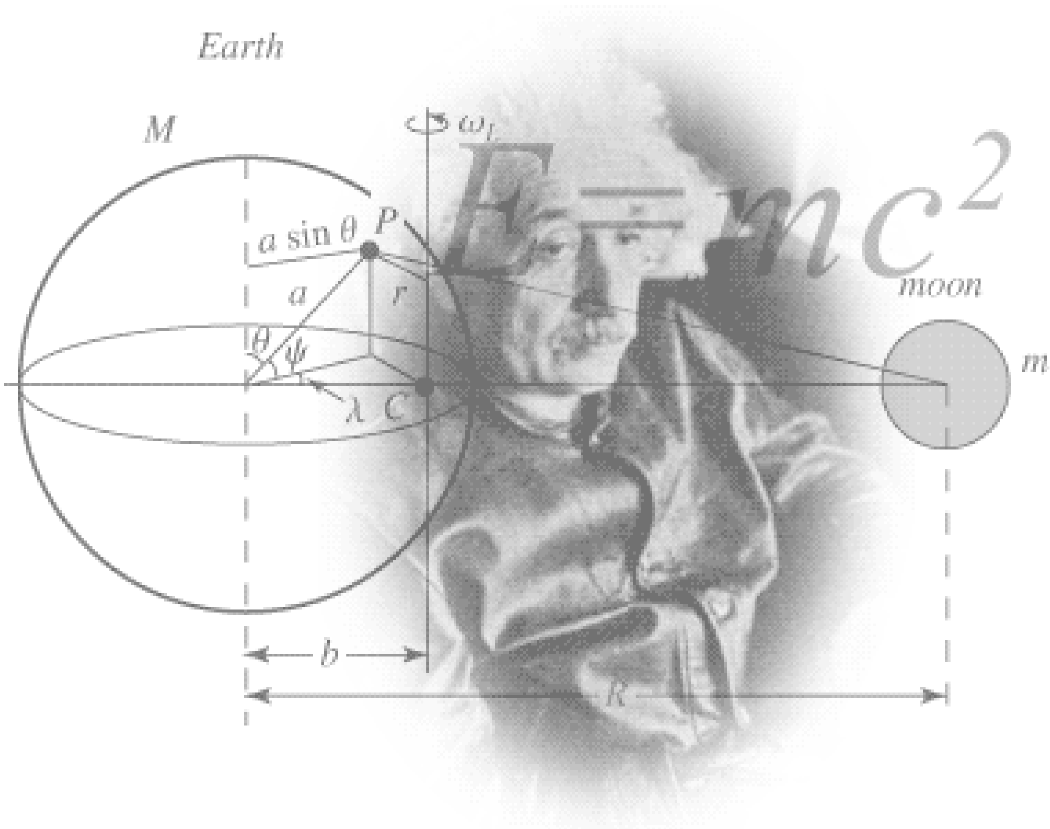


Figure 1 http://scienceworld.wolfram.com/physics/images/main-physics.gif

This pack contains a programme of activities and resources to prepare you to start an A level in Physics in September. It is aimed to be used after you complete your GCSE, throughout the remainder of the Summer term and over the Summer Holidays to ensure you are ready to start your course in September.

Pre-Knowledge Topics

Below are ten topics that are essential foundations for you study of A-Level Physics. Each topics has example questions and links where you can find our more information as you prepare for next year.

Symbols and Prefixes

Prefix	Symbol	Power of ten
Nano	n	x 10^{-9}
Micro	μ	x 10^{-6}
Milli	m	x 10^{-3}
Centi	c	x 10^{-2}
Kilo	k	x 10^{3}
Mega	M	x 10^{6}
Giga	G	x 10^{9}

At A level, unlike GCSE, you need to remember all symbols, units and prefixes. Below is a list of quantities you may have already come across and will be using during your A level course

Quantity	Symbol	Unit
Velocity	v	ms^{-1}
Acceleration	a	ms^{-2}
Time	t	S
Force	F	N
Resistance	R	Ω
Potential difference	V	V
Current	I	A
Energy	E or W	J
Pressure	P	Pa
Momentum	p	$kgms^{-1}$
Power	P	W
Density	ρ	kgm^{-3}
Charge	Q	C

Solve the following:

1. How many metres in 2.4 km?
2. How many joules in 8.1 MJ?
3. Convert 326 GW into W.
4. Convert 54600 mm into m.
5. How many grams in 240 kg?
6. Convert 0.18 nm into m.
7. Convert 632 nm into m. Express in standard form.
8. Convert 1002 mV into V. Express in standard form.
9. How many eV in 0.511 MeV? Express in standard form.
10. How many m in 11 km? Express in standard form.

Standard Form

At A level quantity will be written in standard form, and it is expected that your answers will be too.

This means answers should be written as ….x 10^y. E.g. for an answer of 1200kg we would write 1.2 x 10^3kg. For more information visit: www.bbc.co.uk/education/guides/zc2hsbk/revision

1. Write 2530 in standard form.
2. Write 280 in standard form.
3. Write 0.77 in standard form.
4. Write 0.0091 in standard form.
5. Write 1 872 000 in standard form.
6. Write 12.2 in standard form.
7. Write 2.4 x 10^2 as a normal number.
8. Write 3.505 x 10^1 as a normal number.
9. Write 8.31 x 10^6 as a normal number.
10. Write 6.002 x 10^2 as a normal number.
11. Write 1.5 x 10^{-4} as a normal number.
12. Write 4.3 x 10^3 as a normal number.

Rearranging formulae

This is something you will have done at GCSE and it is crucial you master it for success at A level. For a recap of GCSE watch the following links:

www.khanacademy.org/math/algebra/one-variable-linear-equations/old-school-equations/v/solving-for-a-variable

www.youtube.com/watch?v=_WWgc3ABSj4

Rearrange the following:

1. E=m x g x h to find h
2. Q= I x t to find I
3. E = ½ m v^2 to find m
4. E = ½ m v^2 to find v
5. v = u + at to find u
6. v = u + at to find a
7. $v^2 = u^2 + 2as$ to find s
8. $v^2 = u^2 + 2as$ to find u

Significant figures

At A level you will be expected to use an appropriate number of significant figures in your answers. The number of significant figures you should use is the same as the number of significant figures in the data you are given. You can never be more precise than the data you are given so if that is given to 3 significant your answer should be too. E.g. Distance = 8.24m, time = 1.23s therefore speed = 6.75m/s

The website below summarises the rules and how to round correctly.

http://www.purplemath.com/modules/rounding2.htm

Give the following to 3 significant figures:

1. 3.4527
2. 40.691
3. 0.838991
4. 1.0247
5. 59.972

Calculate the following to a suitable number of significant figures:

6. 63.2/78.1
7. 39+78+120
8. (3.4+3.7+3.2)/3
9. 0.0256 x 0.129
10. 592.3/0.1772

Recording Data

Whilst carrying out a practical activity you need to write all your raw results into a table. Don't wait until the end, discard anomalies and then write it up in neat.

Tables should have column heading and units in this format quantity/unit e.g. length /mm

All results in a column should have the same precision and if you have repeated the experiment you should calculate a mean to the same precision as the data.

Below are link to practical handbooks so you can familiarise yourself with expectations.

http://filestore.aqa.org.uk/resources/physics/AQA-7407-7408-PHBK.PDF

http://www.ocr.org.uk/Images/295483-practical-skills-handbook.pdf

http://www.ocr.org.uk/Images/295483-practical-skills-handbook.pdf

Below is a table of results from an experiment where a ball was rolled down a ramp of different lengths. A ruler and stop clock were used.

1) Identify the errors the student has made.

	Time			
Length/cm	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**
10	1.45	1.48	1.46	1.463
22	2.78	2.72	2.74	2.747
30	4.05	4.01	4.03	4.03
41	5.46	5.47	5.46	5.463
51	7.02	6.96	6.98	6.98
65	8.24	9.68	8.24	8.72
70	9.01	9.02	9.0	9.01

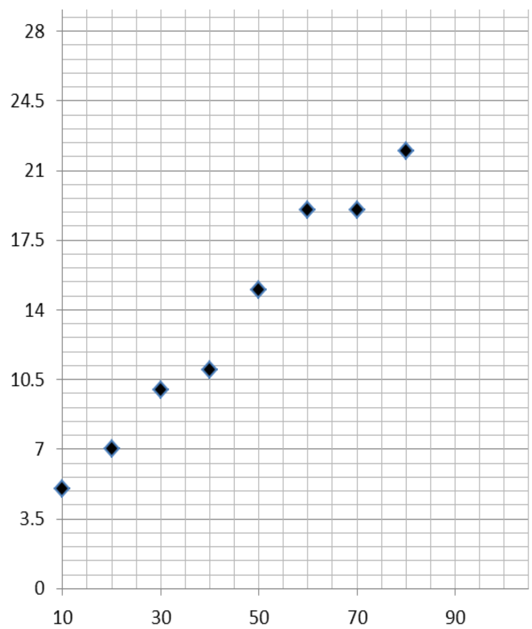
Graphs

After a practical activity the next step is to draw a graph that will be useful to you. Drawing a graph is a skill you should be familiar with already but you need to be extremely vigilant at A level. Before you draw your graph to need to identify a suitable scale to draw taking the following into consideration:

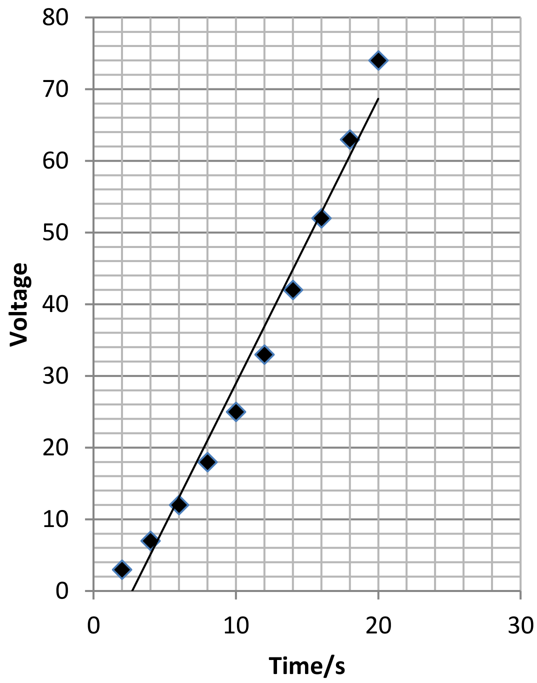
- the maximum and minimum values of each variable
- whether 0.0 should be included as a data point; graphs don't need to show the origin, a false origin can be used if your data doesn't start near zero.
- the plots should cover at least half of the grid supplied for the graph.
- the axes should use a sensible scale e.g. multiples of 1,2, 5 etc)

Identify how the following graphs could be improved

Graph 1



Graph 2



Forces and Motion

At GCSE you studied forces and motion and at A level you will explore this topic in more detail so it is essential you have a good understanding of the content covered at GCSE. You will be expected to describe, explain and carry calculations concerning the motion of objects. The websites below cover Newton's laws of motion and have links to these in action.

http://www.physicsclassroom.com/Physics-Tutorial/Newton-s-Laws

http://www.sciencechannel.com/games-and-interactives/newtons-laws-of-motion-interactive/

Sketch a velocity-time graph showing the journey of a skydiver after leaving the plane to reaching the ground.

Mark on terminal velocity.

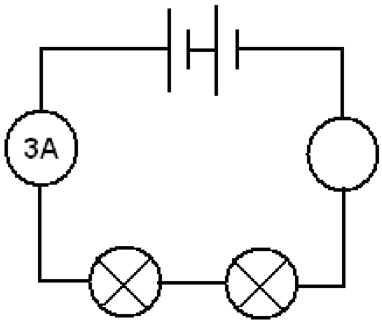
Electricity

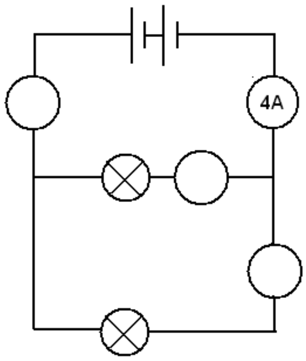
At A level you will learn more about how current and voltage behave in different circuits containing different components. You should be familiar with current and voltage rules in a series and parallel circuit as well as calculating the resistance of a device.

http://www.allaboutcircuits.com/textbook/direct-current/chpt-1/electric-circuits/

http://www.physicsclassroom.com/class/circuits

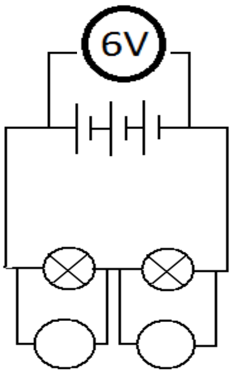
1a) Add the missing ammeter readings on the circuits below.

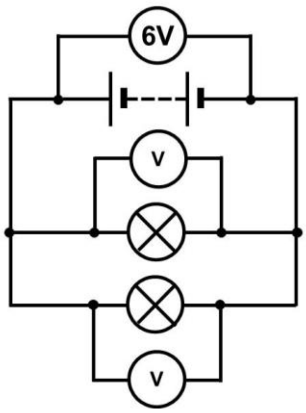




b) Explain why the second circuit has more current flowing than the first.

2) Add the missing potential differences to the following circuits





Waves

You have studied different types of waves and used the wave equation to calculate speed, frequency and wavelength. You will also have studied reflection and refraction.

Use the following links to review this topic.

http://www.bbc.co.uk/education/clips/zb7gkqt

https://www.khanacademy.org/science/physics/mechanical-waves-and-sound/mechanical-waves/v/introduction-to-waves

https://www.khanacademy.org/science/physics/mechanical-waves-and-sound/mechanical-waves/v/introduction-to-waves

1) Draw a diagram showing the refraction of a wave through a rectangular glass block. Explain why the ray of light takes this path.

2) Describe the difference between a longitudinal and transverse waves and give an example of each

3) Draw a wave and label the wavelength and amplitude

Pre-Knowledge Topics Answers:

Symbols and prefixes

1. 2400
2. 8 100 000
3. 326 000 000 000
4. 54.6
5. 240 000
6. 1.8×10^{-8}
7. 6.32×10^{-7}
8. 1.002
9. 5.11×10^{-5}
10. 1.1×10^{4}

Standard Form:

1. 2.53
2. 2.8
3. 7.7
4. 9.1
5. 1.872
6. 1.22
7. 2400
8. 35.05
9. 8 310 000
10. 600.2
11. 0.00015
12. 4300

Rearranging formulae

1. $h = E / (m \times g)$
2. $I = Q/t$
3. $m = (2 \times E)/v^2$ or $E/(0.5 \times v^2)$
4. $v = \sqrt{((2 \times E)/m)}$
5. $u = v - at$
6. $a = (v-u)/t$
7. $s = (v^2 - u^2) / 2a$
8. $u = \sqrt{(v^2 - 2as)}$

Significant figures

1. 3.35
2. 40.7
3. 0.839
4. 1.02
5. 60.0
6. 0.809
7. 237
8. 3.4
9. 0.00330
10. 3343

Atomic Structure

contains protons, neutrons and electrons

Relative charge:

protons are positive (+1)

electrons are negative (-1)

neutrons are uncharged (0)

Relative mass:

proton 1

neutron 1

electron (about) 1/2000

protons and neutrons make up the nucleus

the nucleus is positively charged

electrons orbit the nucleus at a relatively large distance from the nucleus

most of the atom is empty space

nucleus occupies a very small fraction of the volume of the atom

most of the mass of the atom is contained in the nucleus

total number of protons in the nucleus equals the total number of electrons orbiting it in an atom

Recording data

Time should have a unit next to it

Length can be measured to the nearest mm so should be 10.0, 22.0 etc

Length 65 trial 2 is an anomaly and should have been excluded from the mean

All mean values should be to 2 decimal places

Mean of length 61 should be 6.99 (rounding error)

Graphs

Graph 1:

Axis need labels

Point should be x not dots

Line of best fit is needed

y axis is a difficult scale

x axis could have begun at zero so the y-intercept could be found

Graph 2:

y-axis needs a unit

curve of best fit needed not a straight line

Point should be x not dots

Forces and motion

Graph to show acceleration up to a constant speed (labelled terminal velocity). Rate of acceleration should be decreasing. Then a large decrease in velocity over a short period of time (parachute opens), then a decreasing rate of deceleration to a constant speed (labelled terminal velocity)

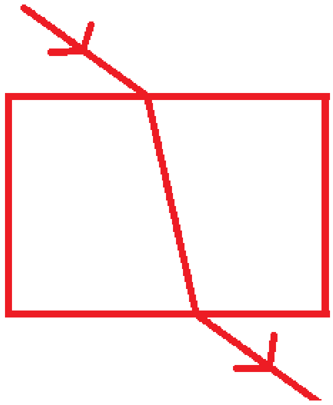
Electricity

1a) Series: 3A, Parallel top to bottom: 4A,2A,2A

b) Less resistance in the parallel circuit. Link to R=V/I. Less resistance means higher current.

2) Series: 3V, 3V, Parallel: 6V 6V

Waves



1) When light enters a more optically dense material it slows down and therefore bends towards the normal. The opposite happened when it leaves an optically dense material.

2) A longitudinal wave oscillates parallel to the direction of energy transfer (e.g. sound). A transverse waves oscillated perpendicular to the direction of energy transfer (e.g. light)

3)

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