

Development of practical skills in physics

1.1 Practical skills assessed in a written examination

1.1.1 Planning and experimental design (page 12)

- 1 Suggestions may include: use a ruler with a mm scale; take more readings (at least six) over a greater range of lengths with equal intervals of 10 cm; take repeat readings of current and potential difference; use a higher resolution (digital) voltmeter that can measure values to ± 0.01 V; consistently record values to the correct number of significant figures.
- 2 Keep control variables the same such as mass of material, starting temperature, time for which the materials are being allowed to cool and the amount of material used for the insulation. The same equipment should be used for each test. The only variable should be the liquid being tested.
- 3
 - (a) $\text{speed} = \text{distance travelled} \div \text{time}$. Data to be collected would be the length of the road and the time taken for each car to travel that distance.
 - (b) To calculate an average value of the car's speed on the road, the length of the distance that the car travels would need to be long enough to account for any acceleration, deceleration and constant speed, so the greater the length of the road, the better. Mark a start and finish line at suitable points as far apart as feasible in the street. Measure the distance with a tape measure or trundle wheel several times and calculate the average value. Stopwatches tend to give accurate values to ± 0.01 s if the reaction time of the timer is taken into account. However, a more precise time measurement could be obtained by using light gates at the start and finish lines. These would record time as the car passed through the light gates and would remove the error caused by the reaction time of the observer.
 - (c) The distance that the cars travel over, as well as the section of the road being covered, would need to be kept the same. Procedures and agreed protocols such as the timing starting when the front of the car passes the start and finish line would also need to be kept constant.
 - (d) The data being collected, distance travelled and time taken, would be valid and the other variables would be controlled. From this you can calculate a value for the average speed if the distance and time are large enough so that errors can be minimised.
- 4 An analogue clock is not suitable as it does not allow the values to be taken to a suitable degree of accuracy. We would need a stopwatch that records to ± 0.01 s. The card would not be suitable as it would reach terminal velocity very quickly due to its low mass to surface area ratio and it could deviate from the vertical path by any air currents. A better method would be to use a more massive object such as a metal ball that will continue to experience the force of gravity, and accelerate with g, for the whole of the vertical descent.

1.1.2 Implementation (page 15)

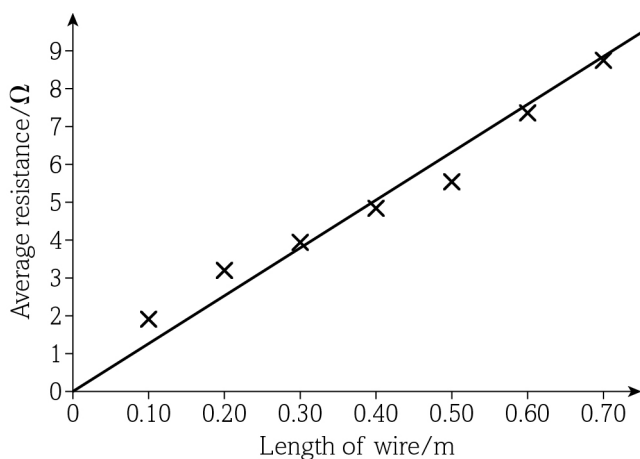
- 1
 - (a) A thermometer, either analogue or digital. Similar and more sophisticated apparatus such as data loggers can be used as long as the values are accurate and fit for purpose.
 - (b) This would depend on the timescale over which the liquid was being heated. For an experiment that is being conducted over a 15 minute or 30 minute period, a temperature reading in $^{\circ}\text{C}$ every minute would be suitable. It may be useful to repeat the investigation or compare with other groups so that the degree of precision can be determined.
- 2 There are insufficient readings taken for the two variables; the units are not provided in the column headings; there is no consistent use of units or significant figures; there are no repeat readings; the time intervals between readings are not constant.

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- 3 (a) A mm scale is not appropriate for a thin piece of string. A micrometer should be used as it can obtain a more accurate value since it can be accurate to ± 0.01 mm.
- (b) The value has not been stated to enough significant figures or decimal places. The micrometer will be able to state a value such as 1.50 mm and not just 1.5 mm.
- (c) Using a metre ruler with a mm scale, you should be stating the value in m to the nearest mm, e.g. the desk had a length of 0.340 m.
- (d) Four readings for voltage and current are insufficient. At least six readings should be taken if a graph is to be plotted. This is fine for repeat readings, but not if, for example, the readings are being taken for different lengths of wire in order to try and determine a link between resistance and length. The results would also need to be repeated to establish the nature of the precision.
- (e) The values are not being stated consistently to the same number of significant figures. If the equipment allows you to determine the values to the nearest 0.01 V, then all values need to be stated to two decimal places. For example, these values, if all correct, should be stated as 3.45 V, 3.40 V, 3.00 V and 3.60 V.
- 4 (a) m
- (b) m^3 or cm^3 or l
- (c) mm – then converted to m for any calculations that would need to be performed
- (d) kg or g – values in g would need to be converted to kg if calculations were to be performed in SI units
- (e) kg m^{-3} or g cm^{-3} – convert to kg m^{-3} if calculations are to be performed in SI units
- (f) m or nm – convert to m for calculations involving SI units
- (g) Hz or kHz – convert to Hz for calculations involving SI units
- (h) m or cm

1.1.3 Analysing data (page 17)

- 1 (a)



- (b) Gradient from data is $12.50 \Omega \text{ m}^{-1}$
- (c) Resistivity value is $1.88 \times 10^{-7} \Omega \text{ m}$
- 2 (a) The gradient of a stress-strain graph will provide the value for the Young modulus directly.
- (b) The gradient of the force-extension graph multiplied by the original length of the wire, l , and then divided by the cross-sectional area of the wire will provide a value for the Young modulus.

$$\text{Young modulus} = \text{gradient} \times \left(\frac{l}{A} \right)$$

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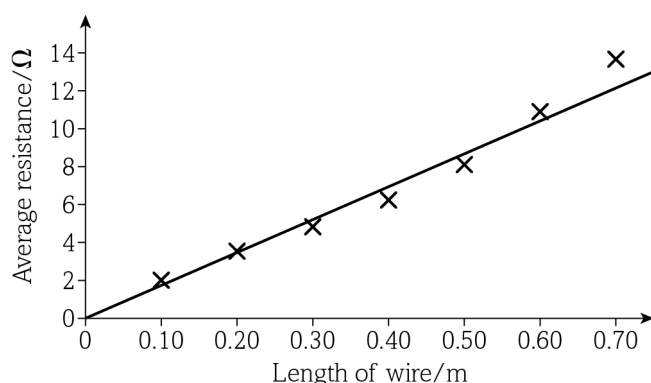
- 3 Data needed would be the time (s) between the initial sound and the detected echo for the different distances (m) from the observer to the wall. The graph plotted would be distance from wall (m) against time (s) between sound being generated and echo detected. Gradient would be obtained and doubled in order to find the speed of sound, since the sound travels to the wall and back in the time that has been recorded.
- 4 0.67 mm is the anomalous value.
- (a) 0.42 mm
- (b) 0.38 mm

1.1.4 Significant figures (page 19)

- 1 (a) 5 significant figures (s.f.), 0 decimal places (d.p.).
- (b) 4 s.f., 2 d.p.
- (c) 2 s.f., 0 d.p.
- (d) 6 s.f., 1 d.p.
- (e) 2 s.f., 8 d.p.
- (f) 2 s.f., no d.p.
- (g) 1 s.f., no d.p.
- 2 First row – 666 cm² and 17 200 cm³.
Second row – 671 cm² and 17 400 cm³.
Third row – 676 cm² and 17 700 cm³.
- 3 60.0, 60.0, 60.1, 5420, 5430, 542, 543, 53 300 000, 43 500 000, 4.70×10^9 , 1.61×10^{-4}
- 4 Volume of sphere = $\frac{4}{3}(\pi r^3) = 3.4 \times 10^{-8} \text{ m}^3$ to 2 s.f.

1.1.5 Plotting and interpreting graphs (page 22)

1



- 2 (a) Values for t^2 corresponding to t values are (from left to right) – 0.061, 0.080, 0.105, 0.116 and 0.141
- (b) Graph of t^2 plotted against height. There are no anomalous results (although points 3 and 4 lie either side of the line of best fit).
- (c) g is equal to twice the gradient, since $g = 2 \frac{s}{t^2}$. The gradient is approximately equal to 5, so g is close to 10.
- (d) There are only 5 data points which is insufficient to be reliable (at least 6 required). There should be more results for t , t^2 and h , and they should be repeated so that precision can be addressed and anomalies identified and eliminated from the data.

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- 3 (a) Plotting v^2 against T will provide a straight line of gradient $4L^2\mu$, from which μ can be found if we know the length of the string, L .
- (b) Plotting v^2 against s will provide a straight line of gradient of $2a$. Halving this value to establish a .

1.1.6 Evaluating experiments (page 25)

- 1 Comment on the obtained value and its comparison with the true or accepted value; comment on the percentage uncertainty in the apparatus; comment on repeatability; comments on any anomalies, limitations and improvements; comment on the scatter of points on a graph; draw a final conclusion with final value and value for uncertainty.
- 2 (a) Percentage uncertainty for a single reading is found from the resolution of a piece of equipment (x) and the measured value (y), then the percentage uncertainty is given by $\left(\frac{x}{y}\right) \times 100\%$.
- (b) Find the gradient of the line that includes the points, and gives a gradient that is greatest in difference from that of the line of best fit. This is called the line of worst fit. Determine the gradient of the line of best fit and worst fit. Find the difference in the gradients. Divide this difference by the gradient of the line of best fit and then multiply by 100% to get the % uncertainty.
- (c) Percentage difference is the difference, expressed as a percentage, between the value or uncertainties of two quantities.
- 3 The following are all relatively easy improvements: parallax errors; systematic errors; using equipment of the appropriate resolution; using a fiducial mark.
- 4 $(0.01 \div 17.61) \times 100\% = 0.06\%$
- 5 $(0.1 \div 6.9) \times 100\% = 1.4\%$
- 6 (a) $\left[\frac{(3.80 - 3.65)}{3.65}\right] \times 100\% = 4.1\%$
- (b) $1.40 \text{ kg} \times 1.041 = 1.46 \text{ kg}$ (assuming that the defect overstates the mass of the cat).

1.1 Practice questions (page 28)

- 1 C [1]
- 2 D [1]
- 3 A [1]
- 4 Correct use of light-gate and timer **or** light-gate and data-logger **or** video technique to determine time interval, car released at top of ramp with zero speed [1].
Speed determined by dividing length of car or interrupt car by time taken (to pass through light gate), repeat to find speed at different distances d along the ramp [1].
Mass of car determined using a balance and $KE = \frac{1}{2} \times \text{mass} \times \text{speed}^2$, find KE at different distances d along the ramp [1].
- 5 The measured value for the cross-sectional area of the wire will be larger than the true value.
The value for the stress will be smaller than the true value since $\text{stress} = \frac{\text{force}}{\text{cross-sectional area}}$.
The value for the Young modulus will be smaller than the true value since the Young modulus is determined by $\frac{\text{stress}}{\text{strain}}$ or by the equation $YM = \frac{Fl}{eA}$ [3].

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- 6 Any two of the following:
 contact resistance due to crocodile clips hence the resistance in the circuit must be greater;
 heating of wire hence the resistance of the wire increases;
 (finite) resistance of ammeter hence the total resistance of circuit increases;
 actual length between crocodile clips is shorter or <0.75 m; hence resistance of wire is greater.
 Allow: zero error on meters (e.g. voltmeter reading is 'higher' or ammeter reading is 'lower') hence the (determined) resistance is greater [4].
- 7 You would need a ruler to measure the length of the wire and a micrometer screw gauge to measure its diameter, and hence determine its cross-sectional area [1].

The resistivity of the wire, ρ can be calculated using the equation $\rho = \frac{RA}{L}$ [1] and a mean value calculated for ρ

from several sets of readings [1], since the resistance R can be calculated from $\frac{V}{I}$, the wire's cross-sectional area A can be calculated from πr^2 and the length L can be measured using a ruler [1].

Also accept, the resistance can be calculated from $\frac{V}{I}$ and the wire's cross-sectional area can be calculated from

πr^2 [1], a graph can be plotted of R against L and the gradient $\frac{\Delta R}{\Delta L}$ can be determined from the line of best fit [1].

Multiplying this value of the gradient by the cross-sectional area, A , gives the resistivity of the wire since $\rho =$

$$\left(\frac{\Delta R}{\Delta L}\right) \times A \text{ [1].}$$

Random errors are errors that occur by chance when a measurement is being made, causing readings to be spread or scattered above and below the true value [1]. Random errors may occur in this experiment due to (one of) reading the value on the ruler/micrometer or ammeter/voltmeter scale incorrectly or inconsistently; the wire may have random variations in diameter along its length [1].

A systematic error causes readings to differ from the true value by a consistent amount each time a measurement is made, and is associated with the apparatus or how it is used by the person conducting the investigation [1].

Systematic errors may occur in this experiment due to any one of the following: zero errors on the voltmeter and ammeter scale; the scale being printed on the ruler incorrectly; a zero error with the micrometer scale; changes in resistance of the wire with increasing temperature (since a greater current causes greater heating) [1].

The effects of random errors can be reduced by taking a number of readings and then finding the mean value [1].

Systematic errors can be reduced by adding or subtracting the absolute error value in each case. For example, if the zero error in a micrometer screw gauge reading is too high by 0.02 mm then this value is subtracted from every value obtained when using the apparatus so that a true value is recorded [1].

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2.1 Physical quantities, units and measurements

2.1.1 Physical quantities and units (page 33)

- 1
 - (a) $0.1 \text{ mm} = 1.0 \times 10^{-4} \text{ m}$
 - (b) $1000 \text{ km} = 1.0 \times 10^6 \text{ m}$
 - (c) $60\,000 \text{ g} = 6.0 \times 10^1 \text{ kg}$
 - (d) $0.46 \text{ nm} = 4.6 \times 10^{-10} \text{ m}$
 - (e) $\text{one day} = 86\,400 \text{ s} = 8.64 \times 10^4 \text{ s}$
 - (f) $\text{one year} = 3.16 \times 10^7 \text{ s}$
 - (g) $624 \text{ cm}^2 = 0.062 \text{ m}^2 = 6.2 \times 10^{-2} \text{ m}^2$
 - (h) A sphere of radius $2 \text{ mm} = 3.4 \times 10^{-8} \text{ m}^3$
 - (i) $400 \mu\text{A} = 400 \times 10^{-6} \text{ A} = 4.00 \times 10^{-4} \text{ A}$
- 2
 - (a) prefixes smaller than pico are femto (10^{-15}), atto (10^{-18}), zepto (10^{-21}) and yocto (10^{-24})
 - (b) prefixes larger than tera are peta (10^{15}), exa (10^{18}), zetta (10^{21}) and yotta (10^{24})
- 3 A length of 60 nm is $6.0 \times 10^{-8} \text{ m}$, $6.0 \times 10^{-2} \mu\text{m}$, $6.0 \times 10^{-5} \text{ mm}$ and $6.0 \times 10^{-11} \text{ km}$.
- 4

Row 2: length of car = $4200 \times 10^{-3} \text{ m}$, 4.2 m

Row 3: volume of room = $10 \text{ m} \times 3.4 \text{ m} \times 85 \text{ m}$, 2890 m^3

Row 4: resistance = $420\,000 \div 0.105 \text{ A}$, $4 \text{ M}\Omega$

Row 5: speed of $20 \text{ km h}^{-1} = 20\,000 \div 3600 = 5.6 \text{ m s}^{-1}$
- 5
 - (a) 4.6 mm
 - (b) $7.8 \times 10^{-7} \text{ m}$
 - (c) 0.4 m^2
 - (d) There is no prefix – the value simplifies to a prefix value of 1.
 - (e) The volume is 200 m^3 and the volume of each biscuit is 0.025 m^3 , so 8000 biscuits can be stored.
- 6 From $Q = It$, we obtain $C = \text{A s}$
- 7 From $F = ma$, we obtain $\text{N} = \text{kg m s}^{-2}$
- 8

Power = energy transferred per second = $\text{J s}^{-1} = \text{N m s}^{-1} = \text{kg m}^2 \text{ s}^{-3}$

Work = joule, $\text{J} = \text{N m} = \text{kg m}^2 \text{ s}^{-2}$

Pressure = force per unit area = $\text{Nm}^{-2} = \text{kg m}^{-1} \text{ s}^{-2}$
- 9 Mass per unit length = kg m^{-1}
- 10 Pressure, $p = h\rho g$, so $\text{kg m}^{-1} \text{ s}^{-2} = \text{m} \times \text{kg m}^{-3} \times \text{m s}^{-2}$, which equates, so the equation is homogenous (the units on each side match).

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2.1.2 Estimating physical quantities (page 35)

- 1
 - (a) About 500 s
 - (b) 1030 s
 - (c) 9×10^{10} (assuming all of the mass of the galaxy is stars, which is actually not true)
 - (d) 250
 - (e) About 2000
- 2 About 3 m s^{-1} if driven continuously without stopping.
- 3
 - (a) An estimate will be just under 1 g cm^{-3} .
 - (b) It will be mostly submerged but will float.
- 4 A mouse will have a mass of around 35 g to 60 g when grown, so 10^{-2} to 10^{-1} would be acceptable approximations.
- 5 A raindrop of 1 mm can be approximated to be a sphere of radius 0.5 mm and density 1 g cm^{-3} . Using $4r^3$ as an approximate volume, we get mass of about $5 \times 10^{-4} \text{ g}$ or $5 \times 10^{-7} \text{ kg}$.
- 6 A bathtub has approximate dimensions of $2 \text{ m} \times 0.5 \text{ m} \times 0.5 \text{ m}$ or a volume of about 0.5 m^3 . A one pence piece has a mass of about 4 g and a volume of about 0.5 cm^3 , so a bathtub can be filled with about 10^6 one pence pieces and so will have a mass of about $4 \times 10^6 \text{ g}$ or $4 \times 10^3 \text{ kg}$.

2.1.3 Systematic errors and random errors (page 37)

- 1 The scale on the metre ruler may be to a greater degree of accuracy, e.g. a mm scale is better than a cm scale for obtaining more accurate results of greater resolution. Some metre rulers may also be the wrong length, meaning that each length taken will be incorrect.
- 2 Examples of systematic error: zero error or parallax error when reading the value from an analogue scale.
Example of a random error: a random gust of wind, extra mass or human force has accidentally caused the reading to be randomly recorded as greater than it should be.
- 3 The scale on the measuring cylinder may be printed incorrectly, leading to a value that is (systematically) too big or too small for all readings. The scale of a ruler for measuring the dimensions of a regular solid may be incorrect, leading to errors for each length, width or height of the shape being recorded. The balance for measuring the mass of the material may have a zero error or it may have been incorrectly calibrated, leading to a constant error in every value that is being taken for the mass of the material.
- 4
 - (a) systematic (zero error)
 - (b) systematic (zero error)
 - (c) random error (although they may all have systematic errors too)
 - (d) random error
 - (e) random error

2.1.4 Precision and accuracy (page 39)

- 1 The readings are all close to the accepted value, so the readings can be claimed to be accurate and have 'a high degree of accuracy'. The repeat readings are all close to one another, with no readings showing a wild deviation from the others, so the readings can also be said to have 'a high degree of precision'.
- 2
 - (a) 'less accurate but more precise' would mean six values that were not close to the accepted value, but were closer in size to each other. For example: 365.1, 365.2, 365.1, 365.0, 365.1, 365.2
 - (b) 'more accurate and more precise' means that the values are closer to the true value and closer to each other. For example: 343.1, 343.1, 343.5, 343.3, 342.9, 343.2
 - (c) 'more accurate but less precise' means closer on average to the true value but showing greater variation in the repeat values. For example: 346.1, 344.9, 344.1, 342.8, 341.5, 340.6

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- 3 (a) Percentage error is 0.2%. The accepted value for the density of gold is 19.3 g cm^{-3} , so the value is not accurate, as the ± 0.04 would still not mean the accepted value was within the range obtained here, which would be from 21.0 g cm^{-3} to 21.8 g cm^{-3} . The obtained value of 21.4 is actually an 11% error compared with the true value.
- (b) The accepted value for the speed of sound in copper is 4600 m s^{-1} , so a quoted value of 5050 from the experiment is $[(5050 - 4600) \div 4600] \times 100\% = 10\%$ error. However, the large uncertainty of $\pm 800 \text{ m s}^{-1}$ means that the true value lies within the range of the quoted values which range from 4250 m s^{-1} to 5850 m s^{-1} .
- (c) The accepted value for the mass of the Earth is $5.97 \times 10^{24} \text{ kg}$, so a value of $5.8 \times 10^{24} \text{ kg}$ is 97% accurate. However, the uncertainty stated in the value here is $\pm 0.9\%$, which means that the true value lies out of the range of the quoted value. It would be better to state a greater uncertainty of $\pm 3\%$ or even $\pm 5\%$ so that the accepted value was within the range of the quoted value. The errors associated with the experiment have possibly been assumed to be lower than they probably were.
- 4 (a) absolute error $= \pi - 3.14 = 0.00159265$ to 6 significant figures.
- (b) percentage error $= [(\pi - 3.14) \div \pi] \times 100\% = 0.05\%$, so 3.14 is 99.5% accurate!

2.1.5 Absolute and percentage uncertainties (page 41)

- 1 $\pm 1 \text{ mm} = \pm 1.3\%$
- 2 The mean value of the four readings is 12.84 s
The range of these four readings is $12.87 - 12.81 = 0.06 \text{ s}$
Absolute uncertainty = 0.03 s
Using this with the mean value we get $(0.03 \div 12.84) \times 100\% = \pm 0.2\%$
- 3 The percentage uncertainty in y will be % uncertainty in a + % uncertainty in b + $3 \times$ % uncertainty in c, so $3\% + 6\% + 6\% = 15\%$
- 4 For the first set of data, the uncertainty is $(0.1/22.7) \times 100\% = 0.44\%$. For the second set of data, the uncertainty is $(0.1/25.6) \times 100\% = 0.39\%$, so the difference in uncertainty is 0.05%
- 5 (a) $7.75 \text{ g cm}^{-3} = 7750 \text{ kg m}^{-3}$
- (b) 0.6%

2.1.6 Graphical treatment of errors and uncertainties (page 43)

- 1 Extrapolating the three lines gives values of the y-intercepts of 112, 105 (best fit line) and 100. The uncertainty in the gradient = 6
So, the percentage uncertainty in the y-intercept will be $(6/105) \times 100\% = 5.7\%$
- 2 Line of best fit gradient (in red) is about $50/40 = 1.25$
The maximum gradient is about 1.33 and the minimum gradient is about 1.00
This means that the uncertainty in the gradient is $0.5 (1.33 - 1.00) = 0.165$, so the percentage uncertainty will be $(0.165/1.25) \times 100\% = 13.2\%$ to 3 significant figures. The best y-intercept value is zero, so it is not possible to find a value for the % error in this as dividing by zero is undefined.

2.1 Practice questions (page 46)

- 1 C [1]
- 2 D [1]
- 3 B [1]
- 4 B [1]
- 5 D [1]
- 6 joule (J) $\rightarrow \text{Nm}$, watt (W) $\rightarrow \text{J s}^{-1}$, newton (N) $\rightarrow \text{kg m s}^{-2}$. All correct: 2 marks, 1 correct: 1 mark.
- 7 kilo $\times$ mega $\rightarrow 10^9$, kilo $\div$ mega $\rightarrow 10^{-3}$, nano $\div$ milli $\rightarrow 10^{-6}$, micro $\times$ milli $\rightarrow 10^{-9}$. All correct: 3 marks, 2 correct: 2 marks, 1 correct: 1 mark.

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- 8 Substitution of $T = 2.25$, $l = 1.250$ into $g = \frac{4\pi^2 l}{T^2}$ [1].
Correct value obtained $g = 9.75 \text{ m s}^{-2}$ [1].
Percentage uncertainty in T is $\left(\frac{0.02}{2.25}\right) \times 100\% = 0.89\%$, so percentage uncertainty in T^2 will be 1.78%.
Percentage uncertainty in l is $\left(\frac{0.001}{1.250}\right) \times 100\% = 0.08\%$ [1].
Percentage uncertainty in g will be $1.78\% + 0.08\% = 1.86\%$ or 2% to 1 significant figure [1].
- 9 Correct substitutions of values for m , v , x_1 and x_2 into the equation for F [1].
Correct value obtained for F of 187.5 N [1].
Calculations of percentage uncertainties in m , v^2 and $(x_2 - x_1)$ calculated as 1%, 6.6% and 18.8% respectively (note, percentage uncertainty in $(x_2 - x_1)$ is $\left(\frac{0.3 \text{ m}}{1.6 \text{ m}}\right) \times 100\%$) [1].
Total percentage uncertainty is found as the sum of the percentage uncertainties and is equal to 26% (to 2 significant figures) [1].
- 10 Correct substitutions of quoted values for mass and volume to obtain 8796 kg m^{-3} [1].
Values obtained for mass of 0.5325 kg as maximum; length, height and width values obtained as 0.0955 m, 0.0145 m and 0.0415 m as minimum values [1].
Correct substitution of values for maximum mass and minimum volume into the equation for density [1].
Maximum density obtained as 9266 kg m^{-3} [1].
Hence maximum value is within 466 kg of the calculated value and so the answer can be quoted as $8800 \pm 500 \text{ kg m}^{-3}$ using 1 significant figure for the uncertainty [1].
- 11 Pressure = force divided by area perpendicular to the force [1].
Circular area is found using r^2 so the percentage uncertainty in r is doubled, hence 6% [1].
Percentage uncertainty in pressure = % uncertainty in force (8%) + % uncertainty in area (6%) so the percentage uncertainty in the pressure is 14% [1].

2.2 Nature of quantities

2.2.1 Scalar and vector quantities (page 51)

- 1 (a) scalar – only the magnitude (or size) is stated.
(b) vector – magnitude and direction are both stated.
(c) scalar – mass is a scalar quantity.
(d) scalar and vector – distance from a point, or displacement, is being referred to.
(e) scalar and vector – the temperature of a body is a scalar quantity, but the change in temperature is a vector quantity.
(f) scalar – density has a size but no direction associated with it.
(g) vector – momentum is a vector quantity.
- 2 (a) 33 m
(b) 13 m at an angle of 23°

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- 3 (a) For $t = 1.0$ s the displacement is 0.28 m at a bearing of 023;
for $t = 2.0$ s, it is 0.40 m due N;
for $t = 3.0$ s it is 0.28 m at 45° E of N;
for $t = 4.0$ s it is back to its original position so the displacement is 0 m.
(b) 0.15 m at 67° E of N and it has travelled 1.1 m.

2.2.2 Scalar and vector calculations (page 53)

- 1 Resultant velocity, $v_R = \sqrt{(30^2 + 40^2)} = 50 \text{ m s}^{-1}$ at an angle of $\tan^{-1}(40/30)$ or 53.1° to the horizontal.
2 Resultant force has a magnitude of 979.5 N and the angle shown is 62.7°
3 Resultant acceleration is 0.73 m s^{-2} and the angle shown is 15.9°
4 256 m s^{-1} at 20.6°
5 Displacement will be 2053 km from the original starting position at a bearing of 083.
6 Resultant speed is about 180.5 km h^{-1} at a bearing of 054.

2.2.3 Resolving vectors (page 55)

- 1 The horizontal component of the vector is $12.8\cos 37 = 10.2 \text{ m s}^{-1}$.
The vertical component of the vector is $12.8\sin 37 = 7.7 \text{ m s}^{-1}$.

- 2 954 N

- 3 (a)

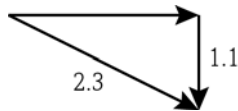


Diagram shows a resultant diagonal vector of 2.3 m s^{-1} and a current parallel to the bank of 1.1 m s^{-1} .

- (b) 2.02 m s^{-1} at 90° to the bank
(c) 32.2 s
4 (a) The horizontal component is $18\cos 42 = 13.4 \text{ m s}^{-1}$
(b) The vertical component is $18\sin 42 = 12.0 \text{ m s}^{-1}$
(c) The horizontal distance travelled is given by $13.4 \times 22.5 = 301.5 \text{ m}$
5 The horizontal component of velocity is constant throughout, since there is no force acting horizontally to accelerate or decelerate the body (ignoring drag). The vertical components of velocity are increasing with time since the force of gravity is causing the velocity to accelerate in a downwards direction. Note that the horizontal and vertical components of motion are independent of each other – vertical motion is not affected by the horizontal motion.

2.2 Practice questions (page 58)

- 1 A [1]
2 C [1]
3 C [1]
4 (a) A vector quantity is a quantity that has both a size and a direction [1].
(b) Examples include force, velocity, acceleration, momentum, impulse, pressure, weight, displacement [2].

Foundations of physics

- 5 (a) $\text{speed} = \left(\frac{2 \times \pi \times 0.60}{20} \right) [1]$
 $\text{speed} = 0.19 \text{ (m s}^{-1}\text{)} [1]$
- (b) Displacement is the direct distance of the locomotive from A, so the graph is symmetrical about $t = 10 \text{ s}$ [1].
 At $t = 20 \text{ s}$ it returns back to A **or** at $t = 10 \text{ s}$ it is 1.2 m from A **or** at $t = 10 \text{ s}$, it is at C [1].
- (c) $\text{resultant force} = (7.0^2 + 5.0^2 - 2 \times 7.0 \times 5.0 \times \cos 40) [1]$
 allow: $\text{resultant force} = [(7.0 - 5.0 \times \cos 40)^2 + (5.0 \times \sin 40)^2]^{1/2}$
 $\text{resultant force} = 4.51 \text{ (N)} [1]$
 allow full marks for a correct scale drawing to determine the resultant force; $\text{resultant force} = 4.5 \pm 0.1 \text{ N}$
 $\text{acceleration} = \frac{4.51}{0.320} = 14 \text{ m s}^{-2} [1]$
 allow full marks for resolving into horizontal and vertical components and combining correctly.
- 6 Horizontal component is given by $F \cos \theta$ and vertical component is given by $F \sin \theta$ [1].
 Horizontal component of force is $20 \cos 30 = 17.3 \text{ N} [1]$.
 Vertical component of force is $20 \sin 30 = 10 \text{ N} [1]$.
- 7 Resultant force is calculated using Pythagoras' theorem, i.e. $F_R = \sqrt{(F_x^2 + F_y^2)} [1]$.
 $\text{Resultant force} = \sqrt{(35^2 + 28^2)}$ which is $44.8 \text{ N} [1]$.
 Angle made with the horizontal floor found using $\theta = \tan^{-1} \left(\frac{F_y}{F_x} \right) [1]$.
 $\text{Angle } \theta = \tan^{-1} \left(\frac{35}{28} \right) = 51.3^\circ [1]$.
- 8 (a) $\text{distance} = \sqrt{(54)^2 + (72)^2} [1] (= 90 \text{ km})$
 $\tan \theta = \frac{54}{72} [1] (= 37^\circ \text{ from the horizontal})$
 The magnitude of the relative velocity of approach of aircraft A to aircraft B can be found using vector arrows for the velocities of A and B. By Pythagoras, the magnitude of the relative velocity is $\sqrt{(1120)^2 + (980)^2} [1] (= 1488 \text{ km h}^{-1})$.
 In 4 minutes, the two aircraft 'close' by a distance of $1488 \text{ km h}^{-1} \times \frac{4}{60} \text{ h} [1] (= 99 \text{ km})$.
- (b) 90 km apart initially so need to 'close' by 70 km
 $t = \frac{70 \text{ km}}{1488 \text{ km h}^{-1}} [1] = 0.047 \text{ h, or } = 0.047 \times 60 \times 60 \text{ s} = 170 \text{ s}$

Forces and motion

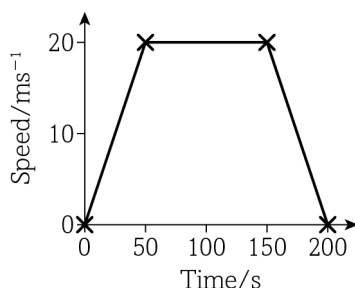
3.1 Motion

3.1.1 Definitions in kinematics (page 63)

- 1 Bob travelled a total distance of 7 km, which is 7000 m
His final displacement from home was 5 km at a bearing of 143
His total speed (speed = distance $\div$ time) was $7000 \text{ m} \div 3780 \text{ s} = 1.85 \text{ m s}^{-1}$
His total velocity (velocity = displacement $\div$ time) = 1.3 m s^{-1} at a bearing of 143
- 2 Acceleration = change in velocity $\div$ time taken or $a = \frac{(v-u)}{t}$
Substituting the values into the equation gives $a = 5.5 \text{ m s}^{-2}$ to 2 significant figures.
- 3 $a = \frac{(v-u)}{t} = \frac{(8-30)}{4.8} = -4.6 \text{ m s}^{-2}$ to 2 significant figures. The negative acceleration shows us that the vehicle has slowed down during this time.
- 4 $a = \frac{(v-u)}{t}$, $4 = \frac{(20-0)}{t}$
Rearranging leads to $t = 5.0 \text{ s}$
- 5 (a) Average speed = $400 \text{ m} \div 48 \text{ s} = 8.3 \text{ m s}^{-1}$
(b) Average velocity = displacement $\div$ time taken. Average velocity = $0 \div 48 \text{ s} = 0 \text{ m s}^{-1}$

3.1.2 Graphs of motion (page 65)

- 1 In each case, the displacement is found by finding the area beneath each of the graphs. This gives the following values:
(a) 270 m
(b) 135 m
(c) 4 squares = 1 m, so answers of $64 \pm 4 \text{ m}$ are acceptable
- 2 (a)

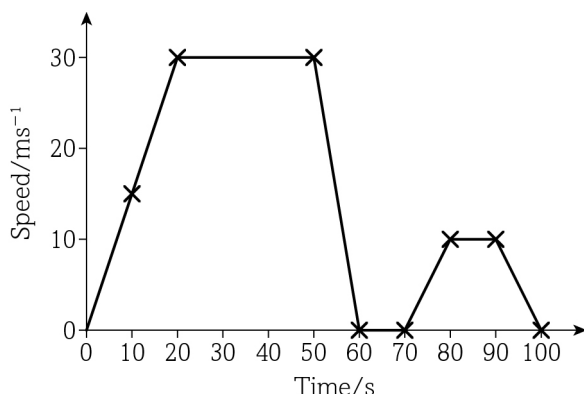


Graph should show a linear increase in speed, followed by a linear decrease in speed until the train eventually stops.

- (b) Maximum speed = 20 m s^{-1}
- (c) Average speed = total distance $\div$ time taken = $2500 \text{ m} \div 200 \text{ s}$ or 12.5 m s^{-1}

Forces and motion

3 (a)



- (b) The car accelerates at 1.5 m s^{-2} from rest for 20 seconds.
It travels at a constant speed for 30 seconds before stopping.
It remained stationary for 10 seconds before accelerating forwards at 1.0 m s^{-2} for 10 seconds.
It travelled at a constant speed of 10 m s^{-1} for 10 seconds before stopping again.
- (c) Greatest acceleration is for the period 0–20 s. Acceleration = 1.5 m s^{-2}
- (d) The total distance travelled = area under the graph = 1550 m, assuming that the acceleration and deceleration that take place are constant.

3.1.3 Constant acceleration equations (page 67)

1 (a) $a = 4.0 \text{ m s}^{-2}$

(b) $s = ut + \frac{1}{2}at^2$, which simplifies to $s = \frac{1}{2}at^2$ since the car is starting from rest.

Substituting, $s = \frac{1}{2}(4)(4)^2 = 32 \text{ m}$.

(c) Using $s = \frac{1}{2}(u + v)t$ gives the same answer since $\frac{1}{2}(16 + 0) \times 4 = 32 \text{ m}$

2 (a) $a = (29 - 22)/70 = 0.1 \text{ m s}^{-2}$

(b) $s = (22 \times 70) + \frac{1}{2}(0.1)(70)^2 = 1785 \text{ m}$. (This is also obtained from the use of $s = \frac{1}{2}(u + v) \times t$)

3 (a) Using $v^2 = u^2 + 2as$ and rearranging to make s the subject,

$$s = \frac{u^2}{2g} = \frac{14^2}{(2 \times 9.8)} = 10.0 \text{ m}$$

(b) From $v = u + at$, we obtain $t = \frac{14}{9.8} = 1.42 \text{ s}$

(c) Time to go up = time to come down, so $t = 2.84 \text{ s}$ in total.

(d) No air resistance, so the ball travels vertically under the force of gravity only and the ball is thrown and caught from the same height.

4 Using $v^2 = u^2 + 2as$, we get $0 = u^2 + 2 \times (-8) \times (28)$. Rearranging, $u = 21 \text{ m s}^{-1}$

5 The weight of the rocket will decrease during the period of the flight as it escapes from the gravitational field of the Earth. Its mass will also decrease as it uses fuel. Therefore, for a constant thrust force the acceleration will increase. The equations covered in this section are only valid for constant acceleration.

Forces and motion

3.1.4 Free fall and projectile motion (page 70)

- 1 Both balls will hit the floor at the same time. If they are released at the same time from the same height, their vertical motion is dependent only on the force of gravity and is independent of any horizontal component of motion that the balls may have.
- 2 Parabolic sketch of path is shown with the correct shape, initial velocity and angle of projection shown.
 - (a) (i) The velocity at the highest point will be $48\cos 72 = 14.8 \text{ m s}^{-1}$ acting horizontally, since there will be no vertical motion of the ball when at its highest point.
 - (b) (i) At $t = 3\text{ s}$, the horizontal component = 14.8 m s^{-1} and the vertical component = 16.3 m s^{-1} , which is obtained from $48\sin 72 - (9.81 \times 3)$.
 - (ii) This gives a resultant velocity of 22 m s^{-1} at an angle of 47.8° from the horizontal.
- 3 (a) (i) Using $v^2 = u^2 + 2as$, $0 = 24^2 - (2 \times 9.81s)$, so maximum height of $s = 29.4 \text{ m}$.
 (a) (ii) From $v = u + at$, $0 = 24 - 9.81t$, so $t = 2.45 \text{ s}$. This is the time taken to reach the maximum height. Since the time to go up is the same as the time to come back down to the thrower, the total time will be equal to 4.9 s .
 (b) The maximum height would be 1.8 m greater, which is 31.2 m . The horizontal distance travelled would be zero, since there is no horizontal component of motion. The time taken to reach the maximum height would still be 2.45 s . The time taken to hit the ground would be greater, since the ball now needs to fall an extra 1.8 m , hence it would now need to fall 31.2 m . This would take 2.52 s . Therefore, the total time = 4.97 s .
- 4 (a) $t = 12 \text{ m} \div 150 \text{ m s}^{-1} = 0.080 \text{ s}$. This calculation can be performed since we can assume that the horizontal component of velocity is constant throughout.
 (b) Using $s = ut + \frac{1}{2}at^2$ and considering the vertical motion, we obtain $s = \frac{1}{2} \times 9.8(0.08)^2$, which gives a vertical drop of 0.031 m or 3.1 cm .
- 5 (a) Using $s = ut + \frac{1}{2}at^2$ for the vertical motion, and substituting, we get $2.0 = \frac{1}{2} \times 9.8t^2$, so $t = 0.64 \text{ s}$
 (b) If the horizontal distance travelled is 7.7 m and the time taken to land is 0.64 s , then the initial horizontal velocity is found from velocity = distance $\div$ time = $7.7 \div 0.64 = 12 \text{ m s}^{-1}$

3.1.5 Measurement of g (page 72)

- 1 (a) Acceleration will be close to g , 9.81 m s^{-2} since the ball will have slowed down due to air resistance, but will not be near reaching terminal velocity.
 (b) From $v = u + at = 9.81 \times 3.5 = 34.3 \text{ m s}^{-1}$
 (c) From $s = ut + \frac{1}{2}at^2$, the ball will have fallen $s = 0.5(9.81)(3.5^2) = 60.1 \text{ m}$
- 2 Yes – the coconut will only fall 28.3 m in a time of 2.4 s , so the squirrel will have escaped.
- 3 Video techniques can be used for slowing down or stopping the observed motion of objects under free-fall. This enables accurate heights and times to be captured, simultaneously, on video, from which the value for g can be calculated. This method is suitable for use when viewing pendulum motion or that of a falling ball.
- 4 (a) Doubling the gradient of 4.89 gives a value for $g = 9.78 \text{ m s}^{-2}$
 (b) Gradient based on line of best fit is 4.89 . Gradient of line of worst fit, using the error bars, is found from $8.8/1.7$ giving a gradient of 5.18 . This gives a value of 10.36
 Using the minimum gradient of $7.9/1.7 = 9.29$
 The percentage error in the value of g will be $[0.5(10.36 - 9.29)/9.78] \times 100\% = 5.5\%$
 (c) Random error, systematic error or an actual variation in the value of g may lead to this value. The value of g is not always 9.81 at every part on the Earth's surface, so it is conceivable that this value is accurate.
 (d) Likely that uncertainty in s is given as $\pm 1 \text{ cm}$ and t by $\pm 0.01 \text{ s}$ (may vary).
 (e) About 2.5% uncertainty.
 (f) Final quoted answer of $9.78 \pm 0.02 \text{ m s}^{-2}$

Forces and motion

- 5 Errors associated with making timing measurements and the measurement of distance. Suggested error values of 5% to 15% would be reasonable, due to the use of a ruler and the effect of drag on the falling card.
- 6 Use a plumb line to see whether the light gates are in the path of the falling ball.

3.1.6 Car stopping distances (page 75)

- 1
 - (a) $72 \times 0.447 = 32.2 \text{ m s}^{-1}$
 - (b) $32.2 \times 120 = 3864 \text{ m}$
 - (c) Total stopping distance = thinking distance + braking distance. At 72 mph, the thinking distance is 21.6 m. The braking distance will be about 80 m, so the total stopping distance will be about 102 m.
- 2
 - (a) Stopping distance = thinking distance + braking distance = $25 + (20 \times 0.65) = 37.4 \text{ m}$
 - (b) $180\,000 \text{ J}$ or $1.8 \times 10^5 \text{ J}$
 - (c) From $\frac{1}{2}mv^2 = Fd$
 $1\,800\,000 \text{ J} = F \times 25 \text{ m}$, so $F = 7200 \text{ N}$
- 3
 - (a) reaction time = 0.7 s, P = 3.5 m, Q = 10.5 m, R = 17.5 m
 - (b)
 - (i) braking distance = $0.08 \times \text{speed}^2$
 - (ii) Using the values from the table for the maximum car speed and from $s = \frac{1}{2}(u + v) \times t$,
 we obtain $72 = 0.5(30 + 0) \times t$, giving a value for t of 4.8 s
 Using $v = u + at$, $0 = 30 + 4.8a$, so $a = 6.25 \text{ m s}^{-2}$
 - (iii) 18 m
- 4 The correct statements are:
 ‘Thinking distance and speed obey a linear relationship’
 ‘Increasing the car speed by a factor of 2 increases the braking distance by a factor of 4’.

3.1 Practice questions (page 78)

- 1 C [1]
- 2 C [1]
- 3 B [1]
- 4 D assuming the car is travelling at constant speed [1].
- 5 The value for the acceleration at time, t , is determined from the gradient of the graph at that point [1].
 The acceleration of the skydiver decreases from a maximum value at $t = 0$ to a final value of zero at the maximum value for t on the x -axis [1].
- 6 Assuming the acceleration a is constant, rearrange $s = ut + \frac{1}{2}at^2$ to give $a = \frac{2s}{t^2}$ [1].
 Substituting the values gives $a = \frac{2 \times 256}{8^2} = 8 \text{ m s}^{-1}$ [1].

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- 7 The time taken for the dropped rock to hit the ground is given by $t = \sqrt{\left(\frac{2s}{g}\right)}$ [1].

Substituting the values gives $t = \sqrt{\left(\frac{400}{9.81}\right)}$ or $t = 6.4 \text{ s}$ [1].

The horizontal distance between the rocks is dependent only on the horizontal component of the rock's velocity, v_x [1].

Assuming the rock is launched at constant speed, if the horizontal component of the velocity is v_x then the distance between the rocks will be $6.4 v_x$ [1].

- 8 (a) It has been assumed that there is negligible air resistance [1].
The long-jumper is moving upwards against the force of gravity/weight [1] which leads to a deceleration in the vertical direction [1].
Using $v = u + at$ for the vertical motion, we obtain $0 = 3.5 - 9.81 t$ [1].
This gives a value of $t = \frac{3.5}{9.81} \text{ s}$ to reach the maximum height [1].
The total time in the air will be twice this, giving a total time of flight of $t = 0.71 \text{ s}$ [1].
The total length of the jump is given by horizontal component of motion (m s^{-1}) $\times$ total time of flight (s) [1].
This gives a distance of $10 \text{ m s}^{-1} \times 0.71 \text{ s}$, which equals 7.14 m or 7.1 m to 2 significant figures [1].
- (b) Increasing the vertical component of velocity does not affect the horizontal component of velocity [1] but leads to a longer time of flight, so the horizontal distance $v_x t$ increases [1].
Increasing the horizontal component of velocity leads to a greater jump distance $v_x t$ [1].

3.2 Forces in action

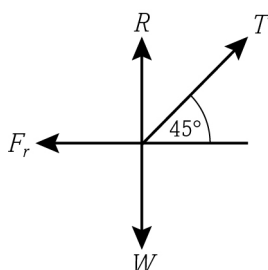
3.2.1 Force and the newton (page 83)

- 1 (a) False – a body will accelerate if it experiences a resultant force. If a body is travelling at a constant speed then the resultant force acting on it will be zero.
(b) False – the force of gravity is the weakest of the four forces of nature.
(c) True – the gravitational force will cause him to accelerate downwards, initially.
(d) True – as mass decreases, a body becomes easier to accelerate for the same resultant force that is acting on it.
- 2 (a) 8000 N
(b) 8000 N
(c) (i) $14\,000 - 8000 = 6000 \text{ N}$
(ii) $a = F/m = 6000/5000 = 1.2 \text{ m s}^{-2}$
(d) Acceleration increases because mass decreases and thrust is constant.

Forces and motion

3.2.2 Dynamics (page 85)

- 1 (a) They are both concerned with the motion of bodies.
(b) Dynamics deals with motion and forces, kinematics deals with motion but without referring to the forces involved.
- 2 (a) $T = mg$, hence $T = 3.4 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 33.4 \text{ N}$
(b) $T - mg = ma$, hence $T = m(g + a) = 3.5 \times (9.81 + 3.2) = 45.5 \text{ N}$
- 3 (a) Forces in vertical direction are equal and opposite; forces in horizontal direction are equal and opposite.
(b) Forces in vertical direction are equal and opposite; forces in horizontal direction are unequal and opposite.
(c) If the skydiver is accelerating then the downward force is greater than the upwards force, if he is travelling at a terminal velocity then the vertical forces acting on him are equal and opposite.
(d) Refer to Figure 7 on page 85 with $\theta = 30^\circ$
- 4 (a)



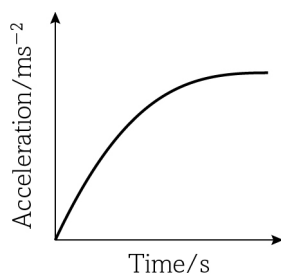
- (b) Resolving gives horizontal force $= T \cos 45$, vertical force $= T \sin 45$
- (c) (i) $T \cos 45 = ma$
(ii) $a = \frac{T \cos 45}{m}$
- 5 (a) Since the mass is 25 kg, we get $a = g \sin 30 = 4.9 \text{ m s}^{-2}$
(b) From $s = ut + \frac{1}{2}at^2$, assuming the block starts from rest, we get $s = 0 + 0.5(4.9 \times 3^2) = 22.1 \text{ m}$

3.2.3 Drag and terminal velocity (page 87)

- 1 (a) A fluid is a liquid or a gas.
(b) The force experienced by objects that are in contact with each other.
(c) The resistive force that acts on a body when it moves through a fluid.
- 2 The ball bearing would be travelling the same distance per unit time once it had reached terminal velocity.
- 3 Determine the measurement uncertainty of each variable. Convert to percentage uncertainties and then add them together to give the percentage uncertainty of the terminal velocity.
- 4 Use equipment to measure distance with a scale that has a high resolution or timing to the nearest 0.01 s or 0.001 s. Make measurement over as long a time and distance as possible.

Forces and motion

5

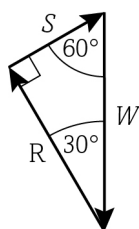


- 6 A greater terminal velocity would be reached due to the more streamlined shape presenting a lower cross-sectional area and hence a lower drag force being experienced.
- 7 Paper cone dimensions are kept the same and only mass is changed, possibly by adding weights or Blutack® inside. Mass is the independent variable, time to fall a known distance is the dependent variable. Measurements taken will involve, mass, distance travelled and time in order to establish a pattern. The distance the cone falls should be controlled to be the same for each test. Use a series of light gates at known distances apart to record the time taken to fall through each successive distance. From this data the velocity can be calculated at each section of the path. Plot a graph of velocity against time, and hence determine the terminal velocity.

3.2.4 Equilibrium (page 89)

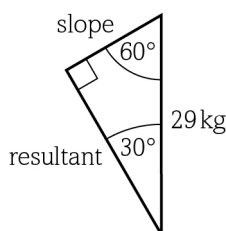
- 1 By measurement and Pythagoras' theorem:
A – 24 N; B – 54 N; C – 24 N; D – 26 N; E – 27 N; F – 83 N

2 (a)



- (b) Force $R = W \cos 30 = 70g \cos 30 = 70 \times 9.81 \times \cos 30 = 595 \text{ N}$
- (c) Force S is such that the component of his weight acting down the slope is balanced by the resistive force. Hence $S = W \sin 30 = 70g \sin 30 = 70 \times 9.81 \times \sin 30 = 343 \text{ N}$

3 (a)



- (b) Force along the slope will be $mg \sin \theta$, leading to $29 \times 9.81 \times \sin 30 = 142 \text{ N}$.
Force perpendicular to the slope will be the reaction force, which if $mg \cos \theta = 29 \times 9.81 \times \cos 30 = 246 \text{ N}$

4 Resolving vertically we obtain weight, $W = 2T \cos \theta = 2 \times 20 \times \cos 30 = 34.6 \text{ N}$ or 35 N

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3.2.5 Turning forces (page 92)

- 1 The S.I. of a moment of a force is N m.
- 2 Going down the answer rows, the missing values are:
Row 1: 5.5 m
Row 2: 420 kN
Row 3: 1310 N
- 3 Assuming that the beam is uniform and that the weight acts through the centre of mass which is at the middle of the beam, we can take moments about point $\times$ as follows:
 $150\,000\text{ N} \times 24\text{ m} = (40\,000\text{ N} \times 16\text{ m}) + (F \times 56\text{ m})$
This gives $F = 2\,960\,000 \div 56 = 52.9\text{ kN}$ to 3 significant figures.
- 4 Taking moments about B leads to $(900 \times 0.7) + (2.5 \times 1450) + (4.7 \times 600) = 5R_1$, which gives a value for R_1 of 1415 N.
- 5 Torque = size of one of the forces $\times$ separation = $8\text{ N} \times 0.5\text{ m} = 4\text{ N m}$
- 6 Taking moments about the pivot gives us:
 $(10\text{ N} \times 2.5\text{ m}) + (15\text{ N} \times 1.0\text{ m}) + 15(1.4 + x) = 70$, so $x = 0.6\text{ m}$ or 60 cm

3.2.6 Centre of mass (page 94)

- 1 For example: a hoop, a rubber tyre, a ring, a horseshoe, a hollow tube, a coat hanger.
- 2 Student's own sketch.
- 3 Accurately drawing vertical lines on the shape without moving it, getting the plumb line to be stationary and truly vertical.
- 4 Student's own sketch.
- 5 A skateboard as it has a greater base area and lower centre of mass so it is more difficult for the centre of mass to fall outside the base and therefore less likely to topple. The centre of mass is higher for a bike and it has a small base area, so will fall over more easily.
- 6 Many sports such as gymnastics, football and karate all require athletes to position their bodies so that they either stay on their feet or develop a turning moment about their centre of mass to perform rotational motion.

3.2.7 Density (page 97)

- 1 (a) density = 0.19 g cm^{-3}
(b) 0.34 g cm^{-3}
(c) 0.49 g cm^{-3}
(d) $2.9 \times 10^{-3}\text{ g cm}^{-3}$
- 2 (a) Mass = $45 \times 10\,500 = 472\,500\text{ kg} = 472.5\text{ tonnes}$
(b) Mass = $(880 \div 10^6) \times 21\,500 = 18.92\text{ kg}$
(c) Volume = $400 \div 2300 = 0.17\text{ m}^3$
- 3 As the temperature of the heated wax increases in the lava lamp, the particles in it will vibrate more and the volume of the wax increases even though the mass of the wax blob has remained constant. This leads to a decrease in the density of the wax, causing it to rise upwards. As it rises further from the heat source it will cool, leading to smaller vibrations of the particles, causing its volume to decrease and its density to increase, so it will sink and the process will repeat.
- 4 Estimate volume of the laboratory, for instance $\sim 10\text{ m} \times 8\text{ m} \times 3\text{ m} = 240\text{ m}^3$. Density of air is 1.29 kg m^{-3} , so the mass will be $240 \times 1.29 = 310\text{ kg}$
- 5 The upthrust from the water provides buoyancy.

Forces and motion

- 6 Volume of wood = 19.8 m^3 . Mass of wood is $102\,000 \text{ N} \div 9.81 = 10\,398 \text{ kg}$. Density of wood = 525 kg m^{-3} . The wood will sink 52.5% into the water, which has a depth of 1.89 m submerged.
- 7 Typically of the order 3 to 10 grams, based on dimensions used.

3.2.8 Pressure (page 99)

- 1 Going down each answer row, the missing values are:
Row 1: 30 N m^{-2}
Row 2: $1\,200\,000 \text{ N}$
Row 3: $3.4 \times 10^{-4} \text{ N m}^{-2}$
Row 4: 670 kN
- 2 Pressure = $h\rho g$, so pressure would be equal to $24 \text{ m} \times 920 \text{ kg m}^{-3} \times 9.81 \text{ N kg}^{-1} = 220 \text{ kPa}$ to 2 significant figures.
- 3 It would sink to a depth of $19.4 \times (1030 \div 789) = 25.3 \text{ m}$
- 4 Mass = volume $\times$ density
Volume of air 1 km high above your head, assuming this to be over an area of 1 m^2 for the purposes of this example, would be $1\,000\,000 \text{ m} \times 1 \text{ m}^2 = 1 \times 10^6 \text{ m}^3$. Mass would be $1 \times 10^6 \text{ m}^3 \times 1.29 \text{ kg m}^{-3} = 1.3 \times 10^6 \text{ kg}$. So, the air directly above your head contains over 1 000 000 kg of air, assuming that the density of air remains constant (which it actually does not).

3.2 Practice questions (page 102)

- 1 D [1]
- 2 A [1]
- 3 B [1]
- 4 D [1]
- 5 (a) The man's weight is given by $W = m \times g$ [1] so $W = 78 \text{ kg} \times 9.81 \text{ N kg}^{-1} = 765 \text{ N}$ [1].
(b) Density = $\frac{\text{mass}}{\text{volume}}$ [1], so his density is $\frac{78 \text{ kg}}{0.08 \text{ m}^3} = 975 \text{ kg m}^{-3}$ [1].
(c) Pressure = $\frac{\text{force}}{\text{area}}$ or $\frac{\text{weight}}{\text{area}}$ [1], so the pressure he exerts is $\frac{765 \text{ N}}{140 \text{ cm}^2} = 5.5 \text{ N cm}^{-2}$, 55 000 Pa or 55 kPa [1].
- 6 (a) Size of torque on steering wheel (N m) = size of one of the forces (N) $\times$ separation (m) [1].
This gives torque = $25 \text{ N} \times 0.36 \text{ m}$ or 9 N m clockwise [1].
(b) Any two of the following answers: increasing the size of the forces [1]; increasing the separation of the forces [1]; increasing the number of forces (i.e. hands turning the steering wheel) [1].
- 7 (a) Initially, with no motion, the only force acting on the girl is due to her weight. This is equal to $W = m \times g$ which is $51 \text{ kg} \times 9.8 \text{ N kg}^{-1}$ or 500 N [1].
She is at rest so the resultant force on her is zero, i.e. $R = W$ [1] = 500 N.
(b) (i) Motion of the lift at a steady speed involves no additional forces [1], so $W = R = 500 \text{ N}$ [1].
(ii) When the girl accelerates upwards with acceleration a , the resultant force on the girl is given by $R - W = ma$ [1].
 $W = 500 \text{ N}$ so $R = (51 \times 1.2) + 500$ or 560 N (to 2 s.f.) [1].
(iii) When the girl accelerates downwards with acceleration a , the resultant force on the girl is given by $W - R = ma$ [1].
 $W = 500 \text{ N}$ so $R = 500 - (51 \times 1.2) = 440 \text{ N}$ (to 2 s.f.) [1].

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- 8 (a) (i) Combined weight (N) = combined mass (kg) $\times$ g (N kg⁻¹) [1]
Combined weight = 26 kg $\times$ 9.81 N kg⁻¹ = 255 N [1]
- (ii) Tension in chains, $T = \frac{mg}{\cos \theta}$ [1]
Tension $T = \frac{255}{\cos 35^\circ} = 311$ N [1]
- (iii) Horizontal force, $P = T \sin \theta$ [1]
Horizontal force, $P = 311 \sin 35 = 178$ N [1]
- (b) (i) The combined weight does not change since the mass of the child and seat have not changed [1].
(ii) The tension in the chains will be greater because the vertical component must balance the weight.
Since the angle has increased, $\cos \theta$ is decreased so T must increase since $T = \frac{mg}{\cos \theta}$ [1].
- 9 (a) ρ is the density of the body, which is its mass per unit volume in kg m⁻³ [1] and A is the cross-sectional area of the body falling through the fluid [1].
- (b) From $F = ma$ [1], the units of F are kg $\times$ m s⁻² [1].
- (c) From $F = K\rho Av^2$ the units of $\frac{F}{K}$ are kg m⁻³ $\times$ m² $\times$ (m s⁻¹)² or kg m s⁻² [1]. Since both expressions for F have the same units, K must be dimensionless (have no units associated with it) [1].
- (d) For a body of mass m , we can rewrite $F = K\rho Av^2$ as $F = mg = K\rho Av^2$ [1].
Rearranging this to make v the subject gives $v = \sqrt{\left(\frac{mg}{K\rho A}\right)}$ [1].
- (e) (i) Cross-sectional area is proportional to the diameter or the radius squared, and $2^2 = 4$ [1].
(ii) The volume of a body is given by $V = \frac{4\pi r^3}{3}$, so increasing the radius by a factor of 2 will increase the volume by a factor of 8 [1]. Since the density of the body is constant (it is made up of the same matter) then the mass must also increase by the same factor, hence it is 8 times heavier [1].
(iii) From $v = \sqrt{\left(\frac{mg}{K\rho A}\right)}$, the weight, mg , will increase by a factor of 8, the cross-sectional area, A , will increase by a factor of 4 [1], so the terminal velocity will increase by a factor of $\sqrt{\left(\frac{8}{4}\right)}$ or $\sqrt{2}$ [1].

3.3 Work, energy and power

3.3.1 Work and the joule (page 107)

- 1 (a) Work done = 240 N $\times$ 500 m = 1.2 $\times$ 10⁵ J
(b) The weight and displacement are perpendicular to each other. The vertical component of weight will not affect the horizontal motion and vice versa.
- 2 (a) Drag 340 N to the left, horse 346 N to the right, man 0 N
(b) Drag = -3400 J, horse = +3460 J, man = 0
(c) 60 J
(d) The barge will accelerate due to the resultant force acting on it.
- 3 Potential energy at top = $mgh = 100 \times 9.81 \times 500 \sin 5 = 42\,750$ J. This is all transferred to kinetic energy under conditions of no friction. The work done against this transfer from gravitational potential energy to kinetic energy by the frictional force is $W = 500 \times 60 = 30\,000$ J. The final kinetic energy will be the difference between these, i.e. 43 000 J - 30 000 J = 13 000 J.

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3.3.2 The conservation of energy (109)

- 1 Examples include:
 - (a) an oil burner or a match
 - (b) a radio
 - (c) a battery operated appliance
 - (d) a nuclear power station
 - (e) pendulum, rollercoaster or swing
 - (f) a generator
 - (g) an electric motor.
- 2 The amount of initial elastic potential energy is finite and is transferred to a finite amount of kinetic energy in the pellet, which will move until the energy transfers into other forms such as sound and heat.
- 3 As the pole-vaulter starts their run, chemical energy in the muscles is transferred to kinetic energy. The pole is then placed into the ground and the kinetic energy begins to transfer into elastic potential energy as the pole bends. Some of this energy is then transferred into gravitational potential energy as the pole-vaulter gains height. At the top of the vault, the gravitational potential energy is converted back to kinetic as he falls back to the ground, where he lands safely.
- 4
 - (a) Energy cannot be destroyed, merely stored or transferred into other forms.
 - (b) There is no such thing as a true vacuum. Energy will always be lost as no process is 100% efficient. The pendulum may swing for a long time, but not forever.
 - (c) No process is 100% efficient and all of the thermal energy cannot be reclaimed – some must be lost to the surroundings.
 - (d) Energy can enter a system from outside so not every system we consider is a closed system in terms of energy transfer.

3.3.3 Potential and kinetic energy (page 111)

- 1
 - (a) 420 J to 3 significant figures
 - (b) 307 J
 - (c) 7.82×10^{10} J
- 2
 - (a) 79 400 J
 - (b) 4.10×10^{-19} J
 - (c) 5.25×10^6 J
- 3
 - (a) 12 J
 - (b) 12 J
 - (c) 2.7 m
- 4 2.4 m
- 5 Vertical height moved = $750 \sin 25 = 317$ m
 Equating gravitational potential energy to kinetic energy gives $2gh = v^2$. If 11% of the energy is not transferred, then $0.89 \times 2gh = v^2$. Substituting the values and square rooting both sides gives $v = 74.4 \text{ m s}^{-1}$

3.3.4 Power and the watt (page 113)

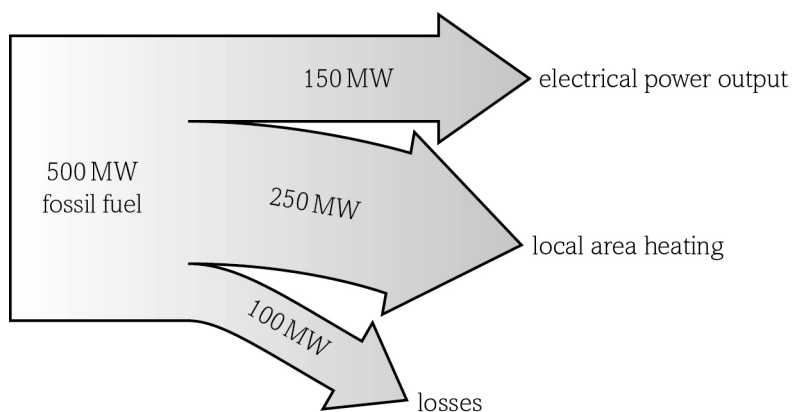
- 1 Power = energy transferred per unit time. Energy = $52 \times 9.81 \times (14 \times 0.18) = 1286$ J. Average time = 3.1 s
 So, power = 410 W to 2 significant figures.
- 2
 - (a) Drag forces on car = 300 N so resultant force is zero, hence no acceleration.
 - (b) Power = force $\times$ velocity, $P = Fv = 300 \text{ N} \times 20 \text{ m s}^{-1} = 6000$ W
 - (c) The extra power required to keep the car moving at 20 m s^{-1} comes from the work done per second against the force of gravity. This is equal to the weight of the car multiplied by the vertical height it rises by in 1 second.
 Power = $900 \times 9.81 \times 1.33 = 11\,700$ W to 3 significant figures.

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- 3 (a) Kinetic energy at $20 \text{ m s}^{-1} = 180\,000 \text{ J}$
Transferred over 10 seconds, so average rate of transfer of kinetic energy = $18\,000 \text{ W}$
- (b) It is three times the power.
- (c) The previous question relates to the power required to maintain the car at a constant speed. This question relates to the power required to accelerate the car. During the acceleration, the speed is increasing so power = force $\times$ velocity will also be increasing.
- 4 $F = ma$, so $F = 1575 \times 27/6 = 7100 \text{ N}$ to 2 significant figures. This value may vary depending on the data obtained.

3.3.5 Efficiency (page 115)

- 1 The missing values from the table are shown below:
refrigerator – $1.92 \times 10^5 \text{ J}$
light bulb – 614 kJ
wind turbine – $4.13 \times 10^9 \text{ J}$
LED – 30%
human muscle – 6.5%
electric motor – 3.8 MJ
- 2 Student's own diagram.
- 3 (a)



- (b) (i) 30%
- (ii) 0.90 times as efficient, as Figure 2 has an efficiency of 33%
- (c) (i) 80% since 400 MW of the 500 MW input power is useful.
- (ii) 2.4 times as efficient, since $80\% \div 33\%$ is 2.4
- (d) The vast majority of the chemical energy in the fossil fuel will be transferred to heat to warm the immediate surroundings rather than being lost at other stages as happens in the power station.

3.3 Practice questions (page 118)

- 1 B [1]
- 2 A [1]
- 3 D [1]
- 4 D [1]

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- 5 (a) (i) Gravitational potential energy, $E_p = m \times g \times h$ [1]
(ii) Kinetic energy, $E_k = \frac{1}{2}mv^2$ [1]
(b) Gain in kinetic energy = loss in gravitational potential energy, so $m \times g \times h = \frac{1}{2}mv^2$ [1].
Rearranging and cancelling the m 's gives $v = \sqrt{2gh}$ [1].
(c) Maximum gravitational potential energy occurs at maximum height h , giving $E_p = 0.5 \text{ kg} \times 9.81 \text{ N kg}^{-1} \times 0.80 \text{ m} = 3.9 \text{ J}$ (to 2 s.f.) [1].
By the principle of conservation of energy, maximum kinetic energy = gravitational potential energy lost when passing through lowest point = 3.9 J [1].
- 6 (a) Power = force $\times$ velocity [1]
Velocity = $\frac{240 \text{ m}}{12 \text{ s}} = 20 \text{ m s}^{-1}$ [1]
Power = $3600 \text{ N} \times 20 \text{ m s}^{-1} = 72 \text{ kW}$ or $72\,000 \text{ W}$ [1]
(b) Kinetic energy = $\frac{1}{2} \text{ mass} \times \text{velocity}^2$ [1]
Kinetic energy = $\frac{1}{2} \times 1450 \times 20^2 = 290\,000 \text{ J}$ or 290 kJ [1]
- 7 (a) (i) Speed (m s^{-1}) = $\frac{\text{distance travelled (m)}}{\text{time taken (s)}}$ [1]
Speed = $\frac{24 \text{ m}}{52 \text{ s}} = 0.46 \text{ m s}^{-1}$ or 0.5 m s^{-1} (to 2 s.f.) [1]
(ii) Kinetic energy = $\frac{1}{2}mv^2$ [1]
Kinetic energy = $\frac{1}{2} \times 28 \times 0.46^2 = 2.98 \text{ J}$ or 3.0 J (to 2 s.f.) [1]
(iii) Maximum increase in gravitational potential energy of skier = mass $\times g \times$ change in height [1]
Maximum change in gravitational potential energy (J) = $28 \times 9.81 \times 4.0 = 1100 \text{ J}$ (to 2 s.f.) [1]
(b) Maximum total mass = $12 \times 30 \text{ kg} = 360 \text{ kg}$ [1]
Change in gravitational potential energy = $360 \text{ kg} \times 9.81 \text{ m s}^{-2} \times 4.0 \text{ m}$ [1] (= 14 126 J)
Power = $\frac{\text{change in gravitational potential energy}}{\text{time}} = \frac{14\,120 \text{ J}}{52 \text{ s}} = 272 \text{ W}$ or 270 W (to 2 s.f.) [1]
- 8 (a) (i) The change in gravitational potential energy required is $45 \text{ kg} \times 9.81 \text{ m s}^{-2} \times 37 \text{ m} = 16\,334 \text{ J}$ [1]
The efficiency of the motor is 78% or 0.78, so for every 100 J, only 78 J are usefully transferred to gravitational potential energy [1]
Total electrical energy supplied as input energy = $\frac{16\,334 \text{ J}}{0.78} = 20\,940 \text{ J}$ [1]
(ii) Total power generated by the motor = $\frac{20\,940 \text{ J}}{11.0 \text{ s}} = 1903 \text{ W}$ [1]
Total useful power generated by the motor = $\frac{16\,334 \text{ J}}{11.0 \text{ s}} = 1485 \text{ W}$ [1]
(b) (i) Gravitational potential energy at maximum height = 16 334 J [1]
Gain in E_k = loss in E_p , so $16\,334 \text{ J} = \frac{1}{2}mv^2$ [1]
Rearranging and substituting gives $v = \sqrt{(2 \times 9.81 \times 37)} = 27 \text{ m s}^{-1}$ [1]
(ii) Assumptions could include any two of the following: negligible air resistance [1]; no energy transferred as sound or heat [1]; no initial speed in the downwards direction [1]; the body does not reach terminal velocity [1]; g is constant throughout [1]

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3.4 Materials

3.4.1 Deformation of materials (page 124)

- 1
 - (i) ductile – it shows a linear relationship between tension and extension until it reaches its elastic limit before starting to show plastic deformation. It will then eventually break.
 - (ii) ductile – mild steel. Normally, steel is thought to be strong and shows no region of plastic behaviour. Here, however, the presence of different amounts of carbon atoms added to the steel make its behaviour more ductile.
 - (iii) shows a lower tension leading to a significantly greater extension, so this would be a material like polyethylene that will readily change length when a tensional force is applied. It is used commonly in the production of plastic bags.
 - (iv) polymeric material – rubber. A small tension force will lead to a large extension. After a certain tension force is reached, the force may be increased but with much less extension. This is due to the straightening of the long chains of rubber molecules.
- 2 Likely words to be used for these materials include:
 - (a) strong, brittle
 - (b) brittle
 - (c) plastic
 - (d) polymeric
 - (e) brittle
 - (f) malleable
- 3 Reference made to a variety of systematic and random errors that would lead to inaccurate values obtained for the magnitude of the force of tension and the extension of the wires. Reference may also be made to the repeating of results to check precision and use averages. Often the results can be taken when loading and unloading for elastic materials. It may be useful to repeat results for more than one sample of the same wire to look for precision in the results.
- 4 Examples of systematic errors may include zero errors on the equipment, parallax error when reading values, incorrect scales or calibrations. Random errors may be due to structural issues or inconsistencies with the materials being tested leading to sudden or unexpected changes in the length of the sample material under tension.

3.4.2 Hooke's law (page 126)

- 1
 - (a)
 - (i) $x = 0.025 \text{ m}$ or 25 mm
 - (ii) $5.0 \times 10^{-2} \text{ J}$
 - (b)
 - (i) 0.0125 m or 12.5 mm
 - (ii) $2.5 \times 10^{-2} \text{ J}$
 - (c)
 - (i) 0.025 m or 25 mm
 - (ii) 0.1 J
- 2
 - (a) 19.6 N m^{-1}
 - (b) A plot of y^2 against h will produce a straight line.
- 3 Student's own answer.

3.4.3 The Young modulus (page 129)

- 1 Young module is stress $\div$ strain, where stress is force per unit area and strain is extension $\div$ original length. Stress will have units of N m^{-2} and strain will be dimensionless as the units cancel. This means that Young modulus will have the same units as stress (and also pressure – N m^{-2} or Pa).
- 2
 - (a) Stress = $5.9 \times 10^5 \text{ Pa}$
 - (b) Strain = extension $\div$ original length = $744 \div 740 = 1.01$
 - (c) Young modulus = stress $\div$ strain = $5.89 \times 10^5 \text{ Pa}$

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- 3 For Figure 5, the Young modulus is $200 \text{ MPa} \div 0.01 = 2.0 \times 10^{10} \text{ Pa}$. The material is strong and elastic until about 250 MPa and then it starts to exhibit plastic behaviour and is ductile up until it breaks at a strain of between 9% and 10%.

For Figure 6, the Young modulus is $240 \text{ MPa} \div 0.004 = 6.0 \times 10^{10} \text{ Pa}$. This material is elastic and breaks at a strain of about 1% so can be classed as brittle.

- 4
$$\text{YM} = \frac{(1.8 \times 10^5 \times 45)}{(0.45 \times \pi(0.4^2))} = 3.58 \times 10^7 \text{ Pa}$$
- 5 (a) tension, stress
(b) stress
(c) Young modulus
- 6 (a) $1.25 \times 10^{11} \text{ Pa}$
(b) Wire is deformed plastically once the stress exceeded $2.5 \times 10^8 \text{ Pa}$.
(c) Area under curve = energy dissipated per unit volume.
(d) (i) The Young modulus would be the same – it is constant for a given material regardless of any change in the material's dimensions.
(ii) Four times (the force per unit extension is directly proportional to the diameter²).

3.4.4 Categorisation of materials (page 131)

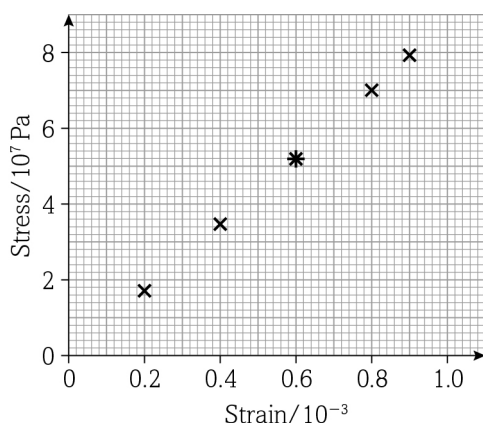
- 1 Answers include:
- | | |
|----------------------------|-----------------------------|
| bone – strong, brittle | cast iron – strong, brittle |
| ceramics – strong, brittle | concrete – strong, brittle |
| copper – ductile | glass – strong, brittle |
| lead – ductile | polyethylene – plastic |
| rubber – elastic | wood – elastic |
- 2 Figure 6 – ductile; Figure 7 – brittle; Figure 8 – polymeric.
- 3 The statements should be joined up as shown below:
- This material has a strain of 300% → The extension of the wire is three times its original length
- After the yield point, the material will show a large strain for a small stress and then break → This material is ductile
- This material is stiff and does not extend before it fractures → This material is brittle
- I would use this material to make roof tiles → This material is malleable
- 4 (a) Graph same shape as Figure 5, but ‘compressed’ so that the maximum stress is at the same value on the y-axis but corresponds to a value of 1.5 on the strain axis.
(b) The lower temperature means that the vibrations of molecules will be smaller (since vibrations are related to kinetic energy which is related to absolute temperature). At macroscopic level, this will result in a lower extension of the sample for the same force and hence a smaller strain.
- 5 (a) Ductile, plastic when wet, so easy to chew and change shape.
(b) Elastic, so easy to knead.
(c) Brittle – easy to snap and does not extend in length before breaking.
(d) Brittle.
(e) Plastic and ductile.

3.4 Practice questions (page 134)

- 1 D [1]
2 C [1]
3 B [1]

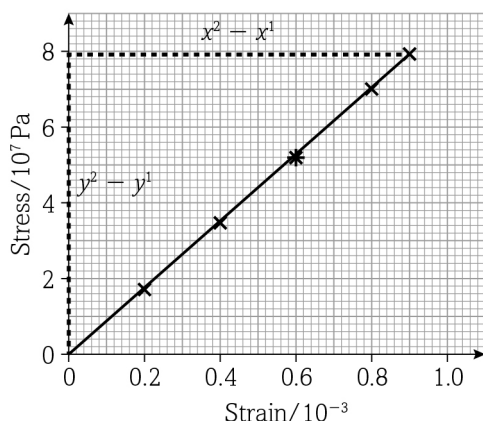
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- 4 C [1]
- 5 (a) Extension will be 1.6×10^{-3} m [1] (since the relationship is proportional it will be twice that for 4.0 N).
 (b) Elastic potential energy = $\frac{1}{2} Fe$ [1] which gives $\frac{1}{2} \times 4.0 \text{ N} \times 0.8 \times 10^{-3} \text{ m} = 1.6 \times 10^{-3} \text{ J}$ [1].
 (c) Point plotted at $(0.6 \times 10^{-3}, 5.21 \times 10^7 \text{ Pa})$ on the graph [1].



- (d) Line of best fit drawn, should go through (0, 0) [1]
 Slope calculated by choosing points that lie on the line of best fit, and are separated as far away as possible from each other (at least half the length of the drawn line) [1]

Slope of the line calculated correctly, e.g. Young modulus = $\frac{(7.9 \times 10^7 - 0.0)}{(0.9 \times 10^{-3} - 0.0)} = 8.8 \times 10^{10} \text{ Pa}$ [1]



- 6 Measured diameter greater than true value means the calculated cross-sectional area is also greater than the true value [1].

Young modulus is given by $\frac{Fl}{eA}$ [1].

Value for A is greater than the true value, so calculated value for the Young modulus will be lower than the true value [1].

- 7 (a) Ductile materials have a large plastic region in their stress–strain relationship and can be easily drawn into wires, e.g. copper.
 (b) Stress equals force per unit cross-sectional area, and has the units Pa or N m^{-2} .
 (c) Strain equals extension divided by original length and has no units (dimensionless).
 (d) Polymeric materials are made from many smaller molecules bonded together, often making tangled chains. These materials often exhibit very large strains of over 300%, e.g. rubber.
 (e) Limit of proportionality is the point at which an elastic body stops obeying Hooke's law.

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- 8 For material X, stress is directly proportional to strain/material X will break when it reaches its elastic limit/no plastic region of stress-strain graph [1]. Material X is brittle [1].
- For material Y, the material is stretched on loading and then returns to its original length on unloading/strain returns to zero [1]. The material is polymeric in nature/does not have a linear stress-strain relationship [1].
- 9 (a) Reference to suitable equipment for measuring length (e.g. metre ruler with millimetre scale) [1]
Reference to suitable equipment needed to measure diameter of wire (e.g. micrometer screw gauge) [1]
Reference to resolution/micrometer can measure to the nearest 0.01 mm [1]
- (b) Tension is found from the size of the force hung on the wire, either the labelled weight or calculated from $W = \text{mass} \times g$ [1], extension is equal to the length of wire under tension minus the original length of the unextended wire [1].
- (c) Equation method: calculate the Young modulus using $\frac{\text{stress}}{\text{strain}}$ or the equation $YM = \frac{Fl}{eA}$ [1] with a number of values used and a mean value calculated [1] to minimise the effect of random measurement errors [1].
- Graph method: Plot a graph of stress against strain [1], draw a straight line of best fit passing through origin [1] and find the gradient which gives the Young modulus [1].
(Alternative answer – from a graph of tension force against extension [1], draw a straight line of best fit passing through origin [1], then multiply the value of the gradient by the length of the wire and divide it by the cross-sectional area of the wire [1], i.e. Young modulus = gradient $\times \left(\frac{1}{A}\right)$.)
- (d) Systematic errors could come from zero errors on the micrometer/balance or a problem with the printed scale on the metre ruler [1]. These can be removed from the measured values by either adding or subtracting the magnitude of the systematic error, as appropriate [1].
- (e) Typically, the Young modulus of a metal wire is of the order 10^{10} to 10^{11} Pa [1].

3.5 Newton's laws of motion

3.5.1 Newton's three laws of motion (page 139)

- 1 Missing from the table, going down by each row of answers:
Row 2: downwards force will be equal to 240 N
Row 3: accelerates to the right at 1 m s^{-2}
Row 4: Upwards force and downwards force both = 360 N. Horizontal values to left and right must be equal.
- 2 (a) Newton's first law is involved since the system will remain at rest or move at a constant speed until a resultant force acts.
The second law relates the acceleration of the trolley to any resultant force acting via $F = ma$.
The third law states that any force applied, such as the technician's hands pushing on the trolley, will be accompanied by an equal and opposite force of the trolley pushing back on the technician.
- (b) Force on trolley from technician = 150 N. Resistance forces = 24 N. Resultant force is 126 N. Mass of the cart when fully loaded is 19.0 kg, and her mass of 65 kg also needs to be considered as she is moving with the cart. Acceleration will be $a = \frac{F}{m} = \frac{126}{84} = 1.5 \text{ m s}^{-2}$
- (c) Free-body diagram for system 1 will have weight and reaction force upwards shown as equal and opposite. The forward horizontal force from left to right will be F_{foot} and there will be a smaller frictional force F acting antiparallel to it from right to left.
Free-body diagram for system 2 will have weight and reaction force upwards shown as equal and opposite. The forward horizontal force from left to right will be F_{floor} and there will be a smaller frictional force F acting antiparallel to it from right to left.

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3.5.2 Momentum (page 141)

- 1 (a) $562.5 \text{ kg m s}^{-1}$
(b) $40\,600 \text{ kg m s}^{-1}$
(c) $1.82 \times 10^{-24} \text{ kg m s}^{-1}$
- 2 Total momentum before collision = total momentum after collision.
 $4500 \times 12 = 3400 \times v$. So, $v = 15.9 \text{ m s}^{-1}$
- 3 $700 \times 3 = (700 + 400) \times v$. So, $v = 1.9 \text{ m s}^{-1}$
- 4 Taking the momentum from left to right as positive, we have:
Total momentum before = $80 \times 8 + (80 \times -6) = 160 \text{ kg m s}^{-1}$
Total momentum after = $160 \text{ kg m s}^{-1} = 160 \text{ kg} \times v$. So, $v = 1 \text{ m s}^{-1}$ (from left to right).
- 5 (a) 0.1 m s^{-1}
(b) 8 N
(c) Some of the gas escapes at very high velocity in the opposite direction to the motion of the bullet, with equal and opposite momentum to that of the bullet. The rifle therefore does not need to 'take up' any of the momentum to conserve momentum of the system of rifle, gas and bullet.
- 6 (a) There are no external forces, so momentum is conserved and the centre of mass of the system cannot move. A mass of gas moves to the rear, so the astronaut must move forward, albeit slowly, to maintain the centre of mass of the system in the same place.
(b) 16 kg m s^{-1}
(c) 0.13 m s^{-1}

3.5.3 Momentum, force and impulse (page 143)

- 1 Impulse = change in momentum = 2.0 N s or 2.0 kg m s^{-1} . Since momentum = $m \times v$, $v = 2.0 \div 0.1 = 20 \text{ m s}^{-1}$.
- 2 Momentum before collision = $0.8 \text{ kg} \times 6 \text{ m s}^{-1} = 4.8 \text{ kg m s}^{-1}$
Momentum after the collision = $0.8 \text{ kg} \times -4.8 \text{ m s}^{-1} = -3.84 \text{ kg m s}^{-1}$
Impulse = change in momentum = $4.8 - (-3.84) = 8.64 \text{ kg m s}^{-1}$
Force = rate of change of momentum = $8.64 \div 0.08 = 108 \text{ N}$ or 110 N to 2 significant figures.
- 3 (a) Each 1 cm^2 square is an impulse of 0.13 N s . The area is approximately 15 squares, giving a total of 1.9 N s .
(b) 42 m s^{-1}
(c) 1200 N
(d) Yes. The area under the curve or under the line to 1.55 ms with the x -axis is equal to the impulse, i.e. both areas are equal.

3.5.4 Elastic and inelastic collisions (page 145)

- 1 In an elastic collision, momentum and kinetic energy are both conserved. In an inelastic collision momentum is conserved but kinetic energy is not conserved.
- 2 The grenade will be stationary initially, before the explosion, so the total momentum before the explosion will be zero. This also needs to be true after the explosion since momentum is always conserved. This means that mass will fly off in different directions at different velocities once the grenade explodes. The pieces with positive momentum (mv) will cancel with all of the pieces that have negative momentum ($-mv$) and the total momentum of all of the grenade pieces will add up to zero.

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- 3 From the conservation of momentum, the final momentum in the x -direction will be 16.8 kg m s^{-1} .
In the direction of the x -axis we obtain $16.8 = (3\cos 34) \times 1.3 + 1.6v\cos\alpha$
In the direction of the y -axis we obtain $3.0 \times 1.3\sin 34 = 1.6v\sin\alpha$
Rearranging we obtain $2.18 = 1.6v\sin\alpha$ and $5.20 = 1.6v\cos\alpha$.
Dividing these equations we obtain $\tan\alpha = (2.18 \div 5.20)$, giving us $\alpha = 22.8^\circ$.
Further substitution will allow us to show that the velocity of the 1.6 kg mass will be 3.5 m s^{-1} at an angle of $\alpha = 22.8^\circ$ to the x -axis.
- 4 (a) The final velocity of m_1 will be 2.6 m s^{-1} . The final velocity of m_2 will be 5.2 m s^{-1} .
(b) The total kinetic energy before and after the collision is 50.6 J so the collision is elastic.

3.5 Practice questions (page 148)

- 1 D [1]
- 2 A (but statement (ii) should say 7 m s^{-1} instead of 1 m s^{-1}) [1]
- 3 (see addition to the question, given below)
A trolley with a mass of 3000 kg is moving at 8 m s^{-1} . It collides with a stationary trolley **of the same mass**, and they move off together at 4 m s^{-1} .
Answer is B (only statements (i) and (ii) are correct) [1].
- 4 C [1]
- 5 (a) $W = mg$, so $W = 3.04 \times 10^6 \text{ kg} \times 9.81 \text{ kg m s}^{-2} = 2.98 \times 10^7 \text{ N}$ [1]
resultant force = upward force – weight [1]
Correct substitution, $3.4 \times 10^7 \text{ N} - 2.98 \times 10^7 \text{ N}$ to obtain $4.2 \times 10^6 \text{ N}$ (answer to at least 2 s.f.) [1]
- (b) $F = ma$ so $a = \frac{F}{m}$ [1]
Correct substitution, $F = \frac{4.2 \times 10^6 \text{ N}}{3.04 \times 10^6 \text{ kg}}$ to obtain 1.38 m s^{-2} [1]
- (c) $v = u + at$ [1]
Correct substitution, $a = \frac{(2390 \text{ m s}^{-1} - 0)}{150 \text{ s}}$ to obtain 15.9 m s^{-2} [1]
- (d) Any suitable suggestion e.g. mass decreasing/weight decreasing/net upward force increasing/fuel used up/gets lighter/ g decreasing/air resistance decreasing with altitude [1]
- 6 (a) A body will remain at rest or continue to move at a constant speed in a straight line [1] until an external force acts upon it [1].
- (b) (i) Any two of the following: they are equal in magnitude [1]; they are forces of the same type [1]; the forces act at the same point [1]; the forces act at the same time [1].
(ii) They are opposite in direction [1]. They act on different objects [1].

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- 7 (a) The resultant force acting on the car is given by $F_R = (4850 \text{ N} - 1230 \text{ N}) = 3620 \text{ N}$. From Newton's second law, $F = ma$, the resultant acceleration of the car will be $\frac{3620}{m}$, where m is the mass of the car.
- (b) From $F = \frac{\Delta mv}{\Delta t}$, we obtain $F\Delta t = \Delta mv$ or alternatively $ma\Delta t = \Delta mv$. Substituting, we obtain a value for the change in momentum of $m \times \frac{3620}{m} \times 1.8 = 6516 \text{ Ns}$.
- 8 Any three of the following:
 The body is originally stationary so remains at rest (first law) [1].
 Air escapes and moves backwards, pushing against the air behind the car and exerting a force on the air [1].
 Force exerted on air results in an equal and opposite force acting forwards on the car (third law) [1].
 Car experiences a resultant external force and so no longer remains at rest and starts to move forwards (first law) [1].
- 9 Maximum of four of the following points:
- (B and) C will stay in their seats [1]
 - A resultant force acts/chair exerts force on (B and) C **or** (B and) C will decelerate [1]
 - Passenger A continues to move (at the same speed) as no resultant force acts/no force from chair [1]
 - Movement of passenger A in terms of Newton's first law means A continues to move at the same speed when the train decelerates rapidly [1]
 - A will collide with B [1]

Electrons, waves and photons**4.1 Electricity: charge and current****4.1.1 Electric circuit components (page 154)**

- 1 (a) Thermistor, filament lamp and junctions of conductors.
(b) Light-dependent resistor (LDR).
- 2 Figure 5 – the cells are facing each other, leading to zero potential difference being delivered from the cells. Even if they were arranged correctly, no current would flow as the voltmeter is placed in series in the circuit and voltmeters have very high resistances.
Figure 6 – the lamp is short circuited due to the switch arranged in parallel across it. The current will flow through the switch rather than the lamp due to its far lower resistance.
Figure 7 – the diode is arranged in reverse bias, so no current will flow through it due to it having an almost infinite resistance when arranged in this way.
- 3 The buzzer will be loudest in Figure 9 since the resistance in the circuit is less. This is due to the low setting on the variable resistor and the bright conditions on the LDR. Conversely, the high value of $2.4 \text{ k}\Omega$ in Figure 8 and the cold temperature registered by the thermistor mean that the current will be very low.

4.1.2 Electric current and charge (page 156)

- 1 From $Q = It$, we obtain $Q = 1.6 \times 10 \times 60 = 960 \text{ C}$
- 2 $I = Q \div t = 4.0 \text{ A}$
- 3 (a) $Q = 0.25 \times 15 \times 60 = 225 \text{ C}$
(b) Number of electrons = total charge $\div$ charge on the electron = 1.41×10^{21} electrons
(c) $t = Q \div I = 5.4 \times 10^{12} \div 0.25 = 2.16 \times 10^{13} \text{ s} = 700\,000 \text{ years to 1 significant figure}$
- 4 $Q = 2300 \times 10^{-3} \times 3600 = 8280 \text{ C}$
- 5 The time that the electrons are travelling for is given by time = distance $\div$ speed = $0.4 \div (3 \times 10^7) = 1.3 \times 10^{-8} \text{ s}$.
The total charge travelling in this time, from $Q = It = 4.0 \times 10^{-3} \times 1.3 \times 10^{-8} = 5.3 \times 10^{-11} \text{ C}$.
The number of electrons will be the total charge divided by the charge on the electron = 3.3×10^8 electrons.

4.1.3 Electron drift velocity (page 159)

- 1 Substituting the respective values from pages 158 and 159 into $I = nAev = 72.5 \text{ A}$.
- 2 Rearranging and substituting values into $I = nAev$ gives $n = 3.4 \times 10^{19}$ which is about 2×10^9 times smaller than the value for copper.
- 3 Semiconductors have values of n that make them suitable for high-speed processing of information. Elements such as silicon are naturally abundant and relatively inexpensive to use.
- 4 $v = 2.7 \times 10^{-6} \text{ m s}^{-1}$
- 5 $v = 8.2 \times 10^{-4} \text{ m s}^{-1}$
- 6 The drift velocity will be of the order $1.4 \times 10^{-3} \text{ m s}^{-1}$, around 0.01 m s^{-1} .

4.1 Practice questions (page 162)

- 1 D [1]
- 2 C [1]
- 3 A [1]
- 4 B [1]

Electrons, waves and photons

- 5 A coulomb of charge contains $\left(\frac{1}{1.602 \times 10^{-19}}\right)$ or 6.24×10^{18} electrons

This means that 7.6×10^{23} electrons is $\frac{7.6 \times 10^{23}}{6.24 \times 10^{18}}$ or 122 000 C [1]

From $Q = It$, the current I flowing in 12 minutes = $\frac{122\,000}{720} = 169$ A [1]

- 6 (a) If the cross section is not changed, then the resistance will be double the initial value so current would halve, it would be 3.2 A [1].
(b) It would increase [1] by a factor of two [1].
(c) It would decrease by a factor of four [1].
(d) The current would decrease [1].
- 7 (a) (i) Positive ions [1] and negative ions [1]
(ii) Electrons [1] flow in the wires
(b) Negative ions are attracted to the positive electrode [1]
Positive ions are attracted to the negative electrode [1]
Positive ions combine with an electron at the negative electrode [1]
Negative ions release an electron at the positive electrode [1]
This results in a flow of electrons from the positive electrode to the negative electrode which will be registered as a movement of charge by any ammeter connected in the circuit [1]
- 8 (a) (i) electron [1]
(ii) ion [1]
(b) (i) $I = \frac{Q}{t} = \frac{650}{5} = 130$ A [1]
(ii) $n = \frac{I}{e} = \frac{130}{1.6 \times 10^{-19}} = 8.13 \times 10^{20}$ [1]
(iii) $I = 10^{29} \text{ Aev}$ giving $8.13 \times 10^{20} = 10^{29} \text{ Av}$ [1]
Rearrange with correct substitution, giving $v = \frac{8.13 \times 10^{20}}{10^{29} \times 3.0 \times 10^{-4}} = 2.7 \times 10^{-5} \text{ m s}^{-1}$ [1].
(c) (i) Because of Kirchhoff's first law or statement of this law [1].
(ii) Using $I = nAev$ so v is proportional to $\frac{1}{A}$ giving $5.4 \times 10^{-5} \text{ m s}^{-1}$ [1].

4.2 Electricity: energy, power and resistance

4.2.1 Potential difference and e.m.f. (page 167)

- 1 'Measured in volts.' – both.
'Maximum value across the cell when no current is flowing in the circuit.' – e.m.f.
'Used when describing energy being transferred to electrical energy from another form.' – e.m.f.
'Used when describing the transfer of electrical energy to another form.' – p.d.
'Can have units J C^{-1} ' – both.
- 2 (a) Both ammeters will read 1.5 A
(b) The ammeter will read 2.0 A and the voltmeters will both read 12 V

Electrons, waves and photons

- 3 (a) (i) $\text{e.m.f.} \times \text{current} \times \text{time} = 54 \text{ J}$
 (ii) $\text{p.d.} \times \text{current} \times \text{time} = 48.6 \text{ J}$
 (b) Some energy has been transferred in heating the circuit, i.e. internal energy
- 4 Work done = QV . Rearranging gives a value for the p.d. of 1.5 V
- 5 (a) $E = QV = 1 \times 1.5 = 1 \text{ J}$
 (b) If the current is I , then the charge passing in 1 minute will be $60 \times I$. The current cannot be obtained from the values given, so the answer can only be stated algebraically.
- 6 $E = QV = 1.6 \times 10^{-19} \text{ J (or 1 eV)}$
- 7 $E = QV = 15 \times 1.6 \times 10^{-19} = 2.4 \times 10^{-18} \text{ J or 2.4 aJ}$

4.2.2 Resistance and Ohm's law (page 170)

- 1 (a) $R = V \div I = 25 \Omega$
 (b) $V = IR = 21 \text{ V}$
 (c) $I = V \div R = 0.026 \text{ A}$
- 2 Going down the table, the missing values are: 120 Ω , 188 V, $8.3 \times 10^{-4} \text{ A}$, 200 M Ω , $1.9 \times 10^{-4} \text{ A}$
- 3 (a) graph B
 (b) graph D
 (c) graph A
- 4 A = 0.72 V, B = 0.05 A, C = 18 V, D = 0.05 A, E = 5571 Ω or 5.6 k Ω

4.2.3 Resistance of circuit components (page 172)

- 1 ohmic conductor – resistor;
 emits light – LED and filament lamp;
 resistance is temperature dependent – thermistor and filament lamp;
 infinite resistance in reverse bias – diode and LED;
 resistance is light dependent – LDR;
 detects changes in the surroundings – LDR and thermistor;
 semiconductor – LED, diode, resistor, LDR and thermistor.
- 2 graph (a) – thermistor; graph (b) – diode or LED; graph (c) – filament lamp;
 graph (d) – diode; graph (e) – resistor, thermistor or LDR; graph (f) – diode.

4.2.4 Resistivity (page 174)

- 1 Resistivity, $\rho = RA \div l = \left[\left(\frac{12}{1.2} \right) \times \pi \left(\frac{1.2}{1000} \right)^2 \right] \div 0.82 = 5.5 \times 10^{-6} \Omega \text{ m}$
- 2 (a) The resistance would halve as stated;
 (b) the current would decrease;
 (c) the resistivity would not change.
- 3 metallic element $\sim 10^{-8}$; alloy $\sim 10^{-6}$; semiconductor $\sim 10^{-3}$; insulator $\sim 10^6$
- 4 $\rho = 1.2 \times 10^{-5} \Omega \text{ m}$
- 5 It depends on the extent to which electrons can move freely through their respective structures. Those materials with high resistivities have electrons that are tightly bound and are not free to move when a p.d. is applied, whereas others, such as graphite, will allow conduction to flow more freely.
- 6 In order of decreasing resistivity: P (best insulator), S, Y, X (best conductor).

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4.2.5 The effect of temperature on resistivity (page 176)

- 1 Using the equation that relates resistivity to temperature, we obtain:
 - (a) $1.65 \times 10^{-8} \Omega \text{ m}$
 - (b) $-224 \Omega \text{ m}$
- 2 The difference in resistivities is given by $1.81 \times 10^{-8} - 1.74 \times 10^{-8} = 7.0 \times 10^{-10} \Omega \text{ m}$
- 3 As the temperature of a metal increases, its ions vibrate more, causing more collisions with the conduction electrons, slowing them down. This means that the resistance will increase with temperature. For a semiconductor, the increased thermal energy leads to greater mobility of the electrons, so the conductive properties increase and the resistance decreases.
- 4
 - (a) a thermistor is used to alter the current flowing in a circuit based on the temperature of the surroundings;
 - (b) a transistor is used as a switch;
 - (c) an LED lights up when the current flowing through it reaches a minimum value, it also acts as a diode and will only allow current to flow through it when in forward bias arrangement;
 - (d) a variable resistor is used to manually change the size of the resistance or current in a circuit;
 - (e) a $1 \text{ k}\Omega$ resistor is used to reduce current and is often used to ensure that the current entering a sensitive semiconductor device is of the correct order of magnitude of around a few mA. It can also be used in potential divider networks to ensure that the correct potential drop occurs across components;
 - (f) a resistor placed in series with an LED ensures that the current flowing through it is not too large or the heat produced from the current could damage the LED.
- 5 Superconductors are materials that show zero electrical resistance, and expel magnetic fields, below a certain 'critical temperature'.

4.2.6 Electrical power (page 179)

- 1
 - (a) $P = IV = 240 \times 0.25 = 60 \text{ W}$
 - (b) 3.6 mW
 - (c) $P = V^2/R = 2000 \text{ W}$ or 2 kW
- 2
 - (a) $I = P/V = 9.6 \text{ A}$
 - (b) 8.3 A
 - (c) Energy = power $\times$ time = $(300 \times 120) - (2000 \times 120) = 36\,000 \text{ J}$ or 36 kJ less energy over the 2 minutes.
- 3
 - (a) 68.6 A
 - (b) $16\,500 \text{ W}$
 - (c) $16\,500 \text{ J}$
- 4
 - (a) 5600 J
 - (b)
 - (i) $P = IV = 220 \text{ W}$
 - (ii) $E = P \times t = 13.2 \text{ kJ}$
 - (c) Efficiency = (useful energy $\div$ total energy supplied) $\times 100\%$;
hence, efficiency = $(5600 \div 13\,200) \times 100\% = 42\%$
- 5
 - (a) $I = P \div V = 6\,000\,000\,000 \div 25\,000 = 240\,000 \text{ A}$ or 240 kA
 - (b) $P = IV = 6\,000\,000\,000 = 400\,000 \times I$, so $I = 15\,000 \text{ A}$ or 15 kA

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4.2.7 Cost of electrical energy (page 181)

1 The missing values for each row are shown below:

kettle – 2 820 000 J, 0.78 kW h, £0.10

shower – 11.5 minutes, 7 200 000 J, £0.26

television – 30 days 21 hours, 111 kW h, £14.22

radio – 3 456 000 J, 0.96 kW h, £0.12

vacuum cleaner – 675 000 J, 0.188 kW h, £0.02

- 2 (a) $417.7 \text{ kW h} = 417.7 \times 3\,600\,000 = 1.5 \times 10^9 \text{ J}$
 (b) $417.7 \text{ kW h} \times 11.8 \text{ p} = £49.29$

4.2 Practice questions (page 184)

1 D [1]

2 D [1]

3 C [1]

- 4 (a) Current in the wire is obtained from $I = \frac{P}{V}$ [1]

Substituting gives $I = \frac{24 \text{ W}}{8 \text{ V}} = 3 \text{ A}$ [1]

- (b) Mean drift velocity is the average velocity of an electron [1] as it travels through a wire due to a potential difference being applied across the ends of the wire [1].

- (c) From $I = nAve$, we rearrange to obtain $v = \frac{I}{nAe}$ [1]

Substituting values into the equation we obtain $v = \frac{3.0}{(8.0 \times 10^{28} \times 1.2 \times 10^{-7} \times 1.602 \times 10^{-19})}$ [1]

Giving a final value for the drift velocity of $v = 0.002 \text{ m s}^{-1}$ [1]

- 5 (a) To obey Ohm's law, the current must be directly proportional to the potential difference across the the component [1].

In this example, the current does not start flowing until the potential difference across the component is around 0.9 V [1].

- (b) The component is a diode or an LED [1]

- 6 (a) The kinetic energy will increase [1] due to increased vibrations caused by the increases in current [1].

- (b) The resistance will increase [1] as the kinetic energy of the atoms has increased due to the greater number of collisions, making it more difficult for electrons to get past the vibrating atoms/fixed positive metal ions [1].

- (c) The energy dissipated as heat per second will increase [1] due to the law $P = I^2 R$ [1], so if the current is doubled, the energy dissipated as heat per second will increase by a factor of four [1].

- 7 (a) Current is calculated from $I = \frac{P}{V}$, so $I = \frac{2400 \text{ W}}{230 \text{ V}}$ [1] giving $I = 10.4 \text{ A}$ [1].

- (b) Resistance $R = \frac{V}{I}$ or $R = \frac{V^2}{P}$ [1] leading to a resistance of $R = 22 \Omega$ [1].

- (c) Energy supplied, $E = VIt$ (or $E = Pt$) [1] which gives a value of $E = 230 \text{ V} \times 10.4 \text{ A} \times 120 \text{ s} = 287\,000 \text{ J}$ (or $E = 2400 \times 120 = 288\,000 \text{ J}$) [1].

- (d) Assumes that energy/current has been supplied at a constant rate/that heat has not been lost to the surroundings [1].

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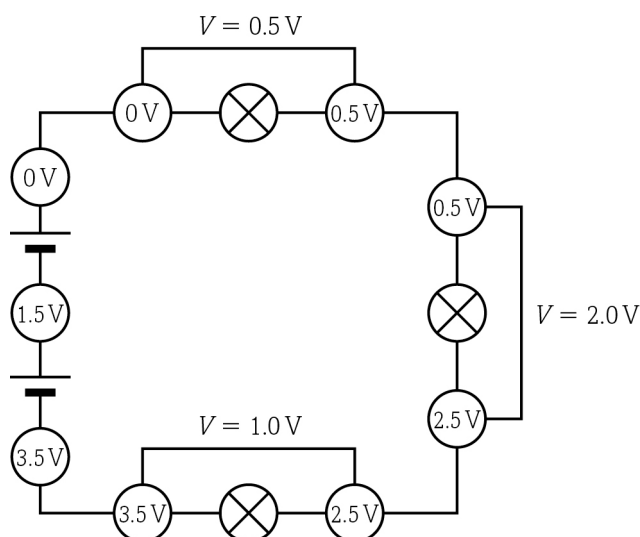
- 8 (a) both are measured in V [1] and both defined as energy per unit charge [1].
 (b) e.m.f. relates to a transfer from any form of energy to electrical energy whereas potential difference relates to a transfer from electrical energy to other forms of energy [1].
 e.m.f. is measured across the terminals of a cell when no current is flowing whereas potential difference is measured across a component [1]/e.m.f. of a cell/source is always greater than the potential difference across the cell/source when current is flowing.
- 9 (a) Energy transferred in kW h = power (kW) × time (h) [1]
 Energy transferred = 0.35 kW × 8 h = 2.8 kW h [1]
 (b) Energy transferred (J) = power (W) × time (s) [1]
 Energy transferred (J) = 350 W × 8 × 60 × 60 s = 10 080 000 J [1]
 (c) Cost of electricity = number of units (kW h) × cost per unit (p) [1]
 Cost of electricity = 2.8 kW h × 12.8 p = 35.84 p or 36 p [1]
- 10 (a) For $E = VIt$, the quantities are energy, potential difference, current and time [1]
 For $E_p = mg\Delta h$, the quantities are energy, mass, gravitational field strength and change in height [1]
 (b) (i) A motor, voltmeter, ammeter and stopwatch [1] to measure the input energy supplied [1] by $E = VIt$.
 A balance to measure the mass being lifted [1] and a ruler to measure the height it is lifted through [1] from the equation $E_p = mg\Delta h$ to determine the change in gravitational potential energy.
 (ii) The principle of conservation of energy [1] is required since it is never violated. From this we would need to use the equations $E = VIt$ to determine the input energy and the equation $E_p = mg\Delta h$ to determine the useful output energy [1] and we would use these in conjunction with the efficiency equation (efficiency = $\frac{\text{useful output energy}}{\text{input energy}}$, or efficiency = $\frac{mg\Delta h}{VIt}$) to calculate the efficiency of the motor in question [1].
 (iii) Systematic errors would come from the zero errors of any ammeters or voltmeters used. There may also be a systematic error associated with the balance when determining the mass of the object being lifted or with the ruler when determining the height through which the mass is being lifted [1]. Systematic errors are removed by either subtracting or adding the size of the error to each reading, as appropriate. For example, if the ammeter reading shown on an analogue ammeter is 0.1 A when no current is flowing, then each reading that is recorded will be 0.1 A bigger than the true value, so 0.1 A must be subtracted from each reading taken [1].
- 11 (a) A resistance value requires an ammeter [1] and a voltmeter [1] in order for it to be calculated using $R = \frac{V}{I}$.
 (b) To calculate the resistivity value from the value for the resistance, we would need to know the length of the wire [1] and the cross-sectional area of the wire, by measuring its diameter [1].
 (c) Length of wire is measured accurately using a metre ruler [1] with a millimetre scale. The cross-sectional area of a wire would be obtained by using a micrometer screw gauge [1] to measure a value for the diameter of the wire to the nearest 0.01 mm.
 (d) (i) The resistivity value would be obtained from calculation by using $\rho = \frac{RA}{l}$ [1] with a number of values used and a mean value calculated for ρ [1].
 (ii) Plot a graph of resistance R against length L [1] for a range of lengths. Determine the gradient of the line of best fit using a gradient triangle that is as large as possible, and multiply the value for the gradient obtained by the cross-sectional area A of the wire to provide a value for the resistivity of the material, ρ [1].
 (e) The increase in temperature of the wire will lead to an increase in the resistance of the wire [1] since electrons will find it more difficult getting past the fixed positive ions in the metal due to their increased vibration/kinetic energy. Since resistivity is directly proportional to resistance, the resistivity will also increase [1].

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4.3 Electricity: electrical circuits

4.3.1 Kirchhoff's first and second laws (page 189)

- 1 $I_3 = 4 \text{ A}$
- 2 The missing value is -1 A (it is actually 1 A flowing into the node, not out as shown).
- 3



- 4 Two simultaneous equations can be set up to give $12 = 4I_1 + 3I_2$ and $8 = 3I_2 - 2I_3$. Solving these gives $I_1 = 1.385 \text{ A}$, $I_2 = 2.154 \text{ A}$ and $I_3 = -0.769 \text{ A}$. (Note when solving that $I_1 = I_2 + I_3$)

4.3.2 Series circuits (page 191)

- 1
 - (a) 300Ω
 - (b) 0.1 A
 - (c) The p.d.s across the 100Ω , 120Ω and 80Ω resistors are 10 V , 12 V and 8 V respectively.
 - (d) $V_1 + V_2 + V_3 = 10 + 12 + 8 = 30 \text{ V} = \text{total p.d.}$ (Kirchhoff's second law).
- 2
 - (a) 0.12 A
 - (b) There will be 6 V across the 50Ω resistor and 18 V across the 150Ω resistor.
- 3 Total resistance $R = 300 \Omega$. This means that the resistances are 50Ω , 100Ω and 150Ω , respectively.
- 4 In the circuit, $V = I \times R = 1.2 \times 120 = 144 \text{ V}$. When the switch is closed, the total resistance in the circuit will now only be equal to 80Ω , so the current will increase to $I = 1.8 \text{ A}$.

4.3.3 Parallel circuits (page 193)

- 1
 - (a) 6Ω
 - (b) 4Ω
- 2 When resistors are connected in parallel, the effective resistance of the network is always less than the resistance of the smallest resistor in the network.
- 3 $V_1 = V_2 = 18 \text{ V}$. $A_2 = 0.9 \text{ A}$, $A_3 = 0.1 \text{ A}$ and so $A_1 = 1.0 \text{ A}$
- 4 1.0Ω , 1.5Ω , 2.0Ω , 3.0Ω , 4.5Ω , 6.0Ω , 9.0Ω

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- 5 (a) (i) $2 \text{ k}\Omega$
 (ii) Total resistance = $1000 + 1000 R/(R + 1000)$
 (c) If $V = 2.0 \text{ V}$, then resistance of the parallel circuit = 666.7Ω
 So, $1/666.7 = 1/1000 + 1/R$
 $R = 2000 \Omega$
 (d) It should be close to infinite.

4.3.4 The potential divider (page 196)

- 1 Going down the answer rows in the table, the missing values are:
 Row 1: 8 V
 Row 2: 1008Ω
 Row 3: 58.3 V
- 2 The fridge compressor needs to be working if the internal temperature is above 5°C and off if below 3°C . Connect the output across a thermistor and choose the resistor value to give the appropriate potential differences to switch the compressor on and off accordingly.
- 3 The p.d. across the 100Ω resistor will increase. Since the resistance of the variable resistor decreases, the share of the p.d. will be greater across the fixed resistor.
- 4 The resistors will be in a ratio of 1:4 with the smaller resistor being the one which the output voltage is measured across.
- 5 The p.d. across the 20Ω resistor = 2.0 V

4.3.5 Internal resistance (page 199)

- 1 (a) 96 V
 (b) 36.8Ω
 (c) 17.2 V
- 2 lost volts = 5.6 V , so internal resistance = $5.6 \div 2.4 = 2.3 \Omega$
- 3 e.m.f. = 108 V and $r = 10 \Omega$
- 4 e.m.f. = 56.0 V (the y-intercept value) and the internal resistance = 20Ω (the gradient).
- 5 the 'lost volts'

4.3.6 Circuit analysis 1 (page 201)

- 1 (a) 33Ω
 (b) 160.6Ω
 (c) 1485.7Ω
- 2 (a) network (a) $I = 0.3 \text{ A}$
 network (b) the current through the end 20Ω and 100Ω resistors = 0.06 A . The current in the 20Ω and 40Ω resistors in the first parallel arrangement = 0.04 A and 0.02 A respectively. The current through the 50Ω and 60Ω resistors = 0.033 A and 0.027 A respectively
 network (c), the current through the $1 \text{ k}\Omega$ and 200Ω resistors = 6.73 mA . The current through the $2 \text{ k}\Omega$, 500Ω and $1 \text{ k}\Omega$ resistors = 0.96 mA , 3.85 mA and 1.92 mA respectively
- (b) network (a), p.d. across each resistor will be 1.8 V , 3.6 V and 4.5 V respectively
 network (b), p.d. across the 20Ω resistor = 1.25 V , the p.d. across the first parallel arrangement = 0.8 V , the p.d. across the next parallel arrangement = 1.65 V and the p.d. across the 100Ω resistor = 6.2 V
 network (c), the p.d. across the $1 \text{ k}\Omega$ resistor = 6.73 V , the p.d. across the parallel network = 1.92 V and the p.d. across the 200Ω resistor = 1.35 V

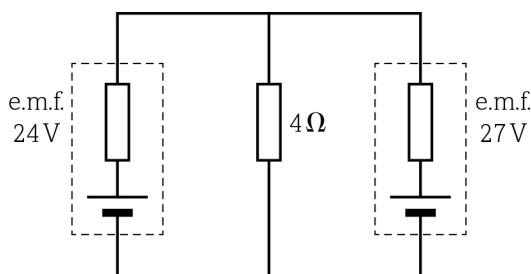
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- 3 With both switches open, the total value for R in the circuit = 21.5Ω , so the current leaving the cell is $I = 0.84 \text{ A}$
- (a) With switch 1 closed, the effective resistance = 9.5Ω , so the current = 1.9 A
The change in current = $+1.06 \text{ A}$
- (b) When switch 2 is closed, the total resistance = 32Ω , so the current flowing in the circuit = 0.56 A
The change in current = -0.28 A
- (c) With both switches closed, the current = 0.9 A , so the change in current = $+0.06 \text{ A}$
- (d) With the 18Ω resistor removed, the current = 0.56 A and the change in current = -0.28 A

4.3.7 Circuit analysis 2 (page 203)

- 1 (a) Overall e.m.f. = 8 V , so $I = 0.47 \text{ A}$
(b) $Q = It = 0.47 \times 3600 = 1694 \text{ C}$
(c) $P = I^2 R = 0.35 \text{ W}$
(d) $E = VIt = 8 \times 0.47 \times 60 = 225.6 \text{ J}$

- 2 (a)



- (b) The current through the 24 V cell = 3 A , the current through the 27 V cell = -1.5 A and the current through the 4Ω resistor = 4.5 A
- (c) Energy = power $\times$ time = $I^2 R t = 4.5^2 \times 4 \times 25 \times 60 = 121\,500 \text{ J}$

4.3 Practice questions (page 206)

- 1 B [1]
2 B [1]
3 C [1]
4 D [1]
5 (a) The current through the 6.0Ω will be 1.5 times smaller than the current through the 4.0Ω resistor since the current and resistance are inversely proportional/must multiply to give the same p.d. across the network of 1.2 V [1]. The current flowing through the 6.0Ω resistor is 0.2 A [1].
(b) 0.3 A , as shown on the diagram [1].
(c) 1.2 V across the 6.0Ω resistor [1], 1.2 V across the 4.0Ω resistor [1] and 2.8 V across the 5.6Ω resistor [1].
(d) The effective resistance of the 6.0Ω and 4.0Ω resistors is found by using the equation for resistors in parallel, leading to $\frac{1}{R} = \frac{1}{6} + \frac{1}{4}$ and giving R for the parallel network of 2.4Ω [1].

The total resistance is then determined by adding this to the 5.6Ω resistance in series with it [1].

Final value for effective resistance of 8.0Ω [1].

- 6 Connected in series, effective resistance = $2 \Omega + 4 \Omega + 8 \Omega + 20 \Omega = 34 \Omega$ [1]

Current through 2Ω resistor when in series with 16 V cell is given by $I = \frac{V}{R} = \frac{16}{34} = 0.47 \text{ A}$ [1]

Current through 2Ω resistor when in parallel arrangement is $\frac{\text{p.d.}}{\text{branch resistance}} = \frac{16}{2} = 8 \text{ A}$ [1]

So ratio of current through 2Ω resistor in parallel arrangement : current in 2Ω in series arrangement is $8 : 0.47$ [1] or about $17 : 1$ [1]

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- 7 The total resistance of the lamps increases by a factor of 1.5. Resistance of each lamp increases with current [1]. Resistance increases because of increased temperature [1]. Lamps are non-ohmic components [1].

- 8 Figure 3: total resistance = $3R$ [1]

Figure 4: total resistance = $\frac{2R}{3}$ [1]

$$\text{Ratio} = \frac{V}{3R} \div \frac{V}{\left(\frac{2R}{3}\right)} = 0.22 \text{ [1]}$$

- 9 R of thermistor decreases as temperature increases [1]

supply V is constant/total R is smaller [1]

current increases as $V = IR$ [1]

- 10 (a) p.d. across 750Ω resistor = $45 - (0.03 \times 1000) = 15 \text{ V}$ [1]

$$\text{current through } 750 \Omega \text{ resistor} = \frac{15}{750} = 0.02 \text{ A [1]}$$

$$\text{current through } R = 0.01 \text{ A [1]}$$

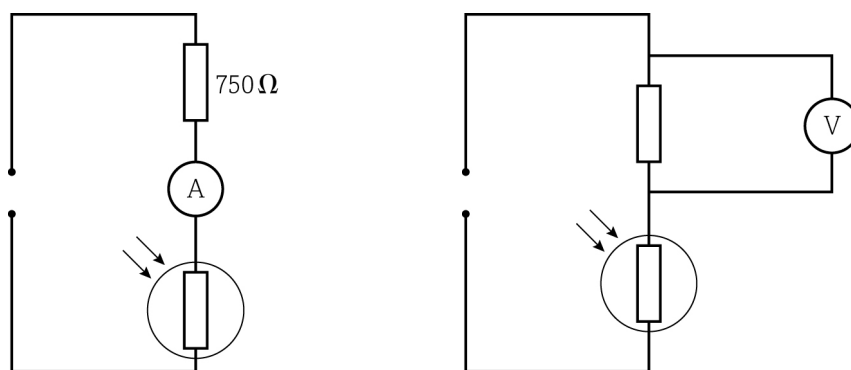
$$R = \frac{15}{0.01} = 1500 \Omega \text{ [1]}$$

(alternatively, find the effective total resistance of the circuit = $\frac{45}{0.03} = 1500 \Omega$ [1], find the

resistance of the parallel pair = $1500 - 1000 = 500 \Omega$ [1]

Hence $R = (500^{-1} - 750^{-1})^{-1}$ [1] = 1500Ω [1], or use potential divider argument)

(b)



A good answer will contain the following points, using a well-developed line of reasoning which is clear and logically structured

correct symbol for LDR [1]

resistor and LDR in series [1]

ammeter in series, voltmeter in parallel with resistor [1]

When light intensity increases resistance of LDR falls [1]

So current in circuit increases or p.d. across resistor increases or p.d. across LDR decreases (meter reading increases) [1]

Resistor of 750Ω gives the largest change on the meter (most sensitive) or need a meter which can display small changes in value of current or voltage [1]

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4.4 Waves

4.4.1 Wave motion (page 210)

- 1 Transverse waves – X-rays, gamma, light, slinky.
Longitudinal – sound, ultrasound, slinky.
- 2 (a) They both transfer energy from one place to another without any overall (net) movement of matter.
(b) Longitudinal waves have vibrations that are parallel to their direction of energy transfer, whereas transverse waves have vibrations that are at right angles to their direction of energy transfer. Longitudinal waves require a medium to travel through, whereas some transverse waves (electromagnetic waves) do not.
- 3 An oscillation describes the periodic motion of a particle about its mean position or equilibrium position, whereas a wave refers to the motion of the energy outwards from the initial disturbance. For example, when a stone is dropped into a pond, the individual water particles will oscillate up and down about their equilibrium positions in the pond, but the water wave will spread out across the surface of the pond, transferring energy as a transverse wave across the pond's surface, and at right angles to the oscillating motion of the water particles.

4.4.2 Wave terminology (page 215)

- 1 To convert from degrees to radians, multiply the angle in degrees by π and then divide by 180.
 - (a) $\frac{\pi}{4}$
 - (b) $\frac{3\pi}{4}$
 - (c) $\frac{3\pi}{2}$
 - (d) $\frac{\pi}{2}$
 - (e) π
- 2 $f = \frac{1}{0.002} = 500 \text{ Hz}$
- 3 (a) $f = 66\,666.7 \text{ Hz}$
(b) $T = 2.5 \times 10^{-7} \text{ s}$
- 4 Clockwise from top left:
amplitude = 1 unit, wavelength = 6.25 m;
amplitude = 1 unit, time period = 12.5 ms, frequency = 80 Hz;
amplitude not possible to determine due to no scale, wavelength = 2 m;
amplitude = 0.04 m, time period = 0.2 s, frequency = 5 Hz.
- 5 You would observe 1.6 complete waves on the screen. The time period of the wave is $6.25 \times 10^{-4} \text{ s}$ and the screen can accommodate the wave that will be equal in time period to 10^{-3} s . The sketch needs to show 1.6 waves, although an amplitude cannot be determined as no information has been provided regarding the vertical axis.
- 6 One complete wavelength on the screen will be equal to 6.25 cm. The actual wave had a wavelength of 7.1 cm. This means that the uncertainty in the wavelength must be $[(7.1 - 6.25)/7.1] \times 100\% = 12\%$. For the frequency calculation, the values would be $[(1600 - 1408)/1600] \times 100\% = 12\%$.

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4.4.3 Wave speed and the wave equation (page 217)

- 1
 - (a) frequency = 5×10^{14} Hz
 - (b) the frequency will be the same in glass as in air = 5×10^{14} Hz
 - (c) the wavelength will be 1.5 times smaller in glass = 400 nm or 4×10^{-7} m
- 2
 - (a) Transmitting wavelength is 50 cm or 0.5 m. Using $c = f\lambda$, $f = 600$ MHz (6×10^8 Hz)
 - (b) 17 m to 1.7×10^{-2} m
 - (c) Speed = 323.8 m s^{-1} , wavelength = 1.08×10^{-1} m
- 3
 - (a) For the floats to move in antiphase and for there to be only one wave crest between them means that there are 1.5 wavelengths between them, so wavelength = 3.0 m. Using $c = f\lambda$, speed = 1.0 m s^{-1}
 - (b)
 - (i) 0.33 Hz, 1.5 m
 - (ii) 0.026 m
- 4 Intensity = energy per second/area. This gives $I = \frac{2.4 \times 10^2}{(\pi \times 3.5^2)} = 6.2 \text{ W m}^{-2}$
- 5
 - (a) The intensity would be four times greater.
 - (b) The intensity would be four times greater.
- 6 Intensity = power/area. Intensity = $\frac{0.8 \times 10^{-3} \text{ W}}{(\pi \times 0.0005^2)} = 1019 \text{ W m}^{-2}$

4.4.4 Common properties of waves (page 220)

- 1 Examples may include the following, although other suitable alternatives may be suggested by students, so the teacher's discretion is required here.
 - (a) Light bouncing off an object and into our eyes so that we can see it.
 - (b) An echo.
 - (c) The apparent depth of an object appears less or a stick looks broken when placed in a glass of water so that it is partially in air and partially submerged in water.
 - (d) Radio waves diffracting when they pass over a hill, meaning that they can be detected by aerials in the valley below. If these waves bounce off the hillside in the valley then they will overlap and interfere.
 - (e) X-ray diffraction, which enables atomic or molecular structures to be shown in detail. The waves will diffract and then interfere to allow an image to be produced.
- 2 Sound has a speed of $\sim 340 \text{ m s}^{-1}$ in air and frequencies that range from 20 Hz to 20 kHz. This means that the wavelength of sound waves is in the region of metres to centimetres. Sound waves will diffract through gaps of this size, such as alleyways, gaps in doors and around corners. Light waves have a very short wavelength and will not diffract through everyday gaps and obstacles, meaning that the phenomenon will be less easily detected for light.
- 3 A suitable experiment would include a source that transmits a sound of a given frequency towards a gap or an obstacle. A detector is used in various positions after the gap/obstacle that shows the sound being measured in directions other than that lying in a straight line from the transmitter. Further details may refer to the extent to which the sound waves diffract based on the relationship between the wavelength of the sound and the gap width or obstacle diameter.
- 4
 - (a) Student's diagram showing an appreciable diffraction pattern.
 - (b) Student's diagram showing some diffraction at the edges, similar to the photo shown in Figure 7 on page 219.

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- 5 (a) As the wave enters the shallower water the wave will begin to slow down and its wavelength will also decrease (the amplitude will increase to conserve the total energy in the wave). The wave has been refracted by the shallow water. The part of the wave crest closer to the shore enters the shallower water first so will move slower than the rest of the wave that is still in deep water. This difference in wave speed will refract the wave as the wave crest in the deeper water catches up. This pattern will continue until all of the wave becomes parallel to the shore, at which point all of the wave will travel into the shallower water at the same time so it will remain parallel to the shore.
- (b) Student's diagram showing that the part of the wave nearest point A enters the shallow water and slows down. The part of the wave nearest point B continues at the original faster speed and travels further for each time period. This refracts the whole wave so that it bends towards the shore. Additional lines added to show that refraction continues until the wave becomes parallel to the shore.
- 6 (a) Reference needs to be made to sound energy reflecting back from the solid surface of the barrier. The answer should also discuss how diffraction will occur over the top of the barrier but the amount of diffraction will vary for different wavelengths of sound.
- (b) Low frequency sounds, due to their larger wavelengths, can diffract over the top of the barriers. Higher frequencies are not diffracted, so carry on in a straight line over the barrier, leaving the houses in the shadow of these waves.
- 7 The reflection means that waves, of the same wavelength and frequency, can now overlap. This can lead to destructive interference and hence a loss of signal. This occurs when the two waves have a phase difference of π radians.

4.4.5 Electromagnetic waves (page 223)

- 1 It could be argued that different EM waves are in different parts of the Venn diagram. It is likely that most of the waves can be found in both the hospital and home (radio, microwave, infrared, visible). It could be argued that UV can be found if somebody has a UV lamp or a sun bed. It is unlikely that X-ray and gamma radiation can be found in the home, but these would be found in the hospital.
- 2 No. It is not possible to say that any type of radiation is ever 100% safe. However, we do know that radio waves are less likely to cause us any damage compared with ionising radiation such as UV, X-rays and gamma rays that can damage the cells in our bodies.
- 3 (a) radio, microwaves, infrared, visible light
 (b) microwaves and infrared
 (c) UV, X-rays and gamma rays are most likely to cause harm
 (d) all of them
 (e) UV
 (f) radio waves
 (g) microwaves
 (h) radio waves, microwaves, infrared, visible light, UV and X-rays.
- 4 They can all be reflected, refracted, diffracted, can interfere and be polarised. They are all transverse waves, composed of an electric and magnetic field, and can all travel through a vacuum.
- 5 radio, microwave, infrared, infrared, UV, X-rays or gamma rays, X-rays or gamma rays.
- 6 $5.36 \times 10^8 \text{ Hz}$

4.4.6 Polarisation (page 226)

- 1 As $I = I_{\max} \cos^2 \theta$, then the intensity of the transmitted light depends upon θ . When $\theta = 0$, then $I = I_{\max}$, and when $\theta = 90^\circ$, then $I = 0$. By summing all the intensity values between 0 and 90° , you find that $I = 0.5 I_{\max}$.
- 2 (a) The signal received rises and falls as the detector is rotated.
 (b) The microwaves being transmitted are polarised.
 (c) The transmitting aerial is orientated vertically.

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4.4.7 Refraction of light (page 229)

- 1 (a) 1.5
(b) glass or a similar material
- 2 Going down the table from top to bottom, the missing values are:
 $\theta_2 = 20^\circ$; $\theta_1 = 41^\circ$; $n_1 = 1.0$; $n_2 = 2.25$
- 3 Refractive index of glass = 1.53 and the refractive index of water = 1.33.
- 4 Upon leaving the material of higher refractive index and re-entering the material of lower refractive index, the light ray speeds up to its original speed, hence making the same angle with respect to the normal.
- 5 The lens of the eye changes its thickness, which changes its refractive index. To read or view objects that are close to the reader, the lens needs to be made thicker so that light rays are refracted more. When reading or viewing distant objects, the lens is thinner as light rays need to be bent less to fall on the retina. Suitable ray diagrams can show this.
- 6 (a) Refractive index = 1.33
(b) Using Snell's law, $1.00 \times \sin 50^\circ = 1.33 \sin \theta_2$, $\theta_2 = 35^\circ$

4.4.8 Total internal reflection (page 231)

- 1 Critical angle = 39.3°
- 2 For the diamond/water arrangement, the critical angle = 33.3°
- 3 (a) Binoculars use internal reflection in prisms to redirect light from the object viewed into the eyepiece for viewing by the observer without the loss of intensity.
(b) Optical fibres use total internal reflection to transmit information in the form of electromagnetic radiation.
(c) Radio waves are totally internally reflected when they interact with the charged layers in the Earth's upper atmosphere, enabling information to be sent from one place to another around the world via a series of internal reflections.
(d) Endoscopes are used for viewing internal structures inside the human body. Light is emitted down cables using internal reflection to send the light around the non-linear pathway of the probe. The light is reflected by the internal organs and sent back through a set of coherent bundles to be viewed by the surgeon. There is minimal loss of light intensity.
- 4 Light must be travelling from a more to less optically dense material (from a material of higher refractive index to one of a lower refractive index).

4.4.9 Interference (page 234)

- 1 (a) Sources or waves which have a constant phase difference – this may be equal to zero, but it must be a constant value and not change.
(b) Coherent waves are usually produced from a single source. It is easy to connect two aerials to a radio transmitter. Light is produced by energy transitions in atoms that are not phase-related over a finite distance except in a laser.
- 2 The overlapping waves shown in (a) and (b) are coherent since they both have a constant phase difference throughout. The waves shown in (c) are non-coherent. Resultant wave diagrams will be the vector sum of the waves shown.

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- 3 (a) Constructive interference, since they have a path difference equal to a whole number of wavelength.
- (b) Constructive interference since a phase difference of 1080° is the same as three complete oscillations or a path difference of 3λ .
- (c) Destructive interference since the waves are out of phase by half a wavelength, leading to crests overlapping with troughs.
- (d) $3\pi/2$ will be between constructive and destructive interference.

4.4.10 The Young double-slit experiment (page 237)

- 1 $\lambda = \frac{ax}{D} = (16 \times 10^{-3}) \times \frac{(1.125 \times 10^{-4})}{2.4} = 7.5 \times 10^{-7} \text{ m}$
- 2 (a) Increasing the value of a will decrease the fringe width.
- (b) Increasing the value of D will increase the fringe width.
- (c) Doubling the values of a and D will lead to no change in the fringe width, x .
- 3 Lower frequencies would mean larger wavelengths, so the distance between overlapping waves that caused constructive or destructive interference would be greater.
- 4 (a) $x = 0.448 \text{ m} = 45 \text{ cm}$
- (b) $x = 0.336 \text{ m} = 34 \text{ cm}$
- 5 (a) $3.9 \times 10^{-3} \text{ m}$
- (b) (i) Increasing the separation of the slits will lead to a decrease in the fringe width.
- (ii) Doubling the distance between the slits and the screen will double the fringe width.
- (c) The fringe width would remain the same provided the slit width remains greater than the wavelength. The light intensity of the fringes would be decreased marginally.
- 6 Green light has a shorter wavelength than red light, so the fringe width will be smaller.
- 7 Calculating $1.4 \times 10^{-3} \div 1.2$ gives a value of 0.001 16, which is very close to the values for $\sin\theta$ and $\tan\theta$ when expressed in radians.

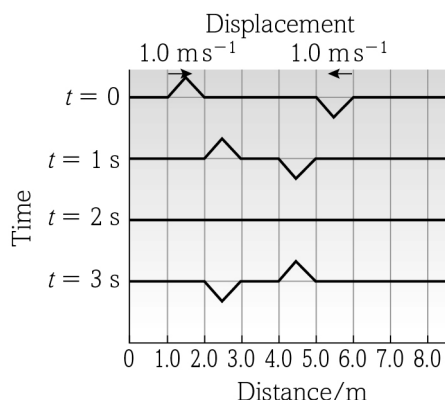
4.4.11 The diffraction grating (page 240)

- 1 Using the diffraction equation, $\lambda = 4.0 \times 10^{-7} \text{ m}$
- 2 Using $n\lambda = d\sin\theta$, we obtain $3 \times 5.7 \times 10^{-7} \times 550\,000 = \sin\theta = 70.1^\circ$
- 3 The highest number of maxima is obtained from d/λ , which gives a value of 2.4. This means that the highest order maxima will be at $n = 2$.
- 4 For green light, $\theta = 17.3^\circ$ and for red light, $\theta = 23.1^\circ$. This means the difference will be 5.8° .
- 5 There will be 11 spots of light visible in total. Calculating d/λ gives a value of $n = 5$ as the highest number of maxima, so there will be 5 maxima either side of the central maxima for $n = 0$.

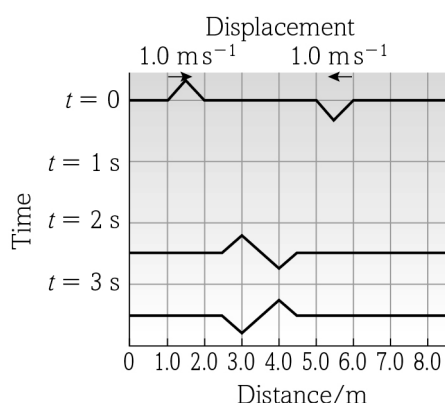
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4.4.12 Stationary waves (page 243)

- 1
 - (a) A stationary wave is produced when two waves of the same frequency and similar amplitude overlap when travelling in opposite directions.
 - (b) Stationary waves are confined to a fixed position whereas progressive waves radiate energy out from a point. For stationary waves, there is no net energy flow, whereas for progressive waves there is.
 - (c) Both waves can be described in terms of their respective wavelengths, frequencies and amplitudes. Reference may also be made to reflection and interference.
 - (d) Stationary waves may include musical waves in pipes or on strings, such as a guitar string; progressive waves may include electromagnetic waves, water waves or sound waves radiating from a source.
- 2
 - (a) half a wavelength
 - (b) half a wavelength
 - (c) one-quarter of a wavelength.
- 3
 - (a)



(b)



- (c) Node at 3.5 m
- 4
 - (a) and (b) Student's own sketches showing the vector sums of the waves as they move into phase and antiphase.
 - (c)
 - (i) 3.5 m, 4.5 m
 - (ii) $1.0 \text{ m} \left(\frac{\pi}{2} \right)$
 - (iii) nodes
 - (d) At 1.0 s potential energy; at 2.0 s kinetic energy.

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4.4.13 Stationary wave experiments (page 245)

- 1
 - (a)
 - (i) π
 - (ii) 0
 - (b)
 - (i) V, X
 - (ii) W, Y
- 2
 - (a) 60 Hz. Figure 8 shows the third harmonic so the fundamental frequency is one-third of the vibration frequency.
 - (b) 90 Hz. Reducing the length of the string increases the fundamental frequency.
- 3
 - (a) Substituting a value of $2T$ into the equation, $f = 60\sqrt{2} = 85$ Hz.
 - (b) This will increase the frequency further as f is proportional to $\mu^{-1/2}$.

4.4.14 Stationary longitudinal waves (page 249)

- 1 The number of antinodes is always greater than the number of nodes in an open pipe by 1. This can be written as $A = N + 1$.
- 2
 - (a) N at water level, A just above top of tube.
 - (b) Arrows shown as appropriate, with size varying from a maximum at the antinode to a minimum at the node.
 - (c) 1.28 m
 - (d) 258 Hz
 - (e) 516 Hz
- 3
 - (a) equal maximum amplitudes in antiphase; at same frequency
 - (b) unequal amplitudes, but in phase
 - (c) R is at rest, a node.

4.4 Practice questions (page 252)

- 1 D [1]
- 2 D [1]
- 3 B [1]
- 4 A [1]

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- 5 (a) (i) Amplitude – the maximum displacement of a wave from its mean or rest position, measured in metres, m [1].
 (ii) Frequency – the number of oscillations in a given unit of time, measured in hertz, Hz [1].
 (iii) Coherent – two waves with a constant phase relationship [1].
 (iv) Period – the time taken for one complete pattern of oscillation, measured in seconds, s [1].
 (v) Wavelength – the smallest distance between one point on a wave and the identical point on the next wave, measured in metres, m [1].
- (b) (i) The value of the frequency would suggest that it is a sound wave, since sound waves have frequencies between 20 Hz and 20 000 Hz whereas light waves have frequencies of the order of 10^{14} Hz. **Or** light is a transverse wave, not longitudinal [1].
- (ii) If it is sound wave, sound travels at around 340 m s^{-1} in air [1], so the wavelength is $\frac{340 \text{ m s}^{-1}}{12\,000 \text{ Hz}}$ which gives a value of 0.028 m or about 3 cm [1].
- (iii) If the frequency of the wave changed then its wavelength would appear different on an oscilloscope. A higher frequency would lead to a shorter wavelength and vice versa. In terms of how the wave would sound, the change in frequency would affect its pitch – a higher frequency means a higher pitch.
- (iv) If the amplitude of the sound wave changed then the height of the wave would change. This has an impact of the loudness of the sound, with louder sounds having a greater amplitude than quieter sounds.
- 6 (a) A – microwaves, B – infrared, C – X-rays.
- (b) (i) Similarities between microwaves and X-rays include: they travel at the same speed in a vacuum, are transverse, can be absorbed, reflected, refracted, diffracted and polarised, can have their photon energy calculated using $E = hf$.
 (ii) Differences between microwaves and X-rays include: photon energies are lower for microwaves, as is the frequency, higher wavelength for microwaves. Microwaves are not ionising whereas X-rays are. Microwaves are used for cooking food or communications, whereas X-rays are used to look at broken bones, etc.
- 7 (a) (i) 600 lines per mm means $d = \frac{1}{600\,000}$ in m [1], so $d = 1.67 \times 10^{-6} \text{ m}$ [1].
 (ii) Substituting the values in the question into $n\lambda = d\sin\theta$ gives $2\lambda = 1.67 \times 10^{-6} \times \sin 38^\circ$ [1].
 $\lambda = 5.1 \times 10^{-7} \text{ m}$ [1].
 (iii) The highest order of observable maxima is given by $n < \frac{d}{\lambda}$ [1] which gives $n < 3.3$ and hence highest order is $n = 3$ [1].
- (b) (i) If the wavelength increases, then $n\lambda$ increases so $\sin\theta$ increases [1], so the angle must also increase [1].
 (ii) If the number of lines per mm decreases then d increases, so $\frac{n\lambda}{d}$ decreases [1], so $\sin\theta$ and hence θ decreases [1].
 (iii) Moving the laser away has no effect [1] since the diffraction only depends on n , d and λ /is independent of how far away the light source is from the diffraction grating [1].
- 8 Using Young's double slit equation, $\lambda = \frac{ws}{D}$ [1], we have $w = 1.4 \times 10^{-4} \text{ m}$, $s = \frac{0.115}{8}$ and $D = 2.8 \text{ m}$.
 Substituting these values we obtain $\lambda = \frac{(1.4 \times 10^{-4} \times 0.014)}{2.8}$ [1] = $7.2 \times 10^{-7} \text{ m}$ [1].

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- 9 (a) Tube pushed into water by $\frac{\lambda}{2}$ / antinode needed at open end and node at water level [1]
- therefore $\frac{\lambda}{2} = 0.506 - 0.170$ giving $\lambda = 0.672$ m [1]
- using $v = f\lambda$ [1]
- $v = 500 \times 0.672 = 336$ m s⁻¹ (3 s.f. required) [1]
- (b) smaller λ means smaller l to measure, so less accurate measurement [1]
- added detail or expansion of argument [1]

4.5 Quantum physics

4.5.1 The photon (page 258)

- 1 Reference needs to be made to the idea of light being thought of as a wave by Newton, being modelled as a wave by Huygens and then eventually being shown to have both wave and particle-like properties by those such as de Broglie and Einstein.
- 2 The energy of a photon is calculated using the equations $E = hf$ and $E = \frac{hc}{\lambda}$. E is the photon energy, h is the Planck constant, c is the speed of light, f is the frequency of the wave and λ is its wavelength.
- 3 (a) $f = (3 \times 10^8 \div 6.0 \times 10^{-7}) = 5 \times 10^{14}$ Hz
- (b) From $E = hf = 3.3 \times 10^{-19}$ J or about 2 eV
- 4 (a) 3.3×10^{-28} J
- (b) 1.9×10^{-15} J
- (c) 4.0×10^{-26} J
- (d) 4.1×10^{-20} J
- 5 A frequency of 840 terahertz is 8.4×10^{14} Hz, leading to a photon energy of 5.6×10^{-19} J. If the power is 24 W, then 24 J of energy is emitted each second. The total number of photons emitted per second will be equal to the total power divided by the energy of one photon, hence number of photons = $24 \div (5.6 \times 10^{-19}) = 4.3 \times 10^{19}$.
- 6 Using $\Delta V / \Delta \left(\frac{1}{\lambda} \right) = (2.44 - 1.77) / (5.4 \times 10^5) = 1.25 \times 10^{-6}$. This equates to $\frac{hc}{e}$ and rearranging gives us a value for h of 6.67×10^{-34} J s

4.5.2 The electronvolt (page 260)

- 1 (a) 8.0×10^{-19} J
- (b) 1.282×10^{-12} J
- (c) 3.204×10^{-9} J
- 2 (a) 3.204×10^{-19} J $\div 1.6 \times 10^{-19}$ J eV⁻¹ = 2 eV
- (b) 48 nJ = 48×10^{-9} J, so $48 \times 10^{-9} \div 1.6 \times 10^{-19} = 3 \times 10^{11}$ eV
- (c) 9.4×10^{18} eV
- (d) 6.24×10^{25} eV
- 3 (a) joules
- (b) eV
- (c) joules
- (d) eV

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- 4 (a) An electron accelerated through 1 V gains 1 eV, so an electron accelerated through 450 V will gain 450 eV of kinetic energy. For the alpha particle, the charge is $2e$, so it will gain 900 eV of kinetic energy.
- (b) The electron gains 7.2×10^{-17} J and the alpha particle gains 1.44×10^{-16} J.
- (c) Using $\frac{1}{2}mv^2$, we rearrange to get a value of v for the electron $= 1.26 \times 10^7$ m s $^{-1}$. For the alpha particle, the value of v will be 2.09×10^5 m s $^{-1}$.

4.5.3 The photoelectric effect 1 (page 263)

- 1 (a) Photoelectrons are electrons that are released from the surface of a metal by incident light photons that are above the threshold frequency of the metal.
- (b) The threshold frequency is the frequency of the photons, above which, electrons will be released from the surface of the metal. Below this value, electrons will not be released.
- (c) The work function is the minimum energy required to release an electron from the surface of the metal.
- (d) Photons are quanta of electromagnetic radiation of energy $E = hf$.
- 2 The electrons are attracted back to the plate by the positive charge.
- 3 The surface may be covered with zinc oxide if the zinc has reacted with the oxygen in the air. This needs to be removed so that zinc metal, and not the zinc oxide, can be exposed to the UV.
- 4 Rearranging the photoelectric effect equation to give $hf - \phi = \frac{1}{2}mv^2$:
- (a) The kinetic of the emitted photoelectrons will increase.
- (b) There will be more photoelectrons emitted, but no change in their kinetic energy as the intensity does not affect their kinetic energy.
- (c) The kinetic of the emitted photoelectrons will increase.
- (d) The kinetic of the emitted photoelectrons will increase.
- 5 (a) A work function, ϕ , of 2.4 eV is equal to 3.8×10^{-19} J. Using $\phi = hf_o$ and rearranging to get the threshold frequency, f_o , leads to a value of 5.8×10^{14} Hz.
- (b) Using $hf - \phi = \frac{1}{2}mv^2$, we obtain $hf = 5.0$ eV. Converting from eV to J and rearranging, we obtain a value for the frequency, $f = 1.2 \times 10^{15}$ Hz.
- 6 (a) $\phi = 2.1 \times 10^{-19}$ J
- (b) $\phi = hf_o$. Using the value for ϕ obtained in part (a) we obtain a value for $f_o = 3.2 \times 10^{14}$ Hz.

4.5.4 The photoelectric effect 2 (page 266)

- 1 (a) 1.0×10^{15} Hz
- (b) Maximum kinetic energy $= 2.2 \times 10^{-18}$ J
- 2 (a) 9.9×10^{14} Hz
- (b) Substituting the values into the equation $V_s = (h/e)c/\lambda - \phi/e$ leads to a stopping potential of -1.96 V
- 3 It will increase. The decrease in the wavelength means that the frequency and photon energy will increase, leading to a greater stopping potential being required.
- 4 From the equation that relates stopping potential to frequency, the gradient will be equal to h/e . Since both of these quantities are constants, then any graph for any metal will have the same gradient. Metals have different work functions, so the intercepts will be different, as the intercept is equal to $\frac{-\phi}{e}$. This means that a series of metals will produce parallel lines of identical gradient but different y -intercept values.

4.5.5 Wave-particle duality (page 269)

- 1 A photon is a particle or quantum of electromagnetic radiation of energy hf . A wave is any longitudinal or transverse means of transferring energy through a vacuum or a medium without any net transfer of matter. Electromagnetic radiation can be considered as either a stream of photons or showing wave properties.

Electrons, waves and photons

- 2 (a) The photoelectric effect and reflection.
(b) Reflection, refraction, diffraction and interference.
- 3 (a) $\lambda = \frac{h}{mv}$, so $\lambda = \frac{6.626 \times 10^{-34}}{(9.11 \times 10^{-31} \times 0.03 \times 3 \times 10^8)} = 8.1 \times 10^{-11} \text{ m}$
(b) $\lambda = \frac{h}{mv}$, so $\lambda = \frac{6.626 \times 10^{-34}}{(0.8 \times 18)} = 4.6 \times 10^{-35} \text{ m}$
(c) In order to notice the wave nature, diffraction needs to occur. This happens when the wavelength of the object is equal to the gap or diameter of an object that the radiation passes through or around. For massive objects moving at low speeds, this value is simply too small for it to be noticed.
- 4 Electrons, when travelling at significant speeds, will have wavelengths that are comparable to that of an atomic spacing or nuclear diameter. This means that it is possible to observe the diffraction effects and ascertain information about the atomic or nuclear structure, which is of the order of between 10^{-10} m to 10^{-15} m in diameter.
- 5 From $\lambda = \frac{h}{mv}$ we get $\lambda = \frac{6.626 \times 10^{-34}}{(1.67 \times 10^{-27} \times 3000)} = 1.3 \times 10^{-10} \text{ m}$

4.5 Practice questions (page 272)

- 1 C [1]
2 D [1]
3 D [1]
- 4 (a) A photon is a quantum of electromagnetic radiation of energy hf [1].
(b) Doubling the intensity of a photon does not affect its photon energy, which only changes if the frequency of the radiation is increased [1]. A greater intensity just means that there will be more photons incident per unit area per second [1], but their photon energy will not change.
- 5 (a) Electrons behave **or** travel as waves [1].
The rings demonstrate that the electrons are diffracted by individual carbon atoms/spacing between carbon atoms [1].
The (de Broglie) wavelength of the electrons is comparable to the 'size' of the carbon atoms or the spacing between carbon atoms [1].
(b) Correct use of $\frac{1}{2}mv^2 = eV$: $v^2 = \frac{1.6 \times 10^{-19} \times 1200}{0.5 \times 9.11 \times 10^{-31}}$ or $v = 2.053 \times 10^7 \text{ m s}^{-1}$ [1]
 $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.053 \times 10^7}$ [1]
wavelength = $3.5 \times 10^{-11} \text{ m}$ [1]
- 6 B [1]
The energy of one photon of light of this wavelength is given by $E = \frac{hc}{\lambda}$ [1], so the photon energy would be
 $E = \frac{(6.626 \times 10^{-34} \times 3 \times 10^8)}{5 \times 10^{-7}}$ [1] leading to $4.0 \times 10^{-19} \text{ J}$
This means that 4.2 J would contain $\frac{4.2}{4.0 \times 10^{-19}}$ [1] or 1.1×10^{19} photons [1]

Electrons, waves and photons

- 7 (a) (i) Monochromatic – light of a single wavelength or frequency [1]
 (ii) Work function – the minimum energy required to release an electron from the surface of a material such as a metal [1]
 (b) (i) $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$ so $2.8 \text{ eV} = 2.8 \times 1.602 \times 10^{-19} [1] = 4.5 \times 10^{-19} \text{ J} [1]$
 (ii) Threshold frequency, $f_0 = \frac{E}{h} [1] = \frac{4.5 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34}} = 6.8 \times 10^{14} \text{ Hz} [1]$
 (iii) Maximum wavelength, $\lambda_0 = \frac{c}{f_0} [1] = \frac{3 \times 10^8}{6.8 \times 10^{14} \text{ Hz}} = 4.4 \times 10^{-7} \text{ m} [1]$
- 8 (a) A good answer will contain six of the following points, using a well-developed line of reasoning which is clear and logically structured
 Adjust the potential divider to low or zero voltage
 connect flying lead to one LED
 increase voltage until LED just lights or strikes (essential)
 repeat several times and average to find $V_{\min}$ (essential)
 repeat for each LED
 shield LED inside opaque tube to judge strike more accurately.
 plot a graph of $V_{\min}$ against $\frac{1}{\lambda}$ – will be a straight line
 through the origin
 so need to calculate values of $\frac{1}{\lambda}$
 then draw line of best fit through origin
 gradient $G = V_{\min} \lambda = \frac{hc}{e}$
 hence $h = \frac{eG}{c}$
- (b) (Note the y-axis labels on Figure 3 are out by a factor of 10, and should read 20×10^{-20} , 40×10^{-20} and 60×10^{-20} , from bottom to top.)
 The wave-model cannot explain the cut-off frequency/threshold frequency [1]
 Nor why the KE of the electrons is dependent on frequency [1]
 Also allow reverse argument in terms of photons, e.g. the photon-model can explain the threshold frequency and why the KE of the electrons is dependent on frequency
- (1) $h = \frac{32 \times 10^{-20}}{5 \times 10^{-14}} [1]$
 $= 6.4 \times 10^{-34} \text{ (J s)} [1]$
 sensible attempt at gradient gains 1 mark
- (2) $8.75 \pm 0.25 \times 10^{14} \text{ (Hz)} [1]$
- (3) $\phi = 6.4 \times 10^{-34} \times 8.75 \times 10^{14} [1]$
 $= 5.6 \times 10^{-19} \text{ J} [1]$