Topic 1 Mechanics
1A Motion

1A.1 Velocity and acceleration

1 (a) 8.33 m s^{-1}
(b) 2.08 m s^{-1}
(c) zero
2 (a) 11.2 m s^{-1}
(b) 1.5 s
(c) 4.5 m s^{-2}
3 (a) 1.5×10^8 m s^{-1}
(b) 8.82×10^{22} m s^{-2}

1A.2 Motion graphs

1 A: The bike is at constant speed for the first 10 s (2 m s^{-1}).
B: The bike is stationary from 10 s to 30 s (20 m distance).
C: The bike is at constant speed from 30 s to 40 s (3 m s^{-1}).
The bike finishes stationary.
2 A: The car has constant acceleration for the first 10 s (0.5 m s^{-2}).
B: The car is at constant speed from 10 s to 30 s (5 m s^{-1}).
C: The car has constant acceleration from 30 s to 40 s (1 m s^{-2}).
D: The car has constant deceleration from 40 s to 50 s (−1.5 m s^{-1}).
3 $d = 240$ m

1A.3 Adding forces

1 12.1 N forwards
2 6621 N at an angle of 65.0° up from the horizontal
3 Students should draw the weight force arrow vertically down from centre of body, exactly the same size as the reaction force from the chair acting vertically upwards on bottom.
4 (a) 800 N, $\theta = 18°$ (accuracy depends on quality of scale drawing)
(b) As part (a)
5 4100 N, 4° left of the forwards direction

1A.4 Moments

1 438 Nm
2 1.51 m
3 If the book swings past the position of the second picture, a moment will then act against the motion, slowing it and pushing it back towards that position with the diagonal vertical. Thus it will oscillate back and forth until it comes to rest as in the second picture. In reality, the swinging is likely to be minimal as the finger friction will be significant.
4 55 cm

1A.5 Newton's laws of motion

1 In terms of Newton's laws of motion:
(a) Weight balanced by reaction force,
so resultant force = zero, so acceleration = zero, as per Newton's first law of motion.
(b) It will accelerate upwards, as per Newton's first law.

(c) Newton's third law: the book will offer an equal and opposite force to that of the hands on the book.

Touch sensors in the skin detect this reaction force.

2 (a) 0.5 kg

(b) accelerating force of 0.5 N

3 (a) $a = 65.4\ \text{m s}^{-2}$

(b) $a = 7.16\ \text{m s}^{-2}$

(c) $a = 9.80\ \text{m s}^{-2}$

(d) $a = 179\ \text{m s}^{-2}$

1A.6 Kinematics equations

1 $4\ \text{m s}^{-1}$

2 40 m

3 (a) $a = 5.4\ \text{m s}^{-2}$

(b) $a = 0.384\ \text{m s}^{-2}$

(c) $a = 0.89\ \text{m s}^{-2}$

4 4.24 s

5 $-122\ \text{m s}^{-2}$

1A.7 Resolving vectors

1 (a) 7.1 cm = $7.1\ \text{m s}^{-1}$ for each arrow

(b) same answers as (a)

2 horizontal = $13.1\ \text{m s}^{-1}$; vertical = $9.18\ \text{m s}^{-1}$

3 horizontal = 207 N; vertical = 388 N

4 $138\ \text{m s}^{-1}$ southwards vector

$197\ \text{m s}^{-1}$ eastwards vector

1A.8 Projectiles

1 (a) 0.98 s

(b) 1.17 m

2 (a) 1.92 s

(b) 5.94 m

3 (a) It will rise 1.08 m, so yes.

(b) No. The horizontal velocity is $3.86\ \text{m s}^{-1}$. Therefore, horizontal time of flight is 0.78 s. Time to maximum height is 0.47 s. Therefore, time from max height to horizontal hoop distance is 0.31. In 0.31 s, the ball falls 0.47 m, so the ball will be below the hoop when it reaches it horizontally. (Even accounting for the diameter of the ball, it would not hit the hoop.)

1A Exam practice

1 B

2 B

3 C

4 C

5 A

6 (a) Magnitude and direction

(b) Direction changing / not a straight line, so velocity is changing / not constant

7 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate; including:

State sufficient quantities to be measured (e.g. s and t or v, u and t or u, v and s)

Relevant apparatus (includes rule and timer/datalogger/light gates)
Describe how a distance is measured
Describe how a speed or time is measured
Further detail of measurement of speed or time
Vary for described quantities and plot appropriate graph
State how result calculated

(b) Repeat and calculate the mean
A suitable precaution relating to experimental procedure

8 (a) Draw a tangent at $t = 4.0$ s:

$$v = \frac{(32\text{ m} - 0\text{ m})}{(6.0 - 2.0\text{ s})}$$

$v = 8.0$ m s^{-1}

(b) $$a = \frac{(v - u)}{t}$$

$$a = \frac{(8.0\text{ m s}^{-1} - 0)}{4\text{ s}}$$

$a = 2$ m s^{-2}

9 (a) (i) Area under graph between 0.5 and 1.0 s / X and Y, or use average velocity between these points × time
(ii) Gradient of line at Y

(b) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate. Include up to four of the following:
Lines not parallel
Acceleration should be the same / both should have same gradient
Max +ve and −ve speeds (from 0.5 s) all the same
There will be some energy losses (bounce, air resistance) so max should have smaller magnitude each time
Velocity at X/Z greater than that at the start
Ball cannot gain energy
Starts with positive velocity
but initial movement is down
Starts with non-zero velocity / graph starts in wrong place
From photo, it is dropped from rest
There is a vertical line
Bounce must take some time / acceleration cannot be infinite
The graph shows a change in direction of velocity between 0 and 0.5 s / release and striking the ground
It is travelling in one direction / down this whole time
Graph shows an initial deceleration
It is actually accelerating downwards

10 (a) $s = ut + \frac{1}{2}at^2$

$$a = \frac{2 \times 2\,500\,000\text{ m}}{((30 \times 60)\text{s})^2}$$

$a = 1.54$ m s^{-2}

(b) $v = u + at$
$v = 0 + 1.5$ m s^{-2} × (30 × 60)s
$v = 1.5$ m s^{-2} × (30 × 60)s
$v = 2700$ m s^{-1}

(c) $F = ma$
$F = 4.5 \times 10^5$ kg × 1.5 m s^{-2}

$F = 675\ 000$ N

11 QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, including the following points:

No acceleration / constant velocity ('constant speed' not sufficient) / (at rest or) uniform motion in straight line unless unbalanced / net / resultant force

Acceleration proportional to force / $F = ma$

Qualify by stating resultant / net force / $\Sigma F = ma$

If (resultant) force zero, then Newton's second law states that acceleration = 0

OR acceleration only non-zero if (resultant) force non-zero.

12 (a) (i) $v = \frac{1.88\text{ m}}{0.88\text{ s}}$

$v = 2.14$ m s^{-1}

(ii) $v = u + at$

$0 = u + (-9.81\text{ m s}^{-2}) \times 0.44\text{ s}$

$u = 9.81\text{ m s}^{-2} \times 0.44\text{ s}$

$u = 4.3$ m s^{-1}

OR

$s = ut + ½at^2$

$0 = (u \times 0.88\text{ s}) + (½ \times (-9.81\text{ m s}^{-2}) \times (0.88\text{ s})^2)$

$u = 4.3$ m s^{-1}

(iii) velocity$^2 = (2.1\text{ m s}^{-1})^2 + (4.3\text{ m s}^{-1})^2$

velocity = 4.8 m s^{-1}

tan of angle = $\frac{4.3\text{ m s}^{-1}}{2.1\text{ m s}^{-1}}$

angle = 63.9°

(b) (i) Air resistance has not been taken into account

OR air resistance acts on the rocket

OR friction of the rocket on the stand has not been taken into account

OR energy dissipated/transferred due to air resistance

(ii) Any two from:

Can watch again

Can slow down / watch frame by frame / stop at maximum height

Too fast for humans to see

Does not involve reaction time

Can zoom in (to see height reached).

Topic 1 Mechanics
1B Energy

1B.1 Gravitational potential and kinetic energies

1 If we assume that the coconut falls 5.0 m, then the speed would be 9.9 m s^{-1}.

2 17.2 m s^{-1}

3 29.7 m s^{-1}

4 1.90 m

5 Air resistance and friction are negligible; energy is only transferred between kinetic and gravitational potential stores.

1B.2 Work and power

1 (a) Work done by lioness is 126 J.
(b) Work done by eagle is 113 J, so lioness does more work by 13 J.

2 4160 J

3 (a) 0.20 W
(b) 0.33 or 33%

4 0.29 or 29%

1B Exam practice

1 A

2 A

3 D

4 B

5 (a) Wind exerts a force / push on the blades, blades move (through a distance in the direction of the force) OR energy is transferred from kinetic energy of wind to (KE of) the blades

(b) (i) Volume per second = 6000 m^2 × 9 m = 54 000 m^3
Total volume in 5 seconds = 54 000 m^3 × 5 s = 270 000 (m^3)
(ii) Mass = 1.2 kg m^{-3} × 270 000 m^3 = 324 000 kg
(iii) $E_k = \frac{1}{2} \times 324\,000 \text{ kg} \times (9 \text{ m s}^{-1})^2 = 13\,122\,000$ J
(iv) Energy from the wind in 5 seconds = 0.59 × 13 100 000 J = 7 741 980 J
Power $= \frac{\text{energy}}{\text{time}} = \frac{7\,741\,980 \text{ J}}{5 \text{ s}} = 1.548$ MW

(c) Any one from:
Would need to stop wind entirely
Wind or air still moving
Wind or air still has KE
Not all the air hits the blades

(d) Any two from:
Wind does not always blow / if there is no wind they do not work / wind speeds are variable / need minimum amount of wind to generate the electricity / need a large amount of wind / cannot be used in very high winds
Only 59% max efficiency
Low power output / need a lot of turbines / need a lot of space

6 (a) $x = 2 \times \pi \times 3.7$ m = 23.2 m

$W = F\Delta x$

W = 800 N × 23.2 m

W = 18 600 J

(b) Power = $\frac{\text{work done}}{\text{time}}$

$= \frac{144 \times 18\,600\text{ J}}{60 \times 60\text{ s}}$

= 744 W (accept any dimensionally correct unit – ignore later units if W used as well)

(use of 20 000 J gives 800 W)

7 QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence. Any six of the following:

It will not strike the student's face / at most will just touch / returns to starting point

The total energy of the pendulum is constant / energy is conserved

It cannot move higher than its starting point because that would require extra gpe

Mention specific energy transfer: gpe → ke / ke → gpe

Energy dissipated against air resistance so will stop it quite reaching its starting point (consequent on attempt at describing energy loss mechanism)

Pushing does work on the ball / pushing provides extra energy if pushed, it can move higher (accept further) and will hit the student

If the face moves (forward) the ball may reach it (before it is at its maximum height)

OR if the face moves (back) the ball will not reach it

8 (a) (i) Horizontal component = 650 N × cos 42°

= 483 (N)

(ii) Work = 483 N × 15 × 7 m

= 50 715 J

(b) Force in the direction of motion

OR force is parallel to the direction of motion

OR force is applied in a horizontal direction

OR there is no vertical component of force

so less applied force

9 $W = mg$

W = 0.98 N OR W = 0.1 (kg) × 9.81 (N kg^{-1}) = 1 N

$W = Fs$ OR $gpe = mgh$

gpe = 0.98 J

$P = \frac{W}{t}$

P = 0.98 W

Topic 1 Mechanics
1C Momentum

1C.1 Momentum

1 (a) 240 kg m s^{-1}

(b) 588 kg m s^{-1}

(c) 2.5×10^{-4} kg m s^{-1}

2 Motorcyclist: estimate mass as 80 kg and speed as 30 m s^{-1}, so p = 2400 kg m s^{-1}

Skateboarder: estimate mass as 65 kg and speed as 4 m s^{-1}, so p = 260 kg m s^{-1}

3 Larger forces cause greater injuries. Force required is proportional to rate of change of momentum (Newton's second law).

The airbag removes momentum in a greater time than the dashboard, so the rate of change of momentum is lower, so the force needed is lower, resulting in less injuries.

4 Students' own answers, using $F = \frac{\Delta p}{t}$:

e.g. a Frisbee's estimated throw speed is 5 m s^{-1} (initially at rest); estimated mass is 100 g; estimated time for which hand applies force to throw is 0.1 s:

$F = \frac{\Delta p}{t} = \frac{0.1 \times 5}{0.1} = 5$ N

1C.2 Conservation of linear momentum

1 0.15 m s^{-1}

2 (a) 0.2 m s^{-1}

(b) 100 N

3 The force that pushes the boy forwards from the boat has an equal and opposite reaction force pushing the boat away, so it is likely that the boat will move out from under him without providing enough forward force to make him reach the jetty before he falls into the water.

4 (a) Longer arrow labelled '1200 kg m s^{-1}' at 80° to shorter arrow labelled '600 kg m s^{-1}'. Either drawn as parallelogram rule, or one after the other, with resultant momentum vector arrow drawn in. Resultant is 1430 kg m s^{-1} at an angle of 56° to the river current (600 kg m s^{-1} vector).

(b) Resulting velocity = 4.77 m s^{-1} at 56° to current, so 2.67 m s^{-1} along current direction and 3.94 m s^{-1} towards riverbank. Time to reach waterfall = 37 s. Time to reach bank = 4.1 s, so they reach the bank safely.

1C Exam practice

1 C

2 B

3 A

4 B

5 A

6 QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence:

Momentum conservation

Total/initial momentum = 0

Momentum of slime equal momentum of bacteria, which moves in opposite direction

OR

Force on slime, so equal and opposite force on bacteria. Thus cause the rate of change of momentum $\frac{\Delta mv}{t}$ to bacteria, which moves in opposite direction.

7 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate. Include the following:

Measurement of appropriate quantity, e.g. height/distance/time

Calculate the speed or inferred by an equation

Speed on impact

Statement of how method shows momentum has been conserved

(b) Collisions inelastic / KE is transferred in collisions to internal energy / thermal energy / to KE of middle balls / to sound

Eventually stops because all energy is transferred

8 (a) The weight of the hanging masses will be transferred as tension in the string to become a resultant force on the trolley. Newton's second law tells us that this will lead to an acceleration equal to $\frac{W}{m}$ (W = weight of hanging masses; m = mass of trolley and hanging masses combined). This acceleration causes a change in velocity which means a change in momentum.

(b) Mass of trolley $= \frac{2.85}{9.81} = 0.291$ kg

Total mass = 0.350 + 0.291 = 0.641 kg

$a = \frac{F}{m} = \frac{2.85}{0.641} = 4.45 \text{ m s}^{-2}$

(c) $p = mv = 0.35 \times 11.1 = 3.89 \text{ kg m s}^{-1}$

(d) The total momentum of all objects involved in a collision, accounting for the vector nature of momentum, will be the same before and after the collision.

(e) Initially, all the momentum of the system is carried by the moving trolley.

When this stops it loses all its momentum.

In order for momentum to be conserved, the second trolley must leave the collision with the amount of momentum that the first one had initially.

As the trolleys are identical, the second trolley will leave at the same speed that the first one came in with.

(f) Initially, all the momentum of the system is carried by the moving trolley.

In order for momentum to be conserved, the combined pair of trolleys must leave the collision with the amount of momentum that the first one had initially.

As the trolleys are identical, the total mass will be double that of the incoming trolley.

So they will leave at half the same speed that the first one came in with.

(g) Tie the two trolleys together, with a compressed spring, or repelling magnets, between them.

With the combination stationary, burn through the tie so that they fly apart in an explosion.

Have light gates to monitor speed of each trolley on either side of the explosion.

9 Award 1 mark for the (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

When objects collide, there is a Newton's third law force pair between

for the duration of the collision

Which means equal and opposite forces act on each object

for the same length of time

The change in the momentum of an object (impulse) is equal to $F \times t$

Each object experiences equal change in momentum (impulse)

but in opposite directions

The total change in momentum is the sum of the individual changes in momentum

so the total change in momentum is zero / momentum is conserved

10 (a) Momentum is initially constant at 0.8 kg m s (towards the goalkeeper) for the first 4 ms.

Over the period 4–8 ms, it changes uniformly by −0.5 kg m s^{-1} per millisecond.

Momentum is then constant at −1.2 kg m s^{-1} away from the goalkeeper for the remaining 2 ms.

(b) The leg pads provide a resultant force on the ball, which will change the momentum according to Newton's second law.

(c) (i) 0 (zero) newtons

(ii) 500 N

(iii) (zero) newtons

(d) Graph with the following points:

First horizontal line at 0.4 kg m s^{-1}, then momentum changes between 4–6 ms

Final horizontal line is at a momentum of −0.6 kg m s^{-1}

Topic 2 Materials
2A Fluids

2A.1 Fluids, density and upthrust

1 1265 kg m^{-3}

2 (a) 1300 kg m^{-3}

(b) 1.3 g cm^{-3}

3 Students' own answers. Volume estimate is likely to be length × width × height in rectangular room, and then multiply by density value of 1.2 from table A to give mass.

4 (a) 0.40 N

(b) 0.042 N downwards

(c) There is a resultant downwards force, so it will accelerate to the bottom (Newton's first law). There, an additional reaction force (Newton's third law) from the bed of the stream will cause a net force of zero so the ball will rest on the bottom stationary (Newton's first law). Extra: initially on reaching the bottom the upwards reaction will be slightly greater to decelerate to rest. Students may also comment on drag forces affecting the rate of acceleration during descent (Newton's second law).

5 1.59 N

6 Students' own answers, using rectangular volume, V = width × depth × height, and density = $\frac{m}{V}$:

e.g. estimated height is 1.7 m; estimated width is 40 cm; estimated depth is 20 cm; estimated mass is 75 kg

$V = wdh = 0.4 \times 0.2 \times 1.7 = 0.136$ m^3

$\rho = \frac{m}{V} = \frac{75}{0.136} = 550$ kg m^{-3}

Alternative route: The body is mostly water, and humans float, so density must be slightly less than water: estimate ρ = 900 kg m^{-3}.

2A.2 Fluid movement

1 Students' own answers

2 Students' own diagrams; streamline flow should have parallel streamlines, while turbulent flow should have uneven flow lines and eddies

3 'At any point' the speed must remain the same over time, but the smoke can move faster or slower as it needs to in order to move over the shape of the car. So, whilst it may move faster up the windscreen than over the roof, at each of those points the speed will be constant over time.

4 Left picture: water surface is smooth, because the flow is laminar, as the water is moving slowly

Right picture: water surface is disturbed in a random/unpredictable way, as the flow is turbulent as the water is moving fast past the bridge supports.

2A.3 Viscosity

1 Water viscosity causes greater drag than air

2 Higher temperature causes reduced liquid viscosity but increases gas viscosity

3 Reduced viscosity would allow greater speeds

4 Decreased viscosity would enable faster flow of liquid chocolate, so faster production

5 Depends on students' own best-fit line, approximate gradient is 1.95×10^{-5}, giving an approximate viscosity of 1.6×10^{-3} Pa s, compared with 20 °C figure in table B of 1.0×10^{-3} Pa s. Answers should discuss possible sources of error to cause this difference.

2A.4 Terminal velocity

1 $F = 1.88 \times 10^{-3}$ N

2 It is not a uniform or small object, and is not likely to fall slowly. Stokes' law does not apply.

3 (a) 3.8×10^9 m s^{-1}

(b) 5.97×10^7 m s^{-1}

(c) Have used Stokes' law, though the answers clearly show that this object is too large and moving too fast for Stokes' law to apply – answer to (a) is faster than the speed of light. Also assumed: viscosity of air at 20 ºC, density of water = 1000 kg m^{-3}.

4 Students' own answers:

e.g. the cat is larger than a golf ball and smaller than a human, so its terminal velocity should be between their terminal velocities: estimate v_{term} = 40 m s^{-1}

5 (a) (i) Volume increases for the same mass, so density reduces with increasing temperature

(ii) Volume increases for the same mass, so density reduces with increasing temperature

(b) Density reduction by glycerine is likely to be more than for the metal of the ball bearing, so upthrust would reduce, likely by only a small amount

(c) Glycerine viscosity falls rapidly with increasing temperature

(d) Stokes' law includes both density comparisons and viscosity. The change in relative densities is likely to be small, but the change in viscosity is much more significant. The gradient is inversely proportional to viscosity, so would increase significantly across the various temperatures used.

(e) The change in viscosity for water is very small, so the differences in terminal velocity, and hence gradient on the graphs, are likely to be imperceptible.

2A Exam practice

1 B

2 C

3 C

4 B

5 C

6 (a) (i) Laminar: at least two roughly parallel lines before object

Turbulent: lines crossing or showing change in direction of greater than 90°

Laminar flow lines should lead directly to turbulent flow lines

Laminar flow lines should continue until they reach the peak of the obstruction

(ii) Laminar flow:

No abrupt change in velocity of flow

OR no abrupt change in speed or direction of flow (must mention both speed and direction)

OR velocity at a point is constant OR flows in layers / flowlines / streamlined

OR layers do not mix / cross OR layers are parallel

Turbulent flow:

Mixing of layers / flowlines / streamlines OR crossing of layers, etc. OR contains eddies

OR contains vortices / whirlpools OR abrupt / random changes in speed or direction

(b) (i) Greater velocity with lower viscosity

(ii) Lower viscosity so faster flow OR greater velocity

7 Viscosity of the oil decreases at higher temperature, so the rate of flow increases and the oil spreads more quickly.

8 (a) (i) Laminar flow:

No abrupt changes in direction or speed of flow OR air flows in layers / flowlines / streamlines OR no mixing of layers OR layers remain parallel OR velocity at a (particular) point remains constant

Turbulent flow:

Mixing of layers OR contains eddies / vortices OR abrupt random changes in speed or direction

(ii) Relative speed of upper surface of ball to air is greater (than at lower surface) OR the idea that the direction of movement at the top (due to spin) is opposite to / against (direction of) air flow

(b) The ball is applying an upward force on the air, so there must be an equal and opposite force on the ball downwards.

(c) (i) Time = $\frac{2.7}{31}$ = 0.087 s

$s = ½ \times 9.81$ m s^{-2} × (0.087 s)^2

= 0.037 (m)

(ii) (Extra) downwards force (on the ball)

Greater downwards acceleration

Greater distance fallen OR drops further (in that time) OR needs to drop 15 cm; 4 cm drop not enough

9 (a) (i) Upthrust / U

Weight / W / mg / gravitational force / force due to gravity

(Viscous) drag / fluid resistance / friction / F / D / V

(ii) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate and including the following points:

Initially viscous drag = 0 OR viscous drag is very small

OR resultant force is downwards OR $W > U$ OR $W > U + D$

Viscous drag increases until forces balanced OR resultant / net force zero OR forces in equilibrium

therefore, no acceleration

(iii) $W = U + D$

(b) (i) Mass = 1.0 × 10^3 kg m^{-3} × 2.1 × 10^{-9} m^3

= 2.1 × 10^{-6} kg

Upthrust = 2.1 × 10^{-6} kg × 9.81 N kg^{-1}

= 2.1 × 10^{-5} N

(ii) F = 5.7 × 10^{-5} N – 2.1 × 10^{-5} N = 3.6 × 10^{-5} N

$$v = \frac{3.6 \times 10^{-5}\text{ N}}{6\pi\eta r}$$

$$v = \frac{3.6 \times 10^{-5}\text{ N}}{6 \times \pi \times 1.2 \times 10^{-3} \times 8 \times 10^{-4}}$$

v = 2.0 m s^{-1}

(c) Viscous drag varies in proportion to radius (or area in proportion to radius squared) but weight varies in proportion to radius cubed. Therefore, terminal velocity is proportional to radius squared.

10 Award 1 mark for (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

Stone's weight is greater than upthrust

Upthrust is equal to the weight of water displaced, which equals the volume of the stone times the density of the water

(OR: resultant = difference in densities × stone's volume)

Resultant downwards force accelerates stone downwards

Drag increases with speed,

reducing resultant force, thus reducing acceleration

until weight = drag when acceleration is zero

Temperature higher in summer

Water viscosity lower with higher temperature

Correct expression of Stokes' law equation OR Stokes' force equation

Thus terminal velocity is higher in summer

Topic 2 Materials
2B Solid material properties

2B.1 Hooke's law

1 7.0 N m^{-1}

2 The line would be steeper.

3 Formula given in text is that $\Delta E_{el} = ½F\Delta x$. Hooke's law has $\Delta F = k\Delta x$ so substituting expression for ΔF into first equation gives the formula $\Delta E_{el} = ½k(\Delta x)^2$

4 (a) From the graph, each square represents 1.25×10^{-3} J. There are approximately 100 squares under the line, so accept estimates of around 0.125 J.

(b) Underneath unloading curve are about 80 squares, so accept estimates of approximately 0.10 J

(c) Students calculate the difference between (a) and (b): approx. 0.025 J

2B.2 Stress, strain and the Young modulus

1 0.072

2 7.81×10^7 Pa

3 5.09×10^9 Pa

4 (a) 3.50×10^5 Pa

(b) 3.50×10^{-5} m, assuming that the elephant's weight is split evenly over two leg bones that are still vertical cylinders

2B.3 Stress–strain graphs

1 Straight line starts to curve beyond stress of 400 MPa.

2 Any temperature variation that should alter the length of the test wire will also occur in the control wire. As the extension is measured relative to the control wire, such temperature extensions will not be measured.

2B Exam practice

1 D

2 C

3 B

4 D

5 C

6 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, and include some of the following points:

Apparatus

- arrangement which secures wire
- arrangement allowing force to be varied

What to measure

- force
- original length
- extension
- diameter

Measurement

- diameter with micrometer
- length with metre rule
- force by adding known weights or use of tensometer
- extension with rule or vernier scale

How to calculate

- substitution in $E = Fx / A\Delta x$ OR plot F v Δx graph OR plot stress–strain graph
- determination gradient of F v Δx graph and process correctly
  OR determine a gradient of stress–strain graph

(b) Any one from:
Eye protection / watch out for feet / foam on floor, etc.

(c) Any suitable precaution and explanation, such as:
Measure diameter in different places
Use a reference marker
Avoid parallax when measuring extension
Do not extend wire past limit of proportionality

7 (a) Straight line / constant gradient shown on graph
So extension or change in length proportional to force
Therefore k is constant

(b) $k = \frac{F}{\Delta x}$

$k = \frac{1.6\ \text{N}}{(0.51\ \text{m} - 0.41\ \text{m})}$

$k = \frac{1.6\ \text{N}}{0.1\ \text{m}}$

$k = 16\ \text{N m}^{-1}$

(c) (i) $F = k\Delta x$
$F = 16\ \text{N m}^{-1} \times (0.41\ \text{m} - 0.09\ \text{m})$
$F = 5.1\ \text{N}$
(ii) $E = ½F\Delta x$
$E = 0.5 \times 5.1\ \text{N} \times (0.41 - 0.09\ \text{m})$
$E = 0.82\ \text{J}$

(d) QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence. Include at least three of the following points:
Change in length greater so the compression greater
More force
More elastic energy / more strain energy
Greater acceleration
Therefore more kinetic energy and greater speed

8

(a) Upthrust = (−)weight
Thrust = (−)viscous drag

(b) Calculate weight of water as $U = W$
m = density × volume
$m = 1030\ \text{kg m}^{-3} \times 7100\ \text{m}^3$
$m = 7.3 \times 10^6\ \text{kg}$
$W = mg$
$W = 7.3 \times 10^6\ \text{kg} \times 9.81\ \text{N kg}^{-1}$
$W = 7.2 \times 10^7\ \text{N}$

(c) (i) Decrease in length

(ii) Pump out water / replace water in tanks with air to decrease weight (accept mass) / to compensate for decreased upthrust / to make density the same as water

(iii) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, and include two of the following points:

A much greater (compressive) strain will be produced

Compresses more easily

Producing a larger decrease in volume

Compressive strain may exceed yield point.

9 (a) $k = \frac{7.7\ \text{N}}{0.008\ \text{m}}$

$k = 960\ \text{N m}^{-1}$

(b) $F = 960\ \text{N m}^{-1} \times 0.047\ \text{m} = 45.1\ \text{N}$

$E_{el} = 0.5 \times 45.1\ \text{N} \times 0.047 = 1.06\ \text{J}$

(c) (i) $\frac{1}{2}mv^2 = 1.1.\ \text{J}$

$v = \sqrt{\frac{(2 \times 1.1\ \text{J})}{0.0094\ \text{kg}}} = 15.3\ \text{m s}^{-1}$

(ii) All elastic energy to kinetic energy / no friction between parts of device for swatting flies

(d) (i) $t = \frac{3.0\ \text{m}}{15.3\ \text{m s}^{-1}} = 0.196\ \text{s}$

$v = 9.81\ \text{m s}^{-2} \times 0.196\ \text{s} = 1.92\ \text{m s}^{-1}$

$v = \sqrt{((15.3\ \text{m s}^{-1})^2 + (1.92\ \text{m s}^{-1})^2)} = 15.4\ \text{m s}^{-1}$

Angle $= \tan^{-1} \frac{1.92\ \text{m s}^{-1}}{15.3\ \text{m s}^{-1}} = 7.15°$

(ii) Use of $s = \frac{1}{2} \times 9.81\ \text{m s}^{-2} \times (0.196\ \text{s})^2$

$s = 18.8\ \text{cm}$

(e) Any sensible suggestion:

e.g. Less air resistance

Less warning given to fly from pressure changes

Less mass so greater speed for same kinetic energy

Less mass so greater acceleration for same force

Topic 2 Waves and the Particle Nature of Light
3A Basic waves

3A.1 Wave basics

1 Graphs from top to bottom: 0.2 m, 80 m, 5.5 m

2 1240 m

3 8.15×10^{14} Hz

4 As frequency is defined as waves per second, multiplying frequency by wavelength is equivalent to dividing a distance by a time.

5 Students' own answers, using $v = f\lambda$:

e.g. estimated wavelength is 5 m; estimated frequency is 1 wave every 3 seconds, so $f = 0.33$ Hz

$v = f\lambda = 0.33 \times 5 = 1.7\ \text{m s}^{-1}$

Accept alternative answers using $\frac{\text{distance}}{\text{time}}$

3A.2 Wave types

1 amplitude = 0.5 cm and wavelength = 4.0 cm

2 (a) The oscillations are perpendicular to the direction of energy travel.

(b) P-waves are longitudinal. Rock particles oscillate back and forth in the same line as the direction of the energy travel, causing regions of higher pressure (compressions) and regions of lower pressure (rarefactions).

3 Greater amplitudes of displacement cause greater pressure variations. These affect the parts of the ear to a greater degree, and the brain interprets this as increased loudness.

3A Exam practice

1 B

2 D

3 A

4 A

5 5(a) The amplitude indicates the energy of the sound waves.

This will decrease as the wave travels, so the echo returns with a lower amplitude than the original pulse.

(b) Time from pulse to echo = 50 ms

Distance sound pulse has travelled = 5900 ′ 50 ′ 10-6 = 0.295 m

Depth of rail = 0.295/2 = 0.15 m

5(a) The amplitude indicates the energy of the sound waves.

This will decrease as the wave travels, so the echo returns with a lower amplitude than the original pulse.

(b) Time from pulse to echo = 50 □s

Distance sound pulse has travelled = 5900 × 50 × 10-6 = 0.295 m

Depth of rail = 0.295/2 = 0.15 m

6 (a) Any three from:

Sound waves are longitudinal waves

Air molecules vibrate

parallel to the direction of travel of the wave

in a series of compressions and rarefactions

(b) Frequency is the number of cycles / oscillations / waves per second / per unit time OR number of cycles / oscillations / waves passing a point per second

(c) $v = 1500\ \text{m s}^{-1} \times 2\ \text{Hz}$

$v = 3000\ \text{m s}^{-1}$

(d) Animals detect infrasound / lower frequencies than humans / vibrations through the ground and infrasound travels faster than the tidal wave

7 $\lambda = \frac{3 \times 10^8\ \text{m s}^{-1}}{95.8 \times 10^6\ \text{Hz}}$

$\lambda = 3.13$ m

8 (a) (i) They are above the audible range / frequency

(ii) Distance = speed × time

$= 1500\ \text{m s}^{-1} \times 0.8 \times 10^{-4}\ \text{s}$

= 0.12 m

(iii) The idea that one pulse must return before the next is sent

(b) (i) X-rays cause ionisation OR can damage DNA / cells / tissue OR can cause mutation

(ii) Any two from:

X-rays transverse, ultrasound longitudinal OR X-rays can be polarised, ultrasound cannot

X-rays travel in vacuum, ultrasound does not

X-rays electromagnetic, ultrasound mechanical

X-rays have (much) higher f / shorter λ / greater speed

9 (a) After reflection, amplitude is reduced

Because the sound has travelled further OR because the sound has lost some energy/become more spread out

(b) (i) There is only one microphone

(ii) Add a second microphone (attached to the oscilloscope)

(iii) Maximum 6 from:

Set the signal generator to a known frequency, f

Place both microphones the same distance from the loudspeaker

Move one microphone further from the loudspeaker until the two traces have gone (out of phase and then) back again to being in phase

Measure the distance between the two microphones.

This distance equals the wavelength, λ

Calculate speed from $v = f\lambda$

The metal plate will introduce reflections/echoes which will confuse the trace comparisons

(c) 3700 × 0.09

= 333 (m/s)

Topic 3 Waves and the Particle Nature of Light
3B The behaviour of waves

3B.1 Wave phase and superposition

1 Rays show the direction of travel of the wave energy, whilst wavefronts show positions of identical phase position. Wavefronts and rays are always at right angles.

2 180° or π radians

3 (a) 0; or 360°; or 2π rad

(b) 180° or π rad

(c) 180°, π rad; or 900°, 5π rad

4 t = 1.0 s: same pulses now separated by 3.0 cm

t = 2.0 s: pulses now overlap by 1.0 cm in the middle, and the overlap portion is at displacement = −1.0 cm

t = 3.0 s: same pulses but now on opposite sides of each other and separated by 1.0 cm

3B.2 Stationary waves

1 λ = 0.75 m; f = 560 Hz

2 (a) 433 m s^{-1}

(b) 293 Hz

3 A graph of f on y-axis against $\frac{1}{L}$ on x-axis. Gradient is approximately 115, making mass per unit length approximately 4.4×10^{-4} kg m^{-1}.

4 Students' own answers, using $v = f\lambda = \sqrt{\frac{T}{\mu}}$

so $\mu = \frac{T}{v^2} = \frac{T}{f^2\lambda^2}$:

e.g. estimated frequency is 256 Hz (middle C); estimated wavelength for fundamental is twice size of piano = 2 m; from school Young modulus experiments, wire snaps after about 2 kg loading, but piano wire is very thick, so estimate tension as 100 N:

$\mu = \frac{T}{f^2\lambda^2} = \frac{100}{(256^2 \times 2^2)} = 3.8 \times 10^{-4}$ kg m^{-1}

3B.3 Diffraction

1 The wave energy could be diffracted around the tanker and still hit the small boat behind.

2 (a) The degree of diffraction depends on the relative size of the diffracting object and the wavelength. The radio wavelength is the same in both cases, and so it is more diffracted in the first instance, where the radio dish is closer to the same size as the wavelength.

(b) General broadcast transmissions would be preferred in the first instance, as the waves spread over a wide area. In the second instance, a directed beam would be preferred for situations in which the intended recipients location is known and fixed, such as communicating with an orbiting satellite.

3 Grating spacing $d = 1 \times 10^{-6}$ m. Therefore, $\lambda_1 = 4.48 \times 10^{-7}$ m; $\lambda_2 = 5.02 \times 10^{-7}$ m; $\lambda_3 = 5.88 \times 10^{-7}$ m

4 For λ_1, $n_{max} = 2$; λ_2, $n_{max} = 1$; λ_3, $n_{max} = 1$

3B.4 Wave interference

1 Coherent waves have the same frequency and a constant phase difference.

2 (a) 0°; they are in phase

(b) $\frac{\lambda}{2}$; they are 180° out of phase

(c) λ; 0°; they are in phase

(d) The fringes would be further apart.

3B Exam practice

1 C

2 B

3 B

4 C

5 D

6 QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence, including:

Identifies two rays of light

Two rays have same frequency / come from same source / are coherent

Path difference (between the two reflected rays)

They superpose (when they meet) / constructive and destructive interference occur

If they meet in phase / nλ / λ path difference, constructive interference / bright fringe

If they meet in antiphase / (n + ½) / λ / ½λ path difference, destructive interference / dark fringe

7 (a) $d = 2 \times 10^{-6}$ m

(b) λ = □□□□Θ/□

$\lambda = 5.18 \times 10^{-7}$ m

(c) □ = □□□□Θ/λ

sin 90° = 1 so $n = \frac{d}{\lambda}$

□ = 4

8 (a) Unit of LHS = m s^{-1}

Unit of T = kg m s^{-2}

Unit of μ = kg m^{-1}

(b) (i) Waves travel in both directions along wire

Waves superpose / interference effect / superposition occurs

Producing nodes and antinodes

OR node is produced where waves are 180º out of phase / antiphase

OR antinode is produced where waves are in phase

OR node produced at a point of destructive interference

OR antinode produced at a point of constructive interference

OR produces points / positions of constructive interference and points / positions of destructive interference

(ii) λ = 4 m

(iii) $v = \sqrt{\frac{150\ \text{N}}{0.005\ \text{kg m}^{-1}}}$

$v = 173$ m s^{-1}

(iv) Any three from:

At most frequencies there is no standing wave / as frequency changes from a standing wave the wave no longer occurs / standing waves only occur at some frequencies

At higher frequencies there are more nodes / antinodes / loops (not 'more waves')

There is always a node at either end OR number of nodes = number of antinodes plus one

Amplitude is less if there is a greater number of nodes

Length = nλ/ 2 / after first standing wave, they occur when frequency ×2, ×3, ×4, etc. / for frequency nf_0

9 (a) Diffraction is the spreading out of a wave (not bending, not bending round, not just change in direction) as it passes (through) a gap / slit / aperture OR passes (around) an obstacle

(b) Indication that two or more (waves) meet / overlap / coincide and the (total) displacement at a point is the sum of the individual displacements

(c) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, including:

Identifies that the rock(s) or gap(s) in the rocks cause diffraction

OR cause wave(front)s to become curved / waves to spread out

Waves / wavefronts (from each gap) overlap / meet

(At some places) waves are in phase (accept path difference equal to whole number of wavelengths)

OR (at some places) waves are in antiphase (accept path difference equal to whole number of wavelengths plus half a wavelength)

Constructive superposition / interference occurs

OR destructive superposition / interference occurs (must correspond to phase differences if referred to elsewhere)

Maximum / large amplitude erodes beach / disturbs sand the most

OR minimum / zero amplitude does not disturb sand (as much)

OR reduced amplitude disturbs sand less

10 (a) Half wave vibration, with wire at a maximum in the centre and S and T still at the fixed points

Some indication that the whole wire moves up and down with a node in the centre and S and T always fixed – perhaps shown as a dashed curve opposite a solid curve

(b) Ends fixed at S and T with 1.5 wavelengths shown in between

Alternate positions for nodes also shown (perhaps as a dashed line)

(c) Plucking the wire sends waves along it.

These reflect from the fixed end points.

The waves and their reflections are coherent / have the same frequency and a constant phase relationship.

So they superpose/interfere (to produce a stationary wave).

Topic 3 Waves and the Particle Nature of Light
3C More wave properties of light

3C.1 Refraction

1 (a) speed reduces
(b) wavelength reduces
(c) frequency is constant

2 The refraction of the light from the body of the giraffe causes it to appear in a false position, whilst the light from the head is unaffected.

3 16.4°

3C.2 Total internal reflection

1 The angle of incidence within a more dense medium, beyond which a ray will be totally internally reflected

2 In all cases, the angle of incidence as the light tries to leave the glass is greater than the critical angle (which is usually about 42° for glass).

3 48.8°

4 From any part of the sky, the angle the rays make underwater with the normal to the water surface must always be less than the critical angle. This limits the range of angles that the fish needs to observe and yet still be able to see everything above the water, as shown in fig F.

3C.3 Polarisation

1 Sound waves are longitudinal, and longitudinal waves cannot be polarised.

2 There are numerous waves with oscillations oriented in all planes, favouring no particular plane.

3 Light reflected from the surface of the snow is likely to be polarised in the horizontal plane, so the vertical Polaroids will absorb this glare.

4 Students' own answers:

e.g. The models show the real outcomes of the design, in order to confirm any theoretical calculations that have been done to check the design.

For large projects, it is important to be able to check the strength of the design using a cheap model before investing in building the real thing.

3C Exam practice

1 D

2 C

3 C

4 B

5 (a) Ray drawn along edge of prism (labelled X)

(b) (i) $n = \frac{3 \times 10^8}{1.96 \times 10^8}$

$n = 1.53$

(ii) sin (critical angle) = $\frac{1}{n}$ OR $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = n$

$c = 41°$

(c) Red light: refraction towards normal at first face but less than refraction for blue light

Refracts into air at second face with angle in air > angle in glass

6 (a) Unpolarised light oscillates/vibrates in many planes/directions while polarised oscillates/vibrates in one plane/direction only

(b) Sunglasses cut out the reflected light / polarised light / glare

but not the light from the fish OR light from fish is unpolarised

(c) Sound is a longitudinal wave and only transverse waves can be polarised.

7 (a) $n = \frac{\sin 48}{\sin 30}$

n = 1.5 (common answer will be 1.49)

(n = 0.67 scores 1 mark for idea of ratio of sin of angles)

(b) (i) QWC (quality of written communication) – spelling of technical terms must be correct and the answer must be organised in a logical sequence, including:

As x increases, y increases

OR at a certain angle / critical angle, y = 90º / the light travels along the boundary

For angles greater than the critical angle (in glass) total internal reflection occurs

(ii) $\sin c = \frac{1}{n}$

c = 42º

8 (a) $\frac{\sin c}{1} = \frac{1.96}{2.03}$

c = 75º

(b) It will be reflected (back into the core) / totally internally reflected

(c) Most of the light will undergo repeated (total internal) reflection and light hits the bottom at less than the critical angle.

9 (a) Refraction

(b) (i) Normal correctly added to diagram

i and r correctly labelled

(ii) Greater refraction than the red light as light enters the raindrop (must be between red light ray and centre)

Reflection followed by refraction away from normal as ray emerges from the raindrop

(c) (i) The angle of incidence (in the denser medium) for which angle of refraction is 90º OR angle of incidence for which a ray is transmitted along the boundary

(ii) $\frac{1}{\sin c} = 1.3$

$\sin c = \frac{1}{1.3}$

c = 50.3º

(d) $\lambda = \frac{2.2 \times 10^{8}\ \mathrm{m\ s^{-1}}}{4.2 \times 10^{14}\ \mathrm{Hz}}$

$\lambda = 5.2 \times 10^{-7}$ m

10 Award 1 mark for the (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

Fibre made of glass

Light is totally internally reflected

when it strikes the edge of the fibre at more than the critical angle

Used for decorative lighting

Used to guide light to the interior of buildings for illumination

Used to communicate information as pulses of light

e.g. broadband internet

Endoscope for medical diagnosis

Has fibre carrying light into body for illumination

and fibre carrying reflection back out to form image

Some fibres are made with core and cladding of similar refractive indices

in order to increase critical angle

and reduce fibre damage / light leakage

and reduce multimode dispersion

Topic 3 Waves and the Particle Nature of Light
3D Quantum physics

3D.1 Wave–particle duality

1 (a) Students' own answers, e.g. two-slit interference, diffraction grating, refraction, polarisation experiments

(b) Students' own answers, e.g. electron diffraction

2 9.95×10^{-19} J

3 Polarisation is a wave property.

4 Students' own answers, explaining wave–particle duality

5 Students should produce diagrams along the lines of fig B, but with only two secondary sources, one at each side of the rock. The multiple wavelets are then overdrawn with the sum (new) wavefront to show diffraction behind the rock.

3D.2 The photoelectric effect

1 2.3 eV

2 (a) Zinc will not do so, and iron has a higher work function than zinc

(b) There would be no change.

3 The stopping voltage is designed to stop and measure the energy of the electrons that are released with maximum kinetic energy.

4 5.07×10^{14} Hz

3D.3 Electron diffraction and interference

1 Electron diffraction: diffraction is a wave phenomenon

2 Resolution is roughly the same size as the wavelength. Higher energy electrons have a shorter wavelength.

3 6.14×10^{-11} m

4 Students' own answers, using $\lambda = \frac{h}{p}$:

e.g. estimated speed of the football is 20 m s^{-1}; estimated mass is 300 g

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{(0.3 \times 20)} = 1.1 \times 10^{-34}$ m

3D.4 Atomic electron energies

1 1.22×10^{-7} m

2 The photon's energy is not enough to lift the electron to any other energy level.

3 1.96 eV

4 Through energy absorbed by conducting electricity

5 The electrical energy will excite electrons in the mercury atoms to various levels. The electrons will then fall various numbers of levels. The variety of level drops equate to a variety of photon energies, and hence various wavelengths (colours).

6 Students' own answers, using photon energy $E = hf$, and intensity I:

e.g. estimated sunlight intensity is 1000 W m^{-2}; estimated width of face is 15 cm; estimated face height is 20 cm; estimated sunlight wavelength is 550 nm:

$A = w \times h = 0.15 \times 0.2 = 0.03$ m^2

$P = I \times A = 1000 \times 0.03 = 30$ J s^{-1}

photon energy, $E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \times 3 \times 10^{8})}{(550 \times 10^{-9})} = 3.6 \times 10^{-19}$ J

$N = \frac{P}{E} = \frac{30}{3.6 \times 10^{-19})} = 8.3 \times 10^{19}$ photons per second

3D Exam Practice

1 C

2 C

3 D

4 D

5 (a) LED 1 green
LED 2 orange
LED 3 red

(b) $E = 6.63 \times 10^{-34}$ Js $\times$ 4.41 $\times 10^{14}$ Hz
$E = 2.92 \times 10^{-19}$ J

6 QWC (quality of written communication) – work must be clear and organised in a logical sequence and include four of the following points:

Particle theory

Reference to $E = hf$ or quanta of energy / packets of energy / photons

Increased f means more energy of photon

Release of electron requires minimum energy / work function

One photon releases one electron

Greater energy of photon means greater *KE* of electrons

More intense light means more photons, therefore more electrons

And, an additional two of the following points:

Wave theory

Wave energy depends on intensity

More intense light should give greater *KE* of electrons

Energy is spread over the whole wave

If exposed for long enough, photons eventually released – does not happen

7 (a) Photon energy is too small / less than work function

(b) Method 1: Use of intercept *x*-axis:
Use of $E = hf$ with $f = 10 \times 10^{14}$ Hz
Divide by 1.6×10^{-19} to convert to eV
$\Phi = 4.1$ (eV)
OR
Method 2: Use of photoelectric equation:
Use of $hf = \Phi + E_{max}$ with any pair of values
Divide by 1.6×10^{-19} to convert to eV
$\Phi = 4.1$ to 4.5 (eV)

(c) Planck's constant / e

(d) Line parallel to original line, cutting *x*-axis with a value less than 10

8 (a) (i) $f = \frac{3 \times 10^8 \text{ m s}^{-1}}{6.56 \times 10^{-7} \text{ m}}$
$f = 4.57 \times 10^{14}$ Hz
(ii) $\frac{3.03 \times 10^{-19}}{1.6 \times 10^{-19}}$
Transition from (−)1.5 eV to (−)3.4 eV

(b) The light from the sun passes through a gas on the way to Earth. This gas has an electron transition for which the energy difference exactly matches the wavelength 656 nm.
That wavelength is absorbed in exciting the electrons of the gas. When the light is re-emitted, it travels in a random direction so most will not come to Earth.

9 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, including:

Reference to photons (may be descriptive, e.g. quantum of energy / light arrives in small packets / light particles, etc.)

Energy of photon greater than or equal to work function (of zinc) / $hf \geq \varphi$

Results in electrons being emitted

So electroscope loses charge / charge decreases and the leaf falls

(b) Photon energy for visible light is less than the work function

OR frequency of visible light less than threshold frequency

(c) $KE = \frac{(6.63 \times 10^{-34} \times 3 \times 10^{8})}{(200 \times 10^{-9} - 6.88 \times 10^{-19})}$

$KE = 3.07 \times 10^{-19}$ J

$v = \sqrt{\frac{(2 \times 3.07 \times 10^{-19})}{9.11 \times 10^{-31}}}$

$v = 8.20 \times 10^{5}$ m s^{-1}

(d) No change, as the photon energy does not change (with distance)

OR photon energy depends (only) on frequency / wavelength

Topic 4 Electric Circuits

4A Electrical quantities

4A.1 Electric current

1 (a) 0.625 A

(b) 7.6 C

(c) 2.35×10^{-8} s

2 (a) 0.167 s

(b) 1.25×10^{11}

3 1.4 A

4A.2 Electrical energy transfer

1 Emf measures energy transferred to electrical energy (a supply voltage); pd measures energy transferred from electrical to other stores

2 (a) 1.58 V

(b) 9.26 V

3 (a) 6.0 eV

(b) 7.68×10^{-13} J

4 Students should include discussion of at least the following ideas in their evaluation of the strengths and weaknesses of the snowpark model of an electric circuit:

The representation of charge carriers – small individual units within a large system is good; different types (snowboarders and skiers) going in the same direction is less good (could be complex electrolysis, but unusual).

A complete circuit is needed – the piste is rather open, but it is the case that skiers will need to follow snow routes all the way and return to the ski lift every time.

Gravitational potential as the analogy for electrical energy – good: easy to understand; both caused by field potentials.

The ski lift as a cell – good modelling of energy input from transfers; height lifted analogy to emf also good.

The snowpark obstacles as components using electrical energy – some energy transferred to kinetic on obstacles rather than only into heat/sound (other stores).

Differing speeds by different skiers – likely to be a poor model as we assume electron drift velocity to be constant all round a circuit.

5 Students' own answers

4A.3 Current and voltage relationships

1 The current between two points is directly proportional to the voltage across them.

$\text{resistance} = \frac{\text{voltage}}{\text{current}}$

2 120 Ω

3 An ohmic conductor has a constant resistance over a wide range of voltages, assuming the temperature remains constant. Non-ohmic conductors have changing resistance with voltage applied.

4 If the resistor is ohmic, then the gradient of the straight line would give the same answer as the resistance value.

5 Component A has a higher resistance of 50 Ω, whilst the resistance of component B is 20 Ω.

4A.4 Resistivity

1 0.71 Ω

2 Maintain constant temperature; measure wire diameter in several places and in right-angled pairs of readings; use longest possible wire length in order to minimise percentage error in length

3 Polyethene: $\sigma = 5.0 \times 10^{-12}$ S m^{-1}
Copper: $\sigma = 5.9 \times 10^{7}$ S m^{-1}
Copper is a much better conductor than polythene, so it has a higher value for conductivity.

4 (a) Resistance = $2.3 \times 10^{-4}\ \Omega$
so resistance of each arm of ring in circuit = $4.6 \times 10^{-4}\ \Omega$
Cross-sectional area = 1.5×10^{-6} m^2
Length = half circumference = 0.0314 m
so $\rho = 2.2 \times 10^{-8}\ \Omega$ m
(b) The high current is dangerous; the percentage error in the diameter and cross-section measurements will be large

5 Students' own answers, using cylinder volume, $V = \pi r^2 h$:
e.g. If the estimated length is 2 cm and the estimated diameter is 1 mm:
$r = 5 \times 10^{-2}$ m
$V = \pi r^2 h = 3.14 \times (5 \times 10^{-4})^2 \times 0.02 = 1.6 \times 10^{-8}$ m^3

4A.5 Conduction and resistance

1 The net rate of movement of the electrons as they cause a current flow
2 $v = 6.0 \times 10^{-4}$ m s^{-1}
3 Conduction electrons have to travel further through the lattice of fixed metal atoms, so there are a greater number of collisions to reduce the drift velocity, reducing the current, which is an effective increase in resistance.
4 Students' own answers; their explanations should include reference to at least the following ideas:
Movement of charge carriers
Fixed lattice ions
Collisions between ions and charge carriers
Increased vibrations of fixed lattice ions with temperature
An evaluation of the strengths and weaknesses of their model
5 Students' own answers, using cylinder volume, $V = \pi r^2 h$ and number density for copper, $n = 8.4 \times 10^{28}$ m^{-3}:
e.g. estimated height is 1 mm; estimated diameter is 2 cm:
$r = 1 \times 10^{-2}$ m
$V = \pi r^2 h = 3.14 \times (1 \times 10^{-2})^2 \times 0.001 = 3.1 \times 10^{-7}$ m^3
$N = nV = 8.4 \times 10^{28} \times 3.1 \times 10^{-7} = 2.6 \times 10^{22}$ electrons

4A.6 Semiconductors

1 Higher temperature gives electrons more energy, so more electrons move up to the conduction band and the charge carrier density increases, thereby increasing current and effectively reducing resistance.
2 If lead is cooled below 7.2 K, its resistance falls to zero.
3 The impurities will need to provide charge carriers for conduction. So the impurities will have a low enough energy band gap that the electrons will be in the conduction band at room temperature.

4A Exam practice

1 C
2 D
3 C
4 A
5 pd is a measure of electrical energy transferred between two points, or the electrical energy transferred to other stores
emf is a measure of the energy supplied to a circuit

6 $I = \frac{(2.6 \times 10^{26} \times 1.6 \times 10^{-19}\ \text{C})}{15\ \text{s}}$

$I = 2.77 \times 10^6$ A

7 (a) Use of $I = nqvA$ with e 1.6×10^{-19} C and 8×10^{-3} A

$v = 2.8 \times 10^{-7}$ m s^{-1}

(b) Value for semiconductor is much greater

n for semiconductor (much) less than for conductor

(c) Its resistance decreases because as temperature increases n increases

OR there are more electrons / charge carriers

8 (a) Resistivity is a constant for the material

OR resistivity is a property of the material

Resistance depends on resistivity and length / area / dimensions as $R = \frac{pl}{A}$

(b) $R = \frac{(1.7 \times 10^{-8}\ \Omega\ \text{m} \times 0.5\ \text{m})}{1 \times 10^{-6}\ \text{m}^2}$

$R = 0.0085\ \Omega$

9 (a) Resistivity is a property of a material OR is constant for a material

Resistance is a property of a wire / component and depends upon the dimensions of the wire / component

(b) Circuit diagram: wire and power supply with an ammeter in series and a voltmeter in parallel with the wire

Quantities measured: current and potential difference OR resistance; length of wire; diameter / thickness of wire

Graph: plot R against l OR plot V against l OR plot R against $\frac{l}{A}$ OR plot RA against l

Determination of resistivity: the gradient of relevant graph, correctly processed to find ρ

10 (a) Current through a conductor is directly proportional to the potential difference across it (providing the temperature of conductor remains constant OR external conditions remain constant)

(b) Ohmic conductor: fixed resistor horizontal straight line

Filament lamp: graph showing increasing resistance (straight line or curve) from a non-zero resistant start

(c) As the temperature of the filament increases resistance of conductor changes OR the ions vibrate more

11 (a) Diode / LED

(b) Infinite OR very high

(c) $R = \frac{0.70\ \text{V}}{0.41\ \text{A}}$

$R = 1.7\ \Omega$

(d) Any one from:

To protect components / circuits

Rectification

Restricts current / flow (of charge) to one direction

AC to DC

Produce DC supply

Power indicator light

Light source, e.g. Christmas tree light, torch

Regulate voltage

12 (a) Voltmeter, ammeter, low voltage supply, build complete circuit incorporating ink circle so current flows from A to B.

Measure current and voltage between A and B

R = V/I

(b) Resistance inversely proportional to area of conductor

- so doubling cross-sectional area halves the resistance

Topic 4 Electric Circuits
4B Complete electrical circuits

4B.1 Series and parallel circuits

1 All ammeter readings show the same current, so the same quantity of charge passes through them per second. As there is only one route the charge can take, it must be conserved.

2 12.0 V

3 0.25 A

4 0.24 × 50 = 12 V, and 0.12 × 100 = 12 V

5 1.53 mA

6 (a) 30 A

(b) 5.0 A

4B.2 Electrical circuit rules

1 0.9 A

2 0.9 A + 0.45 A = 1.35 A

3 pd = I_2R_3 = 0.9 × 5.0 = 4.5 V = cell emf

4 11.4 V

4B.3 Potential dividers

1 4.15 V

2 11.3 V

3 Drawing as per fig G, with lamp symbol replaced by a motor; LDR replaced by fixed resistor and the fixed resistor becomes a thermistor

4 The rotating contact is a variable resistance, which in series with the lamp forms a potential divider. As the contact rotates clockwise, its resistance increases, so its share of the voltage increases, and so the lamp voltage and brightness decrease.

4B.4 Emf and internal resistance

1 0.5 Ω

2 0.77 Ω

3 (a) The potential difference across the internal resistance will be proportional to its resistance value. If this is high, the potential difference across the starter motor may be too low to turn it.

(b) The car battery also powers the car headlights. As the starter draws a high current, the voltage lost across the internal resistance leaves a lower pd for the headlights, so they dim.

4 Plot *V* on *y*-axis and *I* on *x*-axis. Internal resistance from gradient is approximately 0.35 Ω; emf from *y*-intercept, $\mathcal{E}$ = 1.49 V.

4B.5 Power in electric circuits

1 20.4 J

2 1.85 W

3 (a) 1460 W

(b) 0.172 W

4 (a) 0.95 or 95%

(b) The input and output energies labelled go together, so for every 100 J supplied, 95 J are delivered as heat, so the efficiency will always be 95%.

4B Exam Practice

1 B

2 A

3 B

4 C

5 A

6 (a) The current in lamp A is equal to the current in lamp B.
The pd across lamp A is less than the pd across lamp B.
The resistance of lamp A is less than the resistance of lamp B.

(b) Bulb A brighter than bulb B; resistors in parallel have same pd
Identifies $P = \frac{V^2}{R}$ OR $P = VI$ and $I_A > I_B$
Uses this equation to state $P_A > P_B$

7 QWC (quality of written communication) – the answer must be clear and organised in a logical sequence, and include some of the following:
Different currents / current divides in parallel circuit
Same potential difference / voltage across each lamp
Use of $P = \frac{V^2}{R}$ OR $P = VI$ if identified $I_A < I_B$
Leading to high resistance, smaller power
Lamp B will be brighter / lamp A dimmer
Each electron loses the same energy
There are more electrons/sec in B
Hence, greater total energy loss / sec in B

8 (a) pd = $\frac{(40 \times 9.0)}{(40 + 80)}$
pd = 3.0 V

(b) QWC (quality of written communication) – work must be clear and organised in a logical sequence and including the following:
Resistance of parallel combination increases as temperature decreases
Total resistance of circuit increases
emf / pd remains constant therefore current decreases

9 (a) $R = \frac{V^2}{P}$
$R = \frac{220 \times 220}{1000}$
$R = 48.4\ \Omega$

(b) Use of $E = Pt$ OR $E = VIt$ OR $E = \frac{V^2 t}{R}$ with 3 OR 3 × 60 as the time
$E = 180\ 000$ J

(c) (i) Attempts to calculate power

Power = 250 W

Time to boil = 12 mins / 720 s

OR

Calculates new current 2.27 A

Use of $E = VIt$ with their current

Time = 12 mins / 720 s

OR

$P \alpha V^2 \alpha$ ¼

$t \alpha 1 / P \alpha 4$

Time = 12 mins

(ii) Use of equation, $V = IR$ OR $P = \frac{V^2}{R}$ OR $P = VI$

This will lead to increased current or power, so causing damage / fuse to melt / circuit breaker to trip / element to burn out / wire to melt

10 (a) $I = \frac{P}{V} = \frac{4.8}{230} = 0.021$ A

(b) (i) $P = VI$, so W = V A

OR V = J C^{-1}, A = C s^{-1} so V A = J C^{-1} × C s^{-1} = J s^{-1} = W

OR 5 V × 0.1 A = 0.5 W

(ii) Efficiency = $\frac{0.5}{4.8} \times 100$

Efficiency = 10.42%

(iii) Energy / power wasted / transferred / lost to thermal or heat energy

11 (a) (i) 4.0 Ω

(ii) $I = \frac{3\text{ V}}{4\,\Omega}$

$I = 0.75$ A

(iii) $P = (0.75\text{ A})^2 \times 3.6\,\Omega$

$P = 2.0$ W

(b) Total resistance (of circuit) will increase so current will decrease

12 Award 1 mark for the (QWC) quality of written communication.

Award a maximum of 5 marks from the following expected answer points:

Current conservation rule is that the vector sum of the currents at any point in a circuit is zero.

This means that the total amount of current entering equals the total leaving that point.

In any given time, this will mean the same quantity of charge entering as leaving that point.

Hence, charge is conserved.

Voltages circuit rule is that the sum of the emfs around any closed circuit loop equals the sum of the pds in the same loop.

This means that the energy gained by any given quantity of charge in that loop will be given up again by the time it has travelled around the complete loop.

This will mean the same quantity of energy entering as leaving that circuit loop.

Hence, energy is conserved.