# 1.1 Units

1 (a) Students' own answers
(b) The full name is correctly written without a capital letter, but the abbreviation is capitalised.

2 (a) $9.2 \times 10^{9}$ W
(b) $4.3 \times 10^{-2}$ m
(c) $6.4 \times 10^{6}$ m
(d) $4.4 \times 10^{-8}$ s

3 (a) 3.6 MJ
(b) 31.536 μs
(c) 10 μA
(d) 1.05 kHz

# 1.2 Estimation

1 (a) $10^{1}$ m
(b) $10^{-1}$ kg
(c) $10^{-1}$ s
(d) $10^{7}$ m
(e) $10^{1}$ °C (or $10^{2}$ K)

2 Students own answers need to include reasonable estimates for quantities needed. Example approaches are:
(a) Estimate diameter of tennis ball = 10 cm = 0.1 m ($r$ = 0.05 m)
Gives volume tennis ball approx. = $5 \times 10^{-4}$ m$^3$
Estimate dimensions of an unknown cathedral = 50 m × 20 m × 20 m
Gives cathedral volume estimate = 20 000 m$^3$
$$\text{Number} = \frac{\text{volume of cathedral}}{\text{volume of tennis ball}} = \frac{20\,000}{(5\times10^{-4})} \approx 4 \times 10^{7} \text{ balls}$$
(b) Estimate body dimensions as cuboid: 2 m × 50 cm × 20 cm
Gives body volume = 0.2 m$^3$
Estimate radius of atom = $1 \times 10^{-10}$ m
Gives volume atom = $4.2 \times 10^{-30}$ m$^3$
$$\text{Number} = \frac{\text{volume of body}}{\text{volume of atom}} = \frac{0.2}{(4.2\times10^{-30})} \approx 5 \times 10^{28} \text{ atoms}$$
(c) Estimate unknown sea dimensions as cuboid: 500 km × 50 km × 30 m
Gives sea volume = $7.5 \times 10^{11}$ m$^3$
Estimate radius of drop = 2 mm = $2 \times 10^{-3}$ m
Gives volume drop = $3.35 \times 10^{-8}$ m$^3$
$$\text{Number} = \frac{\text{volume of sea}}{\text{volume of drop}} = \frac{(7.5\times10^{11})}{(3.35\times10^{-8})} \approx 2 \times 10^{19} \text{ drops}$$
(d) Estimate working career = 50 years
Estimate average salary point over lifetime for employee with Physics A Level = £30 000
Estimate salary increases for inflation of 50% per decade
Gives average decade salaries of £30k, £45k, £67.5k, £101.25k, £151.875k p.a.
(totals for each decade = £300k, £450k, £675k, £1012.5k, £1518.75k)
Lifetime total ≈ £4 million
(e) Estimate flying time = 10 hours = 600 minutes
Estimate Fermi takes 2 minutes per question
Total = 300 questions ignoring meal breaks, sleeping or watching movies

# 2.1 Motion

## 2.1.1 Velocity and acceleration

1 (a) 8.33 m $s^{-1}$
(b) 2.08 m $s^{-1}$
(c) zero

2 (a) 11 m $s^{-1}$
(b) 1.5 s
(c) 4.4 m $s^{-2}$ (accept 4.5 m $s^{-2}$)

3 (a) $1.5 \times 10^8$ m $s^{-1}$
(b) $8.82 \times 10^{22}$ m $s^{-2}$

## 2.1.2 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 $s^{-2}$)

3 (a) $d$ = 240 m

## 2.1.3 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

## 2.1.4 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

## 2.1.5 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) $\boldsymbol{a} = 65.4 \text{ m s}^{-2}$

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

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

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

## 2.1.6 Kinematics equations

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

2 40 m

3 (a) $\boldsymbol{a} = 5.8 \text{ m s}^{-2}$

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

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

4 4.24 s

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

## 2.1.7 Resolving vectors

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

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

## 2.1.8 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.)

## 2.1 Answers to Exam-style questions

1 (c)

2 (c)

3 (b)

4 (a) Magnitude and direction

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

5 (a) W = mg

$W = 3.04 \times 10^6$ kg × 9.81 kg m s$^{-2}$

$= 2.98 \times 10^7$ N

Resultant force = $3.4 \times 10^7$ N – $2.98 \times 10^7$ N = $4.2 \times 10^6$ N

(b) $a = \dfrac{F}{m}$

$= 4.2 \times 10^6$ N / $3.04 \times 10^6$ kg

$= 1.38$ m s$^{-2}$

(c) $a = \dfrac{(v-u)}{t}$

$= \dfrac{(2390 \text{ m s}^{-1} - 0)}{150 \text{ s}}$

$= 15.9$ m s$^{-2}$

(d) Any one from:

mass decreasing / weight decreasing / net upward force increasing / fuel used up / gets lighter / g decreasing / air resistance decreasing with altitude

6 (a) Ruler to measure length of trolley and a light gate (connected to computer / data logger) to measure time for the trolley to pass.

(b) Human error in using stopwatch, but no human error using ICT.

Different reaction time for different people, or on different occasions.

7 (a) QWC – 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 ruler and timer/data logger/ 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:

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

$= 8.0\text{ m s}^{-1}$

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

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

$= 2\text{ m s}^{-2}$

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 – 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 can't 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) $s = ut + \frac{1}{2}at^2$

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

$= 1.54\text{ m s}^{-2}$

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

(c) $F = ma$
$= 4.5 \times 10^5\text{ kg} \times 1.5\text{ m s}^{-2}$
$= 675\,000\text{ N}$

11 QWC – 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 $2^{nd}$ law states that acceleration = 0

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

12 (a) (i) $v = \dfrac{1.83 \text{ m}}{0.88 \text{ s}}$

$= 2.14 \text{ m s}^{-1}$

(ii) $v = u + at$

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

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

$= 4.3 \text{ m s}^{-1}$

OR

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

$0 = (u \times 0.88 \text{ s}) + (\frac{1}{2} \times (-9.81 \text{ ms}^{-2}) \times (0.88\text{s})^2)$

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

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

$\text{velocity} = 4.8 \text{ m s}^{-1}$

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

angle = 63.9º

(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).

# 2.2 Energy

## 2.2.1 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 interconverted between kinetic and gravitational potential forms.

## 2.2.2 Work and power

1 (a) Work done by lioness is 12.9 J.
(b) Work done by eagle is 11.6 J, so lioness does more work by 1.3 J.

2 4160 J

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

4 0.29 or 29%

## 2.2 Answers to Exam-style questions

1 (a)

2 (a)

3 (b)

4 (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 = 6 000$m^2$ × 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) $E_k$ = ½ × 324 000 kg × (9 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 = energy/second = 7 741 980 J/5s = 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 doesn't always blow / if there is no wind they don't work / wind speeds are variable / need minimum amount of wind to generate the electricity / need a large amount of wind / can't be used in very high winds.
- Only 59% max efficiency
- Low power output / need a lot of turbines / need a lot of space.

5 (a) work = force × distance

$= 150\ \text{N} \times 2.5 \times 10^{-2}\ \text{m}$

$= 3.75\ \text{J}$

(b) $3.75\ \text{J} = \frac{1}{2} \times 0.0075\ \text{kg} \times v^2$

$v^2 = 1000\ \text{m}^2\ \text{s}^{-2}$

$v = 31.6\ \text{m s}^{-1}$

(c) (i) $v_v = v \sin \theta$

$= 32\ \text{m s}^{-1} \times \sin 40°$

$= 20.6\ \text{m s}–^{-1}$

(ii) $v_h = v \cos \theta$

$= 32\ \text{m s}^{-1} \times \cos 40°$

$= 24.5\ \text{m s}^{-1}$

Time to max height, $t = (v - u)/a$

$= 20.6\ \text{m s}^{-1} / 9.81\ \text{m s}^{-2}$

$= 2.1\ \text{s}$

Total time = 2 × 2.1 s = 4.2 s

range $= v \times t$

$= 24.5\ \text{m s}^{-1} \times 4.2\ \text{s}$

$= 103\ \text{m}$

(d) Any plausible suggestions using correct scientific justification, such as:

Air resistance / friction on cork as it leaves the bottle

Work done → energy dissipated OR air resistance decelerates cork / reduces speed of cork OR friction with bottle reduces acceleration / launch speed OR reduces kinetic energy of the cork.

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

$W = F\Delta x$

$= 800\ \text{N} \times 23.2\ \text{m}$

$= 18\,600\ \text{J}$

(b) Power = work done / time

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

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

(use of 20 000 J gives 800 W)

7 (a) QWC – 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 won't reach it.

8 (a) (i) Horizontal component = 650 N × cos 42º
= 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 = W/t
P = 0.98 W

# 2.3 Momentum

## 2.3.1 Momentum

1 (a) 240 kg m s$^{-1}$
(b) 588 kg m s$^{-1}$
(c) $2.5 \times 10^{-4}$ kg m s$^{-1}$

2 Motorcyclist: estimate mass as 80 kg and speed as 30 ms$^{-1}$, so $p$ = 2 400 kgms$^{-1}$.

Skateboarder: estimate mass as 65 kg and speed as 4 ms$^{-1}$, so $p$ = 260 kgms$^{-1}$.

3 Larger forces cause greater injuries. Force required is proportional to rate of change of momentum (Newton II). 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 $\boldsymbol{F} = \dfrac{\Delta p}{t}$

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

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

## 2.3.2 Conservation of linear momentum

1 0.0315 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.

## 2.3 Answers to Exam-style questions

1 (b)

2 (a)

3 (b)

4 QWC – 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 Δmv/t to bacteria, which moves in *opposite* direction.

5 (a)* QWC – 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.

6 (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 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 = 2.85/9.81 = 0.291 kg
Total mass = 0.350 + 0.291 = 0.641 kg
a = F/m = 2.85/0.641 = 4.45 m $s^{-2}$

(c) p = mv = 0.35 × 11.1 = 3.89 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.

7 Award 1 mark for the 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.

8 (a) Momentum is initially constant at 0.8 kg m $s^{-1}$ (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) 0 (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. The final horizontal line is at a momentum of -0.6 kg m $s^{-1}$

# 3.1 Electrical quantities

## 3.1.1 Electric current

1 (a) 0.625 A

(b) 7.6 C

(c) $2.35 \times 10^{-8}$ s

2 (a) 0.167 s

(b) $1.25 \times 10^{11}$

3 1.4 A

## 3.1.2 Electrical energy transfer

1 Emf measures energy transferred into electrical energy (a supply voltage), pd measures energy transferred from electrical into other forms.

2 (a) 1.58 V

(b) 9.26 V

3 (a) 6.0 eV

(b) $7.68 \times 10^{-13}$ 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 converted to kinetic on obstacles rather than only into heat/sound (other forms).
- *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

## 3.1.3 Current and voltage relationships

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

## 3.1.4 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 that polythene, so it has a higher value for conductivity.

4 (a) Resistance = $2.3 \times 10^{-4}$ Ω,
so resistance of each arm of ring in circuit = $4.6 \times 10^{-4}$ Ω
Cross-sectional area = $1.5 \times 10^{-6}$ m$^2$
Length = half circumference = 0.0314 m,
so $\rho = 2.2 \times 10^{-8}$ Ω 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, $V = \pi r^2 h$.
For example, 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$^3$

## 3.1.5 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

## 3.1.6 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.

## 3.1 Answers to Exam-style questions

1 (c)

2 (d)

3 (c)

4 p.d. is electrical energy transferred between two points, or the electrical energy transformed or converted to other forms

e.m.f. is the energy supplied to a circuit.

5 $I = (2.6 \times 10^{26} \times 1.6 \times 10^{-19}\ \text{C}) \div 15\ \text{s}$

$I = 2.77 \times 10^{6}\ \text{A}$

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

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

(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.

7 (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 $R = pl/A$

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

$R = 0.0085\ \Omega$

8 (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 $l/A$ OR plot $RA$ against $l$.

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

9 (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.

10 (a) Diode / LED

(b) Infinite OR very high

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

$R = 1.7\ \Omega$

(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

# 3.2 Complete electrical circuits

## 3.2.1 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

## 3.2.2 Electrical circuit rules

1 0.9 A

2 0.9 + 0.45 A = 1.35 A

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

4 11.4 V

## 3.2.3 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.

## 3.2.4 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 p.d. 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.

## 3.2.5 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%.

5 The electrical energy supplied is only converted into light by the gas in a compact fluorescent lamp. The filament lamp produces light by converting the electrical energy into heat, making the filament very hot, so there is a lot of wasted heat.

## 3.2 Answers to Exam-style questions

1 (b)

2 (a)

3 (b)

4 (a) *n*; number of charge carriers per unit volume OR number of charge carriers OR charge carrier density
*v;* drift velocity (of charge carriers) OR average velocity OR drift speed
(b) Units of l and q: A and A s OR C $s^{-1}$ and C
Units of n: $m^{-3}$
Units of v and A: m $s^{-1}$ and $m^2$

5 (a) The current in lamp A is *equal to* the current in lamp B.
The p.d. across lamp A is *less than* the p.d. 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 p.d.
Identifies $P = V^2\ /\ R$ OR $P = VI$ and $I_A > I_B$
Uses this equation to state $P_A > P_B$

6 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 $P = V^2 / R$ 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

7 (a) p.d. = 40 × 9.0 / (40 + 80)
p.d. = 3.0 V
(b) 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
e.m.f. / p.d. remains constant therefore current decreases.

8 (a) Volt is a Joule $\text{coulomb}^{-1}$ OR V = J $C^{-1}$ OR $V = W/Q$
Amp is a Coulomb $\text{sec}^{-1}$ OR A = C $s^{-1}$ OR $I = Q/t$
Show units / symbols cancelling and equating to a watt (J $s^{-1}$)
(b) (i) $E = 700 \times 7 \times 60$
$E = 294\ 000$ J
(ii) QWC – spelling of technical terms must be correct and answer must be organised in a logical sequence, including:
internal resistance / *r*
current will be less
less energy / power is lost in internal resistance or wasted
energy / power is reduced or reduced lost volts or it is more efficient.

9 (a) $R = V^2 / P$

$R = 220 \times 220 / 1000$

$R = 48.4\ \Omega$

(b) Use of $E = Pt$ OR $E = VIt$ OR $E = V^2t / R$ 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 Energy = $VIt$ 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 $P = V^2 / R$ 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 converted / wasted / transferred / lost to thermal or heat energy.

11 (a) (i) 4.0 Ω

(ii) $I = 3$ V / 4 Ω

$I = 0.75$ 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 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.

# 4.1 Fluids

## 4.1.1 Fluids, density and upthrust

1 915 $kgm^{-3}$

2 (a) 0.82 $gcm^{-3}$

(b) 820 $kgm^{-3}$

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

(c) There is a resultant downwards force, so it will accelerate to the bottom (Newton I). There, an additional reaction force (Newton III) from the bed of the stream will cause a net force of zero so the ball will rest on the bottom stationary (Newton I). 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 II).

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 40cm; estimated depth is 20 cm; estimated mass is 75 kg:

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

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

*Alternative route*: The body is mostly water, and humans float, so density must be slightly less than water: estimate $\rho = 900\ kgm^{-3}$.

## 4.1.2 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 'In the gentle time of a late summer, a creek over boulder flowed smooth.'

- Late summer ∴ low water level, slow moving streamline flow.

'As autumn fell, floating leaf after leaf skipped round the rock, chasing like giddy schoolgirls playing "Follow the Leader".'

- Still streamline flow as leaves follow each other around rock.

'In winter's depth, all frozen stood, ice on stone, stone on ice.'

- Stream is frozen: zero flow.

'The bright thaw springs a maelstrom, water currents churning and swirling as drunken Maypolers.'

- Very fast flow: turbulent flow with no order or uniformity.

## 4.1.3 Drag act

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 $1.95 \times 10^{-5}$, giving an approximate viscosity of $1.6 \times 10^{-3}$ Pa s; compared with 20 °C figure in **table B** of $1.0 \times 10^{-3}$ Pa s. Answers should discuss possible sources of error to cause this difference.

## 4.1.4 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) $3.8 \times 10^{9}$ m s$^{-1}$

(b) $5.97 \times 10^{7}$ 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. Also assumed: viscosity of air at 20 ºC; density of water = 1000 kgm$^{-3}$.

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 $\boldsymbol{v}_{\text{term}} = 40$ 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.

## 4.1 Answers to Exam-style questions

1 (c)

2 (c)

3 (b)

4 (a) (i) 3 correct labelled arrows:

Upthrust, *U*

weight, *W*

(viscous) drag, water resistance, viscous force, V, F, D

(ii) upthrust + drag = weight

forces in equilibrium / balanced forces / no resultant force / no acceleration / constant velocity

(b) (i) Particle falling down and along to the right (in direction of the flow)

(ii) Any from:

lines crossing, eddies, sudden changes in direction, changes in direction > 90°, lines disappearing and appearing.

(iii) Laminar constant velocity at a point / no eddies / lines don't cross, but turbulent keeps changing direction / eddies / lines cross.

(iv) Turbulent flow → eddies / continual changes will disturb particle back into the flow / stop particle from continuing downwards / lifts particle.

5 (a) (i) Laminar: at least 2 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.

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

7 (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 = 2.7 / 31 = 0.087 s

$s = \frac{1}{2} \times 9.81 \text{ m s}^{-2} \times (0.087 \text{ s})^2$

$= 0.037$ (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.

8 (a) (i) Upthrust / $U$

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

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

(ii) QWC – Work must be clear and organised in a local 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 = $1.0 \times 10^3$ kg m$^{-3}$ × $2.1 \times 10^{-9}$ m$^3$

$= 2.1 \times 10^{-6}$ kg

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

$= 2.1 \times 10^{-5}$ N

(ii) $F = 5.7 \times 10^{-5}\ \text{N} - 2.1 \times 10^{-5}\ \text{N} = 3.6 \times 10^{-5}\ \text{N}$

$$v = \frac{3.6\times10^{-5}\ \text{N}}{6\pi\eta r}$$

$$= \frac{3.6\times10^{-5}\ \text{N}}{6\times\pi\times1.2\times10^{-3}\times8\times10^{-4}}$$

$= 2.0$ 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.

9 Award 1 mark for the 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 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.

# 4.2 Solid material properties

## 4.2.1 Hooke's law

1 7.0 $Nm^{-1}$

2 The line would be steeper.

3 Formula given in text is that $\Delta E_{el} = \frac{1}{2}\Delta x$. And Hooke's law has $\Delta F = k\Delta x$ so substituting expression for $\Delta F$ into first equation gives the formula $\Delta E_{el} = \frac{1}{2}k(\Delta x)^2$.

4 (a) From the graph, each square represents $1.25 \times 10^{-3}$ 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.

5 Students' own answers, using $E = F\Delta x$

E.g. estimated extension is 10 cm; estimated force to extend is same as holding up 500 g mass, so 5 N.

$E = \frac{1}{2}F\Delta x = \frac{1}{2} \times 5 \times 0.1 = 0.25$ J

Braces have two elastics, so total elastic potential energy is 0.5 joules.

## 4.2.2 Stress, strain and the Young modulus

1 0.072

2 $7.81 \times 10^{7}$ Pa

3 $5.09 \times 10^{9}$ Pa

4 (a) $3.50 \times 10^{5}$ Pa

(b) $3.50 \times 10^{-5}$ m, assuming that the elephant's weight is split evenly over two femurs that are still vertical cylinders.

## 4.2.3 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.

## 4.2 Answers to Exam-style questions

1 (d)

2 (c)

3 (b)

4 QWC – Work must be clear and organised in a logical manner using technical wording where appropriate, and include four of the following points:

small extension means it is hard to measure accurately (or converse)
small extension gives large percentage uncertainty (or converse)
(thin wire has) small area
stress = force / area
so a smaller area gets larger stress (for a given force)
don't need such a large force
greater extension – linked to thinner wire
strain = extension / original length
grater extension – linked to longer length
Alternatively:
Young modulus = stress / strain OR $E = Fx / A\Delta x$, where $\Delta x$ = extension.

5 (a) limit of proportionality – stress proportional to strain / obeys Hooke's law / force proportional to extension up to this point

tensile strength – greatest stress before fracturing

yield point – point at which plastic deformation begins / point at which material shows a larger increase in strain for a smaller increase in stress

(b) Mark 'limit of proportionality' and the 'yield point' on the graph:

L shown at end of linear part

Y shown beyond L and up to maximum stress

6 (a) QWC – 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. $\Delta x$ graph OR plot stress-strain graph
- determination gradient of $F$ v. $\Delta x$ 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

don't 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) $k = F / \Delta x$

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

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

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

(c) (i) $F = k\Delta x$

$= 16\ \text{N m}^{-1} \times (0.41\ \text{m} - 0.09\ \text{m})$

$= 5.1\ \text{N}$

(ii) $E = \frac{1}{2}F\Delta x$

$= 0.5 \times 5.1\ \text{N} \times (0.41 - 0.09\ \text{m})$

$= 0.82\ \text{J}$

(d) QWC – 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) Label upthrust, weight and viscous drag
(b) Upthrust = (-)Weight
Thrust = (-)Viscous drag
(c) calculate weight of water as $U = W$
$m$ = density × volume
$= 1030\ \text{kg m}^{-3} \times 7\,100\ \text{m}^3$
$= 7.3 \times 10^6\ \text{kg}$
$W$ = mg
$W = 7.3 \times 10^6\ \text{kg} \times 9.81\ \text{N kg}^{-1}$
$= 7.2 \times 10^7\ \text{N}$
(d) (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 – 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) $k = 7.7\ \text{N} / 0.008\ \text{m}$
$k = 960\ \text{N m}^{-1}$
(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) $\frac{1}{2}mv^2 = 1.1.\ \text{J}$
$v = \sqrt{(2 \times 1.1\ \text{J} / 0.0094\ \text{kg})} = 15.3\ \text{m s}^{-1}$
(ii) All elastic energy to kinetic energy / no friction between parts of gun
(d) (i) $t = 3.0\ \text{m} / 15.3\ \text{m s}^{-1} = 0.196\ \text{s}$
$v = 9.81\ \text{m s}^{-2} \times 0.196\ \text{s} = 1.92\ \text{m s}^{-1}$
$v = \sqrt{(15.3\ \text{m s}^{-1})^2 + (1.92\ \text{m s}^{-1})^2)} = 15.4\ \text{m s}^{-1}$
angle $= \tan^{-1}(1.92\ \text{m s}^{-1} / 15.3\ \text{m s}^{-1}) = 7.15°$
(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.

# 5.1 Basic waves

## 5.1.1 Wave basics

1 (Graphs from top to bottom:) 0.2 m; 80 m; 5.5 m

2 1240 m

3 $8.15 \times 10^{14}$ 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.
$v = f\lambda = 0.33 \times 5 = 1.7$ m s$^{-1}$
Accept alternative answers using distance/time.

## 5.1.2 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.

## 5.1 Answers to Exam-style questions

1 (b)

2 (d)

3 (a)

4 (a) The answer must be clear, organised in a logical sequence and use appropriate scientific terms, including:
Interference (pattern) produced / superposition occurs / standing wave formed
Maxima related to constructive interference / antinode and / or minima related to destructive interference / node
Maxima / antinode formed where the waves are in pahse / path difference $n\lambda$
Minima / node formed where the waves are in antiphase / path difference = $(n + ½)\lambda$
(i) Distance between adjacent maxima = $\lambda$ / 2
Wavelength = 0.1 m
(ii) $v = 3300 \times 0.1$
$v$ =330 m s$^{-1}$
(mark (i) and (ii) as one section
Minima never have a zero value because there is not complete cancellation / overall displacement is not zero / not total destructive interference.
The minima gradually decrease as the waves have different amplitudes / amplitude decreases with distance
OR
Energy loss due to reflection or spreading out
OR
As the microphone moves towards the plate, the path difference decreases.

5 (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.

6 $\lambda = (3 \times 10^8\text{ ms}^{-1}) / 95.8 \times 10^6\text{ Hz}$
$\lambda = 3.13\text{ m}$

7 (a) (i) They are above the audible range / frequency.
(ii) Distance = speed × time
Distance = $1500\text{ m s}^{-1} \times 0.8 \times 10^{-4}\text{ s}$
Distance = 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, US longitudinal OR X rays can be polarised, US can't
X rays travel in vacuum, US doesn't
X rays Electromagnetic, US mechanical
X rays have (much) higher $f$ / shorter $\lambda$ / greater speed.

# 5.2 The behaviour of waves

## 5.2.1 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

## 5.2.2 Stationary waves

1 $\lambda = 0.75$ m; $f = 560$ Hz

2 (a) $433\text{ m s}^{-1}$
(b) 293 Hz

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

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

So $\mu = \dfrac{T}{v^2} = \dfrac{T}{f^2\lambda^2}$

For example, 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:

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

## 5.2.3 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 were 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 $\lambda_1$, $n_{max} = 2$; $\lambda_2$, $n_{max} = 1$; $\lambda_3$, $n_{max} = 1$

## 5.2.4 Wave interference

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

2 (a) 0°; they are in phase

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

(c) $\lambda$; 0°; they are in phase

(d) The fringes would be further apart.

## 5.2 Answers to Exam-style questions

1 (c)

2 (b)

3 (b)

4 (a) Distance = (330 m s$^{-1}$ × 25 × 10$^{-3}$ s) ÷ 2

Distance = 4.125 m

(b) Any one from:

One pulse must return before the next one is sent

OR

So that time interval between transmitted and received pulses can be measured

OR

No overlap between pulses

OR

No interference between pulses.

5 QWC – 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) / contructive and destructive interference occur

If they meet in phase / n$\lambda$ / $\lambda$ path difference, constructive interference / bright fringe

If they meet in antiphase / (n + ½) / $\lambda$ / ½ $\lambda$ path difference, destructive interference / dark fringe.

6 (a) Unpolarised light has oscillations in all orientations; plane polarised light has oscillations in only one plane.

(b) The light is horizontally polarised when it reflects off the surface of the water. The sunglasses will only allow vertically polarised light to pass through, cutting out the reflected glare from the water surface.

(c) Sound waves are longitudinal. Only transverse waves can be polarised.

7 (a) Unit of LHS m $s^{-1}$

Units of T = kg m $s^{-2}$

Units of $\mu$ = 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) $\lambda$ = 4m

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

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

(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 No of nodes = no of antinodes plus one
- Amplitude is less if there is a greater number of nodes
- Length = n$\lambda$ / 2 / after first standing wave, they occur when frequency × 2, × 3, × 4 etc / for frequency $nf_0$

8 (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 – 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* doesn't disturb sand (as much)

OR reduced *amplitude* disturbs sand less

# 5.3 Optics

## 5.3.1 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°

## 5.3.2 Total internal reflection

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

2 In both 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**.

## 5.3.3 Lenses

1 The distance along the principal axis from the centre of a lens to the point where, initially, parallel rays are focussed.

2 [Author note: this question requires students to measure from the picture in the book; as these answers are based on measurements taken prior to publication, they may not be 100% accurate.]

diverging lens: $f = 1.55$ cm $\therefore$ $P = 64.5$ D

converging lens: $f = 1.65$ cm $\therefore$ $P = 60.6$ D

3 The lens produces a virtual focus or parallel rays, and this cannot be observed on a screen.

4 Students should draw the following: the rays are focussed by the convex lens, to cross over midway between the lenses; when they reach the concave lens, they are diverged further by that lens.

5 $P_{total} = -0.58$ D

## 5.3.4 Image formation

1 Image drawn should be inverted and the same size, 12.0 cm from the lens on the other side.

2 smaller (diminished), virtual, upright (erect)

3 As the angle on each side of the lens is the same, they are similar triangles. This means that the ratio of image height to object height (i.e. magnification) is the same as the ratio of image distance to object distance.

4 When $y = 0$, this means $\frac{1}{v} = 0$, so from the lens equation, $\frac{1}{u} = \frac{1}{f}$.

5 For example, comparison of eye widths: 7 mm in magnifying glass and 4 mm in unmagnified image.

So: $m = \frac{7}{4} = 1.75 \times$ magnification

## 5.3.5 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. For example:

- 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.

## 5.3 Answers to Exam-style questions

1 (a)

2 (c)

3 (b)

4 (b)

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

(i) $n = 3 \times 10^8 \div 1.96 \times 10^8$

$n = 1.53$

(b) (ii) sin (critical angle) = 1 / $n$ OR $\sin i / \sin r = v_1 / v_2 = n$

$c = 41^o$

(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 / polarise light / glare

but not the light from the fish OR light from fish is upolarised.

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

7 (a) (i) 6.67 D

(ii) 26.7 D

(b) 1/f - 1/u = 1/v; v = 24.8 cm

(c) m = v/u; m = 0.652

8 (a) $n$ = 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 – 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, $y = 90^o$ / the light travels along the boundary

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

(ii) Use of $\sin c = 1 / n$

$c = 42^o$

9 (a) $\sin c / 1 = 1.96 / 2.03$

$c = 75^o$

(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.

10 (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) $1 / \sin c = 1.3$

$\sin c = 1 / 1.3$

$c = 50.3^{\circ}$

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

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

11 Award 1 mark for the 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.

# 5.4 Quantum Physics

## 5.4.1 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 $9.95 \times 10^{-19}$ 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.

## 5.4.2 The photoelectric effect

1 2.3 eV

2 (a) We have seen that 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 $5.07 \times 10^{14}$ Hz

## 5.4.3 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 $6.14 \times 10^{-11}$ 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

## 5.4.4 Atomic electron energies

1 $1.22 \times 10^{-7}$ 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 $Wm^{-2}$; 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

## 5.4 Answers to Exam-style questions

1 (c)

2 (c)

3 (d)

4 (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

5 QWC – 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 on 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, doesn't happen.

6 (a) *Photon* energy is too small / less than work function.

(b) *Method 1: Use of intercept x-axis*

Use of $E = hf$ with $\underline{f = 10 \times 10^{14}\text{ Hz}}$

Divided by $1.6 \times 10^{-19}$ 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 $1.6 \times 10^{-19}$ to convert to eV

$\Phi = 4.1 – 4.5$ (eV)

(c) Planck's constant / e

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

7 (a) (i) $f = \dfrac{3\times10^{8}\text{ m s}^{-1}}{6.56\times10^{-7}\text{ m}}$

$f = 4.57 \times 10^{14}$ Hz

(ii) $\dfrac{3.03\times10^{-19}}{1.6\times10^{-19}}$

Transition *from* (–)1.5 eV *to* (–)3.4 eV

(b) Wavelength increased or stretched / frequency decreased / red shift / Doppler effect, so the galaxy is moving away (from us / sun)

8 (a) QWC – 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 …)

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

Results in electron 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) $KE = (6.63 \times 10^{-34} \times 3 \times 10^{8}) / 200 \times 10^{-9} – 6.88 \times 10^{-19}$

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

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

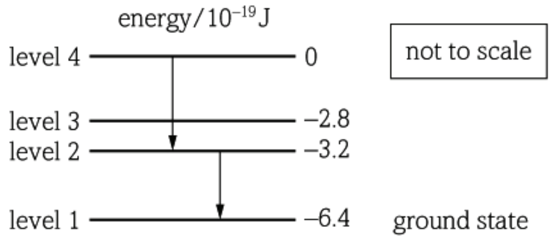
 

$v = 8.20 \times 10^5$ m s$^{-1}$

(d) No change, as the photon energy doesn't change (with distance)
OR photon energy depends (only) on frequency / wavelength.

9 (a) Allowed / possible energy of atoms / electrons
Discrete energy of an atom / electron

(b) Correct pairs of levels, 4 and 2 AND levels 2 and 1.




(c) Any three from:
Electron gains energy and moves to a higher level.
Electron has discrete energies so can only move between fixed levels.
Electron falls to a lower level.
By emitting energy in the form of photons.
Photons have a specific energy / frequency.

(d) Smallest energy difference is $0.4 \times 10^{-19}$ J
$f = 0.4 \times 10^{-19}$ J / $6.63 \times 10^{-34}$ J s
$f = 6.03 \times 10^{13}$ Hz

(e) Energy = $6.4 \times 10^{-19}$ J / $1.6 \times 10^{-19}$ C
Energy = 4.0 eV