Physics

2024 Insight Publications Trial Examination

Worked solutions

This book contains:

- worked solutions
- explanatory notes
- mark allocations
- tips.

Section A – Multiple-choice questions

Question	**Answer**
1	*B*
2	*C*
3	*B*
4	*A*
5	*D*
6	*B*
7	*C*
8	*A*
9	*C*
10	*A*
11	*D*
12	*C*
13	*A*
14	*A*
15	*B*
16	*C*
17	*A*
18	*C*
19	*B*
20	*A*

Question 1

Answer: B

Explanatory notes

Option B is correct as acceleration is given by $a = \dfrac{\Delta v}{\Delta t} = \dfrac{3-18}{5} = -3 \text{ m s}^{-2}$.

Question 2

Answer: C

Explanatory notes

Options A and B are incorrect as they describe applications of Newton's third law of motion. Option D is incorrect as it is a misinterpretation of the motions observed: the ball accelerates more because it has a smaller mass.

Question 3

Answer: B

Explanatory notes

Option B is correct. The kinetic energy of the car is given by $E_k = \dfrac{1}{2}mv^2$. The work done by the braking force is given by $W = F \times d$. By the conservation of energy we have $E_k = W$.

Thus, in the first instance, $\dfrac{1}{2}mv^2 = Fd$ and so $v = \sqrt{\dfrac{2Fd}{m}}$.

When the stopping distance is 2d, $v = \sqrt{\dfrac{2F2d}{m}} = \sqrt{2}\sqrt{\dfrac{2Fd}{m}} = \sqrt{2}v$.

Alternatively, the initial velocity of the car can be obtained by rearranging $v^2 = u^2 + 2as$ to obtain $u = \sqrt{v^2 - 2as}$.

Given that the final velocity is zero, the stopping distance is d and the acceleration is negative, the initial velocity, v, can be expressed as $v = \sqrt{2ad}$.

When the stopping distance is 2d, $v = \sqrt{2a(2d)} = \sqrt{2}\sqrt{2ad} = \sqrt{2}v$.

Question 4

Answer: A

Explanatory notes

Option A is correct. A spring balance measures force. Thus a reading on the force scale will be correct wherever it is taken. This is because it is calibrated using Hooke's law, $F_s = kx$.

However, its reading on the mass scale is calibrated to the acceleration due to gravity on the surface of Earth, 9.81 m s^{-2}, or the gravitational field strength on the surface of Earth, 9.81 N kg^{-1}. Thus, on Mars, the mass reading will be incorrect.

Question 5

Answer: D

Explanatory notes

Option A is incorrect, as the magnetic field is not uniform (being stronger closer to the wire). Options B and C are incorrect as all currents produce a magnetic field. An AC current produces a magnetic field that changes with time. Thus option D is the only correct description.

Question 6

Answer: B

Explanatory notes

By convention the field lines around a positive point charge, or the north pole of a long magnet, point outwards, hence option B is correct. The other options are incorrect, as the field lines around these objects point inwards.

Question 7

Answer: C

Explanatory notes

Only option C is a correct. As the satellite falls towards Earth because of gravity, its motion traces a circular path that follows the curvature of the Earth.

Question 8

Answer: A

Explanatory notes

Option A is correct. According to the right-hand slap rule, to reverse the direction of the force either the magnetic field or the current needs to switch directions.

Question 9

Answer: C

Explanatory notes

Option C is correct. From the graph we see that three full sine waves occur in $600\ \text{ms}$. Thus the period of the AC output is $\frac{600}{3} = 200\ \text{ms}$. The frequency is given by $f = \frac{1}{T} = \frac{1}{200 \times 10^{-3}} = 5\ \text{Hz}$.

Question 10

Answer: A

Explanatory notes

Option A is correct. The RMS voltage is given by $V_{\text{RMS}} = \frac{V_{\text{peak}}}{\sqrt{2}} = \frac{V_{\text{p-p}}}{2\sqrt{2}} = \frac{36}{2\sqrt{2}} = 12.7\ \text{V}$.

Question 11

Answer: D

Explanatory notes

Option D is correct. When a coil is compressed or stretched, the area inside the coil changes. (The stretch that causes Shape A to become Shape B increases the area; the stretch that causes Shape B to become Shape C decreases the area.) If the coil is inside a magnetic field, the change in area results in a change of magnetic flux, and a changing magnetic flux results in an EMF (as described by Faraday’s law). This occurs when Shape A becomes Shape B and when Shape B becomes Shape C.

Tip

- *The VCAA Physics exam often provides novel ways in which a change in magnetic flux could be generated, ranging from bringing a coil closer to a current-carrying conductor to placing conductor coils at the ends of a solenoid. It is vital to be able to identify whether a change in magnetic flux is possible for any given experimental design. The change could be generated by switching on or switching off an electromagnet, by changing the magnetic field strength, by changing the area of the coil (as in this question) or in other ways.*

Question 12

Answer: C

Explanatory notes

Option C is correct. When the coil changes from Shape A to Shape B, the area enclosed by the coil increases; therefore there is an increase in magnetic flux going into the page. According to Lenz’s law the induced EMF produces a flux that opposes this change in flux, with an anticlockwise current. This produces a magnetic flux out of the page (as shown by the right-hand grip rule). The reverse happens when the coil changes from Shape B to Shape C: the area enclosed by the coil decreases, thereby reducing the magnetic flux going into the page. The induced EMF opposes this change with a clockwise current. This produces a magnetic flux into the page (as shown by the right-hand grip rule).

Question 13

Answer: A

Explanatory notes

None of the Options B, C, or D could produce 9 V using these cells. Thus, Option A is correct.

Question 14

Answer: A

Explanatory notes

Option A is correct. The standing wave depicted is the second harmonic. Therefore the fundamental frequency is $f_0 = \frac{294}{2} = 147 \text{ Hz}$, which is option B. Thus option A would not produce a standing wave pattern. Options C and D are the frequencies of the third and fourth harmonic of the string and both would create standing waves.

Question 15

Answer: B

Explanatory notes

Option B is incorrect because this propulsion system works by the transfer of momentum from the photons to the sail, which imparts a force on it. While the equation correctly describes the energy of a photon, that quantum of energy is not transferred directly to the sail as kinetic energy.

Question 16

Answer: C

Explanatory notes

The diagram depicts an electron in its second excited state, $n = 3$. Therefore there are three possible transitions for the electron as it returns to ground state ($n = 1$): $3 \rightarrow 2$, $3 \rightarrow 1$ and $2 \rightarrow 1$.

Question 17

Answer: A

Explanatory notes

Option A correctly describes the standing wave model of the electron. The others are incorrect.

Question 18

Answer: C

Explanatory notes

Options A, B and D are incorrect because the object's direction of motion is constantly changing and therefore each object is accelerating. Thus they are not in an inertial frame of reference.

Tip

- *Make sure you note the wording of questions involving speed (a scalar with magnitude only) and velocity (a vector with magnitude and direction), as the difference is significant in topics on circular motion and special relativity.*

Question 19

Answer: B

Explanatory notes

Option B is correct. Given the description of the experiment described, the variable being measured is the oscillation period, T, which is therefore the dependent variable. The variable that will be changed to observe the effect on the dependent variable is the mass, m, which is therefore the independent variable. The same spring is used throughout the experiment, so the spring constant, k, is the controlled variable.

Question 20

Answer: A

Explanatory notes

Option A is correct. Based on the equation given for the spring constant, $k = 4\pi^2 \dfrac{m}{T^2}$, m is directly proportional to T^2. Thus a graph of T^2 against m, or vice versa, will yield a linear relationship.

Section B

Question 1a.

Worked solution

34 m s^{-1}

Explanatory notes

The final speed is given by $v = u + at = 0 + 8.1 \times 4.2 = 34.0 \text{ m s}^{-1}$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 1b.

Worked solution

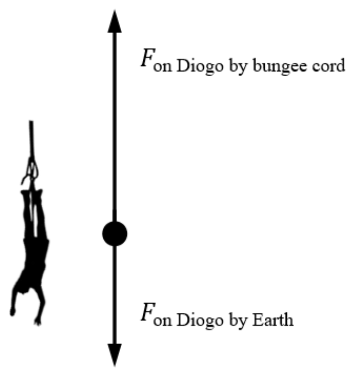
The net force on Diogo is given by $F_{\text{net}} = ma = 70 \times 8.1 = 567 \text{ N}$.

Mark allocation: 1 mark

- 1 mark for correctly substituting the values of mass and acceleration into the equation for force

Question 1c.

Worked solution



Explanatory notes

The two forces acting on Diogo are shown in the diagram above. As Diogo is slowing down, the force of the bungee cord must be greater than gravity, so that there is a net force upwards.

Mark allocation: 2 marks

- 1 mark for the correctly labelled up arrow
- 1 mark for the correctly labelled down arrow

Note: Deduct 1 mark if the down arrow is equal to, or longer than, the up arrow.

Question 2a.

Worked solution

1340 N

Explanatory notes

As the speed is constant, there is no net force. Therefore the size of F_{engine} must equal the sum of the resistive forces: $F_{\text{engine}} = 730 + 610 = 1340\text{ N}$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 2b.

Worked solution

Magnitude: 0.305 m s^{-2}

Direction: east

Explanatory notes

The net force on the ute and trailer is the sum of the resistive forces, as calculated in **part a.**
The sum of the two masses is $3200 + 1200 = 4400\text{ kg}$.

The acceleration is given by $a = \frac{F_{\text{net}}}{m} = \frac{1340}{4400} = 0.3045\text{ m s}^{-2}$, which rounds to 0.305 m s^{-2}.

As the ute and trailer are slowing down while travelling to the west, the direction of their acceleration must be to the east.

Mark allocation: 3 marks

- 1 mark for the correct magnitude

Note: a consequential mark may be awarded for using the value of force from **part a.** that is wrong. In this case, $a = \frac{\text{Ans }\textbf{part a.}}{4400}$

- 1 mark for correctly rounding the answer to 3 significant figures
- 1 mark for the correct direction

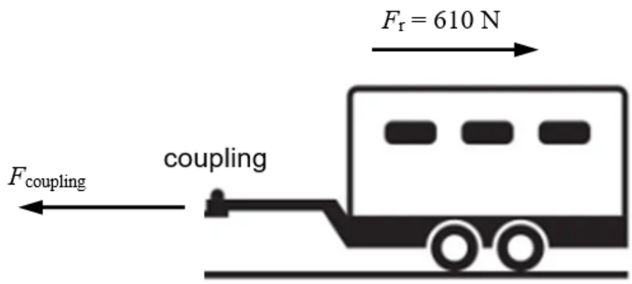
Question 2c.

Worked solution

2.4×10^2 N

The net force on the trailer can be determined from the acceleration of the trailer:
$F_{net} = ma = 1200 \times 0.305 = 366$ N, acting to the east (i.e. to the right in the figure below).

The net force on the trailer is provided by the resistive force as well as the force on the coupling, which is assumed to be acting to the west (i.e. to the left in the figure below).



$F_{net} = F_{coupling} - F_r = F_{coupling} - 610 = -366$ N

$F_{coupling} = 610 - 366 = 244$ N

Mark allocation: 2 marks

- 1 mark for the correct net force
- 1 mark for the correct answer

Note: consequential marks may be awarded for using the value of acceleration from **part b.** that is wrong to calculate the net force. In this case, $F_{net} = 1200 \times \text{Ans}$ **part b.** and subsequently $F_{coupling} = 610 - F_{net}$.

Question 3a.

Worked solution

The vertical component of the ball's initial speed is given by $v_v = v \times \sin\theta = 38\sin 34° = 21.2$ m s^{-1}.

Mark allocation: 1 mark

- 1 mark for the correct formula and substitutions

Question 3b.

Worked solution

The horizontal component of the ball's initial speed is given by $v_h = v \times \cos\theta = 38\cos 34° = 31.5$ m s^{-1}.

Mark allocation: 1 mark

- 1 mark for the correct formula and substitutions

Question 3c.

Worked solution

27.4 m

Considering the vertical motion of the ball, the initial velocity is $u = 21.2 \text{ m s}^{-1}$ up. At the top of its flight the ball's velocity is $v = 0 \text{ m s}^{-1}$. By rearranging $v^2 = u^2 + 2as$ we obtain the distance above the ball's starting position: $s = \dfrac{v^2 - u^2}{2a}$ where a, the gravitational field strength, is -9.81 m s^{-2}.

Thus $s = \dfrac{0^2 - 21.2^2}{2 \times (-9.81)} = 22.9 \text{ m}$.

This distance must be added to the height of the driving platform to obtain the maximum height of the ball above the ground: $22.9 + 4.5 = 27.4 \text{ m}$.

Mark allocation: 2 marks

- 1 mark for the correct value for the distance above the starting position
- 1 mark for the correct answer for the maximum height

Tip

- *Be careful to note when different starting positions (or final positions) are specified, as in this question. Students often forget to add the initial (or final) difference in positions, thereby losing marks.*

Question 3d.

Worked solution

4.5 s

As the flight of the ball is not a symmetrical parabola (because the starting point is above the landing point), the solution is obtained by considering the time it takes the ball to reach maximum height separately and adding it to the time it takes the ball to fall to the ground.

In **part 3a**. we found that the vertical component of the ball's initial speed is $u = 21.2 \text{ m s}^{-1}$ up. At the top of its flight, the ball's velocity is $v = 0 \text{ m s}^{-1}$. By rearranging $v = u + at$ we obtain the time to reach the maximum height: $t = \dfrac{v-u}{a}$ where a, the gravitational field strength, is -9.81 m s^{-2}.

Thus $t = \dfrac{0-21.2}{-9.81} = 2.16 \text{ s}$.

We then consider the motion from the maximum height to the ground. This time the initial velocity is 0 m s^{-1}. In **part 3c.** we found that the ball reached a maximum height of 27.4 m. By rearranging $s = ut + \dfrac{1}{2}at^2 = \dfrac{1}{2}at^2$ and taking gravity to be positive, we obtain the time to reach the ground:

$t = \sqrt{\dfrac{2s}{a}}$.

Thus $t = \sqrt{\dfrac{2 \times 27.4}{9.81}} = 2.36 \text{ s}$.

The total flight time is $2.16 + 2.36 = 4.52 \text{ s}$.

Mark allocation: 3 marks

- 1 mark for the correct value for the time to reach maximum height
- 1 mark for the correct value for the time to reach the ground from the maximum height
- 1 mark for the correct final answer

Note: consequential marks may be awarded *for this part only* if the maximum height calculated in **part c.** is wrong. In this case, $t = \sqrt{\dfrac{2 \times \text{Ans } \textbf{part c.}}{9.81}}$.

Question 4a.

Worked solution

Physics principle: the conservation of momentum

It is assumed that there is no friction or air resistance; hence, the interaction between the spring and the trains is isolated and momentum is conserved.

Mark allocation: 2 marks

- 1 mark for correctly naming the conservation of momentum as the physics principle
- 1 mark for the correct assumption that the interaction is isolated

Tip

- *It is vital to be able to distinguish between 'isolated collision' and 'elastic collision'. Elastic collision refers to the conservation of kinetic energy in the system, whereas isolated collision refers to the conservation of momentum (no friction or air resistance on the system). It is possible to conserve momentum without conserving kinetic energy.*

Question 4b.

Worked solution

Magnitude: 0.15 m s^{-1}

Direction: left

The initial momentum of the system is zero, as both trains are stationary. As the system is isolated, the final momentum of the system, which is given by $p_{\text{final}} = m_{\text{left}}v_{\text{left}} + m_{\text{right}}v_{\text{right}}$, should also be zero. Substituting the given values, and taking right as positive, we obtain

$$p_{\text{final}} = 0.3v_{\text{left}} + 0.2 \times 0.219 = 0$$
$$0.3v_{\text{left}} = -0.0438$$
$$v_{\text{left}} = \frac{-0.438}{0.3} = -0.146 \text{ m s}^{-1}$$

The magnitude of v_{left} is 0.15 m s^{-1} and the direction is left, as indicated by the negative sign.

Mark allocation: 3 marks

- 1 mark for correct substitutions into the formula for final momentum and equating it to zero
- 1 mark for the correct answer
- 1 mark for the correct direction

Question 4c.

Worked solution

8.0×10^{-3} J

The kinetic energy of the train on the left is $E_{\text{k}} = \frac{1}{2}m_{\text{left}}{v_{\text{left}}}^2 = \frac{1}{2} \times 0.3 \times 0.146^2 = 3.20 \times 10^{-3}$ J.

The kinetic energy of the train on the right is $E_{\text{k}} = \frac{1}{2}m_{\text{right}}{v_{\text{right}}}^2 = \frac{1}{2} \times 0.2 \times 0.219^2 = 4.80 \times 10^{-3}$ J.

The total is $3.20 \times 10^{-3} + 4.80 \times 10^{-3} = 8.00 \times 10^{-3}$ J.

Mark allocation: 2 marks

- 1 mark for at least one correct kinetic energy
- 1 mark for the correct final answer

Note: a consequential mark may be awarded *for this part only* if the value of the velocity calculated in **part b.** is wrong. In this case, $E_{\text{k}} = 0.15 \times (\text{Ans } \textbf{part b.})^2$.

Question 4d.

Worked solution

8.0×10^{-3} J

As energy losses can be ignored, the elastic potential energy of the spring is converted to the kinetic energy of the two trains which, from **part 4c.**, is 0.80 J.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 4e.

Worked solution

82 N m^{-1}

The spring extension is given by the difference between the spring length after and before the trains are released: $x = 42 - 28 = 14 \text{ mm} = 0.014 \text{ m}$.

Rearrange the equation for elastic potential energy, $E_s = \frac{1}{2}kx^2$, to obtain

$$k = \frac{2E_s}{x^2} = \frac{2 \times 8 \times 10^{-3}}{0.014^2} = 81.6 \text{ N m}^{-1}.$$

Mark allocation: 2 marks

- 1 mark for the correct spring extension
- 1 mark for the correct answer

Question 5a.

Worked solution

The gravitational force of Earth on the satellite is given by

$$F_g = G\frac{m_1 m_2}{R^2} = 6.67 \times 10^{-11} \frac{5.97 \times 10^{24} \times 5.58 \times 10^3}{(4.25 \times 10^7)^2} = 1.23 \times 10^3 \text{ N}.$$

Mark allocation: 1 mark

- 1 mark for the correct answer

Tip

- *When working with formulas involving squares of quantities (such as the gravitational force or the electric force), you must remember to square those quantities. A common mistake is forgetting to square the distance between the two masses or charges when calculating the magnitude of the force between them.*

Question 5b.

Worked solution

$3.1 \times 10^3 \text{ m s}^{-1}$

The gravitational force of Earth on the satellite is also the centripetal force on the satellite. Thus

$F_g = F_c = \frac{mv^2}{r} = 1.23 \times 10^3 \text{ N}$.

By rearranging the equation we obtain $v = \sqrt{\frac{1.23 \times 10^3 r}{m}} = \sqrt{\frac{1.23 \times 10^3 \times 4.25 \times 10^7}{5.58 \times 10^3}} = 3.06 \times 10^3 \text{ m s}^{-1}$.

Mark allocation: 2 marks

- 1 mark for equating the centripetal force to the gravitational force on the satellite
- 1 mark for the correct answer

Question 5c.

Worked solution

Gravitational potential energy: decreases

Kinetic energy: increases

Orbital period: decreases

Explanatory notes

As the satellite's orbital radius decreases, its gravitational potential energy would decrease as well; however, its orbital speed must be greater, and so its kinetic energy increases. Increasing its speed while simultaneously decreasing its orbital radius will make it orbit Earth faster, which means that its orbital period will decrease.

Mark allocation: 3 marks

- 1 mark for each correct answer

Question 5d.

Worked solution

$3.72 \times 10^8 \text{ J}$

The difference in gravitational potential energy can be determined by examining the area under the force–distance graph, which in this case is the F_g vs R graph. The two data points used are $(4.22 \times 10^7, 1248)$ and $(4.25 \times 10^7, 1230)$.

Using the formula for the area of a trapezium, we obtain

$$A = \frac{1}{2}(a+b)h = \frac{1}{2}(1248+1230)(4.25 \times 10^7 - 4.22 \times 10^7) = 3.72 \times 10^8 \text{ J}.$$

Mark allocation: 2 marks

- 1 mark for correctly substituting the values to calculate the area under the graph
- 1 mark for the correct answer

Tip

- *You must be alert for broken or truncated axes in graphs, such as in Figure 8, as the area under a graph can be miscalculated if you overlook them.*

Question 6a.

Worked solution

upwards

Explanatory notes

Applying the right-hand push rule, the current is to the right (opposite to the direction of the electron) within a magnetic field into the page and the direction of the magnetic force will be upwards.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 6b.

Worked solution

As these particles get closer to Earth, the magnetic field strength, B, becomes stronger. Since the mass, m, the speed, v, and the charge on these particles, q, are constant, the radius of their circular paths becomes smaller, according to the formula $r = \frac{mv}{Bq}$.

Mark allocation: 3 marks

- 1 mark for noting that the magnetic field will become stronger the closer the winds get to Earth
- 1 mark for noting that the mass, speed and charge remain constant
- 1 mark for using the radius formula to explain that, under these conditions, the radius of the circular paths becomes smaller

Question 7a.

Worked solution

Magnitude: 7.6×10^{-2} N

Direction: down

$$F = nIlB = 50 \times 1.3 \times 2.5 \times 10^{-2} \times 47 \times 10^{-3} = 7.64 \times 10^{-2} \text{ N}$$

Explanatory notes

From the right-hand push rule, if the current is going into the page and the magnetic field is directed to the right, the direction of the magnetic force is down.

Mark allocation: 2 marks

- 1 mark for the correct magnitude
- 1 mark for the correct direction

Question 7b.i.

Worked solution

Yes

Explanatory notes

There will be a force on side XY because the current on that side is perpendicular to the magnetic field.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 7b.ii.

Worked solution

No

Explanatory notes

The coil will not rotate because the force on XY will not create torque (i.e. a turning force) about the coil's axis of rotation.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 8a.

Worked solution

The area of the coil is $A = (38 \times 10^{-3})^2 = 1.444 \times 10^{-3}\ \text{m}^2$. The maximum flux when the magnetic field strength is maximum is therefore $\Phi_\text{B} = BA = 0.8 \times 1.444 \times 10^{-3} = 1.155 \times 10^{-4}\ \text{Wb}$, which can be rounded to 1.16×10^{-4} Wb.

Mark allocation: 2 marks

- 1 mark for the correct area of the coil
- 1 mark for correctly substituting the values into the appropriate equation

Question 8b.

Worked solution

The rotating magnet produces a magnetic flux through the coil that changes direction every half turn. This in turn causes the induced current to change direction.

Mark allocation: 2 marks

- 1 mark for stating that the rotating magnet causes a magnetic flux through the coil that changes direction as the magnet turns
- 1 mark for connecting the changing flux to the change in direction of the induced current

Question 8c.

Worked solution

0.42 V

The period of one rotation of the coil is $T = \frac{1}{f} = \frac{1}{12} = 8.333 \times 10^{-2}$ s. Hence the duration of a quarter turn is $t = \frac{T}{4} = \frac{8.333 \times 10^{-2}}{4} = 2.083 \times 10^{-2}$ s.

The average EMF over a quarter turn is $\boldsymbol{\varepsilon} = -N\frac{\Delta\Phi_{\mathrm{B}}}{\Delta t} = -75\frac{1.16 \times 10^{-4}}{2.083 \times 10^{-2}} = 0.418$ V.

Mark allocation: 3 marks

- 1 mark for the correct period of rotation
- 1 mark for correct substitutions into the formula for EMF
- 1 mark for the correct answer

Note: one method mark for correct substitutions may be awarded even if the wrong duration of a quarter turn is used in the calculation of the average EMF (but provided that N and $\Delta\Phi_{\mathrm{B}}$ are correct). This is the only method mark allowed.

Question 9a.

Worked solution

23 W

The power output is $P = VI = 23 \times 1 = 23$ W .

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 9b.

Worked solution

series

Explanatory notes

The positive terminal of one panel is connected to the negative terminal of the next panel, in a continuous manner. This creates a series circuit.

In parallel circuits the positive terminals of every panel are connected together, and the negative terminals of every panel are also connected together.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 9c.

Worked solution

Voltage: $230\ \text{V}$

Current: $1\ \text{A}$

Explanatory notes

The output voltage is $V_{\text{bank}} = n_{\text{panel}} V_{\text{panel}} = 10 \times 23 = 230\ \text{V}$.

Since the same current flows through all the panels, the current is the same as it is for one panel, $I = 1\ \text{A}$.

Mark allocation: 2 marks

- 1 mark for each correct answer (up to 2 marks)

Question 9d.

Worked solution

Device A is an inverter.

The DC output from the bank of solar cells has to be converted into AC, as either the charger operates on AC or the step-down transformer in the charger requires AC to operate.

Mark allocation: 2 marks

- 1 mark for identifying Device A as an inverter
- 1 mark for the correct explanation of its role in the circuit

Question 9e.

Worked solution

The current will be higher.

The step-down transformer will drop the voltage from $230\ \text{V}_{\text{rms}}\ \text{AC}$ to a lower value. According to the conservation of energy, the electrical power on the primary side must equal the electrical power on the secondary side. Since $P = VI$, a decrease in voltage must result in an increase in current if overall power is to be conserved.

Mark allocation: 2 marks

- 1 mark for stating that the current will be higher, together with a reasonable attempt at explaining why the current increases
- 1 mark for the correct explanation of why the current increases

Question 10a.

Worked solution

Yes. Diffraction occurs significantly when $\frac{\lambda}{w} \approx 1$. Since in this case $\frac{\lambda}{w} = \frac{580 \times 10^{-9}}{0.45 \times 10^{-6}} = 1.29$, diffraction will be observed.

Mark allocation: 2 marks

- 1 mark for stating that significant diffraction would be expected
- 1 mark for justifying that significant diffraction would be expected, using a correct calculation

Note: a correct calculation alone is insufficient.

Question 10b.

Worked solution

Cody is correct.

Since diffraction causes image quality to deteriorate, the lower the value of $\frac{\lambda}{w}$, the better the quality.

As the wavelength of violet light is shorter than the wavelength of red light, violet light should be used.

Mark allocation: 2 marks

- 1 mark for identifying Cody as correct, together with a reasonable attempt to justify the choice
- 1 mark for the correct explanation of why violet light should be used

Question 11a.

Worked solution 1

471 THz

The photon energy of light at the frequency of 492 THz is given by
$E = hf = 4.14 \times 10^{-15} \times 492 \times 10^{12} = 0.204 \text{ eV}$.

The most energetic electrons have a kinetic energy of 0.088 eV, corresponding to the stopping voltage of 88 mV.

Since $E_{\text{k max}} = hf - \Phi = E - \Phi$ and $\Phi = hf_0$, we can rearrange and substitute to find f_0:
$f_0 = \frac{E - E_{\text{k max}}}{h} = \frac{2.04 - 0.088}{4.14 \times 10^{-15}} = 4.71 \times 10^{14} = 471 \text{ THz}$.

Mark allocation: 3 marks

- 1 mark for the correct photon energy
- 1 mark for correct substitution of the formula for work function
- 1 mark for the correct answer

Note: one method mark may be awarded if the wrong value of photon energy is used in the calculation of the cut-off frequency (provided that the values of $E_{\text{k max}}$, eV and h are correct). This is the only method mark allowed.

Worked solution 2

471 THz

The most energetic electrons have a kinetic energy given by $E_{\text{k max}} = hf - \Phi$.

Substituting the equation for the work function, $\Phi = hf_0$, we obtain $E_{\text{k max}} = hf - hf_0 = h(f - f_0)$, which can be rearranged as $f_0 = f - \frac{E_{\text{k max}}}{h}$.

Since $E_{\text{k max}}$ corresponds to the stopping voltage of 88 mV or 0.088 eV,

$$\frac{E_{\text{k max}}}{h} = \frac{0.088}{4.14 \times 10^{-15}} = 2.13 \times 10^{13} = 21.3 \text{ THz.}$$

Thus $f_0 = 492 - 21 = 471$ THz.

Mark allocation: 3 marks

- 1 mark for the correct intermediate value of 21 THz
- 1 mark for correct substitutions into the formula to calculate the intermediate value
- 1 mark for the correct answer

Note: one method mark may be awarded if the wrong intermediate value is used in the calculation of the cut-off frequency (provided that f is correct). This is the only method mark allowed.

Question 11b.

Worked solution

According to the wave model, the energy of the photons is transferred continuously to the metal sample, and this is independent of the light's frequency. Hence photoelectrons should be emitted whatever the frequency of light (provided that the light has sufficient intensity), and therefore, the model does not predict the existence of a cut-off frequency.

The particle model suggests that the energy of incident photons is quantised and is proportional to their frequency. Therefore photoelectrons should only be emitted if the incident photons have sufficient frequency, with energy greater than the work function of the metal sample. This minimum frequency is called the threshold frequency.

Mark allocation: 4 marks

- 1 mark for a correct description of the wave model energy transfer
- 1 mark for a correct explanation of why the wave model fails to explain the photoelectric effect
- 1 mark for a correct description of the quantised nature of light
- 1 mark for a correct description of how the particle model explains the cut-off frequency

Question 11c.

Worked solution

Adrian is incorrect. The photocurrent produced by the photoelectric effect is in proportion to the photoelectrons liberated by the photons. Since the number of photons emitted by the LED is related to the power of the light source, operating the LED at higher power will increase the photocurrent.

Mark allocation: 2 marks

- 1 mark for stating that Adrian is incorrect
- 1 mark for a correct explanation of the relationship between the photocurrent and light power

Question 12a.

Worked solution

Electrons initially with zero energy that are accelerated between a 500 V potential will have 500 eV of work done on them. This is equivalent to $500 \times 1.60 \times 10^{-19} = 8.0 \times 10^{-17}$ J.

Mark allocation: 1 mark

- 1 mark for correctly converting the work done from electron volts to joules

Question 12b.

Worked solution

particle model

Explanatory notes

Electrons in an electric field are better modelled as particles.

Mark allocation: 1 mark

- 1 mark for correctly identifying the model

Question 12c.

Worked solution 1

5.5×10^{-11} m

The velocity of the electrons can be calculated from the kinetic energy:

$E_\text{k} = \frac{1}{2}mv^2 = 8 \times 10^{-17}$ J, which leads to $v = \sqrt{\frac{2E_\text{k}}{m}} = \sqrt{\frac{2 \times 8 \times 10^{-17}}{9.11 \times 10^{-31}}} = 1.33 \times 10^7$ m s^{-1}.

The momentum of the electrons is $p = mv = 9.11 \times 10^{-31} \times 1.33 \times 10^7 = 1.21 \times 10^{-23}$ N s.

The de Broglie wavelength is $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{1.21 \times 10^{-23}} = 5.48 \times 10^{-11}$ m.

Mark allocation: 3 marks

- 1 mark for the correct value of kinetic energy
- 1 mark for the correct value of momentum of electrons
- 1 mark for the correct answer

Note: a maximum of one method mark may be awarded if, in either step 2 or step 3, an incorrect value from the previous step is substituted, provided that all other values are correct. This is the only method mark allowed.

Worked solution 2

5.5×10^{-11} m

The momentum of the electrons is given by

$p = \sqrt{2E_k m} = \sqrt{2 \times 8 \times 10^{-17} \times 9.11 \times 10^{-31}} = 1.21 \times 10^{-23}$ N s.

The de Broglie wavelength is $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{1.21 \times 10^{-23}} = 5.48 \times 10^{-11}$ m.

Mark allocation: 3 marks

- 1 mark for the correct formula for momentum of electrons
- 1 mark for correct value of the momentum of electrons
- 1 mark for the correct answer

Note: a method mark may be awarded if the wrong momentum is used in the final step of calculation (provided that the value of h is correct).

Tip

- *Some formulas, such as the one for calculating the momentum from the kinetic energy, are not provided in the VCAA Formula Sheet. Therefore it would be advantageous to include this formula (and other useful ones) on the A3 sheet of pre-written notes that you are permitted to take to the Physics examination.*

Question 12d.

Worked solution

2.3×10^4 eV

The wavelength of the X-rays must be the same as the de Broglie wavelength of the electrons to produce the same diffraction pattern with the same metal foil: 5.48×10^{-11} m.

The energy of the X-rays can be found from $E = \dfrac{hc}{\lambda} = \dfrac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{5.48 \times 10^{-11}} = 2.27 \times 10^4$ eV.

Mark allocation: 2 marks

- 1 mark for equating the X-ray wavelength with the de Broglie wavelength
- 1 mark for the correct answer

Tips

- *An issue that could be confusing is that X-ray energy could also be specified in electron volts (eV). This is the photon energy of the X-rays, which is given by* $E = hf = \frac{hc}{\lambda}$. *This is not the same as the accelerating voltage of the electrons used to determine the kinetic energy of electrons accelerated from rest:* $E_\text{k} = qV$.
- *It is important to note that electrons with the same momentum as photons will produce the same diffraction pattern. This is because matter particles and electromagnetic photons with the same momentum will also have the same wavelength:* $\lambda_\text{de Broglie} = \frac{h}{p} = \frac{h}{mv}$ *and* $\lambda_\text{EM} = \frac{h}{p}$.

Question 13a.

Worked solution

$\gamma = 1.52$

Explanatory notes

The length of the car in Diaz's frame of reference is $L = 3.00\ \text{m}$, whereas the length of the car in Luisa's frame of reference is $L_0 = 4.56\ \text{m}$. The Lorentz factor is $\gamma = \frac{L_0}{L} = \frac{4.56}{3.00} = 1.52$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 13b.

Worked solution

$0.753c$

Rearranging the formula for the Lorentz factor to make v the subject:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1-\frac{v^2}{c^2} = \frac{1}{\gamma^2}\ \therefore$$

$$v = c\sqrt{1-\frac{1}{\gamma^2}} = c\sqrt{1-\frac{1}{1.52^2}} = 0.753c.$$

Mark allocation: 2 marks

- 1 mark for correctly substituting into the formula the value of the Lorentz factor from **part a.**
- 1 mark for the correct answer

Note: consequential marks may be awarded for using the wrong value of the Lorentz factor derived in **part a.** to calculate the velocity. In this case, $v = c\sqrt{1-\frac{1}{\text{Ans }\mathbf{part\ a.}^2}}$.

Question 13c.

Worked solution

Luisa is correct. Length contraction is observed in the moving frame of reference, and since the drive-through is in the moving frame of reference, its observed length will be shorter than the proper length of 3.00 m.

Mark allocation: 2 marks

- 1 mark for stating that Luisa is correct, together with a reasonable attempt at explaining why she is correct
- 1 mark for explaining that length contraction is observed in the moving frame of reference and that the drive-through is in the moving frame of reference

Question 14a.

Worked solution

When an electron in an atom moves between energy levels, the atom absorbs or emits light of particular frequencies. The corresponding energy is the difference between these energy levels according to the equation $\Delta E = hf$. This suggests that light is quantised or particle-like.

On the other hand, the movement of an electron between discrete energy levels within an atom suggests that electrons exist in the form of standing waves and that the energy levels correspond to the harmonics of these waves.

Mark allocation: 3 marks

- 1 mark for relating the difference in the energy levels in electron transition with the discrete frequencies of the light absorbed or emitted
- 1 mark for stating that electrons exist as standing waves
- 1 mark for stating that the energy levels correspond to the harmonics of standing waves

Question 14b.i.

Worked solution

From $n = 4$ to $n = 3$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 14b.ii.

Worked solution

left

Explanatory notes

As this transition corresponds to the lowest difference between energy levels, ΔE, the frequency of the emitted photon will also be lower than the others shown.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 15a.

Worked solution

$\pm 5\times10^{-4}$ m

Explanatory notes

The uncertainty in the measurement is half the smallest gradation or measurement possible (which is 1 mm or 10^{-3} m). Therefore the uncertainty is $0.5\times10^{-3} = 5\times10^{-4}$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 15b.

Worked solution

The uncertainty in the stopwatch measurement is $\pm 5\times10^{-3}$ s, which is about 1% (or very small) in comparison with Priya's reaction time. Therefore her reaction time is more significant.

Mark allocation: 1 mark

- 1 mark for a correct explanation

Question 15c.

Worked solution

The uncertainty in the measurement of a time interval is a fixed value. By measuring the time interval of two oscillations and then dividing that by two, Priya and Conor could also divide the fixed amount of uncertainty between the two oscillations to obtain a smaller uncertainty. Therefore the period for one oscillation is more valid.

When they measure the time interval for one oscillation, the uncertainty in the measurement is the same for the repeated measurement. The reason for this is that when they add up the two measurements to find the average, they must also add up the uncertainty of each measurement. Hence the uncertainty in the average period is the same as the uncertainty in each measurement.

Mark allocation: 4 marks

- 1 mark for noting that the uncertainty is a fixed value
- 1 mark for noting that the uncertainty is divided among the oscillations in a single measurement in method 1, therefore reducing the uncertainty and improving validity
- 1 mark for noting that the uncertainty for each measurement in method 2 is the same
- 1 mark for noting that the averaging process does not reduce the uncertainty of a measurement

Question 15d.

Worked solution

$s^2\ kg^{-1}\ m^{-3}$

Explanatory notes

Rearranging the equation leads to $K = \frac{T^2}{mL^3}$. Therefore the units for K are $s^2\ kg^{-1}\ m^{-3}$.

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 15e.

Worked solution

$1.1\ s^2\ m^{-3}$

Taking any two points on the line of best fit (e.g., $(0.6, 0.66)$ and $(0.1, 0.11)$) and using their difference to calculate the gradient gives $\frac{0.66-0.11}{0.6-0.1} = 1.1$.

Mark allocation: 2 marks

- 1 mark for using points on the line of best fit
- 1 mark for an answer between 1.0 and 1.2

Tips

- *To calculate the gradient you must use the line of best fit that you drew. Therefore you need to select two points on that line and show your working in full.*
- *Do not calculate the gradient from two actual data points in the table.*

Question 15f.

Worked solution

$0.40\ kg$

Substituting K into the equation gives $T^2 = 2.74mL^3$.

The gradient of the graph is equivalent to $\frac{\Delta T^2}{\Delta L^3} = 2.74m$.

Taking the gradient to be 1.1 gives $m = \frac{1.1}{2.74} - 0.401\ kg$.

Mark allocation: 3 marks

- 1 mark for correctly substituting K and the gradient into the equation
- 1 mark for correctly rearranging the equation
- 1 mark for the correct answer

Note: consequential marks may be awarded if the gradient taken from **part e.** is wrong:

$m = \frac{\text{Ans } \textbf{part e.}}{2.74}$.