Neap

VCE Physics Units 3&4

Suggested Solutions

2024 Trial Examination

Section A – Multiple-choice questions

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

Question 1 B

Momentum is conserved in all collisions and so the total momentum before an inelastic collision is equal to the total momentum after the collision. Thus, $p = 0$.

In an inelastic collision, some of the initial total kinetic energy is converted to heat, sound and possibly material deformation such that the total kinetic energy before the collision is greater than the total kinetic energy after the collision. Thus, E is greater than zero.

Question 2 D

$$\begin{aligned} E_{\mathrm{s}} &= E_{\mathrm{k}} \\ \frac{1}{2}kx^2 &= \frac{1}{2}mv^2 \\ \frac{1}{2} \times k \times 0.10^2 &= \frac{1}{2} \times 0.010 \times 10^2 \\ k &= \frac{1.0}{0.010} \\ &= 100 \text{ N m}^{-1} \end{aligned}$$

Question 3 B

The impulse is represented by the area under the force, F, versus time, t, graph. Each rectangle in the graph grids has a value of $50 \times 0.02 = 1$ N s. Therefore, $\frac{5.0}{1} = 5$ rectangles are required.

Calculating the number of rectangles under each graph gives:

- graph **A**: $\frac{1}{2} \times 4 \times 4 = 8$
- graph **B**: $\frac{1}{2} \times 2 \times 5 = 5$
- graph **C**: $\frac{1}{2} \times 6 \times 5 = 15$
- graph **D**: $\frac{1}{2} \times 8 \times 4 = 16$

Therefore, **B** is correct.

Question 4 A

At the top of the loop, the normal force is zero, leaving the centripetal force to be the force due to gravity. Therefore:

$$\begin{aligned} \frac{mv^2}{r} &= mg \\ g &= \frac{v^2}{r} \\ v^2 &= gr \end{aligned}$$

Thus:

$$\begin{aligned} E_{\mathrm{k}} &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}mgR \end{aligned}$$

Question 5 C

The current-carrying loop is in an anticlockwise circle. Using the right-hand grip rule, where the thumb represents the current tangent and the curled fingers represent the magnetic field, the fingers curl into the page on the outside of the loop and outside of the page on the inside of the loop. Hence, the magnetic field is represented by crosses outside the loop and dots inside the loop.

Question 6 C

Electric field due to charge 2Q at position P:

$$\begin{aligned} E_{2\text{Q}} &= \frac{k2Q}{(2R)^2} \\ &= \frac{2kQ}{4R^2} \\ &= \frac{kQ}{2R^2} \end{aligned}$$

direction $= \longrightarrow$

Electric field due to charge Q at position P:

$$\begin{aligned} E_{\text{Q}} &= \frac{kQ}{(R)^2} \\ &= \frac{kQ}{R^2} \end{aligned}$$

direction $= \longleftarrow$

The magnitude of the electric field due to charge Q at position P is twice the magnitude of the field due to charge 2Q.

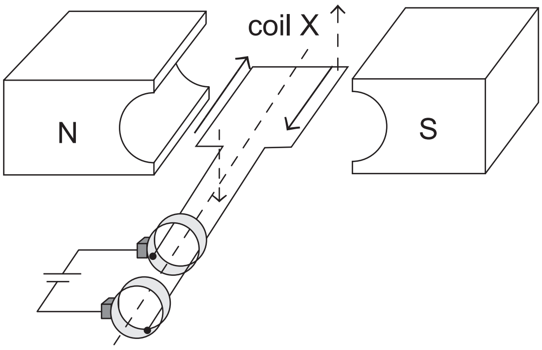
Question 7 C

Reading from the graph, the peak voltage is 2 V and the period is 2 ms. Therefore:

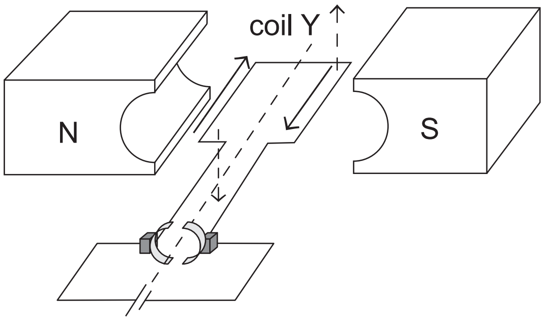
$$\begin{aligned} f &= \frac{1}{\text{period (s)}} \\ &= \frac{1}{0.002} \\ &= 500\ \text{Hz} \end{aligned}$$

Question 8 B

In both coils, the current travels in the direction of the solid arrows shown below on the sides nearest to the magnetic poles. Using the right-hand palm rule, the force acting on the coil sides nearest to the north pole will be down and the force acting on the coil sides nearest to the south pole will be up, as indicated by the dashed arrows. This causes an initial anticlockwise rotation in both coils.



Generator 1



Generator 2

Coil X uses slip rings, which preserve the direction of the current, and so the forces acting on the sides of the coil nearest to the poles do not change direction. Therefore, coil X makes a quarter-turn anticlockwise, then oscillates and comes to rest in the vertical position.

On the other hand, coil Y uses a split ring, which alternates the direction of the current relative to the coil every half-rotation cycle, and so the forces acting on the sides of the coil nearest to the poles alternate direction every half rotation. Therefore, coil Y rotates in the anticlockwise direction continuously.

Question 9 A

A is correct. Device X is an inverter, which alters the DC output voltage from the photovoltaic array to AC input voltage. Device Y is a transformer, which steps down the AC voltage from the electrical grid to an AC input voltage of 240 V RMS.

B is incorrect. Device X does not output DC, and device Y steps down the voltage from the electrical grid, assuming that the voltage from the electrical grid is greater than 240 V.

C and **D** are incorrect. These options describe device X functioning as a transformer, but device X is an inverter. These options describe device Y functioning as an inverter, but device Y is a transformer.

Question 10 D

The speed of all wavelengths of light is *c*; that is, it is constant.

Question 11 C

The third harmonic is shown, where the harmonic frequency is given by

$$f = \frac{\text{harmonic number} \times \text{wave speed}}{2 \times \text{string length}}.$$

Therefore:

$$\begin{aligned}\text{wave speed} &= \frac{2 \times f \times \text{string length}}{\text{harmonic number}} \\ &= \frac{2 \times 935 \times 0.65}{3} \\ &= 405\ \text{m s}^{-1}\end{aligned}$$

Question 12 C

C is correct. The two images appear as one because the light that passes each object has a large enough $\frac{\lambda}{w}$ ratio (at least 0.1) to cause diffraction. Diffraction forms bright and dark bands that overlap, producing a blurred overall image.

A and **B** are incorrect. A large distance between the objects would cause a greater separation of the images, possibly resulting in two distinct images.

D is incorrect. A small $\frac{\lambda}{w}$ ratio would reduce diffraction, possibly resulting in two distinct images.

Question 13 B

Given that the spreads of the diffraction patterns are the same for both beams on the same surface, the electrons have the same de Broglie wavelength as the X-rays. Therefore:

$$\lambda = \frac{h}{p}$$

$$\lambda = \frac{h}{mv}$$

$$\begin{aligned}v &= \frac{h}{\mathrm{m}\lambda} \\ &= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 0.154 \times 10^{-9}} \\ &= 4.73 \times 10^{6}\ \text{m s}^{-1}\end{aligned}$$

Question 14 B

The electrons strike the screen at multiple, specific positions. Given that the electrons strike the screen at more positions than there are slits, the electrons are behaving in a wave-like nature, constructively interfering with themselves. However, given that the electrons strike the screen at specific positions, the electrons also display particle-like behaviour.

Question 15 B

B is correct. The purpose of the Michelson–Morley experiment was to measure the speed of light on Earth at different times of the year where the Earth moved in two positions tangentially at right angles to each other. It was expected that Earth was moving through a material medium called the aether, which would result in different values of the speed of light for these positions. However, the experiment showed that the speed of light values were not significantly different for the two positions and so the result was declared null.

A is incorrect. The non-existence of the aether was implied by the result of the experiment but was not the result itself.

C is incorrect. This statement is false and was not the result of the Michelson–Morley experiment.

D is incorrect. Einstein postulated this statement from the analysis of the null result of the Michelson–Morley experiment.

Question 16 C

$$
\begin{aligned}
L &= \frac{L_0}{\gamma} \\
&= \frac{L_0}{\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}} \\
&= L_0 \times \sqrt{1-\frac{v^2}{c^2}} \\
&= 120 \times \sqrt{1-\frac{(0.80c)^2}{c^2}} \\
&= 120 \times \sqrt{1-0.80^2} \\
&= 72 \text{ m}
\end{aligned}
$$

Question 17 A

A is correct. Blue light has a higher frequency than red light and so a photon of blue light is more energetic than a photon of red light. Thus, given that $V_{\text{stopping}} = \frac{hf - \phi}{q}$ (where h (Planck's constant), ϕ (the metal's work function) and q (the electronic charge) are constant), the stopping voltage (the x-axis intercept) depends on the photon frequency only. Thus, the stopping voltage of blue light is greater than that of red light, resulting in a curve that begins to the left of the red-light curve.

Given that the blue light is more intense than the red light, more of its photons strike the metal surface, releasing more electrons proportionally. This results in a greater plateau current for the blue light on the right-hand side of the graph.

B is incorrect. This graph indicates that the blue light has less energy per photon and lower intensity than the red light.

C is incorrect. This graph indicates that the blue light has the same intensity as the red light.

D is incorrect. This graph indicates that the blue light has less energy per photon than the red light but the same intensity as the red light.

Question 18 C

The spread of the diffraction pattern is directly proportional to the wavelength of the colour. Green light has a greater frequency than orange light and so it has a shorter wavelength. Thus, the maxima in intensity (peaks) for green light are closer together in the horizontal plane than those for orange light.

Question 19 D

The energy produced is the result of the mass difference between the products and the reactants, with the mass of the reactants being greater than the mass of the products. The difference in mass is then multiplied by c^2 to convert the value to energy. Hence, the energy produced by the fusion reaction is given by $\left(2m_{\text{He-3}} - m_{\text{He-4}} - 2m_p\right)c^2$.

Question 20 A

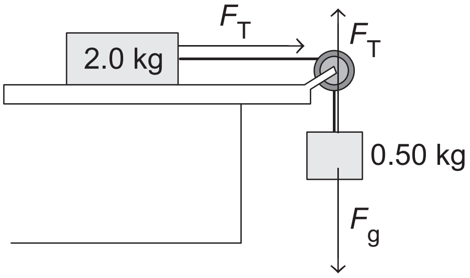
The measurement error is the difference between the reading and the true value. In this case, that is 9.50 – 8.50 = 1.00 cm.

The uncertainty is an acceptable range of variation of a reading based on the scale of the measuring instrument. This is usually half of the smallest division. In this case, as the smallest division is 0.10 cm, then the uncertainty is ±0.05 cm.

Section B

Question 1 (4 marks)

a. The diagram below shows the forces acting on the blocks.



The only force acting on the 2.0 kg block is tension, F_T, which is, therefore, the net force. Applying Newton's second law to the 2.0 kg block gives:

$$F_T = ma$$
$$= 2.0a \qquad \text{(equation 1)}$$

The forces acting on the 0.50 kg block are F_T and the force due to gravity, F_g. Applying Newton's second law to the 0.50 kg block gives:

$$F_g - F_T = ma$$
$$F_g - F_T = 0.50a$$
$$0.50 \times 9.81 - F_T = 0.50 \times a \qquad \text{(equation 2)}$$

Adding the right-hand sides and left-hand sides of equation 1 and equation 2 gives:

$$F_T + 0.50 \times 9.81 - F_T = 2.0a + 0.50a$$ 1 mark

$$0.50 \times 9.81 = 2.5a$$

$$a = \frac{0.50 \times 9.81}{2.5}$$ 1 mark

$$= 1.96 \text{ m s}^{-2}$$

b. **Method 1:**

$$F_{net} = F_T$$ 1 mark

$$= ma$$
$$= 2.0 \times 1.96$$
$$= 3.9 \text{ N}$$ 1 mark

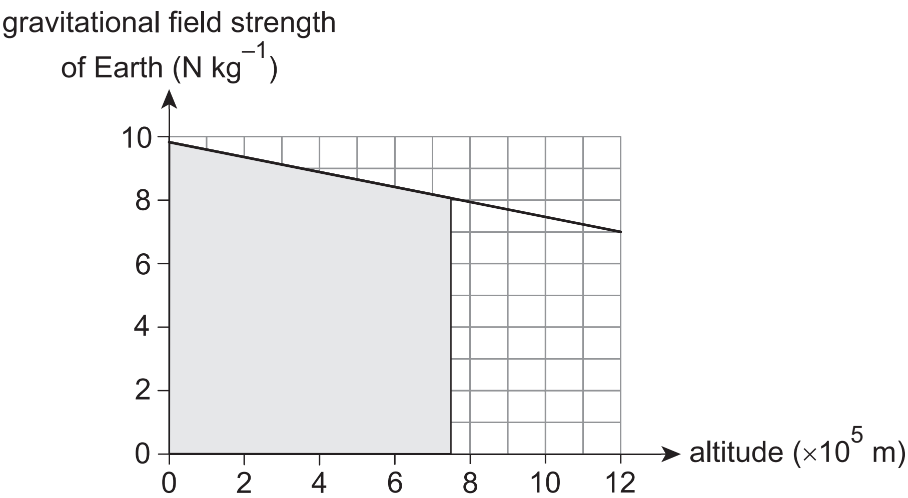
Method 2:

$$F_{net} = F_T$$
$$F_g - F_T = ma$$
$$F_T = F_g - (0.50 \times 1.96)$$
$$= (0.50 \times 9.81) - (0.50 \times 1.96)$$ 1 mark
$$= 3.9 \text{ N}$$ 1 mark

Question 2 (7 marks)

a. **Method 1:**

The minimum energy required per kilogram is represented by the area under the graph from the surface of Earth to the altitude of 7.50×10^5 m.



$$A_{\text{trapezium}} = \left(\frac{9.80 + 8.00}{2}\right) \times 7.50 \times 10^5$$ 1 mark

$$= 6.675 \times 10^6$$

$$E_{\text{minimum required}} = m_{\text{rocket}} \times A_{\text{trapezium}}$$

$$= 5.00 \times 10^5 \times 6.675 \times 10^6$$ 1 mark

$$= 3.34 \times 10^{12}\ \text{J}$$ 1 mark

Note: Award a maximum of 2 marks if the response uses an incorrect area.

Method 2:

$$E_{\text{minimum required}} = m_{\text{rocket}} \times A_{\text{under graph}}$$

$$= m_{\text{rocket}} \times \text{number of squares} \times A_{\text{one square}}$$

$$= 5.00 \times 10^5 \times 66.75 \times \left(1 \times 1 \times 10^5\right)$$ 1 mark

$$= 5.00 \times 10^5 \times 6.675 \times 10^6$$ 1 mark

$$= 3.34 \times 10^{12}\ \text{J}$$ 1 mark

b. $\dfrac{R_{\text{orbit}}{}^3}{T_{\text{orbit}}{}^2} = \dfrac{GM_{\text{E}}}{4\pi^2}$

Determining the radius of the orbit gives:

$$R_{\text{orbit}} = R_{\text{E}} + \text{altitude}$$
$$= 6.37 \times 10^6 + 7.50 \times 10^5$$
$$= 7.12 \times 10^6 \text{ m}$$ 1 mark

$$T_{\text{orbit}}{}^2 = \frac{4\pi^2 \times R_{\text{orbit}}{}^3}{GM_{\text{E}}}$$

$$T_{\text{orbit}}{}^2 = \frac{4\pi^2 \times (7.12 \times 10^6)^3}{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}$$ 1 mark

$$T_{\text{orbit}}{}^2 = 3.57\ldots \times 10^7$$

$$T_{\text{orbit}} = \sqrt{3.57\ldots \times 10^7}$$ 1 mark

$$= 5.98 \times 10^3 \text{ s}$$ 1 mark

Note: Award a maximum of 2 marks if the response uses an incorrect radius of the orbit.

Question 3 (5 marks)

a. Force of attraction is given by Newton's law of universal gravitation.

$$F_{\text{attraction}} = G\frac{m_{\text{Mars}}m_{\text{Phobos}}}{r^2}$$

$$= 6.67 \times 10^{-11} \times \frac{6.42 \times 10^{23} \times 1.07 \times 10^{16}}{(5.99 \times 10^6)^2}$$ 1 mark

$$= 1.28 \times 10^{16} \text{ N}$$ 1 mark

b. $F = \dfrac{mv^2}{r}$

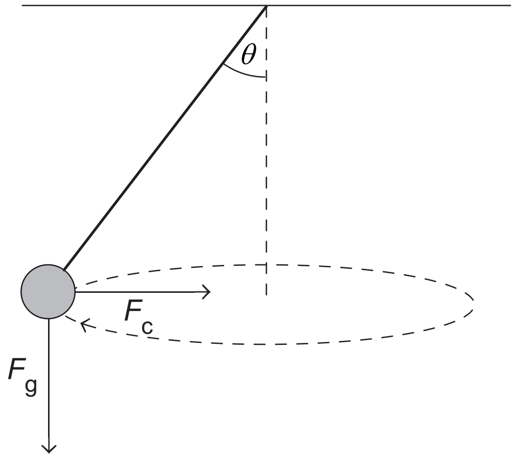
$$v = \sqrt{\frac{Fr}{m}}$$ 1 mark

$$= \sqrt{\frac{1.28 \times 10^{16} \times 5.99 \times 10^6}{1.07 \times 10^{16}}}$$ 1 mark

$$= 2.68 \times 10^3 \text{ m s}^{-1}$$ 1 mark

Note: Consequential on answer to ***Question 3a.***

Question 4 (3 marks)
The forces acting on the ball are shown in the diagram below.



Horizontally, the ball undergoes circular motion and experiences a centripetal force, F_c, due to the horizontal component of the tension. The vertical component of the tension in the string is balanced by the force due to gravity, F_g, acting on the ball. Therefore, $F_T = \sqrt{F_c{}^2 + F_g{}^2}$.

Hence:

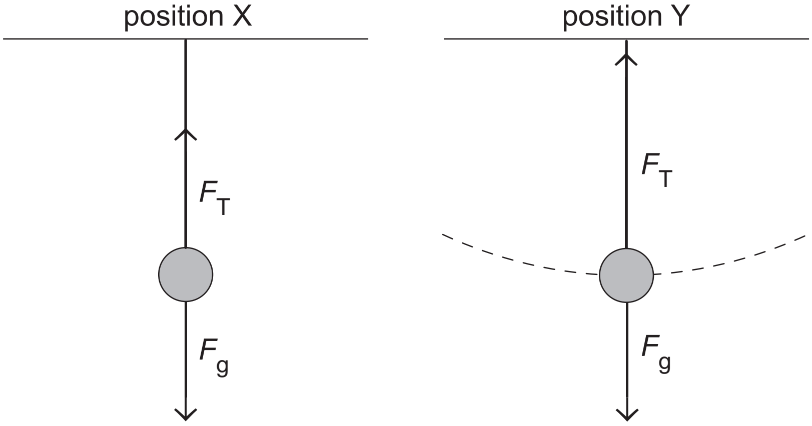
$$F_T \times \sin(\theta) = F_c$$
$$= \frac{mv^2}{r}$$
$$= \frac{0.200 \times 1.96^2}{0.500}$$
$$= 1.53664\ \text{N}$$ 1 mark

$$F_T \times \cos(\theta) = F_g$$
$$= mg$$
$$= 0.200 \times 9.81$$
$$= 1.962$$

$$F_T = \sqrt{1.53\ldots^2 + 1.962^2}$$ 1 mark
$$= 2.49\ \text{N}$$ 1 mark

Question 5 (3 marks)

In both positions, the ball has two vertical forces acting on it: the upward tension (F_T) in the string and the downward force due to gravity (F_g), as shown in the diagram below.



In position X, there is no net force acting on the ball because the ball is stationary. Thus, the tension force equals the force due to gravity acting on the ball. 1 mark

In position Y, there is a net centripetal force towards the centre of the circular arc as the ball undergoes circular motion. Thus, the tension force is greater than the force due to gravity acting on the ball. 1 mark

Hence, the tension in the string when the ball is in position Y is greater than when the ball is in position X. 1 mark

Question 6 (5 marks)

a. The vertical distance travelled by the cork can be considered as vertical displacement, taking its upwards motion as positive values. When the cork is at the peak of its arc:

- $V_{top} = 0$
- $t = 0.80$ s
- $g = -9.81$ m s^{-2}

Method 1:

$$s_{vertical} = V_{top}t - \frac{1}{2}gt^2$$

$$= 0 \times 0.80 - \frac{1}{2} \times 9.81 \times 0.80^2 \quad \text{1 mark}$$

$$= 3.1392 \text{ m} \quad \text{1 mark}$$

maximum height above the floor $= 3.1392 + 1.2$

$= 4.3$ m 1 mark

Method 2:

$$0 = u - 9.81 \times 0.8$$

$$u = 7.848 \text{ m s}^{-1} \quad \text{1 mark}$$

$$s = \frac{u^2}{2g}$$

$$= \frac{7.848^2}{2 \times 9.81}$$

$$= 3.1392 \text{ m} \quad \text{1 mark}$$

maximum height above the floor $= 3.1392 + 1.2$

$= 4.3$ m 1 mark

b. $E_{\text{k gained}} = \text{loss of potential energy}$

$= mgs_{\text{vertical}}$

$= 0.010 \times 9.81 \times 1.2$ 1 mark

$= 0.12\,\text{J}$ 1 mark

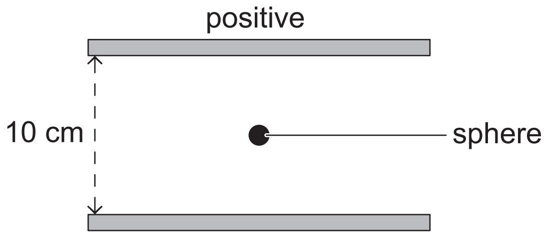
Question 7 (5 marks)

a. $E = \dfrac{V}{d}$

$= \dfrac{2.0 \times 10^3}{0.10}$ 1 mark

$= 2.0 \times 10^4\ \text{N C}^{-1}$ 1 mark

b.



1 mark

Note: For the sphere to be stationary, it must have a net force of zero. Given that the force due to gravity acting on the sphere is down, the electric force acting on the sphere must be upwards. Hence, the electric field is downwards, meaning that the upper plate is positive.

c. $mg = qE$

$m = \dfrac{qE}{g}$

$= \dfrac{5.00 \times 10^{-6} \times 2.0 \times 10^4}{9.81}$ 1 mark

$= 0.010\,\text{kg}$ 1 mark

Note: Consequential on answer to ***Question 7a.***

Question 8 (3 marks)

The coil rotates if there is a net torque.

The forces on sides *EF* and *GH* are required to exist in opposite directions to maintain the same rotation direction/torque. 1 mark

In order for the forces to sum to zero, they must be equal in value. 1 mark

The values of the forces are given by:
number of turns × magnetic field strength × current × side length

These quantities are the same for sides *EF* and *GH*. Therefore, *EF* and *GH* have the same value, making them equal. 1 mark

Question 9 (3 marks)

a. The charges in path B could have greater mass than those in path A. 1 mark

Path B has charges of smaller value than path A. 1 mark

Note: The force acting on the charges is the magnetic force, which results in circular motion. Considering $\frac{mv^2}{r} = qvB$, *where r is the radius of the arc,* $r = \frac{mv}{qB}$. *The magnetic field, B, is the same for both paths and the charges are travelling at the same speed. Therefore, there are two factors that could have resulted in path B having a greater radius than path A: m and q.*

b. into the page 1 mark

Note: Using the right-hand palm rule, the positive charges are moving downwards (represented by the thumb) and the force is to the right (represented by the force out of the palm). Therefore, the fingers point into the page.

Question 10 (10 marks)

a. $\Phi_B = B_{\perp}A$

$= 0.10 \times 0.10^2$ 1 mark

$= 1.0 \times 10^{-3}$ Wb 1 mark

Note: Award 1 mark only if the response includes the number of turns in the calculation.

b. A rotation rate of 1.0 Hz implies one rotation occurs in 1.0 s. Therefore:

quarter of a full rotation from the starting position = 0.25 s 1 mark

The magnitude of the flux at 0.25 s from the starting position is 0 Wb.

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

$$= -10 \times \frac{0 - 1.0 \times 10^{-3}}{0.25}$$ 1 mark

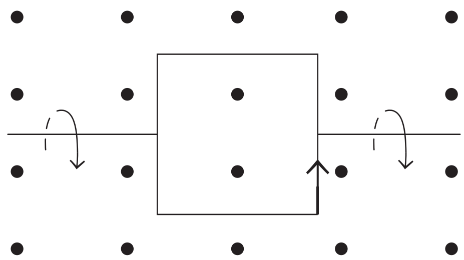
$$= 0.040 \text{ V}$$ 1 mark

*Note: Consequential on answer to **Question 10a.***

c. A new rotation rate of four times the original rate implies that the same change in flux occurs in one quarter of the original time. 1 mark

Given that EMF is dependent on the rate of flux change, the new EMF value would be four times 0.040 V. 1 mark

d.



1 mark

As the coil rotates from the position shown, the exposed area decreases and, therefore, the external magnetic flux through the coil decreases. 1 mark

According to Lenz's law, the coil will provide its own (induced) flux to oppose the difference. Given that the external flux is out of the page and diminishing, and the difference is into the page, the induced flux compensates for the loss by being directed out of the page. 1 mark

Note: Using the right-hand grip rule, the fingers point in the direction of the induced flux, and the thumb points in the direction of the induced current. Therefore, the direction of the induced current is anticlockwise.

Question 11 (5 marks)
The voltage at the food centre needs to be determined. Power and voltage reduce as electricity transmits from the generator to the food centre.

During the busiest period, the generator supplies a current of 40 A to the primary coil of T_1. Therefore, the voltage of the secondary coil of T_1 is:

$$\frac{V_{T_1\text{ secondary}}}{V_{T_1\text{ primary}}} = \frac{N_{T_1\text{ secondary}}}{N_{T_1\text{ primary}}}$$

$$\begin{aligned}V_{T_1\text{ secondary}} &= \frac{N_{T_1\text{ secondary}}}{N_{T_1\text{ primary}}} \times V_{T_1\text{ primary}}\\ &= \frac{5}{1} \times 240\\ &= 1200\text{ V}\end{aligned}$$

1 mark

Current in the transmission line:

$$\frac{I_{\text{secondary}}}{I_{\text{primary}}} = \frac{N_{T_1\text{ primary}}}{N_{T_1\text{ secondary}}}$$

$$\begin{aligned}I_{\text{secondary}} &= \frac{N_{T_1\text{ primary}}}{N_{T_1\text{ secondary}}} \times I_{\text{primary}}\\ &= \frac{1}{5} \times 40\\ &= 8.0\text{ A}\end{aligned}$$

1 mark

Voltage of the primary coil of T_2:

$$\begin{aligned}V_{T_2\text{ primary}} &= V_{T_1\text{ secondary}} - I_{\text{line}} \times R_{\text{line}}\\ &= 1200 - 8.0 \times 8.0\\ &= 1136\text{ V}\end{aligned}$$

1 mark

Voltage of the secondary coil of T_2:

$$\begin{aligned}V_{T_2\text{ secondary}} &= \frac{N_{T_2\text{ secondary}}}{N_{T_2\text{ primary}}} \times V_{T_2\text{ primary}}\\ &= \frac{1}{5} \times 1136\\ &= 227.2\text{ V}\end{aligned}$$

1 mark

Therefore, the appliances will be operational as the voltage supply surpasses the 220 V minimum. 1 mark

Question 12 (9 marks)

a. white 1 mark

Position P is at the centre of the screen. All colours of light have a central band of constructive interference for a zero path difference; therefore, they all have a central coloured band *(that is, at position P)*. 1 mark

As all the colours converge on position P, they combine to form a band of white light. 1 mark

b. The spectrum shows a collection of equally spaced, coloured bands that can only be explained by the constructive and destructive interference of waves as they pass through the two slits. 1 mark

Each of the seven-coloured bands are at different positions due to their different wavelengths, requiring constructive interference at their relative positions. 1 mark

Thus, this indicates that the nature of light is wave-like. 1 mark

c. The position of a coloured band is given by $\Delta x = \frac{\lambda L}{d}$. Therefore:

$$x = \frac{\lambda_{\text{red}} L}{d} - \frac{\lambda_{\text{violet}} L}{d}$$ 1 mark

$$= \frac{663 \times 10^{-9} \times 3.00}{200 \times 10^{-6}} - \frac{405 \times 10^{-9} \times 3.00}{200 \times 10^{-6}}$$ 1 mark

$$= 3.87 \times 10^{-3} \text{ m}$$ 1 mark

Question 13 (10 marks)

a. The wave model relates the amplitude of a wave to its energy and intensity. For a variable intensity and the same light colour (frequency), the wave model predicts that light should pass different amounts of energy to electrons. 1 mark

If this were the case, a different stopping voltage would be recorded for different incident intensities because the photoelectrons would have varying kinetic energies. 1 mark

The data of experiment A does not reflect this; thus, the wave model fails to account for the photoelectric effect. 1 mark

b. Increasing the intensity would increase the number of photons per second irradiating the photocathode plate. 1 mark

Given that electrons absorb one photon each, doubling the intensity would double the number of photoelectrons released without any change to their energy or to the associated stopping voltage. 1 mark

The measured current refers to the amount of charge moving per second; therefore, the circuit current results would be approximately double. 1 mark

c. **Method 1:**

$\phi = hf_{\text{critical}}$, where:

- $h = 4.14 \times 10^{-15}$ eV s
- f_{critical} is the frequency intercept of 3.9×10^{14} Hz.

$\phi = 4.14 \times 10^{-15} \times 3.9 \times 10^{14}$ 1 mark

$= 1.6$ eV 1 mark

Method 2:

$\phi = hf - qV_{\text{stopping}}$, where:

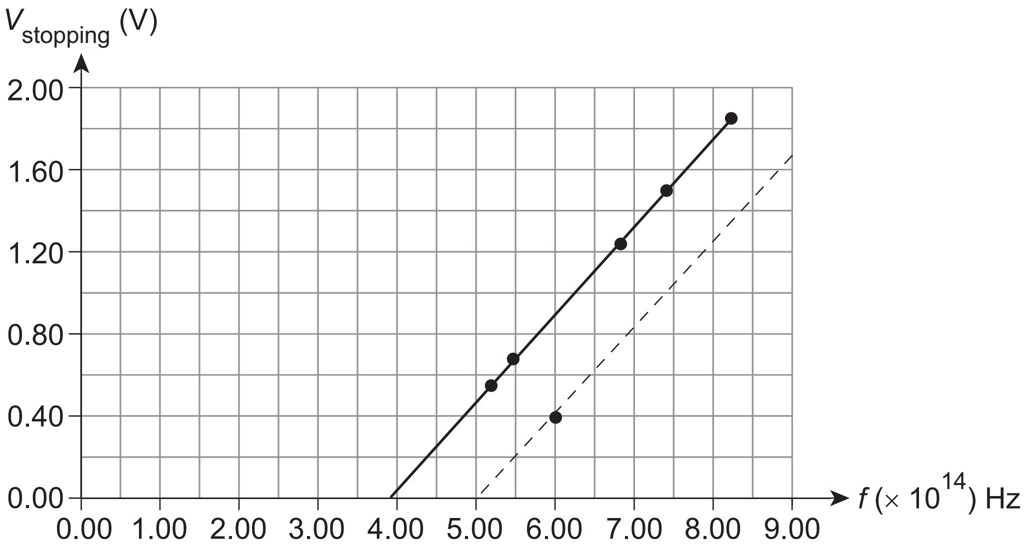
- $q = 1$ C
- $h = 4.14 \times 10^{-15}$ eVs
- V_{stopping} and f = data point pair (for example, $f = 6.88 \times 10^{14}$ with $V_{\text{stopping}} = 1.25$ V)

$\phi = 4.14 \times 10^{-15} \times 6.88 \times 10^{14} - 1 \times 1.25$ 1 mark

$= 2.84832 - 1.25$

$= 1.6$ eV 1 mark

d.



2 marks

1 mark for plotting the coordinate (0.40, 6.00).

1 mark for sketching a line with a gradient that is the same as the data from experiment B.

Note: The data is collinear and has the same gradient as the data from experiment B because the gradient represents Planck's constant and is independent of the type of metal used for the photocathode.

Question 14 (5 marks)

a. $\lambda = \dfrac{h}{p}$

$= \dfrac{h}{mv}$

$= \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.36 \times 10^{6}}$ 1 mark

$= 1.67 \times 10^{-10}$ m 1 mark

b. The reflected electrons of both beams meet at position A, with the electrons reflected from atom 2 having travelled an extra distance of 3.34×10^{-10} m. This is the path difference. 1 mark

The electrons' de Broglie wavelength indicates that the electrons display wave behaviour in their interaction with each other.

$n = \dfrac{\text{path difference}}{\lambda} = \dfrac{3.34 \times 10^{-10}}{1.67 \times 10^{-10}} = 2$ 1 mark

This indicates that the electrons constructively interfere with each other at position A due to their wave nature, leaving a trace on the screen. 1 mark

Question 15 (4 marks)

a. $E = 3.75 - 3.61$

$= 0.14$ eV

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

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

$= \dfrac{4.14 \times 10^{-15} \times 3.00 \times 10^{8}}{0.14}$ 1 mark

$= 8.87 \times 10^{-6}$ m 1 mark

Note: When electrons transition from higher energy levels to lower energy levels, they emit the difference in energy in the form of light. The longest wavelength is for light of the lowest frequency, which is emitted where there is the smallest difference between the energy levels. For a sodium atom, the smallest difference occurs when an electron transitions from $n = 5$ to $n = 4$ level. The 3.91 eV level is disregarded because electrons do not reside there as a fixed level but rather it is an energy edge after which electrons are liberated from the atom.

b. Quantisation refers to the existence of specific or discrete orbits in which electrons exist in an atom, such as a sodium atom. 1 mark

The electrons of a sodium atom can only have energies that correspond to the specific orbits of the atom and cannot exist in energy levels between the orbits. Hence, the energy levels of the atom are quantised. 1 mark

Question 16 (7 marks)

a. According to an observer on Earth, the time of existence for a muon is dilated. Thus, the distance travelled by muons is given by speed × dilated time.

$t = \gamma t_0$

$= 7.09 \times 2.2 \times 10^{-6}$

$= 1.5598 \times 10^{-5}$ s 1 mark

Therefore, the distance travelled by muons according to the observer is:

distance = speed × dilated time

$= 0.99 \times 3.00 \times 10^{8} \times 1.5598 \times 10^{-5}$ 1 mark

$= 4.6 \times 10^{3}$ m 1 mark

b. Given that muons travel at close to the speed of light, the observation of time passing according to the observer on Earth is greater and so the distance that muons travel according to the observer is greater than 650 m. 1 mark

The two distances are consistent with each other in the relativistic sense as muons experience the shorter distance as a length contraction of the distance moving past them. Equivalently, the observer experiences the muons travelling for longer due to time dilation and, therefore, further than the distance in the muon's frame of reference. 1 mark

c. $E_{total} = \gamma mc^2$

$= 7.09 \times 106$ 1 mark

$= 752$ MeV 1 mark

Question 17 (12 marks)

a.

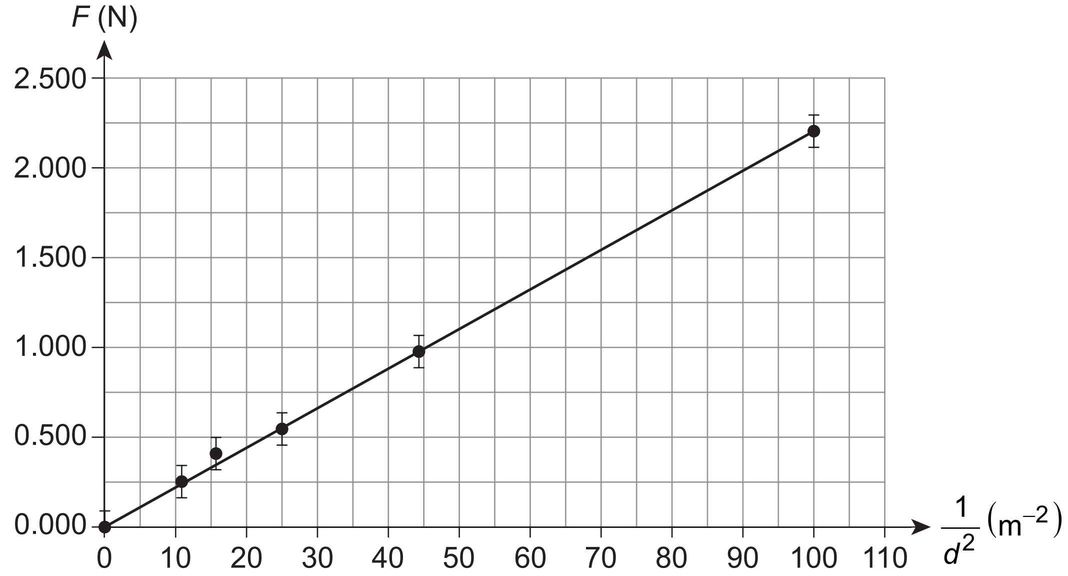
d (m)	F (N)	$\frac{1}{d^2}\left(\mathrm{m}^{-2}\right)$
0.100	2.20	100
0.150	0.96	**44**
0.200	0.55	**25**
0.250	0.40	**16**
0.300	0.25	**11**

1 mark

1 mark for at least three correct values.

Note: Award 0 marks if two or fewer values are correct. Responses are not required to show consistent significant figures to obtain full marks.

b.



6 marks

*1 mark for plotting the data points from **part a.***
1 mark for plotting the point (0,0).
1 mark for using an appropriate scale on the vertical.
1 mark for using an appropriate scale on the horizontal axis.
1 mark for including uncertainty bars for at least three points.
1 mark for drawing a straight line of best fit.
*Note: Consequential on answer to **Question 17a.***

c. *For example, using (0, 0) and (100, 2.20):*

$$\text{gradient} = \frac{\text{rise}}{\text{run}}$$ 1 mark

$$= \frac{2.20 - 0}{100 - 0}$$

$$= 2.20 \times 10^{-2}\ \text{N m}^{-2}$$ 1 mark

*Note: Responses must be given to three significant figures to obtain full marks. Accept values in the range 2.00×10^{-2}–2.50×10^{-2} N m^{-2}. Consequential on answer to **Question 17b.***

d. Coulomb's law relates the distance between the spheres and the charge values with the force acting.

$$F = \frac{kq_{\text{fixed}}q_{\text{test}}}{d^2}$$
$$= \frac{\text{gradient}}{d^2}$$

Therefore:

$$\text{gradient} = kq_{\text{fixed}}q_{\text{test}}$$ 1 mark

$$q_{\text{test}} = \frac{\text{gradient}}{kq_{\text{fixed}}}$$
$$= \frac{2.20 \times 10^{-2}}{8.99 \times 10^9 \times 1.0 \times 10^{-6}}$$ 1 mark

$$= 2.4 \times 10^{-6}\text{ C}$$ 1 mark

*Note: Accept values in the range 2.2 × 10^{-6}–2.8 × 10^{-6} C. Consequential on answer to **Question 17c.** Award 1 mark only if a response is within the accepted range but achieved without using the gradient in the application of Coulomb's law.*