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YEAR 12 *Trial Exam Paper*

2019

PHYSICS

Written examination

Worked solutions

This book contains:

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

SECTION A – Multiple-choice questions

Question 1

Answer: B

Explanatory notes

The uniform electric field exerts a constant force in the downward direction, resulting in a parabolic path. This parabolic path is like that of projectile motion due to the constant, downward gravitational force.

The uniform magnetic field exerts a constant force perpendicular to the path of the particle, resulting in a circular path. This circular path is like that of uniform circular motion due to a centripetal force that acts perpendicular to the direction of motion.

Question 2

Answer: B

Explanatory notes

The magnitude of the force between an alpha particle and an electron is given by

$F = \frac{kq_1q_2}{r^2} = \frac{8.99 \times 10^9 \times 2 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{(5 \times 10^{-6})^2} = 1.84 \times 10^{-17}$ N.

Tip

- *Remember to square the distance between the two charges when calculating the magnitude of the force.*

Question 3

Answer: C

Explanatory notes

Due to the inverse square law, the electric field around an electric charge is not uniform in space. The magnitude of the force does not change in time, and so it is constant. Since the particle is stationary in deep space, the electric field is also static.

Question 4

Answer: C

Explanatory notes

The magnitude of the magnetic force on a current-carrying wire is given by $F = nIlB$.

Hence, the magnetic field strength is $B = \frac{F}{nIl} = \frac{3.7 \times 10^{-3}}{10 \times 0.70 \times 0.45} = 1.17 \times 10^{-3}$ T.

Question 5

Answer: C

Explanatory notes

The gravitational potential is given by $g = \frac{GM_E}{{R_E}^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(6.38 \times 10^6)^2} = 9.80$ N kg^{-1}.

Question 6

Answer: C

Explanatory notes

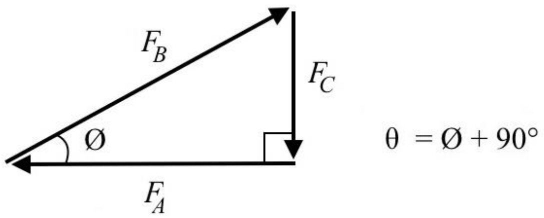
On a distance–time graph, acceleration is represented by a parabola, and zero speed is represented by a horizontal line.

Question 7

Answer: A

Explanatory notes

The three forces may be arranged in a vector diagram as a right-angled triangle, because forces that result in zero net force form a closed shape.



The angle θ is the sum of 90°and Ø, the angle between F_A and F_B.

$\varnothing = \cos^{-1}\frac{F_A}{F_B} = \cos^{-1}\frac{12}{13} = 22.62°$

$\theta = 90° + 22.62° = 112.6°$

Question 8

Answer: B

Explanatory notes

Since both satellites are at the same altitude, they share a common orbital period. Hence, they must be orbiting at the same speed. It is not necessary for them to share the same orbital path. Their orbital period does not depend on their mass. Their relative masses do not affect their relative speeds.

Tip

- *In satellite motion, the orbital period is independent of the mass of the satellite. The orbital period and the orbital radius are connected via the satellite equation,* $\frac{R^3}{T^2} = \frac{GM_{central}}{4\pi^2}$.

Question 9

Answer: C

Explanatory notes

The tension of the rope is providing the centripetal force that enables the ball to execute uniform circular motion. This tension force cannot exceed the breaking strength of the rope; hence, $F_c \leq 750$ N.

Since $F_c = \frac{mv^2}{r}$, then $v = \sqrt{\frac{F_c r}{m}} = \sqrt{\frac{750 \times 2.3}{12}} = 12.0$ m s^{-1}.

Question 10

Answer: B

Explanatory notes

Decreasing the radius while maintaining the same speed requires a higher centripetal force to maintain the circular motion. The higher centripetal force will exceed the breaking strength of the rope, causing it to break. Each of the other options results in the ball requiring a lower centripetal force.

Question 11

Answer: C

Explanatory notes

Option A is incorrect because the total energy of the mass is maximum at zero extension, but reduces to zero at maximum extension because gravitational potential energy is zero and kinetic energy is also zero.

Options B and D are incorrect because the kinetic energy of the mass (which is also the same as the kinetic energy of the system) is maximum halfway between zero and maximum extension.

This means that Option C is the correct option.

Tip

- *Be careful to distinguish between the 'total energy of the system' and the 'total energy of the mass', as the system energy is the sum of the mass energy and the spring energy; that is,* $E_{system} = E_{mass} + E_{spring}$.

Question 12

Answer: A

Explanatory notes

Only the frequency of the laser has not changed. The intensity is reduced slightly due to partial reflection at the interface between air and glass. The speed and wavelength are also reduced, giving rise to refraction.

Question 13

Answer: D

Explanatory notes

The fringe spacing of the interference pattern is given by $\Delta x = \frac{\lambda L}{d}$.

Thus, the wavelength of the laser is

$\lambda = \frac{\Delta x d}{L} = \frac{3.1 \times 10^{-3} \times 250 \times 10^{-6}}{1.912} = 4.05 \times 10^{-7}$ m = 405 nm.

Question 14

Answer: D

Explanatory notes

The uncertainty in each of the quantities provided is half of the least significant figure of each quantity.

Quantity	Value	Uncertainty	% Uncertainty
Δx	3.1 mm	0.05 mm	$\frac{0.05}{3.1} \times 100 = 1.61\%$
L	1.912 m	0.0005 m	$\frac{0.0005}{1.912} \times 100 = 0.03\%$
d	250 μm	0.5 μm	$\frac{0.5}{250} \times 100 = 0.20\%$

As the wavelength is the product and quotient of the three quantities, the uncertainty of the wavelength is the sum of all the percentage uncertainties: 1.61 + 0.03 + 0.20 = 1.84%.

Question 15

Answer: A

Explanatory notes

In terms of an electron’s frame of reference, as the electron speeds up from rest to nearly the speed of light, the length of the stationary ruler, as observed by the electron, contracts from 1 m to nearly zero.

The observed length, L, is related to the proper length, L_0, by $L = \frac{L_0}{\gamma}$. Since relativistic effects are low when the speed of the electron is low, there is little change in L initially. As γ increases from 1 (when the speed of the electron is zero) towards infinity (when the speed of the electron is close to the speed of light), the observed length of the ruler will contract towards zero.

Question 16

Answer: C

Explanatory notes

The energy, in joules, of the electrons that is needed to be converted is
$E_{\mathrm{k}} = qV = 1.6 \times 10^{-19} \times 36 = 5.76 \times 10^{-18}$ J.

The de Broglie wavelength of the electrons is
$\lambda = \frac{h}{\sqrt{2m_{\mathrm{e}}E_{\mathrm{k}}}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 5.76 \times 10^{-18}}} = 2.05 \times 10^{-10}$ m.

Tip

- *This formula for the de Broglie wavelength is not on the formula sheet; thus, it would be useful to memorise. It may be derived from the kinetic energy of the body,* $E_{\mathrm{k}} = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2E_{\mathrm{k}}}{m}}$*. Since* $\lambda = \frac{h}{p} = \frac{h}{mv}$*, substituting for v will yield* $\lambda = \frac{h}{m\sqrt{\frac{2E_{\mathrm{k}}}{m}}} = \frac{h}{\sqrt{2mE_{\mathrm{k}}}}$.

Question 17

Answer: C

Explanatory notes

If a higher frequency light source is used, it would increase the rate of photoelectrons being liberated from the metal; thus, the magnitude of the photocurrent would increase.

Question 18

Answer: D

Explanatory notes

The discrete nature of the harmonics of standing waves; that is, n = 1, 2, 3, … helps explain how electrons orbit as matter waves at discrete energy levels. When electrons transition between energy levels, energy in the form of light is emitted, with the differences between these energy levels corresponding to the light frequency according to the equation $\Delta E = hf_{\mathrm{emitted}}$.

Question 19

Answer: B

Explanatory notes

Systematic errors are due to faults in the apparatus and equipment, and cannot be reduced by making repeated measurements and taking the average value of all measurements. All the other errors could be reduced or eliminated by having different experimenters and multiple measurements, which would tend to even out the errors.

Question 20

Answer: A

Explanatory notes

Since the force on the conductor changes according to the amount of current, it is a dependent variable because its magnitude depends on the amount of current. The amount of current is the independent variable, as its magnitude can take any value within the limits of the available apparatus and equipment. All other variables, including the length of the conductor and the magnetic field strength, must be controlled.

Tip

- *Remember that any variable that is measured must depend on changes in the variable that is modified. Hence, measured variables are dependent variables; whereas modified variables are independent. All others must remain the same or be controlled.*

SECTION B

Question 1a.

Worked solution

0 N

Mark allocation: 1 mark

- 1 mark for correctly identifying that the electrical force on a body without any electrical charge is 0 N

Question 1b.

Worked solution

4.0×10^{-3} mC

The positive charges on S1 will be distributed evenly between the two identical spheres, so eventually the charge on both spheres will be equal to half that which was originally on S1. Answer must be to 2 significant figures and use the scale of 10^{-3} mC = 1 μC.

Mark allocation: 2 marks

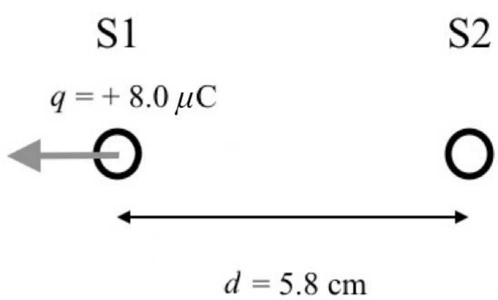
- 1 mark for the correct answer
- 1 mark if answer is to 2 significant figures

Tip

- *It is easy to confuse significant figures and decimal places. To avoid this, express your numerical answers in standard index form: $m \times 10^{n}$, where $1 \leq m < 10$. The number of significant figures is determined by the number of significant figures in the value of m. For example, the number* 0.0078 *has four decimal places, but when expressed as 7.8×10^{-4}, it becomes clear that the number has only two significant figures.*

Question 1c.

Worked solution



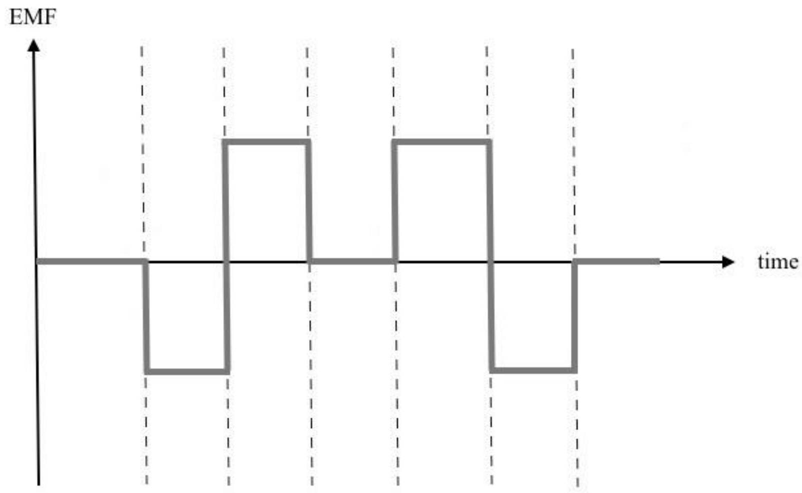
Since both spheres are positively charged, the spheres would repel each other. S1 would experience a force to the left by S2.

Mark allocation: 2 marks

- 1 mark for correct direction of arrow pointing left
- 1 mark for correct explanation of answer

Question 2a.

Worked solution



Explanatory notes

An EMF is induced in the loop due to changes in the magnetic field strength of the electromagnet, according to the formula $= -N\frac{\Delta\Phi}{\Delta t}$, with the magnitude of the EMF proportional to the rate of change of the field strength.

Mark allocation: 3 marks

- 1 mark for four equal magnitude waves drawn in the correct time intervals – if incorrect, no further marks awarded
- 1 mark for square waves, not sinusoidal or any other shapes
- 1 mark for symmetrical pattern for 'down-up-up-down' or 'up-down-down-up'

Question 2b.

Worked solution

8.22×10^{-5} Wb

The magnetic flux through the loop is given by
$\Phi = BA = 0.06 \times 13.7 \times 10^{-4} = 8.22 \times 10^{-5}$ Wb.

Mark allocation: 1 mark

- 1 mark for correct answer

Question 2c.

Worked solution

9.13×10^{-4} V

The EMF generated is given by $\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = \frac{8.22 \times 10^{-5}}{0.09} = 9.13 \times 10^{-4}$ V.

Mark allocation: 2 marks

- 1 mark for substituting correct values into the correct formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the flux obtained in **part b.** EMF = Answer (**b**)/0.09.

Question 3a.

Answer: E

Worked solution

Using the right-hand push rule or Fleming's left-hand rule, the direction of the field is upwards from north to south; the direction of the current is from positive to negative through the conductor; hence, the direction of the force is away from the magnet towards the current source.

Mark allocation: 2 marks

- 1 mark for correct direction
- 1 mark for correct explanation of direction

Question 3b.

Worked solution

2.88×10^{-4} T

Using $F = nIlB \rightarrow B = \frac{F}{nIl} = \frac{7.3 \times 10^{-6}}{0.39 \times 6.5 \times 10^{-2}} = 2.88 \times 10^{-4}$ T.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Question 4a.

Worked solution

81.8 A

Using $P = IV \rightarrow I = \frac{P}{V} = \frac{4.5 \times 10^3}{55} = 81.8$ A.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Question 4b.

Worked solution

24.5 V

Using $V_{\text{drop}} = IR = 81.8 \times 0.3 = 24.5$ V.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the current obtained in **part a.** $V_{\text{drop}} = IR = \text{Answer }(\mathbf{a}) \times 0.3$ V

Question 4c.

Worked solution

30.5 V

$V_{\text{lamp}} = V_{\text{generator}} - V_{\text{drop}} = 55 - 24.5 = 30.5$ V

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the voltage drop obtained in **part b.** $V_{\text{lamp}} = V_{\text{generator}} - \text{Answer }(\mathbf{b})$ V

Question 4d.i.

Worked solution

27.3 A

$I_{\text{line}} = I_{\text{sec}} = \frac{I_{\text{prim}}}{N} = \frac{81.8}{3} = 27.3$ A

Mark allocation: 1 mark

- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the current obtained in **part a.** $I_{\text{line}} = \frac{\text{Answer (a)}}{3}$

Question 4d.ii.

Worked solution

165 V

$V_{\text{sec}} = V_{\text{prim}}N = 55 \times 3 = 165$ V

Mark allocation: 1 mark

- 1 mark for correct answer

Question 4e.

Worked solution

8.18 V

Using the new value for the transmission line current, $V_{\text{drop}} = IR = 27.3 \times 0.3 = 8.18$ V.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the current obtained in **part d.i.** $V_{\text{drop}} = IR =$ Answer (**d.i.**) × 0.3 V

Question 4f.

Worked solution

157 V

$V_{\text{prim step-down}} = V_{\text{sec step-up}} - V_{\text{drop}} = 165 - 8.18 = 156.8$ V

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the voltage obtained in **part d.ii.** and the voltage drop obtained in **part e.**
$V_{\text{prim step-down}} =$ Answer (**d.ii.**) − Answer (**e**) V.

Question 4g.

Worked solution

52.3 V

$V_{\text{sec}} = \frac{V_{\text{prim}}}{N} = \frac{156.8}{3} = 52.3$ V

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the voltage obtained in **part f.** $V_{\text{sec}} = \frac{\text{Answer (f)}}{3}$ V.

Question 5a.

Worked solution

38.9 m s^{-1}

Conversion factor of 3.6 km h^{-1} = 1 m s^{-1}, $v = \frac{140}{3.6} = 38.9$ m s^{-1}.

Mark allocation: 1 mark

- 1 mark for correct answer

Question 5b.

Worked solution

4.35×10^6 J

Use the kinetic energy formula, $E_{\text{k}} = \frac{1}{2}mv^2 = \frac{1}{2} \times 5750 \times 38.9^2 = 4.35 \times 10^6$ J.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the correct formula
- 1 mark for correct answer

  Note: It is possible to award consequential marks for using the value of the speed obtained in **part a.** $E_{\text{k}} = 2875 \times \text{Answer }(\mathbf{a})^2$ J.

Question 5c.

Worked solution

2.09×10^6 J

The truck gains gravitational potential energy as it rises a vertical distance of 40 m.
$\Delta E_{\text{g}} = mg\Delta h = 5750 \times 9.8 \times 40 = 2.254 \times 10^6$ J

Its kinetic energy at the top of the ramp is therefore
$E_{\text{k, top}} = E_{\text{k, bottom}} - \Delta E_{\text{g}} = 4.348 \times 10^6 - 2.254 \times 10^6 = 2.09 \times 10^6$ J.

Mark allocation: 3 marks

- 1 mark for correctly substituting values into the formula for gravitational potential energy (GPE)
- 1 mark for correct answer for the gain in GPE
- 1 mark for correct answer for the kinetic energy at the top of the ramp

  Note: It is possible to award consequential marks for using the value of the kinetic energy obtained in **part b.** However, the correct answer for the gain in GPE must have already been obtained. $E_{\text{k, top}} = \text{Answer }(\mathbf{b}) - 2.254 \times 10^6$ J.

Question 5d.

Worked solution

83.8 m

The gravel does work on the truck to reduce its kinetic energy down to zero.

$W = E_{\text{k, top}} = F_{\text{friction}}d \rightarrow d = \frac{E_{\text{k, top}}}{F_{\text{friction}}} = \frac{2.09 \times 10^6}{25 \times 10^3} = 83.8\text{ m}$

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

  Note: It is possible to award consequential marks for using the value of the kinetic energy obtained in **part c.** $d = \frac{\text{Answer }(\mathbf{c})}{25 \times 10^3}$ m.

Question 6a.

Worked solution

0.20 m

The bowling ball gained gravitational potential energy (GPE) by an amount of $\Delta E_{\mathrm{g}} = mg\Delta h = 7.1 \times 9.8 \times 0.89 = 61.93$ J.

This is the same amount as the elastic potential energy (EPE) stored in the compressed spring initially. The formula for EPE, $E_{\mathrm{EP}} = \frac{1}{2}k(\Delta x)^2$, is rearranged to obtain spring compression: $\Delta x = \sqrt{\frac{2E_{\mathrm{EP}}}{k}} = \sqrt{\frac{2 \times 61.93}{261}} = 0.689$ m.

The distance, d, is the difference between the height the ball rises to and the compression of the spring: $d = 0.89 - 0.69 = 0.20$ m.

Mark allocation: 4 marks

- 1 mark for correct answer for the gain in GPE
- 1 mark for equating the gain in GPE with the stored EPE of the spring
- 1 mark for correct answer for the spring compression, Δx
- 1 mark for correct answer of distance, d

Question 6b.

Worked solution

0.267 m

The ball stopped accelerating upwards when the net force on the ball is zero, or when the upward spring force is the same size as the downward gravitational force; that is:

$$F_{\mathrm{spring}} = F_{\mathrm{gravity}} \rightarrow k\Delta x = mg$$

After rearranging the equation, the compression of the spring is $\Delta x = \frac{mg}{k} = \frac{7.1 \times 9.8}{261} = 0.267$ m.

Mark allocation: 3 marks

- 1 mark for noting that the net force on the ball is zero or that the spring force is equal to the gravitational force
- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Question 7a.

Worked solution

4.32 m s^{-1}

First, we must find the duration of Jackie's projectile motion through the air. Consider first the vertical component of her motion. Initial speed u_y is zero and acceleration $a = g$. The vertical distance travelled is $s_y = 6.3$ m. The time taken for Jackie to travel from the first building to the next can be derived from

$$s_y = u_y t + \frac{1}{2}at^2 \rightarrow s_y = \frac{1}{2}gt^2 \rightarrow t = \sqrt{\frac{2s_y}{g}} = \sqrt{\frac{2 \times 6.3}{9.8}} = 1.134 \text{ s}$$

This is the duration available to Jackie to cover the horizontal distance between the two buildings. Hence, her minimum horizontal speed must be $v = \frac{s}{t} = \frac{4.9}{1.134} = 4.32$ m s^{-1}.

Mark allocation: 3 marks

- 1 mark for correctly substituting values into the formula to obtain the duration of Jackie's motion through the air
- 1 mark for correct answer for the duration of Jackie's motion through the air
- 1 mark for correct answer for the minimum horizontal speed

Question 7b.

Worked solution

11.1 m s^{-1}

The vertical component of her motion with initial speed $u = 0$, $a = g$ and $s = 6.3$ m. Using $v^2 = u^2 + 2as \rightarrow v = \sqrt{2gs} = \sqrt{2 \times 9.8 \times 6.3} = 11.11$ m s^{-1}.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Tip

- *When considering the vertical component of projectile motions, it is easy to be confused by whether the sign of gravity should be positive or negative. The sign depends on whether you have defined 'up' as positive or 'down' as positive. To help you decide which to pick and to remember which way is positive, mark an arrow on the diagram in the direction you have chosen as positive, and label it with a '+' sign.*

Question 7c.

Worked solution

615 N

Momentum method: Jackie's momentum will reduce from $p = mv = 72 \times 11.1 = 800$ N s to zero. Average force can be calculated from $F_{\text{av}}\Delta t = \Delta p \rightarrow F_{\text{av}} = \frac{\Delta p}{\Delta t} = \frac{800}{1.3} = 615$ N.

Kinematics method: Jackie's velocity will reduce from $u = 11.1$ m s^{-1} to zero in $\Delta t = 1.3$ s. Average force can be calculated from $F_{\text{av}} = ma = m\frac{\Delta v}{\Delta t} = 72 \times \frac{11.11}{1.3} = 615$ N.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Note: It is possible to award consequential marks for using the value of the vertical speed obtained in **part b.** $F_{\text{av}} = 55.38 \times \text{Answer } (\mathbf{b})$ N.

Question 8a.

Worked solution

Friction force is given by $F_{\mathrm{F}} = 4.51m = 4.51 \times 12 = 54.1$ N.

Mark allocation: 2 marks

- 1 mark for correctly substituting the values into the equation
- 1 mark for correct answer

Question 8b.

Worked solution

3.24 m s^{-2}

The acceleration of box A is the same as the acceleration of the two-box system, as the boxes are rigid and next to each other. Net force on the system is the push force of 248 N less the friction forces: $F_{\mathrm{net}} = 248 - 54.1 - 90.2 = 103.7$ N.

Total mass of boxes is 20 + 12 = 32 kg.

Acceleration $a = \frac{F_{\mathrm{net}}}{m_{\mathrm{total}}} = \frac{103.7}{32} = 3.24$ m s^{-2}.

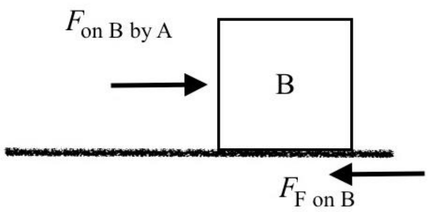
Mark allocation: 3 marks

- 1 mark for obtaining the correct value of the net force
- 1 mark for correct substitution of values into the formula to calculate the acceleration
- 1 mark for correct answer

Question 8c.

Worked solution

93 N



The forces on box B are the force on box B by box A and the friction force of the floor on box B. The net force on box B is then $F_{\text{net}} = F_{\text{on B by A}} - F_{\text{F on B}}$. Its magnitude can be calculated from the acceleration of box B: $F_{\text{net}} = ma = 12 \times 3.24 = 38.88$ N.

Thus, the force on box B by box A is the sum of the net force on box B and the friction force; that is: $F_{\text{on B by A}} = 38.9 + 54.1 = 93$ N.

Mark allocation: 3 marks

- 1 mark for obtaining the correct value of the net force
- 1 mark for correctly substituting values into the formula to calculate the force on box B by box A
- 1 mark for correct answer

Note 1: It is possible to award consequential marks for using the value of the acceleration obtained in **part b.** $F_{\text{on B by A}} = 12 \times \text{Answer } (\mathbf{b}) + 54.1$ N.

Note 2: It is also possible to find $F_{\text{on B by A}}$ using Newton's third law and $F_{\text{on A by B}}$, by first considering the net force on box A: $F_{\text{net on A}} = m_{\text{A}}a = 20 \times 3.24 = 64.8$ N.

And then summing up the forces on box A:

$$F_{\text{net on A}} = F - F_{\text{friction}} - F_{\text{on A by B}} = 248 - 90.2 - F_{\text{on A by B}} = 157.8 - F_{\text{on A by B.}}$$

Thus, $F_{\text{on A by B}} = 157.8 - 64.8 = 93$ N.

Question 9a.

Worked solution

7.14×10^{10} kg

The orbital radius is half the orbital diameter, $R = \frac{3480}{2} = 1740$ m. The mass of the asteroid, which is the central body in the satellite equation, can be found from
$\frac{R^3}{T^2} = \frac{GM_{\text{central}}}{4\pi^2} \rightarrow M_{\text{central}} = \frac{4\pi^2 R^3}{GT^2} = \frac{4\pi^2 \times 3480^3}{6.67 \times 10^{-11} \times 209\,000^2} = 7.14 \times 10^{10}$ kg.

Mark allocation: 3 marks

- 1 mark for correctly stating the satellite equation
- 1 mark for correctly substituting the values into the equation
- 1 mark for correct answer

Question 9b.

Worked solution

The absolute uncertainty of the orbital period is 900 s. The percentage uncertainty of the orbital period is $\Delta T = \frac{900}{209\,000} \times 100 = 0.43\%$.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Question 9c.

Worked solution

$g = 5.29 \times 10^{-5}$ N kg^{-1}

The gravitational field strength is given by
$g = \frac{GM_{\text{central}}}{r^2} = \frac{6.67 \times 10^{-11} \times 7.14 \times 10^{10}}{300^2} = 5.29 \times 10^{-5}$ N kg^{-1}.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into equation
- 1 mark for correct answer

  Note: It is possible to award consequential marks for using the value of the mass obtained in **part a.** $g = 7.41 \times 10^{-16} \times \text{Answer } (\mathbf{a})$ N kg^{-1}.

Question 10a.

Worked solution

2.44 m s^{-1}

The circumference of the circle that Andrew's centre of mass is inscribing around the merry-go-round is $C = 2\pi r = 2\pi \times 1.9 = 11.94$ m. His speed is $v = \frac{C}{t} = \frac{11.94}{4.9} = 2.44$ m s^{-1}.

Mark allocation: 1 mark

- 1 mark for correct value of the speed

Question 10b.

Worked solution

147 N

The net force on Andrew is the centripetal force on him, given by
$F_c = \frac{mv^2}{r} = \frac{47 \times 2.44^2}{1.9} = 147$ N.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

  Note: It is possible to award consequential marks for using the value of the speed obtained in **part a.** $F_c = 24.74 \times \text{Answer } (\mathbf{a})^2$ N.

Question 10c.i.

Worked solution

decrease

Mark allocation: 1 mark

- 1 mark for correctly identifying that the net force will decrease

Question 10c.ii.

Worked solution

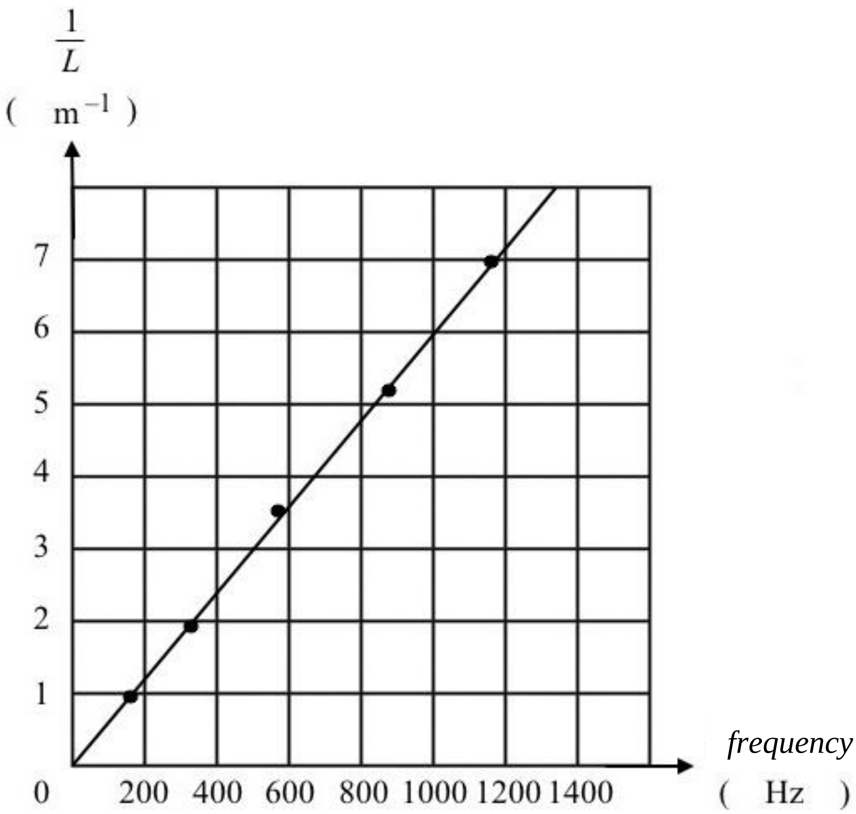
As the merry-go-round is still moving at the same rate of rotation, the net force on Andrew, which is the centripetal force, would decrease according to the equation
$F_c = \frac{mv^2}{r} = \frac{m(2\pi rf)^2}{r} = 4\pi^2 f^2 rm$, since the radius, r, is smaller.

Mark allocation: 2 marks

- 1 mark for showing that the centripetal force is directly proportional to the radius, *r*
- 1 mark for connecting the lower centripetal force to the smaller radius

Question 11a.

Worked solution



Mark allocation: 5 marks

- 2 marks for correctly plotted points (deduct 1 mark for up to two errors; deduct 2 marks for three errors or more)
- 2 marks for correct scales and units on each axis
- 1 mark for correct line of best fit

Question 11b.

Worked solution

0.006 s m^{-1}

The lower bound of the gradient is 0.0057, calculated from (0, 0) and (1400, 8).

The upper bound of the gradient is 0.0063, calculated from (0, 0) and (800, 5).

Mark allocation: 2 marks

- 1 mark for selecting two data points that are on the line of best fit and correctly substituting into the formula
- 1 mark for value of gradient between 0.0057 and 0.0063

Note: It is possible to award consequential marks for using a different line of best fit if the correct procedure and calculation are used.

Tip

- *You must use the line of best fit that you drew to calculate the gradient. Do not calculate the gradient from two actual data points in the table. When possible, use two data points on the line of best fit that are at the intersection of grid lines (e.g. (0, 0) and (1000, 6)), which give the value in the solution:* $m = \frac{6-0}{1000-0} = 0.006$. *Otherwise, use two data points on the line of best fit where it crosses a horizontal grid line (e.g. (180, 1) and (680, 4)), which give a value equal to the one in the solution:* $m = \frac{4-1}{680-180} = 0.006$.

Question 11c.

Worked solution

333 m s^{-1}

Gradient $m = \frac{L^{-1}}{f} = \frac{1}{fL}$ and $L = \frac{\lambda}{2}$; therefore, $m = \frac{2}{f\lambda}$.

So $v = f\lambda = \frac{2}{m} = \frac{2}{0.006} = 333$ m s^{-1}.

Mark allocation: 3 marks

- 1 mark for correctly deriving equation relating *v* and *m*
- 1 mark for correctly substituting gradient value
- 1 mark for correctly calculated value between 317 and 351 m s^{-1}

Note: It is possible to award consequential marks for using a different gradient if the correct procedure and calculation are used.

Tip

- *The units of measurements often can be used to work out how to find the required data, being speed of sound in this instance. The units of the gradient of the graph is* $\frac{\text{m}^{-1}}{\text{s}^{-1}} = \text{s m}^{-1}$*, which is the reciprocal of the units of speed,* m s^{-1}.

Question 12a.

Worked solution

$n_{\text{Perspex}} = 1.49$

Using Snell's law, $n_{\text{Perspex}} \sin i = n_{\text{air}} \sin r$.

Substituting the given values gives $n_{\text{Perspex}} \sin 42.2° = 1.00 \times \sin 90°$.

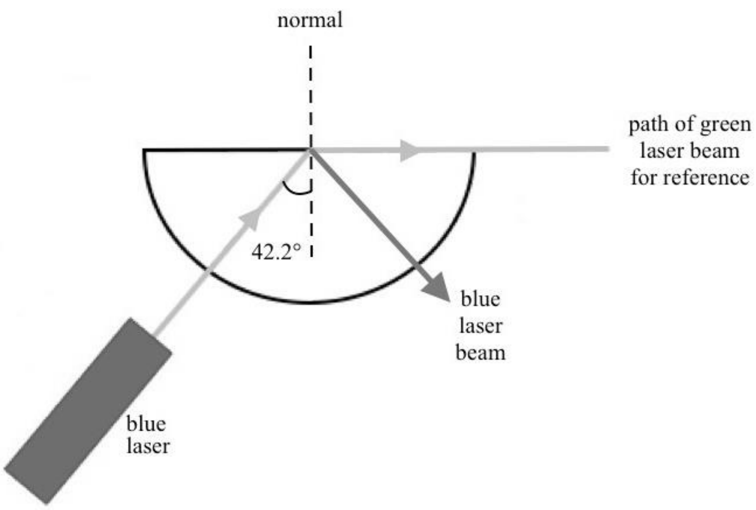
Rearranging the equation, we get $n_{\text{Perspex}} = \frac{1}{\sin 42.2°} = 1.489$.

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the formula
- 1 mark for correct answer

Question 12b.

Worked solution



Explanatory notes

The blue laser has a shorter wavelength and therefore it is refracted more than the green laser; thus, its critical angle is lower than that of the green laser. At the same angle of incidence, $i = 42.2°$, it will undergo total internal reflection. It is not necessary to show the beam exiting the block; however, note that the reflected beam exits the block without any deviation; that is, it is not refracted because the incident angle is 0°.

Mark allocation: 2 marks

- 2 marks for one beam that is a reflection of the incident beam, off the straight edge of the semi-circular Perspex block. No marks if there are any additional beams sketched on the diagram (e.g. part reflection and part transmission)

Note: Deduct 1 mark if the reflected beam has an angle of reflection that is significantly different from the angle of incidence, or if the reflected beam is refracted after exiting the block.

Question 13

Worked solution

Bharat is correct.

Asha is incorrect because the interference patterns will be the same only if the photon momentum is equal to the electron momentum. This is not possible when the energies are the same.

Chantel is incorrect because electrons can behave like particles as well as like waves.

Mark allocation: 3 marks

- 1 mark for correctly identifying that Bharat is correct
- 1 mark for correctly pointing out the mistake in Asha's explanation
- 1 mark for correctly pointing out the mistake in Chantel's explanation

Question 14a.

Worked solution

Equating the electrical potential energy of the electrons due to the charged plates and the kinetic energy of the electrons gives $E_{\mathrm{p}} = E_{\mathrm{k}} \rightarrow qV = \frac{1}{2}mv^2$.

After rearranging for velocity, we get $v = \sqrt{\frac{2qV}{m}}$.

Substituting the values gives $v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2.4 \times 10^{6}}{9.1 \times 10^{-31}}} = 9.19 \times 10^{8}$ m s^{-1}.

Mark allocation: 2 marks

- 1 mark for correctly equating the E_{p} and the E_{k} of the electrons
- 1 mark for substituting the values into the equation, and demonstrating that the given value is obtained

Question 14b.

Worked solution

The expected velocity is higher than the speed of light, $c = 3 \times 10^{8}$ m s^{-1}. This is not possible because, according to Einstein's theory of special relativity, the speed of light is absolute for all observers regardless of their frames of reference.

Mark allocation: 2 marks

- 1 mark for pointing out that the expected velocity is superluminal (i.e. faster than light)
- 1 mark for stating that this is not possible

Question 15

Worked solution

$\gamma = 5.69$

Relativistic kinetic energy is given by $E_\text{k} = (\gamma - 1)mc^2$.

Rearranging for gamma, we obtain $\gamma = \frac{E_\text{k}}{mc^2} + 1 = \frac{3.84 \times 10^{-13}}{9.1 \times 10^{-31} \times (3 \times 10^{8})^2} + 1 = 5.69$.

Mark allocation: 2 marks

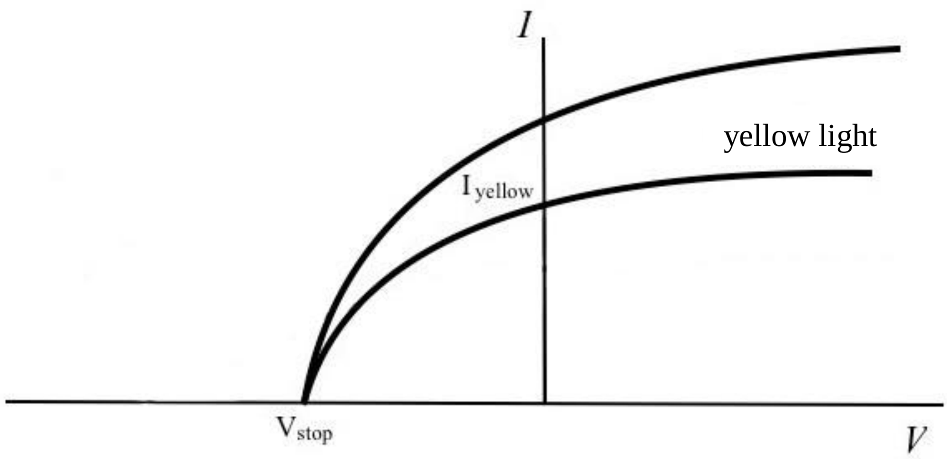
- 1 mark for correctly substituting into the equation
- 1 mark for the correct answer

Tip

- *The presence of c^2 appears regularly in physics. Noting that $c^2 = 9 \times 10^{16}$ can save you time and reduce calculator errors when you are under examination pressure.*

Question 16a.

Worked solution



Explanatory notes

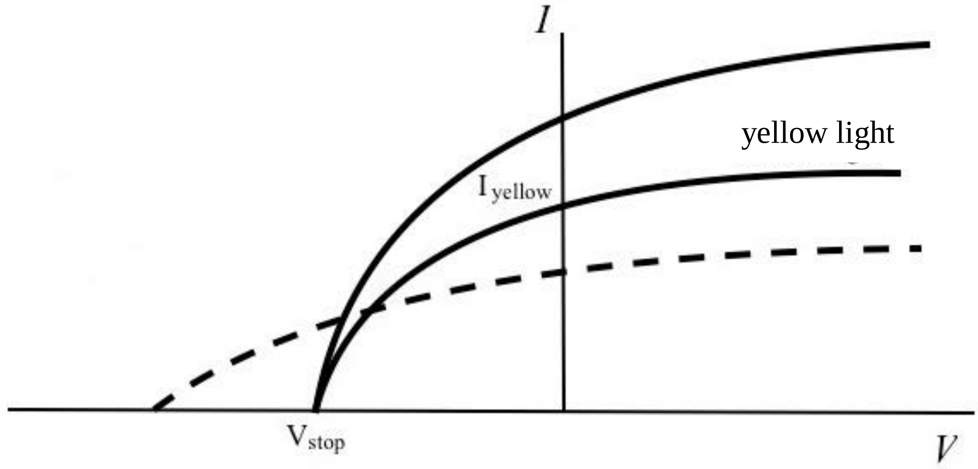
Using the same light frequency will produce photoelectrons with the same maximum kinetic energy; hence, the stopping voltage, V_{stop}, will not change. However, the higher light intensity will increase the number of photons incident on the metal plate, thereby increasing the number of photoelectrons and producing a higher photocurrent.

Mark allocation: 1 mark

- 1 mark for the same V_{stop} but higher photocurrent

Question 16b.

Worked solution



Explanatory notes

Green light has a higher frequency and therefore will produce photoelectrons with a higher maximum kinetic energy. Hence, the stopping voltage will have a higher magnitude; that is, it will be on the *x*-axis to the left of V_{stop}.

For the same light power output incident on the metal plate, a higher frequency light will have a correspondingly lower number of photons, according to the light beam energy equation $E_{\text{beam}} = nhf$. This will result in a lower photocurrent.

Mark allocation: 2 marks

- 2 marks for sketching the *x*-intercept to the left of the V_{stop} but having lower photocurrent

Question 17

Worked solution

3.00×10^2 V

Since the two diffraction patterns are the same, the wavelength of the X-rays must be the same as the de Broglie wavelength of the electrons. The first step is to determine the wavelength of the X-ray from the energy:

$E_{\text{X-ray}} = \frac{hc}{\lambda} \rightarrow \lambda = \frac{hc}{E_{\text{X-ray}}} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{1.75 \times 10^{4}} = 7.097 \times 10^{-11}$m.

This is also the de Broglie wavelength of the electrons.

The de Broglie wavelength of the electrons could be used to calculate the electron energy, in joules:

$E_{\text{e}} = \frac{h^2}{2m_{\text{e}}\lambda^2} = \frac{(6.63 \times 10^{-34})^2}{2 \times 9.1 \times 10^{-31} \times (7.097 \times 10^{-11})^2} = 4.795 \times 10^{-17}$J.

Converting to eV, we obtain $E_{\text{e}} = \frac{4.795 \times 10^{-17}}{1.6 \times 10^{-19}} = 300$ eV.

Therefore, the voltage required is 300 V.

Mark allocation: 3 marks

- 1 mark for correct value of the X-ray wavelength
- 1 mark for obtaining the electron energy, in joules
- 1 mark for correct answer for the voltage required to accelerate the electrons

Tip

- *A potentially confusing issue is the X-ray energy being given in the unit electron-volt (eV). This is not the accelerating voltage of the electrons that will produce the same diffraction pattern, as X-rays are electromagnetic radiation, whereas electrons are particles. Since the X-ray energy is given in electron-volts (eV), using the electron-volt second (eV s) version of Planck's constant could save some time by removing the extra step of converting the answer from joules (J) to electron-volts (eV), had the joule second (J s) version of Planck's constant been used. It is also important, when deciding which version to use, to check the units of the quantities involved in formulas to ensure consistency.*

Question 18a.

Worked solution

Photons are emitted with a wavelength that corresponds to the difference of the energy levels that electrons transition between.

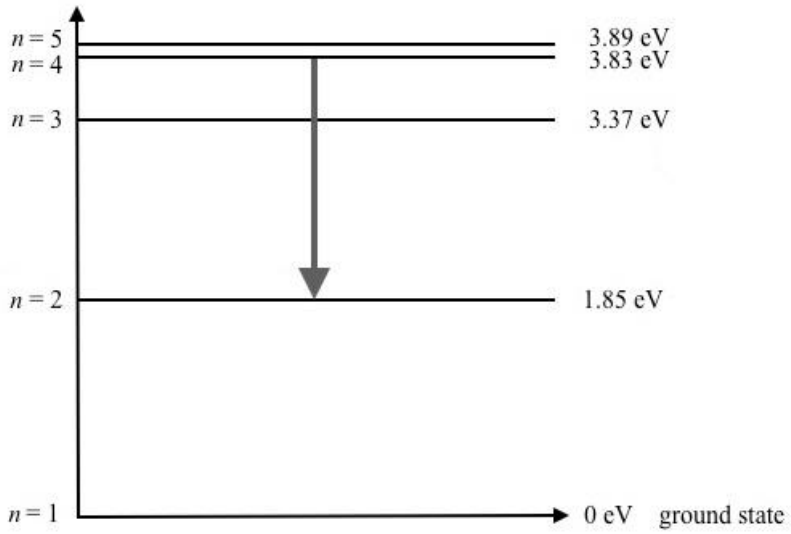
The relationship $E_{\text{difference}} = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{627 \times 10^{-9}} = 1.98$ eV, as required.

Mark allocation: 2 marks

- 1 mark for selecting the correct equation and substituting the correct values
- 1 mark for obtaining the correct value of photonic energy

Question 18b.

Worked solution



Explanatory notes

The electron transition is between $n = 4$ and $n = 2$; that is:
$E_{\text{difference}} = 3.83 - 1.85 = 1.98$ eV.

Mark allocation: 1 mark

- 1 mark for an arrow between $n = 4$ and $n = 2$

Note: The tail of the arrow must touch only $n = 4$ and the arrowhead must be touch only $n = 2$.)

Question 19

Worked solution

Figure 17	**a.** continuous, polychromatic	**b.** incandescent light
Figure 18	**a.** discrete, monochromatic	**b.** laser
Figure 19	**a.** discrete, polychromatic	**b.** mercury vapour lamp

Mark allocation: 3 marks

- 1 mark each for fully correct answers for the descriptions and correct identification of the light source (up to 3 marks)

Question 20

Worked solution

Yosi is correct.

Xabi is incorrect because the electron's speed is irrelevant to Heisenberg's uncertainty principle, which is concerned with the uncertainty of the electron's momentum in the *x*-direction and the uncertainty of the electron's position in the *x*-direction.

Zin is incorrect because knowing that the uncertainty in the electron's momentum in the *x*-direction is small leads to a large uncertainty in the electron's position in the *x*-direction.

Mark allocation: 3 marks

- 1 mark for correctly identifying that Yosi is correct
- 1 mark for correctly pointing out the mistake in Xabi's explanation
- 1 mark for correctly pointing out the mistake in Zin's explanation

Tip

- *It is important to distinguish between the momentum of the electron in the direction it is incident to the slit (in this case, the y-direction) and the transverse direction (in this case, the x-direction). The Heisenberg uncertainty principle involves the uncertainty of the electron's momentum in the transverse direction. To help you remember which one is relevant, recall that the uncertainty of the electron's position is dependent on the slit width, which is the transverse direction of the electron's motion.*

END OF WORKED SOLUTIONS