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YEAR 12 *Trial Exam Paper*

2022
PHYSICS
Written examination

Worked solutions

This book contains:

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

SECTION A

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

Question 1

Answer: D

Explanatory notes

As the positron enters the uniform magnetic field it will experience a force that is perpendicular to the direction of travel. Hence, the positron's direction will change. However, since the force is perpendicular to the direction of travel, its speed will remain the same. Its *velocity* will change as it changes direction, but the magnitude will remain the same.

Tip

- *Make sure you distinguish between speed (a scalar with magnitude only) and velocity (a vector with magnitude and direction), as the difference is significant.*

Question 2

Answer: D

Explanatory notes

Repeated measurements reduce the effect of random errors. Higher precision may be achieved by improving the measuring techniques and using instruments that are more sensitive to changes. Systematic errors (that is, those that affect accuracy) may be reduced by calibrating the instrument to ensure that it is in good working order and is not damaged.

Question 3

Answer: A

Explanatory notes

The magnetic field strength along the top of the solenoid, far from the two poles, is constant.

Question 4

Answer: A

Explanatory notes

The acceleration due to gravity is inversely proportional to the distance from the centre of Earth: $g \propto \frac{1}{R^2}$.

Thus the position, R_2, at which the acceleration due to gravity, g_2, is 4.9 m s^{-2} is given by

$$g_2 R_2{}^2 = g_E R_E{}^2$$

$$R_2 = \sqrt{\frac{g_E R_E{}^2}{g_2}} = \sqrt{\frac{9.8 \times \left(6.37 \times 10^6\right)^2}{4.9}} = 9.01 \times 10^6 \text{ m}$$

Alternatively, since the acceleration due to gravity follows the inverse-square law, a decrease in g by $\frac{1}{2}$ corresponds to an increase in R by a factor of $\sqrt{2}$.

Thus, $R_2 = R_E \sqrt{2} = 6.37 \times 10^6 \times \sqrt{2} = 9.01 \times 10^6$ m

Therefore, the altitude is $R_2 - R_E = 9.01 \times 10^6 - 6.37 \times 10^6 = 2.64 \times 10^6$ m.

Tips

- *When working with formulas involving the 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.*
- *When altitude is specified, remember to add the radius of the body being orbited to the altitude to obtain the orbital radius.*

Question 5

Answer: B

Explanatory notes

The magnetic force on the bundle is given by $F = nBIL$ which can be rearranged to $B = \frac{F}{nIL}$.

By substituting the appropriate values, we obtain $B = \frac{7.3 \times 10^{-3}}{7 \times 0.5 \times 0.35} = 5.96 \times 10^{-3}$ T.

Question 6

Answer: A

Explanatory notes

Using the right-hand push rule, the direction of the magnetic force is perpendicular to both the current and the magnetic field, and is directed upwards; that is, in direction P.

Question 7

Answer: D

Explanatory notes

In the vertical position, the area of the loop through which the magnetic field passes is at its maximum. Thus, the magnitude of the magnetic flux is maximum.

When the magnitude of the magnetic flux is at its maximum, the magnitude of the rate of change of the flux is at its minimum.

Question 8

Answer: B

Explanatory notes

The input power is $P = VI = 230 \times 0.85 = 195.5$ W. Since the transformer is ideal, the output power is the same. Hence, the output current is $I = \frac{P}{V} = \frac{195.5}{20} = 9.78$ A.

Alternatively, use the ratio of primary and secondary voltages: $\frac{V_1}{V_2} = \frac{I_2}{I_1}$.

$$I_2 = I_1 \times \frac{V_1}{V_2} = 0.85 \times \frac{230}{20} = 9.78 \text{ A.}$$

Question 9

Answer: D

Explanatory notes

At the lowest point, the tension in the rope is given by

$$T = F_c + mg$$
$$= \frac{mv^2}{r} + mg$$

Since $v = 2\pi rf$, the equation above becomes $T = m4\pi^2 rf^2 + mg$

$$= 12 \times 4\pi^2 \times 2.3 \times 3^2 + 12 \times 9.8$$
$$= 9.92 \times 10^3 \text{ N}$$

Question 10

Answer: C

Explanatory notes

Since the tension in the rope is related to the centripetal force on the mass, and the centripetal force is given by $F_c = \frac{m4\pi^2 r}{T^2} = m4\pi^2 rf^2$, the correct way to reduce the centripetal force is to reduce the radius of the rotation (while keeping the rate of rotation or frequency, *f*, the same).

Question 11

Answer: D

Explanatory notes

Option A is incorrect. Since the gravitational potential energy of the mass decreases as the spring extends, the total mechanical energy of the mass decreases. Option B is incorrect because the gravitational potential energy of the mass is at its maximum at the point of release. Option C is incorrect because the elastic potential energy of the spring is at its maximum at maximum extension. Option D is correct because the system comprises both the mass and the spring.

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,* $E_{\text{system}} = E_{\text{mass}} + E_{\text{spring}}$.

Question 12

Answer: B

Explanatory notes

The sound from the ambulance siren is a wave and therefore subject to the Doppler effect when heard by a stationary observer. The frequency of a sound source increases as it travels towards an observer, and decreases as it travels away from an observer. Thus, the diagram shows that the ambulance must be approaching Mina from the east, because the frequency of the sound is higher in this direction.

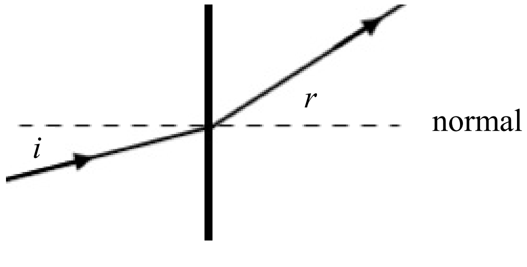
Options C and D are incorrect because the graphs show that the ambulance is not accelerating. If the source of a sound is accelerating, then the observed frequency would change with the velocity of the source.

Question 13

Answer: B

Explanatory notes

Solve this problem by drawing a normal line at the interface between the two media:



It is apparent that the angle of refraction, *r*, is greater than the angle of incidence, *i*. This can occur only if the index of refraction has decreased.

A good rule of thumb is: when light travels from a medium with a higher refractive index to a medium with a lower refractive index, it will bend away from the normal.

Question 14

Answer: B

Explanatory notes

Consider the shape of the wave a short moment later:

It can be seen that point X is rising and point Y is falling.

Question 15

Answer: B

Explanatory notes

Option A is incorrect because light intensity has no effect on V_{stop} and thus on the kinetic energy of the photoelectrons. Option C is incorrect because the DC voltage must be increased until the work done on each photoelectron is sufficient to reduce the photocurrent to zero; this is the explanation provided by Option B. Option D is incorrect because photoelectrons can be emitted without delay.

Question 16

Answer: B

Explanatory notes

Planck's constant, h, could be obtained from the work function, $W = hf_0$, which can be rearranged to

$$h = \frac{W}{f_0} = \frac{3.4 \times 10^{-19}}{6.5 \times 10^{14}} = 5.23 \times 10^{-34} \text{ J s}$$

Question 17

Answer: C

Explanatory notes

The fringe spacing of the interference pattern is given by $\Delta x = \dfrac{\lambda L}{d}$, which can be rearranged to obtain the slit separation

$$d = \frac{\lambda L}{\Delta x} = \frac{1064 \times 10^{-9} \times 1.912}{3.1 \times 10^{-3}} = 6.56 \times 10^{-4} \text{ m.}$$

This is equivalent to $6.56 \times 10^{-4} \times 10^{6} = 656\ \mu\text{m}$.

Question 18

Answer: D

Explanatory notes

Bobbi did not take into account the 0.5 mm between the edge of the ruler and the '0' marking. The actual fringe spacing is therefore 3.6 mm, and not 3.1 mm as reported.

Question 19

Answer: A

Explanatory notes

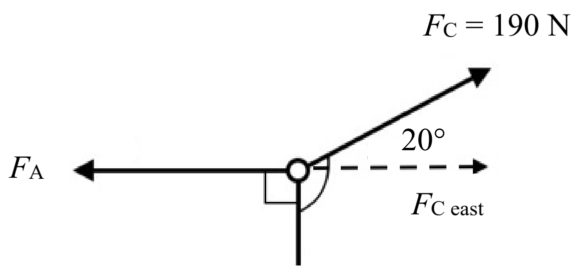
The Lorentz factor for the kaon is $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{1}{\sqrt{1-\dfrac{(0.697)^2}{c^2}}} = 1.3946$, which is 1.39 when rounded to 3 significant figures.

Question 20

Answer: D

Explanatory notes

Since the net force on the ring is 0 N, the sum of forces in the east–west direction, F_A, must be equal to $F_{C\ east}$, the easterly component of F_C.



$$\Sigma F_{\text{east–west}} = 0 = F_A - F_{C\ \text{east}}$$

$$F_A = F_{C\ \text{east}}$$

$$F_A = F_C \cos(20°) = 190\cos(20°) = 179\ \text{N}$$

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SECTION B

Question 1a.

Worked solution

$5.6\times10^{8}\ \mathrm{N\,C^{-1}}$

The electric field strength at P due to q_1 is given by

$$E=\frac{kq_1}{r^2}=\frac{8.99\times10^{9}\times2.5\times10^{-3}}{0.2^2}=5.62\times10^{8}\ \mathrm{N\,C^{-1}}$$

Mark allocation: 2 marks

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

Question 1b.i.

Worked solution

$1.1\times10^{5}\ \mathrm{N}$

The force on q_1 due to q_2 is given by

$$F=\frac{kq_1q_2}{r^2}=\frac{8.99\times10^{9}\times2.5\times10^{-3}\times5\times10^{-3}}{1^2}=1.12\times10^{5}\ \mathrm{N}$$

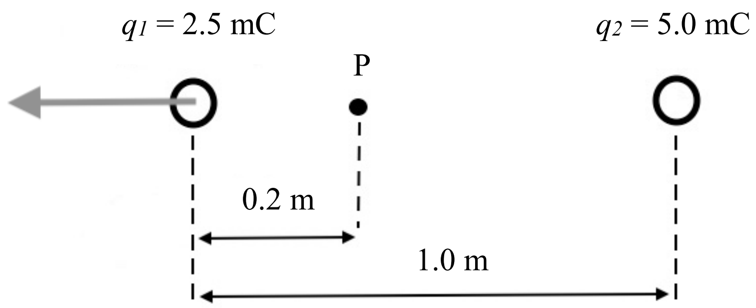
Mark allocation: 2 marks

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

Question 1b.ii.

Worked solution

The force is to the left because both charges are positive and repel each other. The diagram should be annotated with an arrow pointing left at q_1:



Mark allocation: 1 mark

- 1 mark for a correctly drawn arrow

Question 2

Worked solution

8.8×10^{7} m

The satellite equation relates the orbital radius to the orbital period of a satellite around a central body:

$$\frac{R^3}{T^2}=\frac{GM_{\mathrm{c}}}{4\pi^2}$$

This can be rearranged to obtain the orbital radius:

$$R^3=\frac{T^2GM_{\mathrm{c}}}{4\pi^2}=\frac{\left(2.36\times10^{6}\right)^2\times6.67\times10^{-11}\times7.35\times10^{22}}{4\pi^2}=6.916\times10^{23}$$

$R=8.8\times10^{7}$ m

Mark allocation: 3 marks

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

Tip

- *Some formulas, including the orbital radius of a satellite, are not provided in the VCAA Formula Sheet. Therefore, it would be advantageous for you to include this formula (and other useful ones) in the A3 pre-written notes that you are permitted to bring to the physics examination.*

Question 3a.

Worked solution

The time taken for a box to reach the entrance can be found by analysing the vertical component of the projectile motion. The initial velocity in the vertical direction, u, is 0. Each box falls under gravity, thus its acceleration is $a = g$. The distance it travels from the end of the conveyor to the entrance of the chute, s, is 1.4 m. The relationship between these variables and the time taken, t, is $s = ut + \frac{1}{2}at^2$. Since $u = 0$, this can be rearranged to

$$t^2 = \frac{2s}{a} = \frac{2 \times 1.4}{9.8} = 0.2857$$

$$t = 0.53 \text{ s}$$

Mark allocation: 2 marks

- 1 mark for the correct formula
- 1 mark for correctly substituting the values for u, s and a

Tips

- *When analysing projectile motion, you need to remember that the vertical component and horizontal component of the motion should be treated separately. In the above question, the time taken for the box to reach the entrance could be found by considering either the horizontal component or the vertical component. However, since the horizontal velocity is not specified, focusing on the horizontal component would not be useful for analysis. This leaves the vertical component, which eventually leads to the required solution.*
- *When considering the vertical component of projectile motion, you may be uncertain about what sign should be given to gravity: 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, draw an arrow on the diagram in the direction you have chosen as positive and label it with a + sign.*

Question 3b.

Worked solution

2.6 m s^{-1}

The time taken by the vertical component of projectile motion is the same as the time taken by the horizontal component. To cover the horizontal distance of 1.4 m in the time given, the speed must be

$$v = \frac{s}{t} = \frac{1.4}{0.53} = 2.64 \text{ m s}^{-1}$$

Mark allocation: 2 marks

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

Question 3c.i.

Worked solution

Keep the speed the same

Mark allocation: 1 mark

- 1 mark for the correct answer

Question 3c.ii.

Worked solution

The time that each box is in the air, between leaving the conveyor and entering the chute, depends only on the acceleration due to gravity. It is independent of the mass of the box. Therefore, the speed of the conveyor belt should remain the same for the boxes to follow the same trajectory.

Mark allocation: 2 marks

- 1 mark for stating that the time is dependent only on acceleration due to gravity
- 1 mark for stating that the speed of the conveyor belt should therefore remain the same

Question 4a.

Worked solution

363 N

Since the bucket is stationary, the force on the bucket by the platform is equal to the force on the bucket by Earth (due to gravity).

Hence, $F_{\text{on bucket by platform}} = F_{\text{g}} = mg = 37.0 \times 9.8 = 362.6 \approx 363$ N.

Mark allocation: 2 marks

- 1 mark for the correct answer
- 1 mark if the answer is correct to 3 significant figures

Question 4b.i.

Worked solution

force decreases

Mark allocation: 1 mark

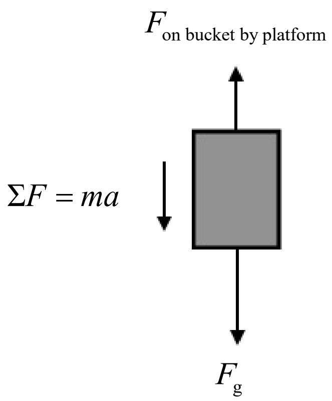
- 1 mark for the correct answer

Question 4b.ii.

Worked solution

As the bucket is accelerating downwards, there is a net force acting on it, which is the vector sum of the force on the bucket by Earth (down) and the force on the bucket by the platform (up):

$\Sigma F = ma = F_{\text{g}} - F_{\text{on bucket by platform}}$



The force on the bucket by the platform must be smaller than the force on the bucket by Earth for the bucket to accelerate downwards.

Mark allocation: 2 marks

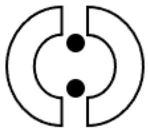
- 1 mark for stating that there is a net force down
- 1 mark for stating that there must be an imbalance of forces on the bucket and identifying that the force on the bucket by the platform is lower than the force on the bucket by Earth

Question 5a.

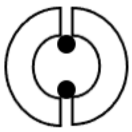
Worked solution

The coil may not turn for the following reasons:

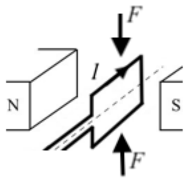
i. There may be no electrical contact between the split-ring commutator and the arms of the coil, which may occur if the arms are positioned in the gap of the split-ring commutator.



ii. One or both arms of the coil could be in contact with both halves of the split-ring commutator, which prevents the current from flowing around the coil.



iii. The twisting forces acting on opposing sides of the coil are not strong enough to cause the coil to rotate.



Mark allocation: 2 marks

- 1 mark each for any of the above explanations (up to 2 marks)

Question 5b.

Worked solution

9.5×10^{-4} N

The magnetic force on side PQ is given by

$$\begin{aligned}F &= nIlB\\ &= 20\times0.6\times0.15\times0.53\times10^{-3}\\ &= 9.54\times10^{-4}\ \text{N}\end{aligned}$$

Mark allocation: 2 marks

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

Question 6a.

Worked solution

4.5×10^{-5} Wb

The area of the coil is the product of WX and XY: $A = 0.04\times0.025 = 10^{-3}\ \text{m}^2$.

The magnetic flux is given by $\Phi = BA = 45\times10^{-3}\times10^{-3} = 4.5\times10^{-5}$ Wb.

Mark allocation: 3 marks

- 1 mark for calculating the correct area of the coil
- 1 mark for correctly substituting values for B and A into the flux equation

  Note: This mark may be awarded even if an incorrect value for A is substituted into the equation.
- 1 mark for the correct answer

Question 6b.

Worked solution

2.2×10^{-2} V

The period of the rotation, T, equals $\frac{1}{f} = \frac{1}{3}$ s.

The time for a quarter turn, t, equals $\frac{T}{4} = \frac{\frac{1}{3}}{4} = \frac{1}{12} = 8.33\times10^{-2}$ s.

The average EMF generated by the coil for each quarter turn of the coil is

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t} = -40\times\frac{4.5\times10^{-5}}{8.33\times10^{-2}} = 2.16\times10^{-2}\ \text{V}$$

Mark allocation: 3 marks

- 1 mark for correctly calculating the time for a quarter turn of the coil
- 1 mark for correctly substituting values into the equation

  Note: This mark may be awarded even if an incorrect value for t is substituted into the equation.
- 1 mark for the correct answer

  Note: A consequential mark may be awarded for using the value of the flux obtained in **part a.**: ε = Ans (**a**) × 480 V .

Question 6c.

Worked solution

X to W

Consider a positive charge between W and X. As the coil rotates anticlockwise, the charge will be going down and the magnetic field is from left to right. Using the right-hand push rule, the force on the positive charge will be out of the page from X to W. The movement of this positive charge represents the current induced by the rotation of the coil.

Alternatively, from Lenz's law, the flux in the coil is initially going from left to right. As the coil rotates, the flux through the coil decreases. This will induce more flux through the coil. Using the right-hand grip rule on the conductor WX with your fingers curling through the coil from left to right, your thumb is pointing from X to W.

Mark allocation: 1 mark

- 1 mark for circling X to W

Question 7a.

Worked solution

4.5 A

The power supply is given by $P = IV$ which can be rearranged to obtain the current.

$$I = \frac{P}{V} = \frac{50\times10^3}{11\times10^3} = 4.54 \text{ A}$$

Mark allocation: 2 marks

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

Question 7b.

Worked solution

48 : 1

The ratio is calculated as follows:

$$\begin{aligned} N_{\text{primary}} : N_{\text{secondary}} &= V_{\text{primary}} : V_{\text{secondary}} \\ &\therefore 11\times10^3 : 230 \\ &= 47.8 : 1 \\ &= 48 : 1 \text{ when rounded to whole numbers} \end{aligned}$$

Mark allocation: 2 marks

- 1 mark for correctly substituting values into the equation
- 1 mark for the correct answer rounded to whole numbers

Question 7c.

Worked solution

Location B

If the step-down transformer is placed at location A, the current flowing in the transmission line is given by the equation $\frac{V_1}{V_2} = \frac{I_2}{I_1}$, which may be rearranged to give

$$I_2 = \frac{V_1 I_1}{V_2} = \frac{P_1}{V_2} = \frac{50 \times 10^3}{230} = 217 \text{ A}$$

The power loss in the transmission line is $P = I^2 R = 217^2 \times 1 = 4.73 \times 10^4$ W, which is nearly the entire amount of power supplied by the grid.

If the step-down transformer is placed at location B, the current in the transmission line is 4.54 A, as calculated in **part a.** Thus the power loss in the transmission line is $P = I^2 R = 4.54^2 \times 1 = 20.7$ W. This is considerably lower than if the transformer is placed at location A.

Alternatively, note that the ratio of turns is 48 : 1. If the transformer is located at A, then the current in the lines will increase by a factor of 48 and the power loss in the transmission line will increase by a factor of $48^2 = 2304$.

Mark allocation: 4 marks

- 1 mark for stating location B
- 1 mark for calculating the current in the transmission line at location A
- 1 mark for calculating the power loss in the transmission line at location A
- 1 mark for calculating the power loss in the transmission line at location B

Note: It is possible to award consequential marks for using the value of the current obtained in **part a.**: $P = \text{Ans } (\mathbf{a})^2$ W .

If the alternative explanation, using the ratio of turns, is used, then:

- 1 mark for stating location B
- 1 mark for stating the use of the ratio of turns of 48 : 1 at location A
- 1 mark for stating that the current in the transmission line at location A would increase by a factor of 48
- 1 mark for stating that the power loss in the transmission line at location A compared to location B would be 48^2 greater

Question 8a.

Worked solution

0.11 s

The tangential speed is given by $v = \frac{2\pi r}{T}$, which can be rearranged to obtain the period.

$$T = \frac{2\pi r}{v} = \frac{2\pi \times 24}{1.4 \times 1000} = 0.108 \text{ s}$$

Mark allocation: 2 marks

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

Question 8b.

Worked solution

5.6×10^2 RPM

The frequency of the rocket is given by $f = \frac{1}{T} = \frac{1}{0.108} = 9.28$ revolutions per second.

To convert to RPM, multiply by 60:

$9.28 \times 60 = 557$ RPM

Mark allocation: 2 marks

- 1 mark for correctly substituting the values into the formula
  Note: It is possible to award consequential marks for using the value of the time period obtained in **part a.**: $f = \frac{1}{\text{Ans } (\mathbf{a})}$
- 1 mark for the correct answer in RPM
  Note: It is possible to award consequential marks for using the value of the time period obtained in **part a.**: $f = \frac{60}{\text{Ans } (\mathbf{a})}$ RPM

Question 8c.

Worked solution

24 MN

The centripetal force on the rocket is given by $F_c = \frac{mv^2}{r} = \frac{295 \times \left(1.4 \times 10^3\right)^2}{24} = 2.41 \times 10^7$ N.

To convert to MN, divide by 10^6:

$$\frac{2.41 \times 10^7}{10^6} = 24.1 \text{ MN}$$

Mark allocation: 2 marks

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

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Question 9a.

Worked solution

The change in the gravitational potential energy of the ball is given by

$\Delta E_{\mathrm{g}} = mg\Delta h = 0.16 \times 9.8 \times (0.89 + 0.17) = 1.66$ J.

This is equal to the work done to compress the spring, thereby storing the change in gravitational potential energy as elastic potential energy.

The elastic potential energy is given as $\frac{1}{2}k(\Delta x)^2 = 1.66$, which can be rearranged as

$k = \frac{2 \times 1.66}{0.17^2} = 115\ \mathrm{N\ m^{-1}}$.

Mark allocation: 3 marks

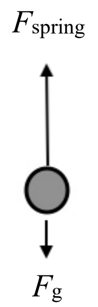
- 1 mark for correctly calculating the change in E_{g}
- 1 mark for equating the loss in E_{g} with the stored potential energy of the spring
- 1 mark for correctly substituting the values to obtain k

Question 9b.

Worked solution

18 N

The forces acting on the cricket ball at its lowest point are the force of gravity downwards and the force of the compressed spring upwards:



The force of the spring is given by $F_{\mathrm{spring}} = kx = 115 \times 0.17 = 19.6$ N .

The force of gravity is given by $F_{\mathrm{g}} = mg = 0.16 \times 9.8 = 1.57$ N .

The net force is therefore upwards, with a magnitude of $F_{\mathrm{spring}} - F_{\mathrm{g}} = 19.6 - 1.57 = 18.0$ N.

Mark allocation: 3 marks

- 1 mark for correctly calculating the spring force
- 1 mark for correctly substituting the spring force value into the net force equation

  Note: This mark may be awarded even if the spring force is incorrect, providing that the correct equation has been written.
- 1 mark for the correct answer for the net force

Question 9c.

Worked solution

1.4 J

The energy stored in the spring is given by $E_s = \frac{1}{2}kx^2 = \frac{1}{2} \times 115 \times 0.17^2 = 1.662$ J .

This energy is imparted to the ball as the spring returns to its natural length. Some of this energy is transformed to gravitational potential energy: $E_g = mgh = 0.16 \times 9.8 \times 0.17 = 0.267$ J.

The balance of the spring potential energy is therefore kinetic energy:

$E_k = E_s - E_g = 1.662 - 0.267 = 1.395$ J

Alternatively, in the absence of air resistance, the kinetic energy of the ball at this point is the same regardless of whether the ball is dropping from the initial position or launched upwards by the spring. The kinetic energy at this point is equal to the loss of gravitational potential energy:

$E_k = \Delta E_g = mg\Delta h = 0.16 \times 9.8 \times 0.89 = 1.396$ J

Mark allocation: 3 marks

- 1 mark for correctly calculating the energy stored in the spring

  Note: This mark may be awarded by restating the change in gravitational potential energy in **part a.** as being the same as the energy stored in the spring. A consequential mark may be given even if the answer in **part a.** is wrong.
- 1 mark for the correct answer for the change in gravitational potential energy
- 1 mark for the correct answer

Question 10a.

Worked solution

5.6 m s^{-1}

The initial momentum of the spaceship is $p = mu = 500 \times 0 = 0$ kg m s^{-1}.

As this interaction between masses is in deep space, momentum may be considered conserved. Thus, the final momentum of the system equals the initial momentum.

The final momentum is:

$$p = m_{\text{module}} v_{\text{module}} + m_{\text{remaining mass}} v_{\text{remaining mass}} = 0$$

$$50 \times (-50) + (500 - 50) v_{\text{remaining mass}} = 0$$

$$-2500 + 450 v_{\text{remaining mass}} = 0$$

$$450 v_{\text{remaining mass}} = 2500$$

$$v_{\text{remaining mass}} = \frac{2500}{450} = 5.56 \text{ m s}^{-1}$$

Mark allocation: 3 marks

- 1 mark for equating the final momentum with the initial momentum, which is zero
- 1 mark for correctly substituting the values into the final momentum equation
- 1 mark for the correct answer

Question 10b.

Worked solution

The interaction is an inelastic interaction because kinetic energy is not conserved.

The initial kinetic energy of the spaceship is $E_\mathrm{k} = \frac{1}{2}mu^2 = \frac{1}{2} \times 500 \times 0^2 = 0 \text{ J}$.

The final kinetic energy of the spaceship–module system is

$$E_\mathrm{k} = \frac{1}{2}m_\text{module}v_\text{module}{}^2 + \frac{1}{2}m_\text{remaining mass}v_\text{remaining mass}{}^2$$
$$= \frac{1}{2} \times 50 \times (-50)^2 + \frac{1}{2} \times 450 \times 5.56^2 \text{ J}$$

Since kinetic energy is gained, the interaction is inelastic.

Mark allocation: 3 marks

- 1 mark for stating that the interaction is inelastic
- 1 mark for correctly calculating the initial and final kinetic energies of the system
- 1 mark for noting that a difference in kinetic energies indicates that the interaction is inelastic

Tip

- *It is vital that you distinguish the term ‘isolated collision’ from the term ‘elastic collision’, as they are often confused with each other. ‘Elastic collision’ refers to the conservation of kinetic energy in the system. It is possible to conserve momentum without conserving kinetic energy.*

Question 11a.

Worked solution

The decay time of pions at rest is also the decay time of pions produced in the particle collider in their frame of reference. As they are travelling at relativistic speeds, the decay time measured by observers in the collider's frame of reference is dilated. This time dilation allows the particles to travel further in the frame of reference of the observer.

Mark allocation: 3 marks

- 1 mark for stating that the decay time of pions is in their frame of reference
- 1 mark for stating that the decay time measured in the laboratory is greater than that in a pion's frame of reference
- 1 mark for stating that the distance travelled is further than it would be if relativistic effects were ignored

Question 11b.

Worked solution

33

The proper distance a pion travels is 250 m, and the contracted length measured in the pion's frame of reference is 7.6 m. The latter is the distance covered by the pion before it decays within the time measured in its frame of reference. The Lorentz factor is therefore

$$\gamma = \frac{L_0}{L} = \frac{250}{7.6} = 32.9$$

You can arrive at the same answer by considering the transit time of the pions. Given that the pions are observed to travel at speed v, and travel 250 m, the observed time is

$$t = \frac{250}{v}\ \text{s}$$

However, the distance observed if time dilation is not taken into account is only 7.6 m. Therefore, the proper time is

$$t_0 = \frac{7.6}{v}\ \text{s}$$

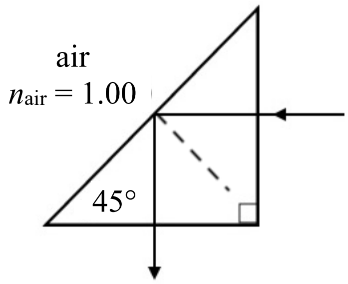
The Lorentz factor is $\gamma = \frac{t}{t_0} = \frac{250}{7.6} = 32.9$.

Mark allocation: 2 marks

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

Question 12a.

Worked solution



ray diagram

Mark allocation: 1 mark

- 1 mark for drawing a line emanating from the point where the light ray arrives at the interface between the prism and air, angled at 45° to the horizontal

Question 12b.

Worked solution

$n_{prism} = 1.41$

Snell's law may be used to calculate the index of refraction of the prism material for an incident angle of 45°: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

$n_1 \sin 45° = 1.00 \sin 90°$

$$n_1 = \frac{1}{\sin 45°} = 1.414$$

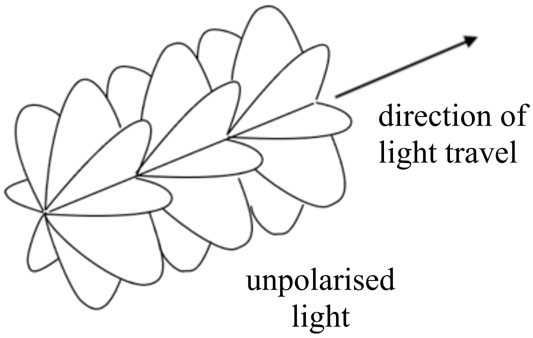
Mark allocation: 2 marks

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

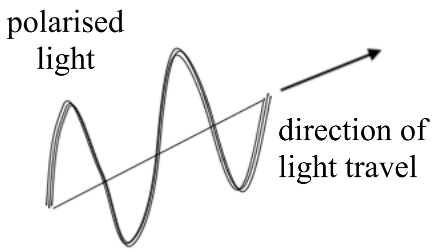
Question 13a.

Worked solution

Unpolarised light is light waves with planes of oscillation in many different directions in space. Most light sources, including sunlight, are unpolarised.



Polarised light is light waves with only one plane of oscillation in space. Polarised light sources include LCD and lasers.



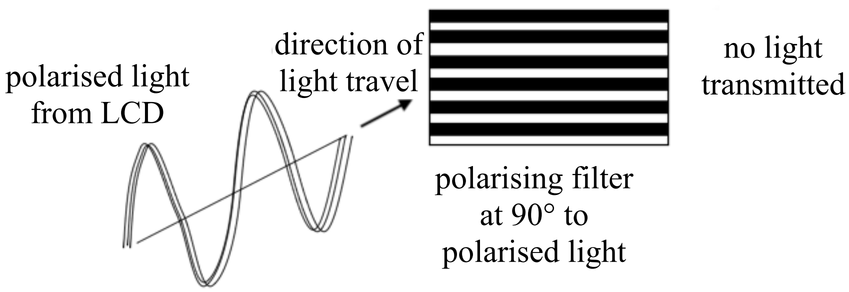
Mark allocation: 2 marks

- 1 mark for referring to light as waves
- 1 mark for describing unpolarised light as waves of many orientations in space or for describing polarised light as waves of only one orientation or plane in space

Question 13b.

Worked solution

Polarising filters can inadvertently block out polarised light from the LCDs on instrument panels if the filters are at 90° to the orientation of the light. This could prevent pilots from reading the displays.



Mark allocation: 2 marks

- 1 mark for explaining that polarising filters block polarised light at 90° orientation
- 1 mark for stating that this can make it difficult for pilots to read LCDs in the cockpit

Question 14a.

Worked solution

Since Shaken is equidistant from *E1* and *E2*, the path difference between the two waves as they approach Shaken is zero. The waves will be in phase with each other and so constructive interference will occur, resulting in a more vigorous shaking.

Mark allocation: 2 marks

- 1 mark for stating that there is zero path difference at Shaken
- 1 mark for concluding that constructive interference will occur at Shaken, resulting in more vigorous shaking

Question 14b.

Worked solution

0.52 km

As Stirred is located on the second nodal point away from the centreline, the path difference would be

$$pd = \left(n - \frac{1}{2}\right)\lambda = \left(2 - \frac{1}{2}\right)\lambda = 1.5\lambda$$

The path difference between the two earthquake waves as they approach Stirred is

$$pd = 3.83 - 3.05 = 0.78 \text{ km}$$

Equating the two equations above, $1.5\lambda = 0.78$ km, which yields $\lambda = \frac{0.78}{1.5} = 0.52$ km.

Mark allocation: 3 marks

- 1 mark for determining the path difference in terms of λ
- 1 mark for calculating the path difference
- 1 mark for equating the two equations for path difference and correctly deriving the wavelength of the waves

Question 14c.

Worked solution

5.7 km s^{-1}

The speed of the waves is given by the equation $v = f\lambda = 11 \times 0.52 = 5.72$ km s^{-1}.

Mark allocation: 2 marks

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

  Note: It is possible to award consequential marks for using the value of the wavelength obtained in **part b.**: $v = 11 \times \text{Ans}\ (\mathbf{b})$ km s^{-1}.

Question 15a.

Worked solution

5.9×10^{-15} eV s

Planck's constant can be estimated from the gradient between the two data points; that is:

$$\frac{\Delta\,\text{stopping voltage}}{\Delta\,\text{frequency}}$$

Therefore, $h=\dfrac{1.17-0.52}{6.25\times10^{14}-5.15\times10^{14}}=5.91\times10^{-15}$ eV s.

Mark allocation: 2 marks

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

Question 15b.

Worked solution

Photoelectrons are not expected to be emitted when a light source with a frequency of 3.95×10^{14} Hz is used because this frequency is below the threshold frequency, f_0. To calculate the threshold frequency, note that

$$E_{\text{k max}}=hf-hf_0$$

This can be rearranged to obtain

$$f_0=f-\frac{E_{\text{k max}}}{h}$$

Using the value for Planck's constant obtained in **part a.**, calculate the threshold frequency for either of the data points in Table 1:

$$f_0=6.25\times10^{14}-\frac{1.17}{5.91\times10^{-15}}=4.27\times10^{14}\ \text{Hz}$$

OR

$$f_0=5.15\times10^{14}-\frac{0.52}{5.91\times10^{-15}}=4.27\times10^{14}\ \text{Hz}$$

Mark allocation: 3 marks

- 1 mark for correctly substituting values into the equation
- 1 mark for the correct answer
- 1 mark for stating that the frequency of the new light source is lower than the threshold frequency, and therefore no photoelectrons will be emitted

Question 16a.

Worked solution

The photon energy is given by $E=\frac{hc}{\lambda}=\frac{6.63\times10^{-34}\times3\times10^{8}}{8.7\times10^{-10}}=2.29\times10^{-16}$ which can be rounded to 2.3×10^{-16} J.

Mark allocation: 1 mark

- 1 mark for correctly substituting values into the equation

Question 16b.

Worked solution

5.3 V

Since the amount of diffraction is proportional to $\frac{\lambda}{d}$, the de Broglie wavelength of the electrons, using the new grating, is $\lambda_{\text{de Broglie}}=\frac{d_{\text{new}}\lambda}{d}=\frac{9.1\times10^{-11}\times8.7\times10^{-10}}{1.48\times10^{-10}}=5.35\times10^{-10}$ m.

The electron momentum is given by $p=\frac{h}{\lambda}=\frac{6.63\times10^{-34}}{5.35\times10^{-10}}=1.24\times10^{-24}$ N s.

The electron velocity is given by $v=\frac{p}{m}=\frac{1.24\times10^{-24}}{9.1\times10^{-31}}=1.36\times10^{6}$ m s^{-1}.

The electron kinetic energy is $E_{\text{k}}=\frac{1}{2}mv^2=\frac{1}{2}\times9.1\times10^{-31}\times\left(1.36\times10^{6}\right)^2=8.44\times10^{-19}$ J which converts to $8.44\times10^{-19}\div\left(1.6\times10^{-19}\right)=5.28\text{ eV}$. Thus, the accelerating voltage is 5.28 V.

Alternatively, the electron kinetic energy may be obtained from the de Broglie wavelength:

$$E=\frac{h^2}{2m_{\text{e}}\lambda^2}=\frac{\left(6.63\times10^{-34}\right)^2}{2\times9.1\times10^{-31}\times\left(5.35\times10^{-10}\right)^2}=8.44\times10^{-19}\text{ J}, \text{ as before.}$$

Mark allocation: 4 marks

- 1 mark for correctly calculating the de Broglie wavelength of the electrons
- 1 mark for the correct value of the electron momentum

  Note: If the alternative formula is used, then this mark is awarded for correctly substituting the values into the formula.
- 1 mark for the correct value for electron kinetic energy
- 1 mark for the correct answer in volts

Tip

- *A potentially confusing issue is that the X-ray energy is given in electron-volts (eV). This is not the accelerating voltage of the electrons that will produce the required diffraction pattern, as X-rays are electromagnetic radiation whereas electrons are particles.*

Question 17a.

Worked solution

The photon energy of a LED with a wavelength of 340 nm is

$$E = \frac{hc}{\lambda} = \frac{4.14\times10^{-15}\times3\times10^{8}}{340\times10^{-9}} = 3.65\ \text{eV}$$

This value does not correspond to the difference between ground state and any higher energy level. Hence, the electrons in the element are unable to absorb a photon and so cannot transition between energy levels.

Mark allocation: 3 marks

- 1 mark for correctly calculating the photon energy of the LED
- 1 mark for pointing out that this does not correspond to the difference between the ground state and a higher energy level
- 1 mark for concluding that an electron is thus unable to absorb a photon

Question 17b.

Worked solution

9 lines

There are 10 possible transitions between the energy levels:

n = 1 to n = 2, ΔE = 1.91 eV	**n = 2 to n = 4, ΔE = 1.91 eV**
n = 1 to n = 3, ΔE = 3.37 eV	n = 2 to n = 5, ΔE = 1.98 eV
n = 1 to n = 4, ΔE = 3.82 eV	n = 3 to n = 4, ΔE = 0.45 eV
n = 1 to n = 5, ΔE = 3.89 eV	n = 3 to n = 5, ΔE = 0.52 eV
n = 2 to n = 3, ΔE = 1.46 eV	n = 4 to n = 5, ΔE = 0.07 eV

However, since there are 2 transitions where ΔE = 1.91 eV (highlighted in **bold**), there would only be 9 lines in the absorption spectrum.

Mark allocation: 3 marks

- 1 mark for the correct answer of 9 lines
- 2 marks for working out the value of ΔE for all ten transitions

Note: Award only 1 mark for working out the value for at least five transitions but fewer than ten.

Question 18

Worked solution

1.4×10^{-11} kg

The mass decrease may be calculated by rearranging the equation $E = mc^2$, giving

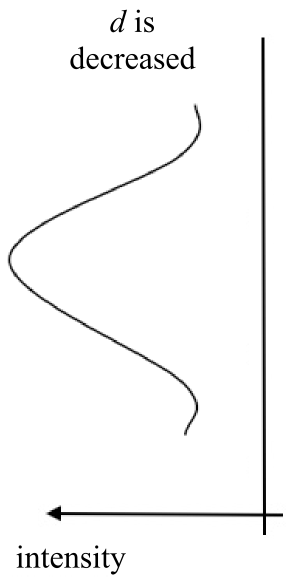
$$m = \frac{E}{c^2} = \frac{1.3\times10^6}{\left(3\times10^8\right)^2} = 1.44\times10^{-11} \text{ kg}$$

Mark allocation: 2 marks

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

Question 19a.

Worked solution



Since diffraction increases as the width of the slit decreases, the intensity graph would become wider and more spread out.

Mark allocation: 1 mark

- 1 mark for drawing a graph of a similar shape

Question 19b.

Worked solution

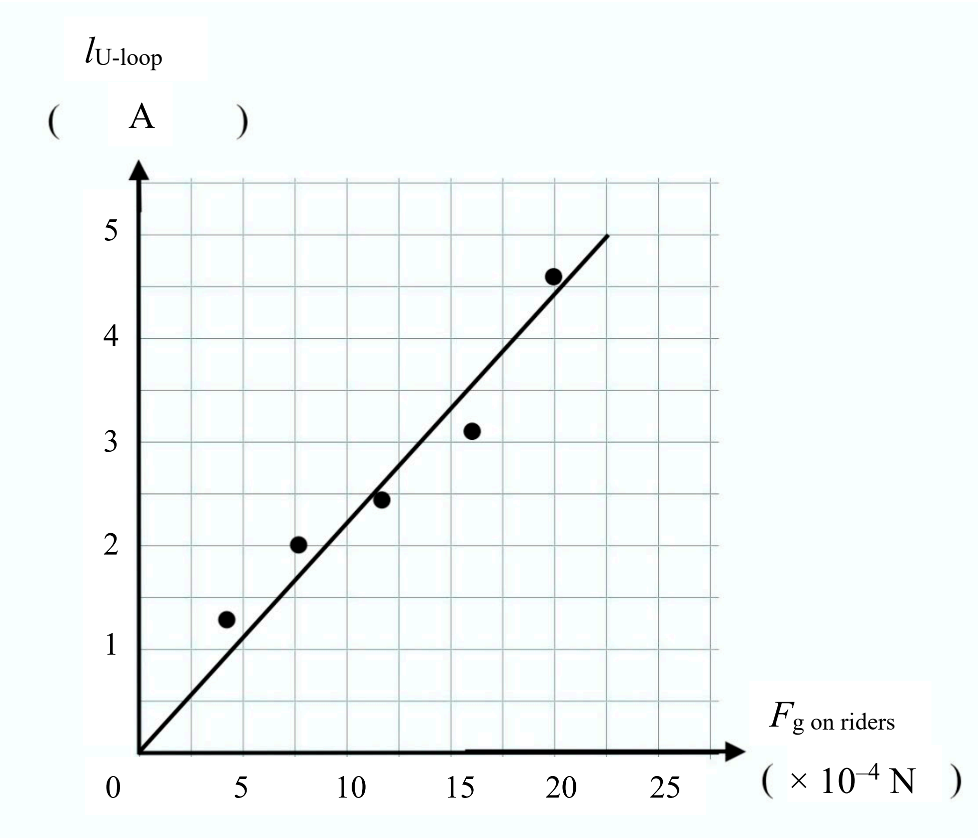
Heisenberg's uncertainty principle states that as the uncertainty of the transverse position of the electrons (which is specified by the slit width, d) is decreased, the uncertainty of the transverse momentum of the electrons is increased. The increase in the uncertainty of the transverse momentum is observed as more spread (diffraction) in the intensity graph.

Mark allocation: 2 marks

- 1 mark for using Heisenberg's uncertainty principle to explain the increase in uncertainty of transverse momentum
- 1 mark for connecting the increase in uncertainty of transverse momentum to greater diffraction

Question 20a.

Worked solution



Mark allocation: 5 marks

- 2 marks for correctly plotting the points. Deduct 1 mark for up to 2 errors. Deduct 2 marks for 3 or more errors
- 1 mark for adding correct units to **both** axes
- 1 mark for adding correct scales to **both** axes
- 1 mark for the correct line of best fit

Question 20b.

Worked solution

2.2×10^{3} A/N

The gradient is calculated using the points (0, 0) and (22.5×10^{-4}, 5) to obtain 2.22×10^{3} A/N.

The lower bound of the gradient is 1.8×10^{3}, calculated from (0, 0.5) to (25×10^{-4}, 5).

The upper bound of the gradient is 2.5×10^{3}, calculated from (2.5×10^{-4}, 0) to (22.5×10^{-4}, 5).

Mark allocation: 2 marks

- 1 mark for selecting two points that are on the line of best fit and correctly substituting them into the formula

Note: Experiment data should not be used unless they are on the line of best fit.

- 1 mark for a value of the gradient between 1800 and 2500

Note: It is possible to award consequential marks for a different but reasonable line of best fit. The procedure and calculation must be correct.

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.*

Question 20c.

Worked solution

1.8×10^{-2} T

Rearranging the formula, the magnetic field strength is given by $B=\dfrac{F}{nIl}$.

As the gradient is $\dfrac{I}{F}$, the inverse of the gradient can be used together with $l=2.5\times10^{-2}$ m and n = 1 to obtain

$$B=\frac{1}{1\times2.22\times10^{3}\times2.5\times10^{-2}}=1.80\times10^{-2}\text{ T}$$

Mark allocation: 3 marks

- 1 mark for correctly deriving the equation for the magnetic field strength, B
- 1 mark for correctly substituting the value of the gradient
- 1 mark for calculating a value of B that is between 1.6×10^{-2} and 2.2×10^{-2} T

END OF WORKED SOLUTIONS