A-Level Physics Past Paper Transcription

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Question 1

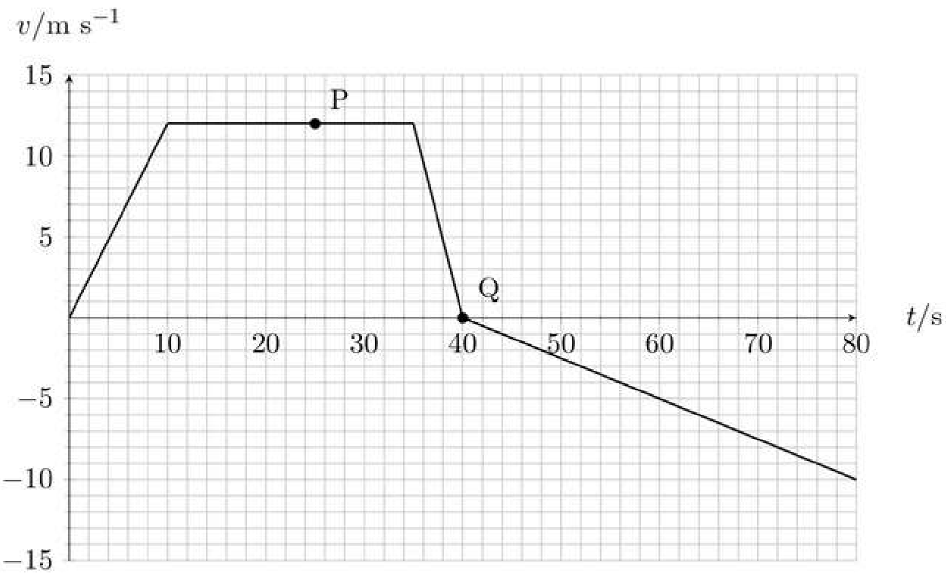
(a) By placing one tick in each row, complete Table 1.1 to identify whether each of the listed quantities is a scalar or a vector. [2]

quantity	scalar	vector
amplitude		
force		
momentum		
power		

Solution

quantity	scalar	vector
amplitude	✓	
force		✓
momentum		✓
power	✓	

(b) A car moves in a straight line along a road. Figure 1.1 shows the variation with time t of the velocity v of the car.



(i) State the feature of the graph that represents the distance travelled by the car between $t = 0$ and $t = 40$ s. [1]

Solution

The distance travelled is represented by the enclosed area bounded by the velocity-time graph and the horizontal time axis.

(ii) Calculate the distance travelled by the car between $t = 0$ and $t = 40$ s. [3]

Solution

Instead of using a single trapezium formula, we can sum the areas of the constituent geometric shapes:

- Area of initial acceleration triangle ($0 - 10$ s): $A_1 = \frac{1}{2} \times 10 \times 12 = 60$ m
- Area of constant velocity rectangle ($10 - 35$ s): $A_2 = 25 \times 12 = 300$ m
- Area of deceleration triangle ($35 - 40$ s): $A_3 = \frac{1}{2} \times 5 \times 12 = 30$ m

Total distance $s = A_1 + A_2 + A_3 = 60 + 300 + 30 = 390$ m.

(iii) Determine the maximum magnitude of the acceleration of the car. [2]

Solution

Acceleration is the gradient of the v-t graph. Let's calculate the gradient for all three non-zero acceleration segments:

- 0 to 10 s: $a = \frac{12-0}{10-0} = 1.2 \text{ m s}^{-2}$
- 35 to 40 s: $a = \frac{0-12}{40-35} = -2.4 \text{ m s}^{-2}$
- 40 to 80 s: $a = \frac{-10-0}{80-40} = -0.25 \text{ m s}^{-2}$

The maximum absolute value among these is $|-2.4 \text{ m s}^{-2}| = 2.4 \text{ m s}^{-2}$.

(iv) At $t = 25$ s the car is at a point P. At $t = 40$ s, the car is at a distance of 150 m from P. After $t = 40$ s the car travels with a constant acceleration of -0.25 m s^{-2} until the car is again at point P. Calculate the speed of the car when it is at point P for the second time. [2]

Solution

At $t = 40$ s, the car comes to a momentary halt ($u = 0$). It is currently $+150$ m away from P. To return to P, it must undergo a displacement of $s = -150$ m. Using the kinematic equation $v^2 = u^2 + 2as$:

$$v^2 = 0^2 + 2(-0.25 \text{ m s}^{-2})(-150 \text{ m})$$

$$v^2 = 75$$

$$v = \sqrt{75} \approx 8.66 \text{ m s}^{-1}$$

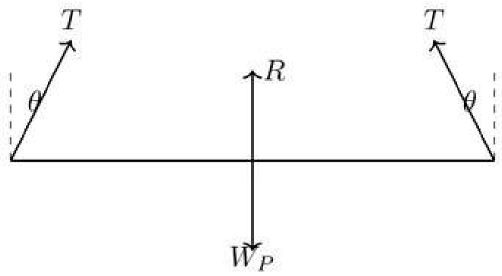
Question 2

(a) State the conditions required for an object to be in equilibrium. [2]

Solution

1. The vector sum of all external forces acting on the object must be zero ($\Sigma F = 0$).
2. The algebraic sum of all moments (torques) about any arbitrary point must be zero ($\Sigma M = 0$).

(b) A block rests in equilibrium on the centre of a uniform horizontal plank. The block is attached to two ropes, each of which passes over a fixed pulley and then attaches to an end of the plank as shown in Figure 2.1. Figure 2.2 shows the directions of the forces acting on the plank and the block.



(i) Use Figure 2.2 to show that $R + W_P = W_B - R$. [1]

Solution

We analyze the vertical equilibrium for both the plank and the block separately:

- **For the plank:** The upward forces are the vertical components of the two tensions ($2T\cos\theta$). The downward forces are its weight (W_P) and the normal reaction from the block (R). Hence: $2T\cos\theta = W_P + R$
- **For the block:** Upward forces are the vertical components of the tensions ($2T\cos\theta$) plus the normal reaction from the plank (R). Downward force is its weight (W_B). Hence: $2T\cos\theta + R = W_B \implies 2T\cos\theta = W_B - R$

Equating both expressions for $2T\cos\theta$ yields:

$$W_P + R = W_B - R$$

(ii) The mass of the block is 8.1 kg. The mass of the plank is 4.5 kg. Calculate the magnitude of R. [2]

Solution

Rearranging the equation derived in (i) to solve for R:

$$2R = W_B - W_P$$

$$R = \frac{m_B g - m_P g}{2} = \frac{g(m_B - m_P)}{2}$$

Substituting the given values ($g = 9.81$ m s^{-2}):

$$R = \frac{9.81 \times (8.1 - 4.5)}{2} = \frac{9.81 \times 3.6}{2} = 17.658 \text{ N}$$

Rounding to appropriate significant figures gives $R = 17.7$ N.

(c) (i) State the name of the law that describes this behaviour (extension proportional to force). [1]

Solution

Hooke's Law.

(ii) State what is meant by elastic deformation. [1]

Solution

Elastic deformation implies a temporary change in shape, meaning the material will completely revert to its original dimensions once the applied stress/force is withdrawn.

Question 3

Two oscillating dippers are used to create progressive transverse water waves...

(a) State what is meant by a progressive wave. [1]

Solution

A progressive wave is a propagation of oscillations that carries energy and momentum from one location to another without physically transporting the medium itself.

(b)(i) Calculate the period of the waves ($f = 3.0$ Hz). [1]

Solution

Period $T = \frac{1}{f} = \frac{1}{3.0\text{ Hz}} \approx 0.33$ s.

(ii) The distance from A to P is 3.9 m. The distance from B to P is 2.4 m. Determine the speed of the waves. [3]

Solution

From the provided interference diagram, point P is situated at the intersection of two wave crests (solid lines), indicating a point of maximum constructive interference. The path difference (Δx) to point P is:

$$\Delta x = 3.9\text{ m} - 2.4\text{ m} = 1.5\text{ m}$$

Since it is the first order of constructive interference shown adjacent to the central axis, $\Delta x = 1\lambda$. Therefore, the wavelength $\lambda = 1.5$ m. Using the wave equation:

$$v = f\lambda = (3.0\text{ Hz})(1.5\text{ m}) = 4.5\text{ m s}^{-1}$$

(c)(i) A ball of mass 0.44 kg is placed at P... Amplitude is 15 cm. Calculate the difference in GPE. [3]

Solution

The total vertical displacement from the lowest point (trough) to the highest point (crest) is equal to twice the amplitude (peak-to-peak distance).

$$\Delta h = 2A = 2 \times 0.15 \text{ m} = 0.30 \text{ m}$$

The change in gravitational potential energy is:

$$\Delta E_p = mg\Delta h = (0.44 \text{ kg})(9.81 \text{ m s}^{-2})(0.30 \text{ m}) = 1.29492 \text{ J} \approx 1.3 \text{ J}$$

(ii) The frequency of oscillation is increased to 4.0 Hz... State and explain whether the amplitude increases, decreases or remains the same. [2]

Solution

The amplitude of the ball **decreases**. Explanation: Since the wave speed v remains constant (it depends only on the water depth) and the frequency f increases, the wavelength $\lambda = v/f$ must decrease. Consequently, the fixed path difference of 1.5 m at location P will no longer correspond to an integer multiple of the new wavelength ($n\lambda$). Thus, P is no longer a point of perfect constructive interference.

Question 4

(a) Calculate the speed of the train. (Mass 1.5×10^4 kg, $E_k = 1.3 \times 10^5$ J). [3]

Solution

Kinetic energy formula: $E_k = \frac{1}{2}mv^2$. Rearranging for velocity v:

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 1.3 \times 10^5}{1.5 \times 10^4}} = \sqrt{17.33} \approx 4.16 \text{ m s}^{-1}$$

(b)(i) Define power. [1]

Solution

Power is defined as the rate at which work is done or energy is transferred with respect to time.

(b)(ii) Determine the resistive force F acting on the train. [3]

Solution

Based on the principle of energy conservation, the total work supplied by the motor equals the sum of the increase in gravitational potential energy and the work done overcoming resistive forces (since speed and thus E_k is constant). Total work by motor: $W_{in} = P \times t = (1.1 \times 10^5 \text{ W})(52 \text{ s}) = 5.72 \times 10^6$ J. Gain in GPE: $\Delta E_p = 13.0 \text{ MJ} - 7.4 \text{ MJ} = 5.6 \times 10^6$ J. Work done against friction: $W_f = W_{in} - \Delta E_p = 5.72 \text{ MJ} - 5.6 \text{ MJ} = 0.12 \text{ MJ} = 1.2 \times 10^5$ J. The distance travelled $s = v \times t = 4.163 \text{ m s}^{-1} \times 52 \text{ s} \approx 216.5$ m. Resistive force $F = \frac{W_f}{s} = \frac{1.2 \times 10^5 \text{ J}}{216.5 \text{ m}} \approx 554$ N (or 555 N depending on intermediate rounding).

(b)(iii) Calculate the percentage efficiency of the motor. ($I = 95$ A, $V = 1400$ V). [3]

Solution

Electrical input power to the motor:

$$P_{in} = VI = (1400 \text{ V})(95 \text{ A}) = 133,000 \text{ W} = 1.33 \times 10^5 \text{ W}$$

Efficiency is the ratio of useful output power to total input power:

$$\text{Efficiency} = \left(\frac{P_{out}}{P_{in}}\right) \times 100\% = \left(\frac{1.1 \times 10^5}{1.33 \times 10^5}\right) \times 100\% \approx 82.7\%$$

Question 5

(a) Derive the equation $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$. [2]

Solution

By Kirchhoff's First Law (conservation of charge), the total current entering the parallel junction must equal the sum of the currents in each branch:

$$I_T = I_1 + I_2 + I_3$$

Since the components are in parallel, the potential difference V across each resistor is identical. Using Ohm's law ($I = V/R$), we can substitute for each current:

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Dividing the entire equation by the common factor V yields:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

(b)(i) Calculate the current in the battery. (Two 2.8 Ω resistors in parallel, 12 V). [2]

Solution

First, find the equivalent resistance of the two identical parallel wires:

$$R_T = \frac{R}{2} = \frac{2.8 \ \Omega}{2} = 1.4 \ \Omega$$

Using Ohm's law to find the main circuit current:

$$I_{total} = \frac{V}{R_T} = \frac{12 \text{ V}}{1.4 \ \Omega} \approx 8.57 \text{ A}$$

(b)(ii) Calculate the average drift speed. [2]

Solution

Because the two wires are identical and in parallel, the total current divides equally. Current in one wire:

$$I = \frac{8.57 \text{ A}}{2} = 4.285 \text{ A}$$

Using the drift velocity equation $I = nAqv$, we rearrange for v:

$$v = \frac{I}{nAe} = \frac{4.285}{(8.5 \times 10^{28})(6.1 \times 10^{-6})(1.60 \times 10^{-19})}$$

$$v \approx 5.16 \times 10^{-5} \text{ m s}^{-1} \approx 5.2 \times 10^{-5} \text{ m s}^{-1}$$

(c)(i) State the name of component X. [1]

Solution

Light-Dependent Resistor (LDR).

(c)(ii) Determine the resistance of component X. [3]

Solution

With X added in series to one branch, the new total current is 5.0 A. The new total equivalent resistance of the circuit is:

$$R_{new} = \frac{V}{I_{new}} = \frac{12 \text{ V}}{5.0 \text{ A}} = 2.4 \ \Omega$$

The circuit consists of a top branch (just a wire, $R_1 = 2.8\ \Omega$) in parallel with a bottom branch (wire + LDR, $R_2 = 2.8\ \Omega + R_X$).

$$\frac{1}{R_{new}} = \frac{1}{R_1} + \frac{1}{R_2} \implies \frac{1}{2.4} = \frac{1}{2.8} + \frac{1}{2.8 + R_X}$$

$$\frac{1}{2.8 + R_X} = \frac{1}{2.4} - \frac{1}{2.8} = \frac{7-6}{16.8} = \frac{1}{16.8}$$

$$2.8 + R_X = 16.8 \implies R_X = 14\ \Omega$$

(c)(iii) State and explain how the environment of X has changed. [2]

Solution

The environment has become **darker** (light intensity decreased). As total current decreased from a fixed 12 V supply, overall circuit resistance must have increased. Since the fixed resistors didn't change, the LDR's resistance must have gone up. An LDR exhibits higher resistance under lower illumination levels.

Question 6

(a) State the observation from the experiment that provides evidence that the atom is mostly empty space. [1]

Solution

The vast majority of alpha particles travelled directly through the gold leaf with zero or negligible deflection.

(b)(i) Show that the momentum of the α-particle before the collision is 3.72×10^{-20} kg m s^{-1}. [2]

Solution

An alpha particle consists of 2 protons and 2 neutrons, thus its mass is approximately 4 u.

$$m_\alpha = 4 \times 1.66 \times 10^{-27} \text{ kg} = 6.64 \times 10^{-27} \text{ kg}$$

The initial momentum p is the product of its mass and initial velocity:

$$p_i = m_\alpha u = (6.64 \times 10^{-27} \text{ kg}) \times (5.60 \times 10^6 \text{ m s}^{-1}) = 3.7184 \times 10^{-20} \text{ kg m s}^{-1}$$

This correctly rounds to 3.72×10^{-20} kg m s^{-1}.

(b)(ii) Use conservation of momentum to calculate the speed of the gold nucleus after the collision. [2]

Solution

Let the initial direction of the alpha particle be positive. Initial total momentum $P_{initial} = 3.718 \times 10^{-20}$ kg m s^{-1}. Final momentum of the alpha particle (moving in the opposite direction):

$$p_{f,\alpha} = m_\alpha v_\alpha = (6.64 \times 10^{-27}) \times (-5.38 \times 10^6) = -3.572 \times 10^{-20} \text{ kg m s}^{-1}$$

By conservation of momentum: $P_{initial} = p_{f,\alpha} + p_{f,Au}$

$$3.718 \times 10^{-20} = -3.572 \times 10^{-20} + p_{f,Au}$$

$$p_{f,Au} = (3.718 + 3.572) \times 10^{-20} = 7.29 \times 10^{-20} \text{ kg m s}^{-1}$$

Mass of gold nucleus $m_{Au} = 197 \times 1.66 \times 10^{-27} = 3.270 \times 10^{-25}$ kg. Velocity of gold nucleus $v_{Au} = \frac{p_{f,Au}}{m_{Au}} = \frac{7.29 \times 10^{-20}}{3.270 \times 10^{-25}} \approx 2.23 \times 10^5$ m s^{-1}.

(b)(iii) Calculate the percentage uncertainty in the change in velocity of the α-particle. [2]

Solution

The change in velocity Δv is calculated by subtracting the initial vector from the final vector:

$$\Delta v = v_{final} - v_{initial} = (-5.38 \times 10^6) - (5.60 \times 10^6) = -10.98 \times 10^6 \text{ m s}^{-1}$$

The absolute value of the change is 10.98×10^6 m s^{-1}. Since we are subtracting two values, we must add their absolute uncertainties to find the total absolute uncertainty:

$$\delta(\Delta v) = (5 \times 10^4) + (5 \times 10^4) = 10 \times 10^4 = 1.0 \times 10^5 \text{ m s}^{-1}$$

The percentage uncertainty is therefore:

$$\% \text{ Uncertainty} = \left(\frac{\delta(\Delta v)}{|\Delta v|}\right) \times 100\% = \left(\frac{1.0 \times 10^5}{10.98 \times 10^6}\right) \times 100\% \approx 0.91\%$$

(c) Determine the number of up quarks in a nucleus of ${}^2_1\text{H}$. [1]

Solution

Hydrogen-2 (Deuterium) has a nucleus containing 1 proton and 1 neutron.

- 1 Proton = 2 up quarks + 1 down quark (uud)
- 1 Neutron = 1 up quark + 2 down quarks (udd)

Total number of up quarks $= 2 + 1 = 3$.

(d) Describe the general quark composition of a meson. [1]

Solution

A meson consists of a quark and an antiquark pair.