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Physics
Higher level
Paper 2

Monday 3 May 2021 (afternoon)

Candidate session number

2 hours 15 minutes

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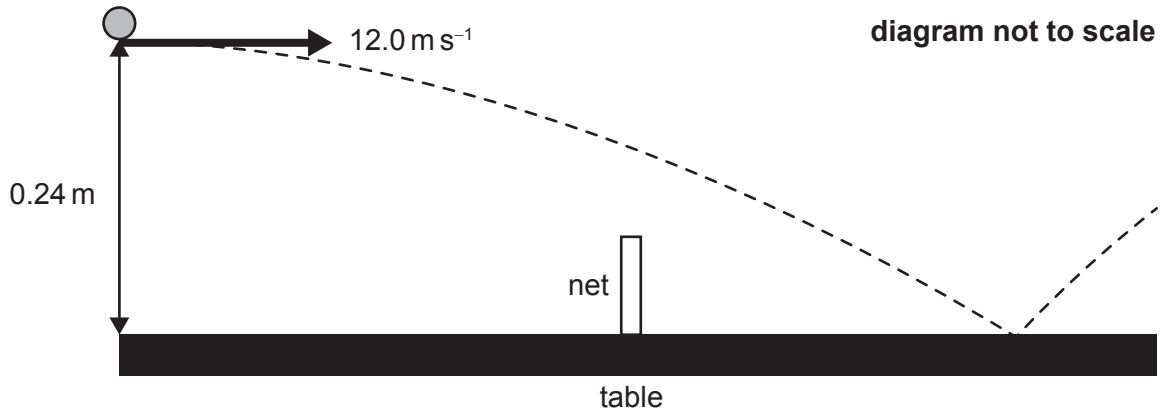
Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.



Answer **all** questions. Answers must be written within the answer boxes provided.

1. Two players are playing table tennis. Player A hits the ball at a height of 0.24 m above the edge of the table, measured from the top of the table to the bottom of the ball. The initial speed of the ball is 12.0 m s^{-1} horizontally. Assume that air resistance is negligible.

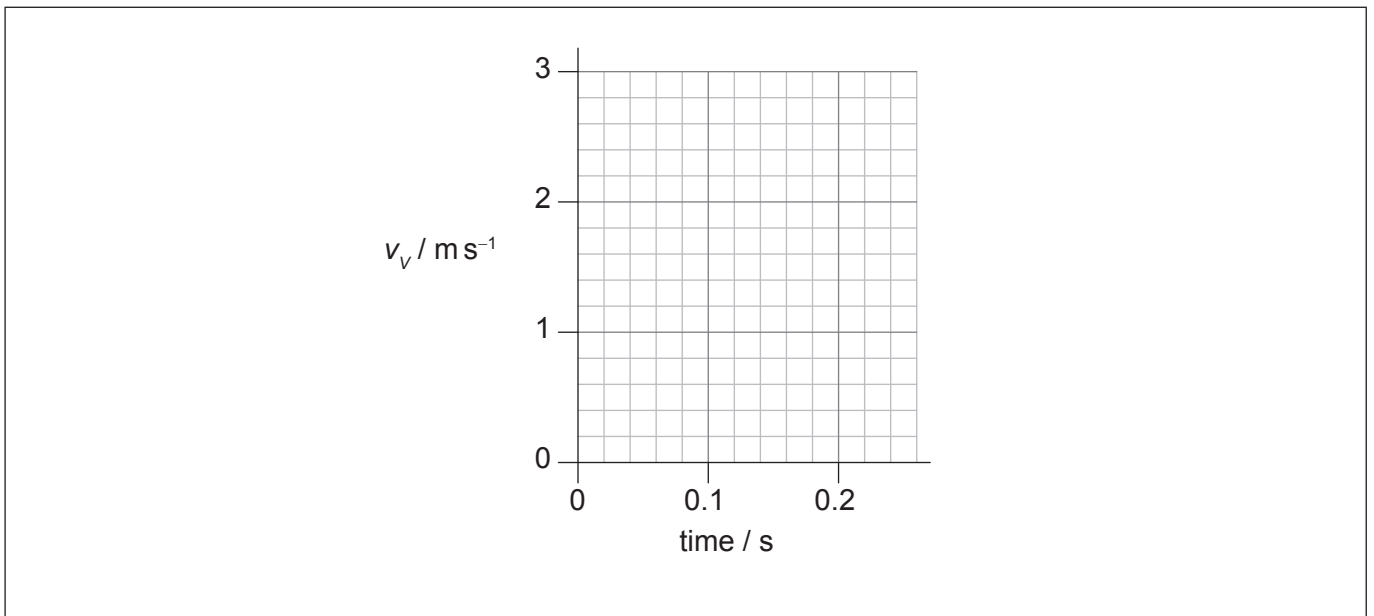


- (a) Show that the time taken for the ball to reach the surface of the table is about 0.2 s. [1]

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- (b) Sketch, on the axes, a graph showing the variation with time of the vertical component of velocity v_v of the ball until it reaches the table surface. Take g to be $+10 \text{ m s}^{-2}$. [2]



(This question continues on the following page)



(Question 1 continued)

- (c) The net is stretched across the middle of the table. The table has a length of 2.74 m and the net has a height of 15.0 cm.

Show that the ball will go over the net.

[3]

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- (d) The ball bounces and then reaches a peak height of 0.18 m above the table with a horizontal speed of 10.5 m s^{-1} . The mass of the ball is 2.7 g.

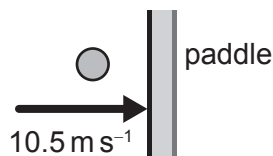
- (i) Determine the kinetic energy of the ball immediately after the bounce.

[2]

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- (ii) Player B intercepts the ball when it is at its peak height. Player B holds a paddle (racket) stationary and vertical. The ball is in contact with the paddle for 0.010 s. Assume the collision is elastic.



Calculate the average force exerted by the ball on the paddle. State your answer to an appropriate number of significant figures.

[3]

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2. A planet is in a circular orbit around a star. The speed of the planet is constant. The following data are given:

- Mass of planet = 8.0×10^{24} kg
- Mass of star = 3.2×10^{30} kg
- Distance from the star to the planet $R = 4.4 \times 10^{10}$ m.

(a) Explain why a centripetal force is needed for the planet to be in a circular orbit. [2]

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(b) Calculate the value of the centripetal force. [1]

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(Question 2 continued)

(c) A spacecraft is to be launched from the surface of the planet to escape from the star system. The radius of the planet is 9.1×10^3 km.

(i) Show that the gravitational potential due to the planet and the star at the surface of the planet is about $-5 \times 10^9 \text{ J kg}^{-1}$. [3]

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(ii) Estimate the escape speed of the spacecraft from the planet–star system. [2]

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3. A mass of 1.0 kg of water is brought to its boiling point of 100 °C using an electric heater of power 1.6 kW.

(a) (i) The molar mass of water is 18 g mol⁻¹. Estimate the average speed of the water molecules in the vapor produced. Assume the vapor behaves as an ideal gas. [2]

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(ii) State **one** assumption of the kinetic model of an ideal gas. [1]

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(b) A mass of 0.86 kg of water remains after it has boiled for 200 s.

(i) Estimate the specific latent heat of vaporization of water. State an appropriate unit for your answer. [2]

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(ii) Explain why the temperature of water remains at 100 °C during this time. [1]

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(Question 3 continued)

- (c) The heater is removed and a mass of 0.30 kg of pasta at -10°C is added to the boiling water.

Determine the equilibrium temperature of the pasta and water after the pasta is added. Other heat transfers are negligible.

Specific heat capacity of pasta = $1.8\text{ kJ kg}^{-1}\text{ K}^{-1}$
Specific heat capacity of water = $4.2\text{ kJ kg}^{-1}\text{ K}^{-1}$

[3]

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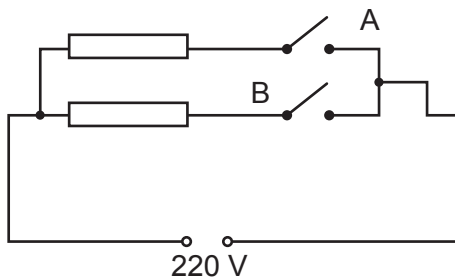
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- (d) The electric heater has two identical resistors connected in parallel.



The circuit transfers 1.6 kW when switch A only is closed. The external voltage is 220 V.

- (i) Show that each resistor has a resistance of about $30\ \Omega$. [1]

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Turn over

(Question 3 continued)

(ii) Calculate the power transferred by the heater when both switches are closed. [2]

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4. A planet orbits at a distance d from a star. The power emitted by the star is P . The total surface area of the planet is A .

(a) (i) Explain why the power incident on the planet is

$$\frac{P}{4\pi d^2} \times \frac{A}{4} \quad [2]$$

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(ii) The albedo of the planet is α_p . The equilibrium surface temperature of the planet is T . Derive the expression

$$T = \sqrt[4]{\frac{P(1-\alpha_p)}{16\pi d^2 e \sigma}}$$

where e is the emissivity of the planet. [2]

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(b) On average, the Moon is the same distance from the Sun as the Earth. The Moon can be assumed to have an emissivity $e = 1$ and an albedo $\alpha_M = 0.13$. The solar constant is $1.36 \times 10^3 \text{ W m}^{-2}$. Calculate the surface temperature of the Moon. [2]

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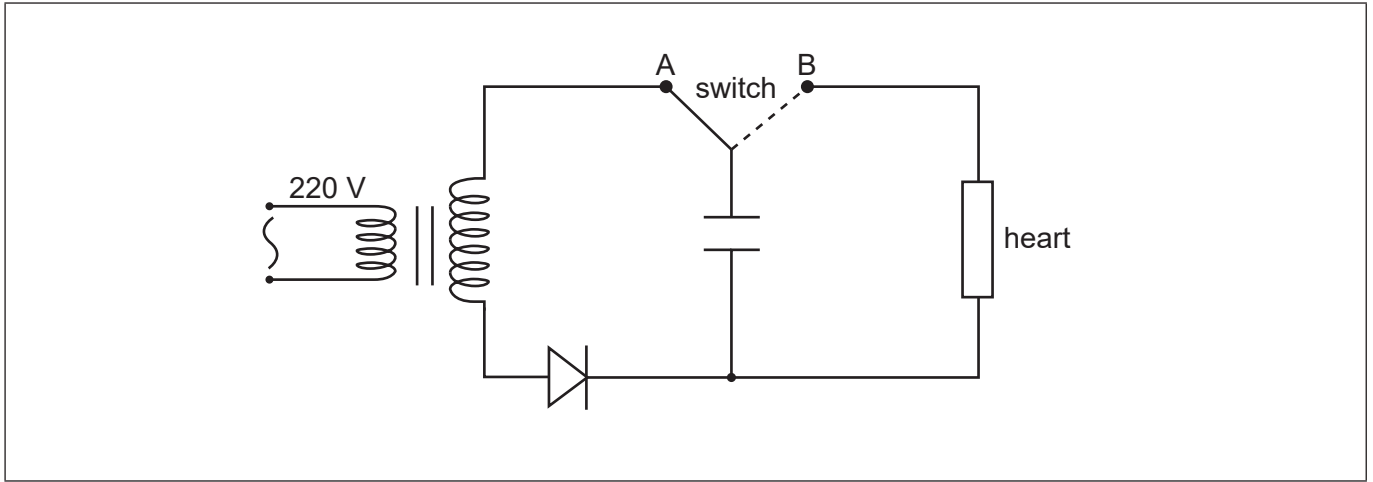
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5. A device sends an impulse of electrical energy to maintain a regular heartbeat in a person. The device is powered by an alternating current (ac) supply connected to a step-up transformer that charges a capacitor of capacitance $30\ \mu\text{F}$.



- (a) Explain the role of the diode in the circuit when the switch is at position A. [2]

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(Question 5 continued)

(b) The voltage across the primary coil of the transformer is 220 V. The number of turns on the secondary coil is 15 times greater than the number of turns on the primary coil.

(i) Show that the maximum energy stored by the capacitor is about 160 J. [2]

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(ii) Calculate the maximum charge Q_0 stored in the capacitor. [1]

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(iii) Identify, using the label + on the diagram, the polarity of the capacitor. [1]

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(Question 5 continued)

(c) The switch is moved to position B.

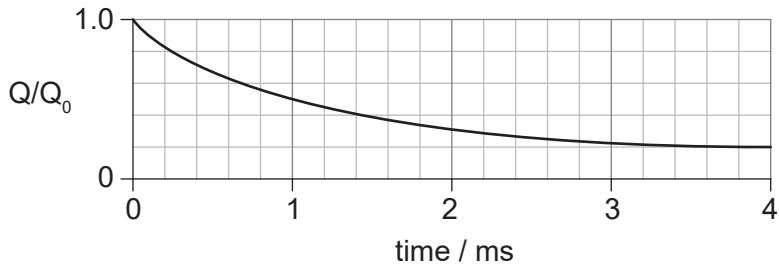
(i) Describe what happens to the energy stored in the capacitor when the switch is moved to position B. [1]

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(ii) Show that the charge remaining in the capacitor after a time equal to one time constant τ of the circuit will be $0.37Q_0$. [1]

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(iii) The graph shows the variation with time of the charge in the capacitor as it is being discharged through the heart.



Determine the electrical resistance of the closed circuit with the switch in position B. [2]

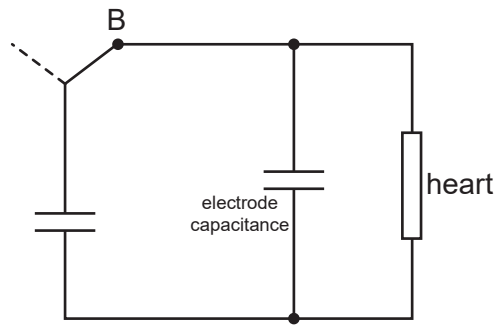
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(Question 5 continued)

- (d) In practice, two electrodes connect the heart to the circuit. These electrodes introduce an additional capacitance.



Explain the effect of the electrode capacitance on the discharge time.

[2]

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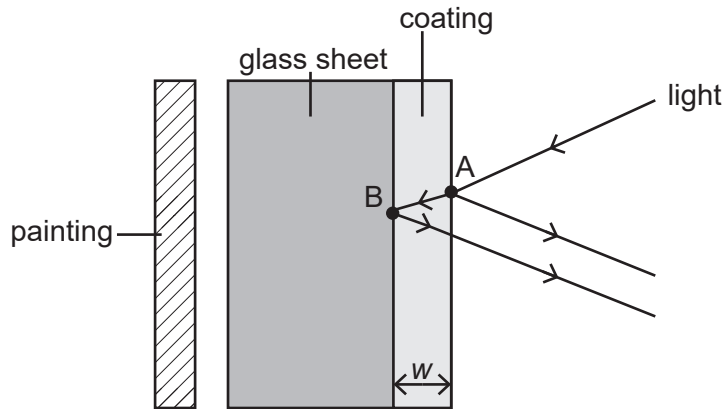
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6. A painting is protected behind a transparent glass sheet of refractive index n_{glass} . A coating of thickness w is added to the glass sheet to reduce reflection. The refractive index of the coating n_{coating} is such that $n_{\text{glass}} > n_{\text{coating}} > 1$.

The diagram illustrates rays **normally** incident on the coating. Incident angles on the diagram are drawn away from the normal for clarity.



- (a) State the phase change when a ray is reflected at B. [1]

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- (b) Explain the condition for w that eliminates reflection for a particular light wavelength in air λ_{air} . [3]

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(Question 6 continued)

(c) (i) State the Rayleigh criterion for resolution.

[1]

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(ii) The painting contains a pattern of red dots with a spacing of 3 mm. Assume the wavelength of red light is 700 nm. The average diameter of the pupil of a human eye is 4 mm. Calculate the maximum possible distance at which these red dots are distinguished.

[2]

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7. Radioactive uranium-238 (${}^{238}_{92}\text{U}$) produces a series of decays ending with a stable nuclide of lead. The nuclides in the series decay by either alpha (α) or beta-minus (β^-) processes.

(a) Uranium-238 decays into a nuclide of thorium-234 (Th).

Write down the complete equation for this radioactive decay. [1]

${}^{238}_{92}\text{U} \rightarrow$

(b) Thallium-206 (${}^{206}_{81}\text{Tl}$) decays into lead-206 (${}^{206}_{82}\text{Pb}$).

Identify the quark changes for this decay. [1]

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(c) The half-life of uranium-238 is about 4.5×10^9 years. The half-life of thallium-206 is about 4.2 minutes.

Compare and contrast the methods to measure these half-lives. [4]

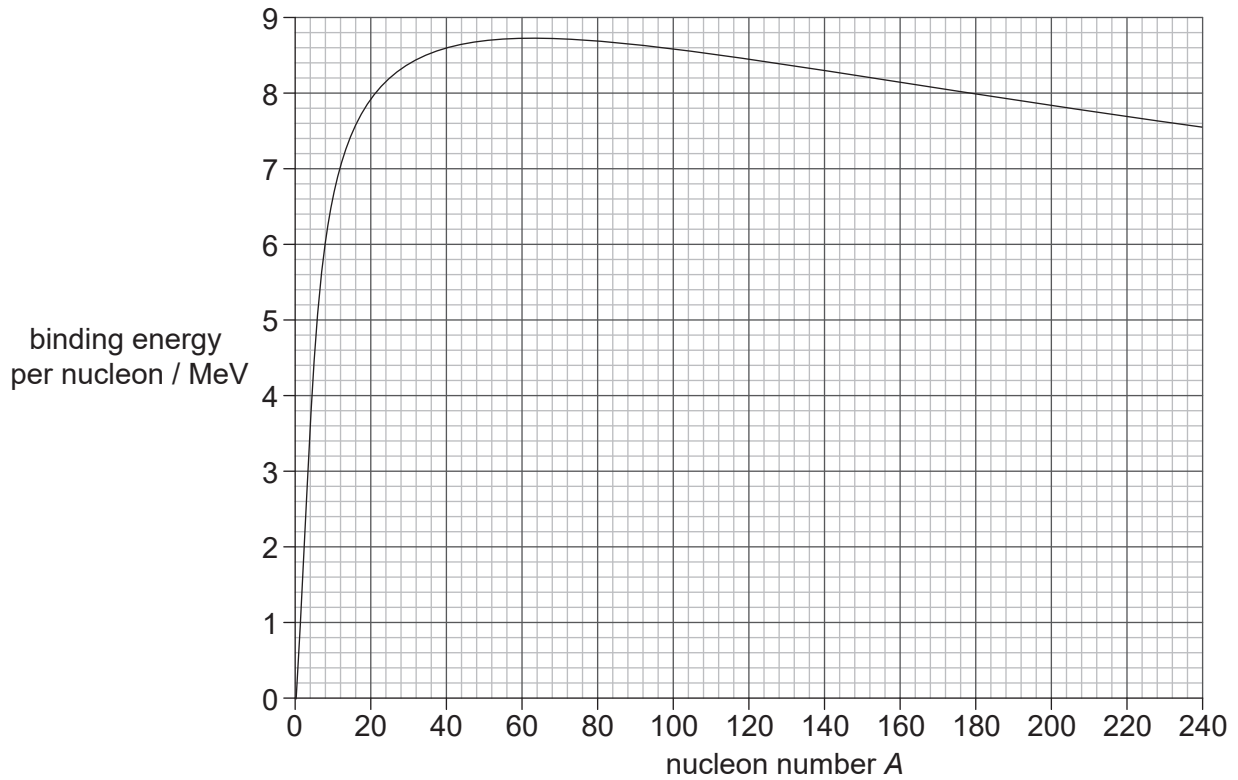
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(Question 7 continued)

(d) The graph shows the variation with the nucleon number A of the binding energy per nucleon.



(i) Outline why high temperatures are required for fusion to occur. [2]

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(ii) Outline, with reference to the graph, why energy is released both in fusion and in fission. [1]

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(This question continues on the following page)



(Question 7 continued)

- (iii) Uranium-235 (${}_{92}^{235}\text{U}$) is used as a nuclear fuel. The fission of uranium-235 can produce krypton-89 and barium-144.

Determine, in MeV and using the graph, the energy released by this fission. [2]

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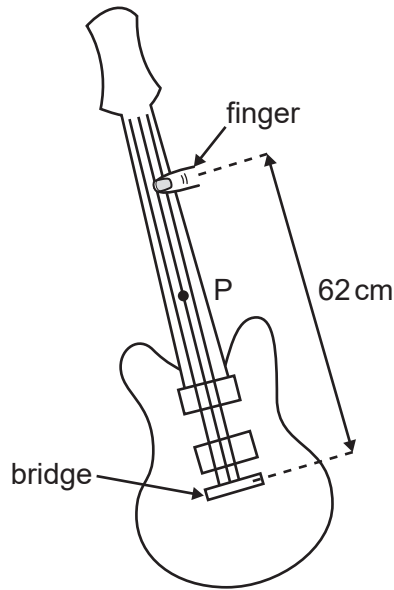
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8. On a guitar, the strings played vibrate between two fixed points. The frequency of vibration is modified by changing the string length using a finger. The different strings have different wave speeds. When a string is plucked, a standing wave forms between the bridge and the finger.



- (a) Outline how a standing wave is produced on the string.

[2]

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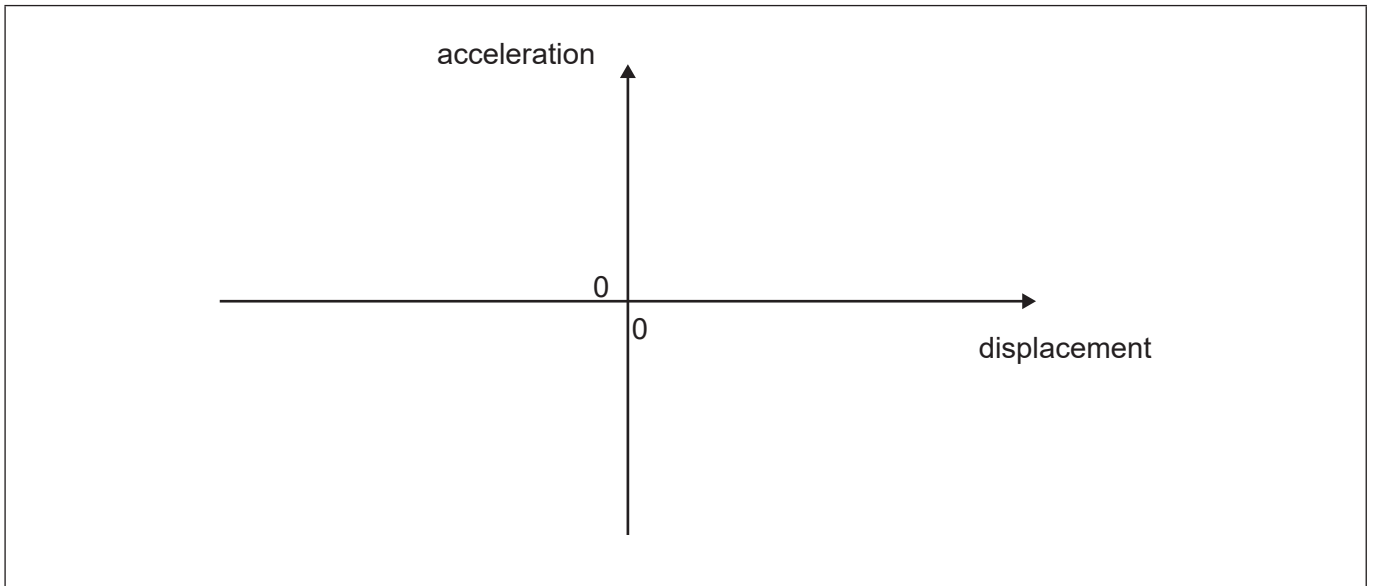
(Question 8 continued)

(b) The string is displaced 0.4 cm at point P to sound the guitar. Point P on the string vibrates with simple harmonic motion (shm) in its first harmonic with a frequency of 195 Hz. The sounding length of the string is 62 cm.

(i) Show that the speed of the wave on the string is about 240 ms^{-1} . [2]

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(ii) Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position. [1]



(iii) Calculate, in ms^{-1} , the maximum velocity of vibration of point P when it is vibrating with a frequency of 195 Hz. [2]

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Turn over

(Question 8 continued)

(iv) Calculate, in terms of g , the maximum acceleration of P.

[2]

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(v) Estimate the displacement needed to double the energy of the string.

[2]

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(c) The string is made to vibrate in its third harmonic. State the distance between consecutive nodes.

[1]

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9. Conservation of energy and conservation of momentum are two examples of conservation laws.

(a) Outline the significance of conservation laws for physics. [1]

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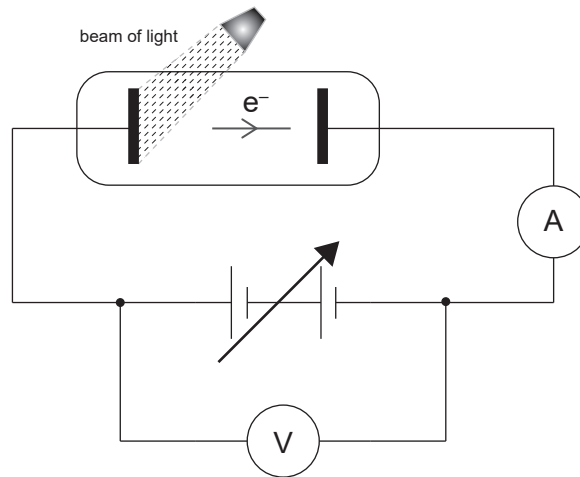
(b) When a pi meson π^- ($d\bar{u}$) and a proton (uud) collide, a possible outcome is a sigma baryon Σ^0 (uds) and a kaon meson K^0 ($d\bar{s}$).

Apply **three** conservation laws to show that this interaction is possible. [3]

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10. In an electric circuit used to investigate the photoelectric effect, the voltage is varied until the reading in the ammeter is zero. The stopping voltage that produces this reading is 1.40 V.



- (a) Describe the photoelectric effect. [2]

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- (b) Show that the maximum velocity of the photoelectrons is 700 km s^{-1} . [2]

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(Question 10 continued)

- (c) The photoelectrons are emitted from a sodium surface. Sodium has a work function of 2.3 eV.

Calculate the wavelength of the radiation incident on the sodium. State an appropriate unit for your answer.

[3]

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References:

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