Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

3 May 2023

Zone A morning | **Zone B** afternoon | **Zone C** morning

Candidate session number

2 hours 15 minutes

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]**.

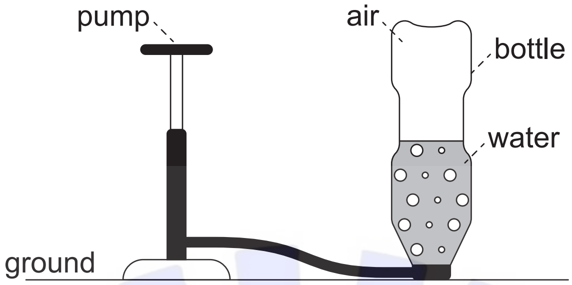
2223 – 6514

24 pages

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

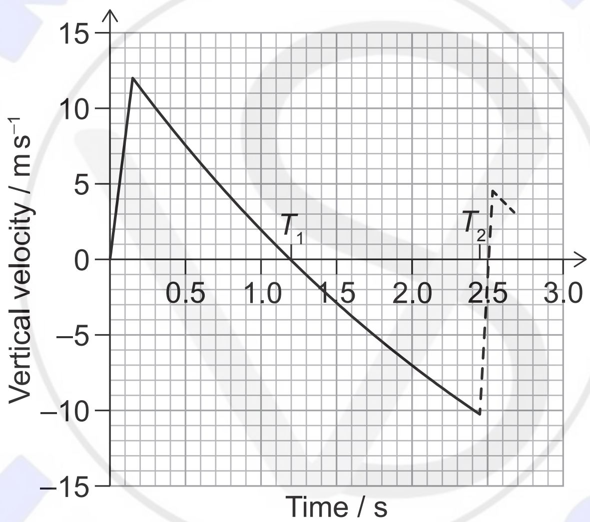
1. A toy rocket is made from a plastic bottle that contains some water.

Air is pumped into the vertical bottle until the pressure inside forces water and air out of the bottle. The bottle then travels vertically upwards.



The air–water mixture is called the propellant.

The variation with time of the vertical velocity of the bottle is shown.



The bottle reaches its highest point at time T_1 on the graph and returns to the ground at time T_2. The bottle then bounces. The motion of the bottle after the bounce is shown as a dashed line.

(a) Estimate, using the graph, the maximum height of the bottle. [3]

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(Question 1 continued)

(b) Estimate the acceleration of the bottle when it is at its maximum height. [2]

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(c) The bottle bounces when it returns to the ground.

(i) Calculate the fraction of the kinetic energy of the bottle that remains after the bounce. [2]

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(ii) The mass of the bottle is 27 g and it is in contact with the ground for 85 ms.

Determine the average force exerted by the ground on the bottle. Give your answer to an appropriate number of significant figures. [3]

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(Question 1 continued)

(d) The maximum height reached by the bottle is greater with an air–water mixture than with only high-pressure air in the bottle.

Assume that the speed at which the propellant leaves the bottle is the same in both cases.

Explain why the bottle reaches a greater maximum height with an air–water mixture. [2]

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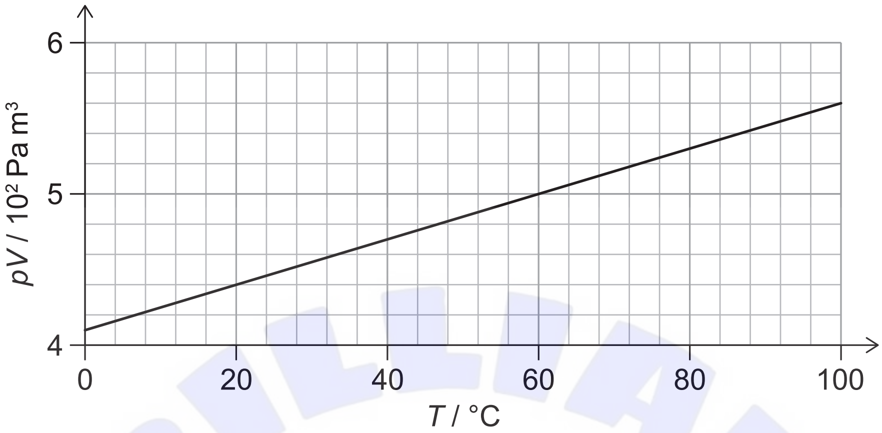
2. Pressure p, volume V and temperature T are measured for a fixed mass of gas. T is measured in degrees Celsius.

The graph shows the variation of pV with T.

The mass of a molecule of the gas is 4.7×10^{-26} kg.



(a) State the unit for pV in fundamental SI units. [1]

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(b) Deduce, using the graph, whether the gas acts as an ideal gas. [3]

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(c) Calculate, in g, the mass of the gas. [3]

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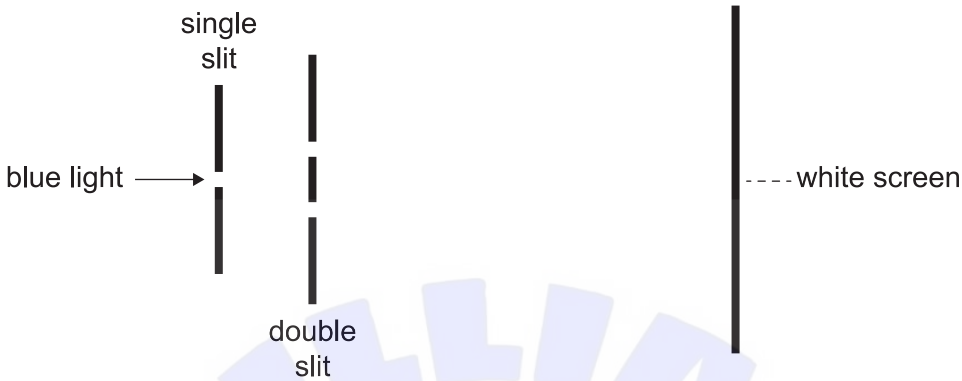
3. Blue light of wavelength λ is incident on a double slit. Light from the double slit falls on a screen. A student measures the distance between nine successive fringes on the screen to be 15 cm.

The separation of the double slit is 60 μm; the double slit is 2.5 m from the screen.



(a) Explain the pattern seen on the screen. [3]

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(b) (i) Calculate, in nm, λ. [3]

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(Question 3 continued)

(ii) The student moves the screen closer to the double slit and repeats the measurements. The instruments used to make the measurements are unchanged.

Discuss the effect this movement has on the fractional uncertainty in the value of λ. [2]

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(c) The student changes the light source to one that emits two colours:

- blue light of wavelength λ, and
- red light of wavelength 1.5λ.

Predict the pattern that the student will see on the screen. [3]

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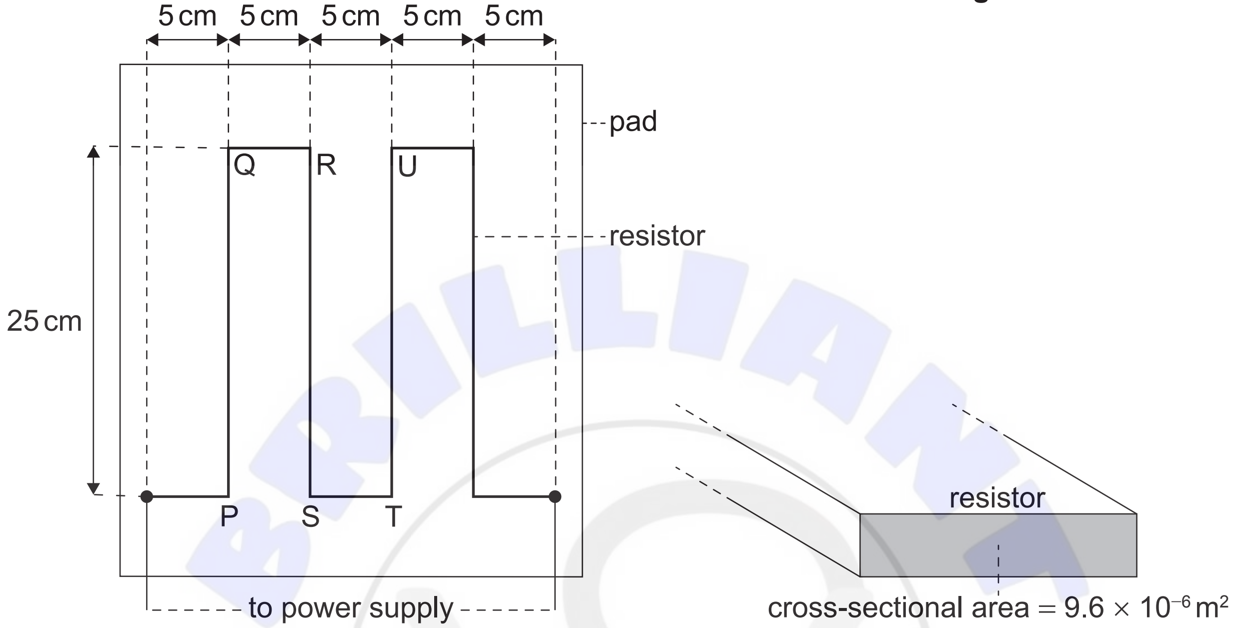
4. An electrically heated pad is designed to keep a pet warm.

The pad is heated using a resistor that is placed inside the pad. The dimensions of the resistor are shown on the diagram. The resistor has a resistance of 4.2 Ω and a total length of 1.25 m.

diagram not to scale



When there is a current in the resistor, the temperature in the pad changes from a room temperature of 20 °C to its operating temperature at 35 °C.

(a) The designers state that the energy transferred by the resistor every second is 15 J.

Calculate the current in the resistor. [1]

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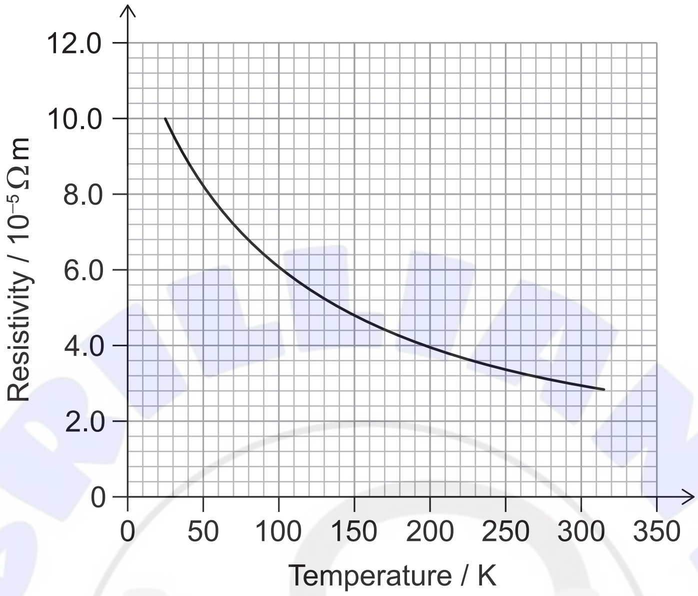
(Question 4 continued)

(b) The designers wish to make the resistor from carbon fibre.

The graph shows the variation with temperature, in Kelvin, of the resistivity of carbon fibre.



(i) The resistor has a cross-sectional area of $9.6 \times 10^{-6}\,\text{m}^2$.

Show that a resistor made from carbon fibre will be suitable for the pad. [3]

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(Question 4 continued)

(ii) The power supply to the pad has a negligible internal resistance.

State and explain the variation in current in the resistor as the temperature of the pad increases. [2]

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(c) When there is a current in the resistor, magnetic forces act between the resistor strips.

For the part of the resistor labelled RS,

(i) outline the magnetic force acting on it due to the current in PQ. [1]

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(ii) state and explain the net magnetic force acting on it due to the currents in PQ and TU. [2]

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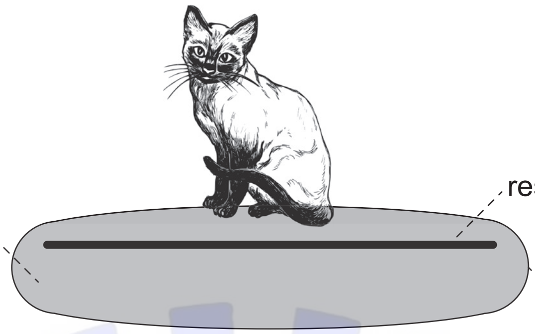
(Question 4 continued)

(d) The design of the pad encloses the resistor in a material that traps air. The design also places the resistor close to the top surface of the pad.



Explain, with reference to thermal energy transfer, why the pad is designed in this way. [3]

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5. When tritium ($^{3}_{1}H$) decays by beta-minus (β^{-}) decay, one of the products is a stable isotope of helium (He).

(a) Outline what is meant by an isotope. [1]

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(b) Identify, for the helium isotope produced in the tritium decay, its

(i) mass number. [1]

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(ii) proton number. [1]

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(c) Outline the quark change that occurs during this decay. [1]

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(Question 5 continued)

(d) Compare the properties of the strong nuclear force and of the electromagnetic force that allow the helium nucleus to be stable. [3]

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(e) A beta-minus particle and an alpha particle have the same initial kinetic energy.

Outline why the beta-minus particle can travel further in air than the alpha particle. [2]

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6. A moon M orbits a planet P. The gravitational field strength at the surface of P due to P is g_P. The gravitational field strength at the surface of M due to M is g_M.

For M and P: $\frac{\text{radius of M}}{\text{radius of P}} = 0.27$ and $\frac{\text{mass of M}}{\text{mass of P}} = 0.055$

(a) Determine $\frac{g_M}{g_P}$. [2]

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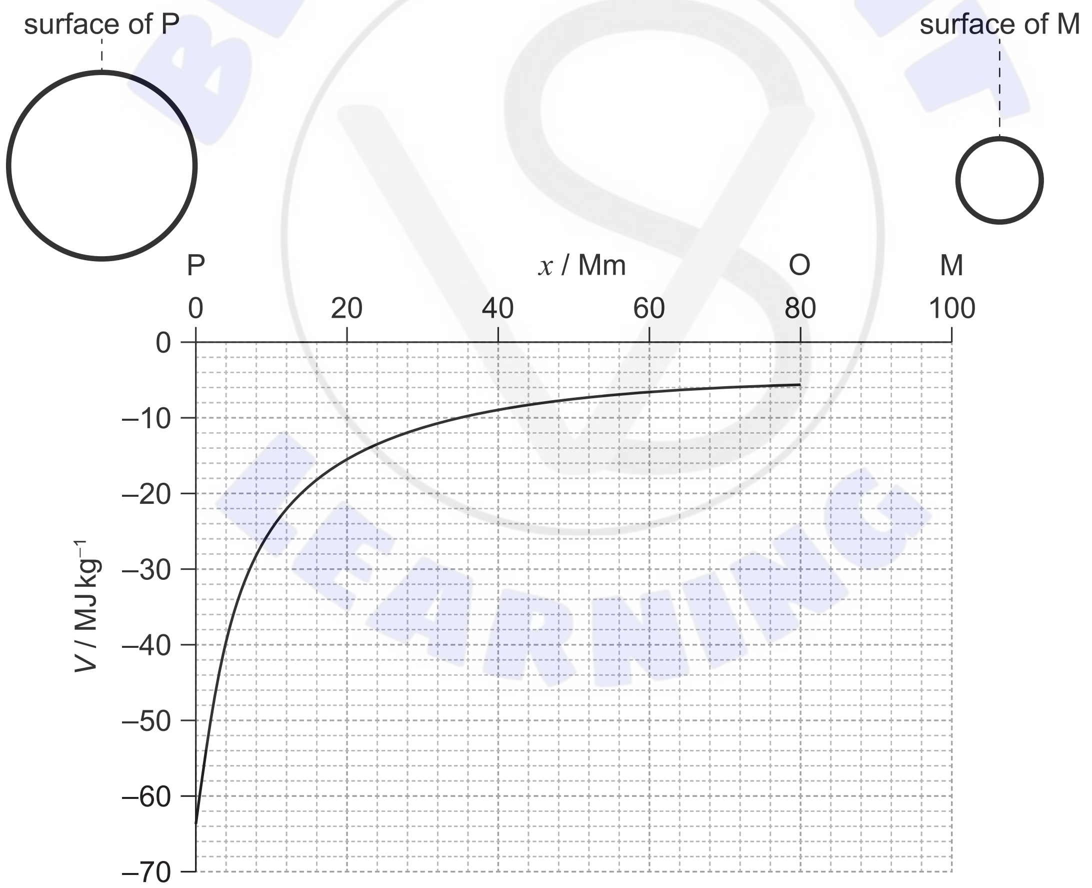
(b) Point O lies on the line joining the centre of M to the centre of P.



The graph shows the variation of gravitational potential V with distance x from the surface of P to O.

The gradient of the graph is zero at point O.

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(Question 6 continued)

(i) State and explain the magnitude of the resultant gravitational field strength at O. [2]

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(ii) Outline why the graph between P and O is negative. [2]

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(iii) Show that the gravitational potential V_P at the surface of P due to the mass of P is given by $V_P = -g_P R_P$ where R_P is the radius of the planet. [2]

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(iv) The gravitational potential due to the mass of M at the surface of P can be assumed to be negligible.

Estimate, using the graph, the gravitational potential at the surface of M due to the mass of M. [2]

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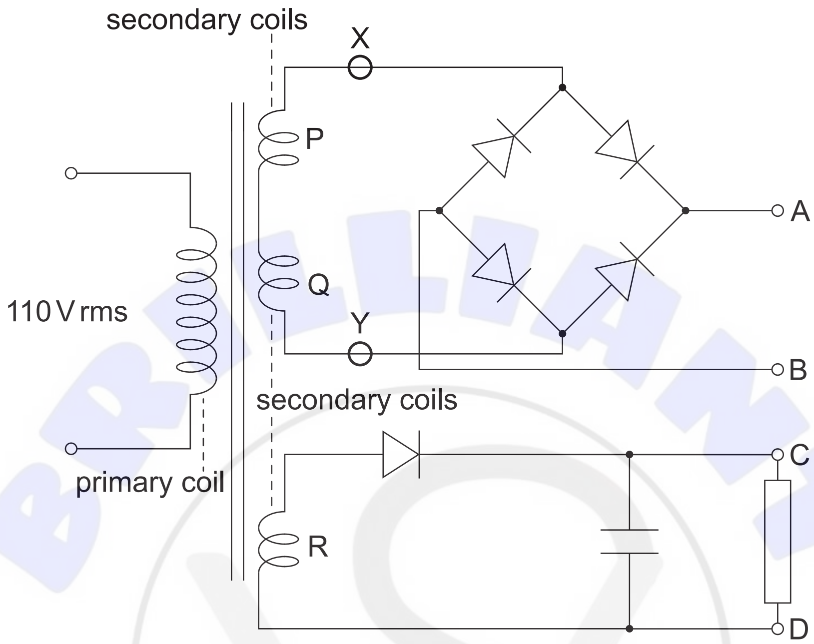
(v) Draw on the axes the variation of gravitational potential between O and M. [1]

7. Three identical secondary coils, P, Q and R, are wound onto the iron core of a transformer. The coils form a power supply that provides two output voltages, one between A and B and another between C and D.

The primary coil of the transformer is connected to a 110 V rms mains supply.

The primary coil has 1500 turns. Each secondary coil has 75 turns.



(a) Two of the secondary coils, P and Q, are connected in series to a diode bridge. There is no load resistor between A and B.

X and Y are points in the circuit connected to the ends of the coils.

(i) Calculate the peak emf between X and Y. [2]

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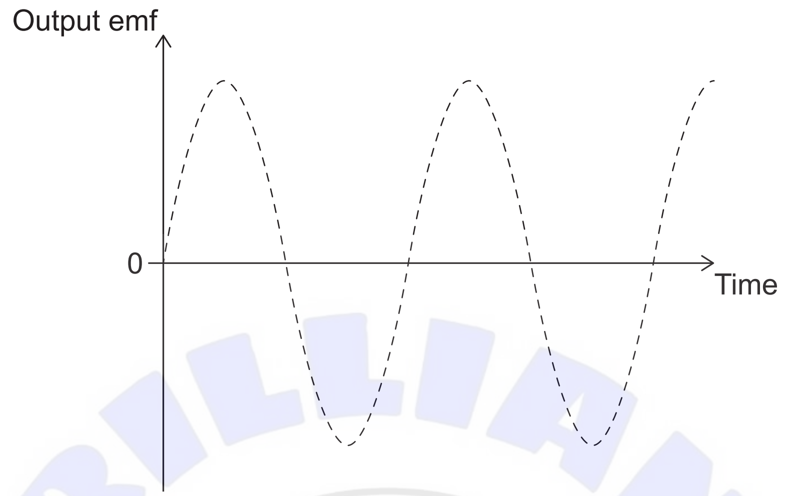
(Question 7 continued)

(ii) The graph shows the variation with time of the output emf between X and Y.



Draw, on the graph, the variation with time of the potential difference between A and B. You do not need to put numbers on the axes. [1]

(b) A resistor is now connected between A and B.

State and explain the reason why the peak potential difference across XY will be smaller than the emf you calculated in (a)(i). [2]

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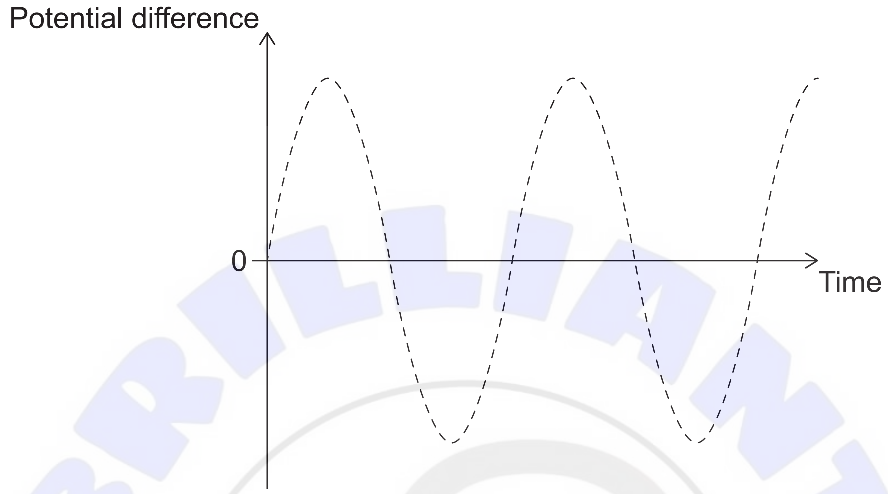
Answers written on this page
will not be marked.

(Question 7 continued)

(c) Coil R is connected to a single diode and a load that consists of a capacitor and a resistor.

The graph shows the variation with time of the potential difference across coil R.



Sketch, on the graph, the potential difference between C and D. [1]

(d) State and explain the effect of adding another capacitor in parallel with the original capacitor. [2]

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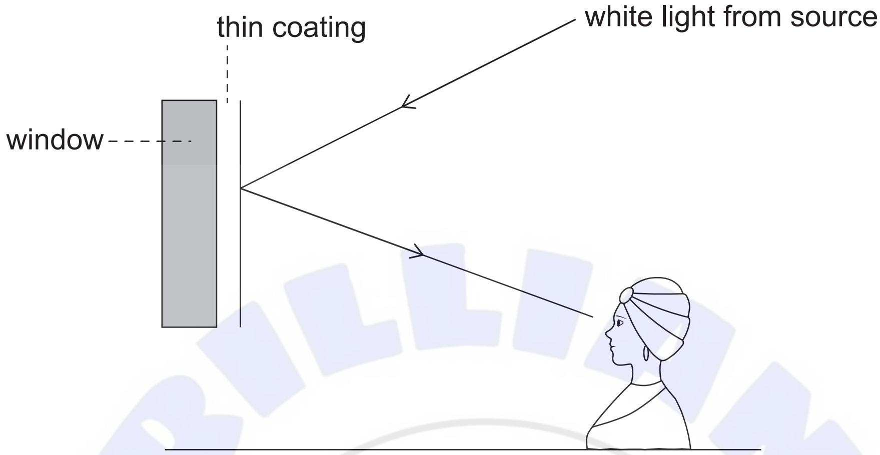
8. A girl looks at a flat vertical glass window on an automobile. The window has a thin transparent coating.

White light from a source is reflected to the girl from the coating and from the window.

diagram not to scale



(a) Outline why the light reflected to the girl has one wavelength missing. [2]

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(b) The refractive index of the coating is 1.63 and the refractive index of the glass is 1.52.

The thickness of the coating is 143 nm.

Determine the wavelength, in nm, that is missing in the light reflected to the girl assuming that the light is incident normally on the window. [3]

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(Question 8 continued)

(c) The automobile is driven directly away from the girl at a steady speed of $15\,m\,s^{-1}$. A musical note is emitted by a loudspeaker in the automobile.

The frequency of the musical note heard by the girl is 410 Hz.

(i) Outline why the driver of the automobile and the girl hear different frequencies for the musical note. [2]

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(ii) The speed of sound in air is $330\,m\,s^{-1}$.

Calculate the frequency of the musical note emitted by the loudspeaker. [2]

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9. Magnesium-27 nuclei ($^{27}_{12}$Mg) decay by beta-minus (β^-) decay to form nuclei of aluminium-27 (Al).

(a) Show, using the data, that the energy released in the decay of one magnesium-27 nucleus is about 2.62 MeV.

Mass of aluminium-27 atom = 26.98153 u

Mass of magnesium-27 atom = 26.98434 u

The unified atomic mass unit is 931.5 MeV c^{-2}. [1]

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(b) A Magnesium-27 nucleus can decay by one of two routes:

Route 1: 70 % of the beta particles are emitted with a maximum kinetic energy of 1.76656 MeV, accompanied by a gamma photon of energy 0.84376 MeV.

Route 2: 30 % of the beta particles have a maximum kinetic energy of 1.59587 MeV with a gamma photon of energy 1.01445 MeV.

The final state of the aluminium-27 nucleus is the same for both routes.

(i) State the conclusion that can be drawn from the existence of these two routes. [1]

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(ii) Calculate the difference between the magnitudes of the total energy transfers in parts (a) and (b). [1]

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(iii) Explain how the difference in part (b)(ii) arises. [1]

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(Question 9 continued)

(c) Small amounts of magnesium in a material can be detected by firing neutrons at magnesium-26 nuclei. This process is known as irradiation.

Magnesium-27 is formed because of irradiation. The products of the beta-particle emission are observed as the magnesium-27 decays to aluminium-27.

(i) The smallest mass of magnesium that can be detected with this technique is 1.1×10^{-8} kg.

Show that the smallest number of magnesium atoms that can be detected with this technique is about 10^{17}. [2]

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(ii) A sample of glass is irradiated with neutrons so that all the magnesium atoms become magnesium-27. The sample contains 9.50×10^{15} magnesium atoms.

The decay constant of magnesium-27 is $1.22 \times 10^{-3}\,s^{-1}$.

Determine the number of aluminium atoms that form in 10.0 minutes after the irradiation ends. [3]

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(Question 9 continued)

(iii) Estimate, in W, the average rate at which energy is transferred by the decay of magnesium-27 during the 10.0 minutes after the irradiation ends. [2]

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References: