Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

Monday 3 May 2021 (afternoon)

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]**.

2221 – 6514

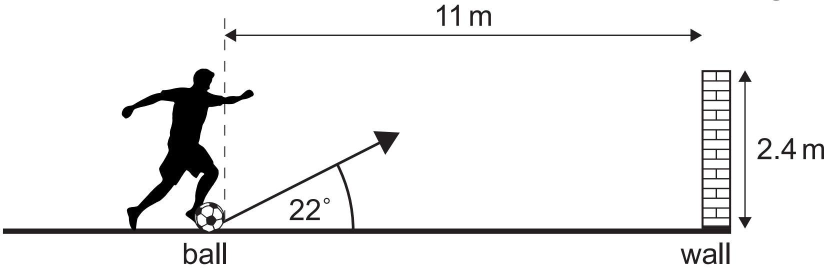
25 pages

International Baccalaureate
Baccalauréat International
Bachillerato Internacional

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

1. A football player kicks a stationary ball of mass 0.45 kg towards a wall. The initial speed of the ball after the kick is 19 m s^{-1} and the ball does not rotate. Air resistance is negligible and there is no wind.

diagram not to scale



(a) The player's foot is in contact with the ball for 55 ms. Calculate the average force that acts on the ball due to the football player. [2]

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(b) (i) The ball leaves the ground at an angle of 22°. The horizontal distance from the initial position of the edge of the ball to the wall is 11 m. Calculate the time taken for the ball to reach the wall. [2]

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(Question 1 continued)

(ii) The top of the wall is 2.4 m above the ground. Deduce whether the ball will hit the wall. [3]

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(c) In practice, air resistance affects the ball. Outline the effect that air resistance has on the vertical acceleration of the ball. Take the direction of the acceleration due to gravity to be positive. [2]

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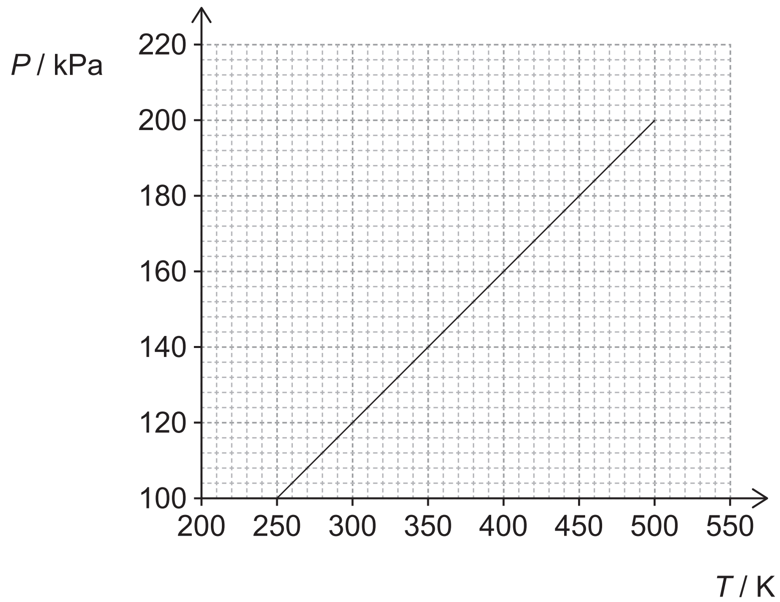
2. The graph shows the variation with temperature T of the pressure P of a fixed mass of helium gas trapped in a container with a fixed volume of $1.0 \times 10^{-3}\,m^3$.



(a) Deduce whether helium behaves as an ideal gas over the temperature range 250 K to 500 K. [2]

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(b) Helium has a molar mass of 4.0 g. Calculate the mass of gas in the container. [2]

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(Question 2 continued)

(c) A second container, of the same volume as the original container, contains twice as many helium atoms. The graph of the variation of *P* with *T* is determined for the gas in the second container.

Predict how the graph for the second container will differ from the graph for the first container. [2]

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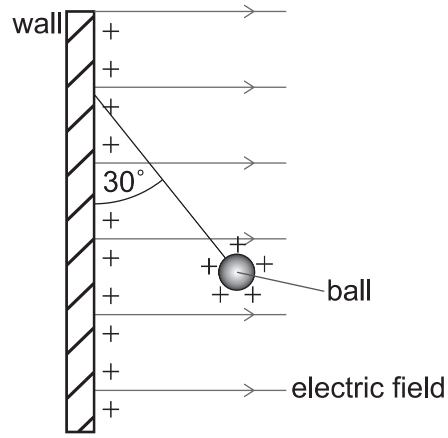
3. A vertical wall carries a uniform positive charge on its surface. This produces a uniform horizontal electric field perpendicular to the wall. A small, positively-charged ball is suspended in equilibrium from the vertical wall by a thread of negligible mass.



(a) The charge per unit area on the surface of the wall is σ. It can be shown that the electric field strength E due to the charge on the wall is given by the equation

$$E = \frac{\sigma}{2\varepsilon_0}.$$

Demonstrate that the units of the quantities in this equation are consistent. [2]

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(b) (i) The thread makes an angle of 30° with the vertical wall. The ball has a mass of 0.025 kg.

Determine the horizontal force that acts on the ball. [3]

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(Question 3 continued)

(ii) The charge on the ball is 1.2×10^{-6} C. Determine σ. [2]

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(c) The thread breaks. Explain the initial subsequent motion of the ball. [3]

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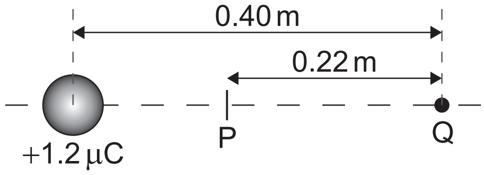
(Question 3 continued)

(d) The centre of the ball, still carrying a charge of 1.2×10^{-6} C, is now placed 0.40 m from a point charge Q. The charge on the ball acts as a point charge at the centre of the ball.

P is the point on the line joining the charges where the electric field strength is zero. The distance PQ is 0.22 m.



(i) Calculate the charge on Q. State your answer to an appropriate number of significant figures. [3]

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(ii) Outline, without calculation, whether or not the electric potential at P is zero. [2]

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4. (a) During electron capture, an atomic electron is captured by a proton in the nucleus. The stable nuclide thallium-205 ($^{205}_{81}\text{Tl}$) can be formed when an unstable lead (Pb) nuclide captures an electron.

(i) Write down the equation to represent this decay. [2]

$$^{\square}_{\square}\text{Pb} + {}^{\square}_{\square}\text{e} \longrightarrow {}^{205}_{81}\text{Tl} + {}^{\square}_{\square}\upsilon_e$$

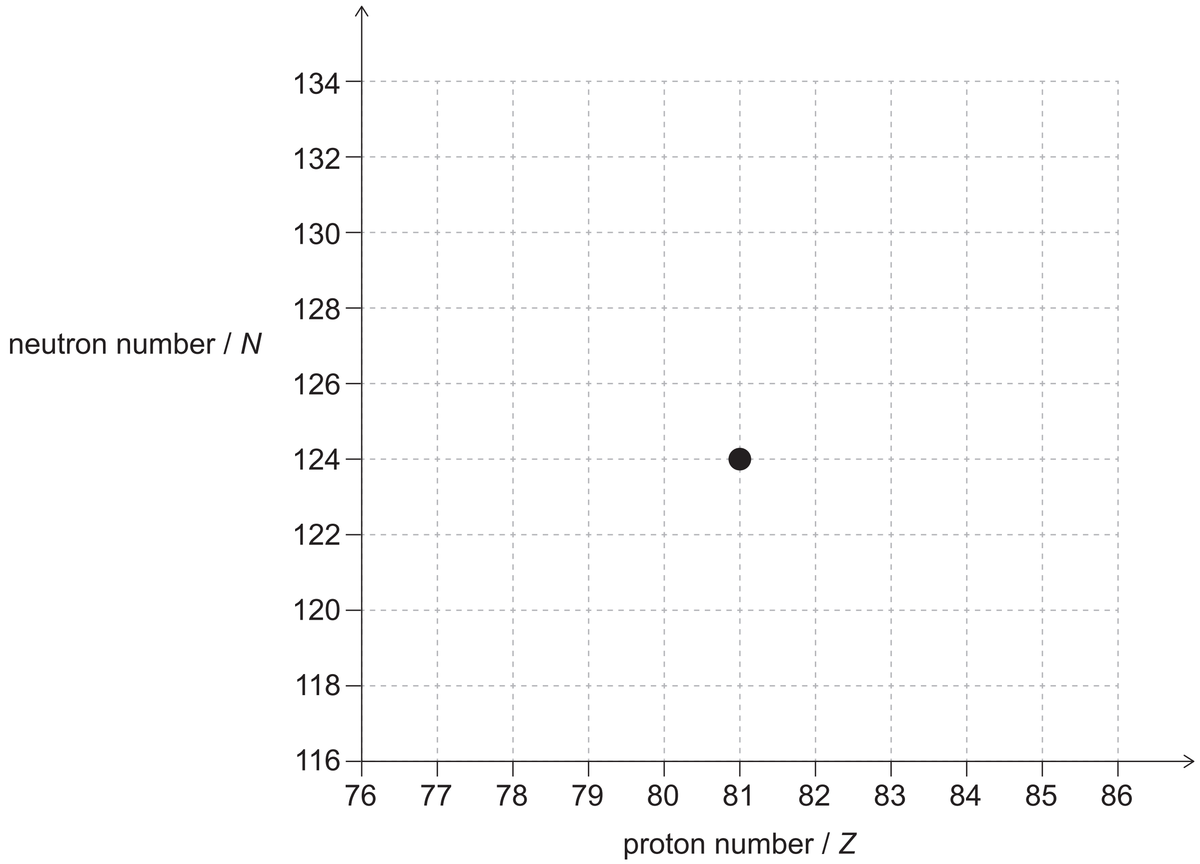
(ii) The unstable lead nuclide has a half-life of 15×10^6 years. A sample initially contains 2.0 μmol of the lead nuclide. Calculate the number of thallium nuclei being formed each second 30×10^6 years later. [3]

(b) The neutron number *N* and the proton number *Z* are not equal for the nuclide $^{205}_{81}\text{Tl}$. Explain, with reference to the forces acting within the nucleus, the reason for this. [2]

(This question continues on the following page)

(Question 4 continued)

(c) Thallium-205 ($^{205}_{81}Tl$) can also form from successive alpha (α) and beta-minus (β^-) decays of an unstable nuclide. The decays follow the sequence $\alpha\ \beta^-\ \beta^-\ \alpha$. The diagram shows the position of $^{205}_{81}Tl$ on a chart of neutron number against proton number.



Draw **four** arrows to show the sequence of changes to *N* and *Z* that occur as the $^{205}_{81}Tl$ forms from the unstable nuclide. [3]

5. (a) Describe **two** ways in which standing waves differ from travelling waves. [2]

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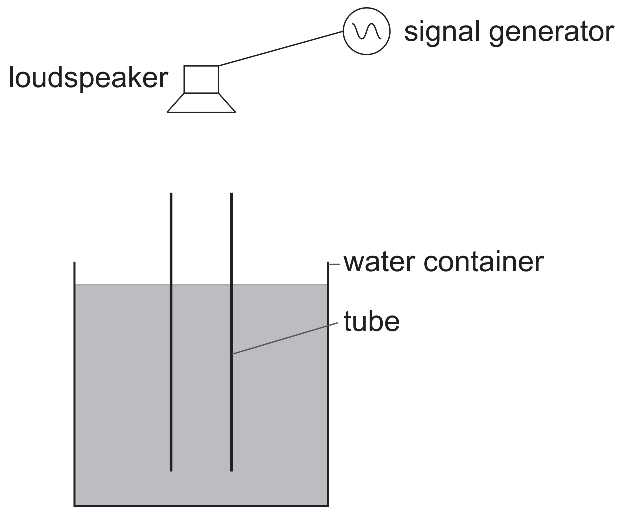
(b) A vertical tube, open at both ends, is completely immersed in a container of water. A loudspeaker above the container connected to a signal generator emits sound. As the tube is raised the loudness of the sound heard reaches a maximum because a standing wave has formed in the tube.



(i) Outline how a standing wave forms in the tube. [2]

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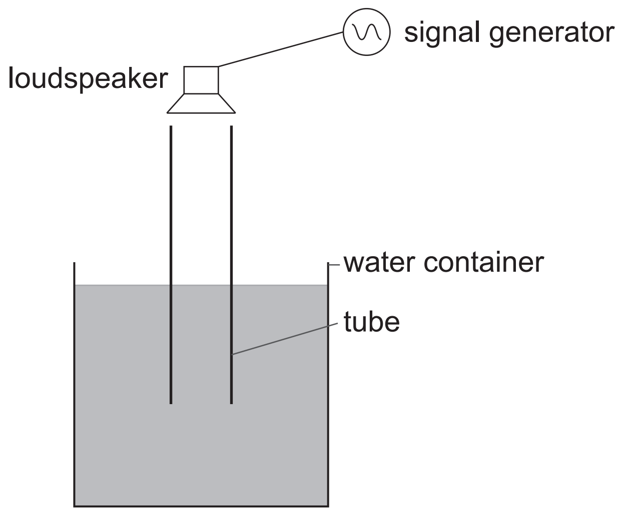
(Question 5 continued)

(ii) The tube is raised until the loudness of the sound reaches a maximum for a **second time**.

Draw, on the following diagram, the position of the nodes in the tube when the second maximum is heard. [1]



(iii) Between the first and second positions of maximum loudness, the tube is raised through 0.37 m. The speed of sound in the air in the tube is 320 m s^{-1}. Determine the frequency of the sound emitted by the loudspeaker. [2]

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6. A photovoltaic cell is supplying energy to an external circuit. The photovoltaic cell can be modelled as a practical electrical cell with internal resistance.

The intensity of solar radiation incident on the photovoltaic cell at a particular time is at a maximum for the place where the cell is positioned.

The following data are available for this particular time:

Operating current = 0.90 A
Output potential difference to external circuit = 14.5 V
Output emf of photovoltaic cell = 21.0 V
Area of panel = 350 mm × 450 mm

(a) Explain why the output potential difference to the external circuit and the output emf of the photovoltaic cell are different. [2]

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(b) Calculate the internal resistance of the photovoltaic cell for the maximum intensity condition using the model for the cell. [3]

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(Question 6 continued)

(c) The maximum intensity of sunlight incident on the photovoltaic cell at the place on the Earth's surface is $680\,\mathrm{W\,m^{-2}}$.

A measure of the efficiency of a photovoltaic cell is the ratio

$$\frac{\text{energy available every second to the external circuit}}{\text{energy arriving every second at the photovoltaic cell surface}}.$$

Determine the efficiency of this photovoltaic cell when the intensity incident upon it is at a maximum. [3]

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(d) State **two** reasons why future energy demands will be increasingly reliant on sources such as photovoltaic cells. [2]

Reason 1: . . . .

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Reason 2: . . . .

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7. (a) The primary coil of a transformer is connected to a 110 V alternating current (ac) supply. The secondary coil of the transformer is connected to a 15 V garden lighting system that consists of 8 lamps connected in parallel. Each lamp is rated at 35 W when working at its normal brightness. Root mean square (rms) values are used throughout this question.

(i) The primary coil has 3300 turns. Calculate the number of turns on the secondary coil. [1]

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(ii) Determine the total resistance of the lamps when they are working normally. [2]

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(iii) Calculate the current in the primary of the transformer assuming that it is ideal. [2]

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(iv) Flux leakage is one reason why a transformer may not be ideal. Explain the effect of flux leakage on the transformer. [2]

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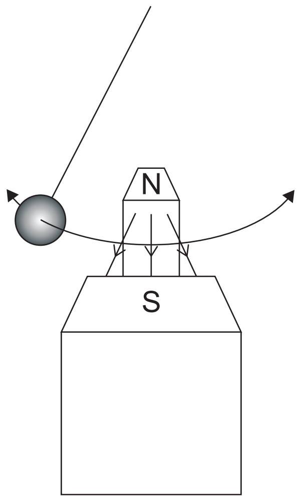
(Question 7 continued)

(b) A pendulum with a metal bob comes to rest after 200 swings. The same pendulum, released from the same position, now swings at 90° to the direction of a strong magnetic field and comes to rest after 20 swings.



Explain why the pendulum comes to rest after a smaller number of swings. [4]

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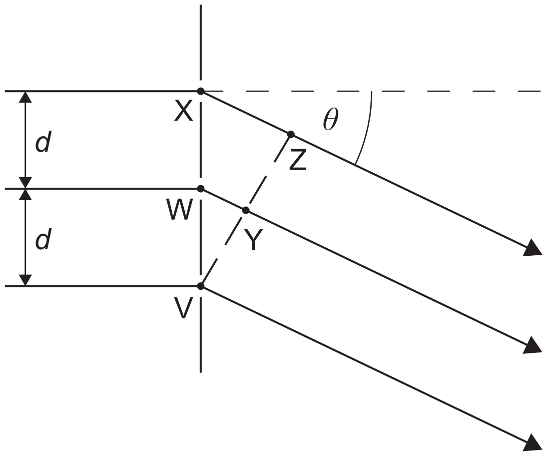
8. (a) Monochromatic light of wavelength λ is normally incident on a diffraction grating. The diagram shows adjacent slits of the diffraction grating labelled V, W and X. Light waves are diffracted through an angle θ to form a **second-order** diffraction maximum. Points Z and Y are labelled.



(i) State the phase difference between the waves at V and Y. [1]

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(ii) State, in terms of λ, the path length between points X and Z. [1]

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(iii) The separation of adjacent slits is *d*. Show that for the second-order diffraction maximum $2\lambda = d\sin\theta$. [1]

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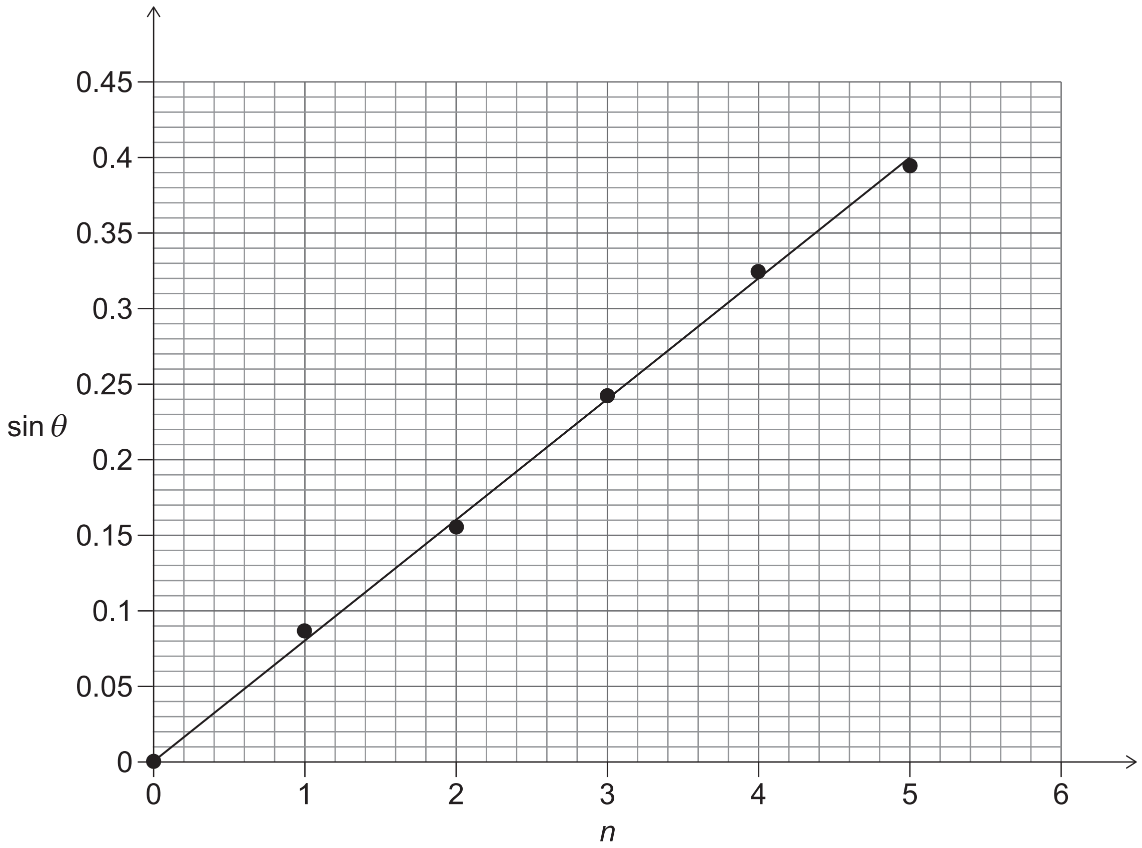
(Question 8 continued)

(b) Monochromatic light of wavelength 633 nm is normally incident on a diffraction grating. The diffraction maxima incident on a screen are detected and their angle θ to the central beam is determined. The graph shows the variation of $\sin\theta$ with the order n of the maximum. The central order corresponds to $n = 0$.



Determine a mean value for the number of slits per millimetre of the grating. [4]

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(Question 8 continued)

(c) State the effect on the graph of the variation of sinθ with n of:

(i) using a light source with a smaller wavelength. [1]

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(ii) increasing the distance between the diffraction grating and the screen. [1]

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9. (a) In an experiment to demonstrate the photoelectric effect, monochromatic electromagnetic radiation from source A is incident on the surfaces of metal P and metal Q. Observations of the emission of electrons from P and Q are made.

The experiment is then repeated with two other sources of electromagnetic radiation: B and C. The table gives the results for the experiment and the wavelengths of the radiation sources.

Radiation source	**Wavelength / 10^{-7} m**	**Metal P**	**Metal Q**
A	3.0	electrons emitted	electrons emitted
B	6.0	electrons emitted	no electrons emitted
C	8.0	no electrons emitted	no electrons emitted

Outline

(i) the cause of the electron emission for radiation A; [1]

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(ii) why electrons are never emitted for radiation C; [1]

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(iii) why radiation B gives different results. [1]

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(b) Explain why there is no effect on the table of results when the intensity of source B is doubled. [1]

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(Question 9 continued)

(c) Photons with energy 1.1×10^{-18} J are incident on a third metal surface. The maximum energy of electrons emitted from the surface of the metal is 5.1×10^{-19} J.

Calculate, in eV, the work function of the metal. [2]

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10. The table gives data for Jupiter and three of its moons, including the radius *r* of each object.

Object	Mass/kg	*r* / m	Orbital radius around Jupiter/m
Jupiter	1.9×10^{27}	7.1×10^{7}	
Io	8.9×10^{22}	1.8×10^{6}	4.9×10^{8}
Ganymede	1.5×10^{23}	2.6×10^{6}	1.06×10^{9}
Callisto	1.1×10^{23}	2.4×10^{6}	1.88×10^{9}

(a) Calculate, for the surface of Io, the gravitational field strength g_{Io} due to the mass of Io. State an appropriate unit for your answer. [2]

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(b) A spacecraft is to be sent from Io to infinity.

(i) Show that the $\dfrac{\text{gravitational potential due to Jupiter at the orbit of Io}}{\text{gravitational potential due to Io at the surface of Io}}$ is about 80. [2]

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(ii) Outline, using (b)(i), why it is not correct to use the equation $\sqrt{\dfrac{2G \times \text{mass of Io}}{\text{radius of Io}}}$ to calculate the speed required for the spacecraft to reach infinity from the surface of Io. [1]

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(Question 10 continued)

(c) An engineer needs to move a space probe of mass 3600 kg from Ganymede to Callisto. Calculate the energy required to move the probe from the orbital radius of Ganymede to the orbital radius of Callisto. Ignore the mass of the moons in your calculation. [2]

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References:

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