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Baccalauréat International
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PHYSICS
HIGHER LEVEL
PAPER 2

Candidate session number

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Monday 6 May 2013 (morning)

2 hours 15 minutes

Examination code

2	2	1	3	–	6	5	1	4

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the 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 *[95 marks]*.

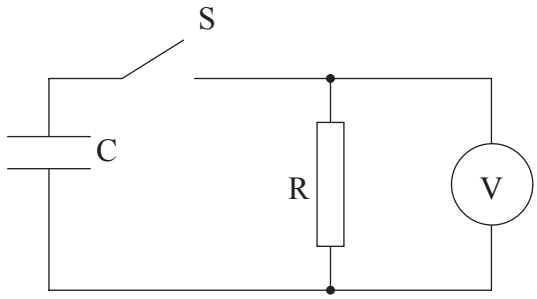
SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

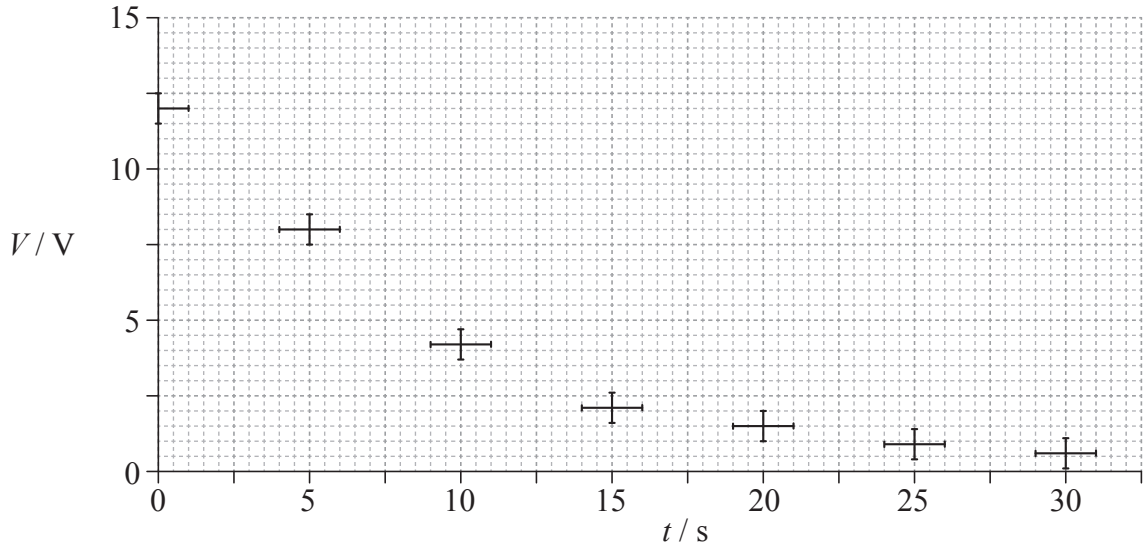
A1. Data analysis question.

A capacitor is a device that can be used to store electric charge.

(a) An experiment was undertaken to investigate one of the circuit properties of a capacitor. A capacitor C was connected via a switch S to a resistance R and a voltmeter V.



The initial potential difference across C was 12 V. The switch S was closed and the potential difference V across R was measured at various times t. The data collected, along with error bars, are shown plotted below.



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(Question A1 continued)

(i) On the graph opposite, draw a best-fit line for the data starting from $t = 0$. *[2]*

(ii) It was hypothesized that the decay of the potential difference across the capacitor is exponential. Determine, using the graph, whether this hypothesis is true **or** not. *[4]*

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(b) The time constant τ of the circuit is defined as the time it would take for the capacitor to discharge were it to keep discharging at its initial rate. Use the graph in (a) to calculate the

(i) initial rate of decay of potential difference V. *[2]*

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(ii) time constant τ. *[1]*

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(This question continues on the following page)

(Question A1 continued)

(c) The time constant $\tau = RC$ where R is the resistance and C is a property called capacitance. The effective resistance in the circuit is 10 MΩ. Calculate the capacitance C. *[1]*

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A2. This question is about kinematics.

(a) Fiona drops a stone from rest vertically down a water well. She hears the splash of the stone striking the water 1.6 s after the stone leaves her hand. Estimate the

(i) distance between Fiona's hand and the water surface. *[1]*

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(ii) speed with which the stone hits the water. *[2]*

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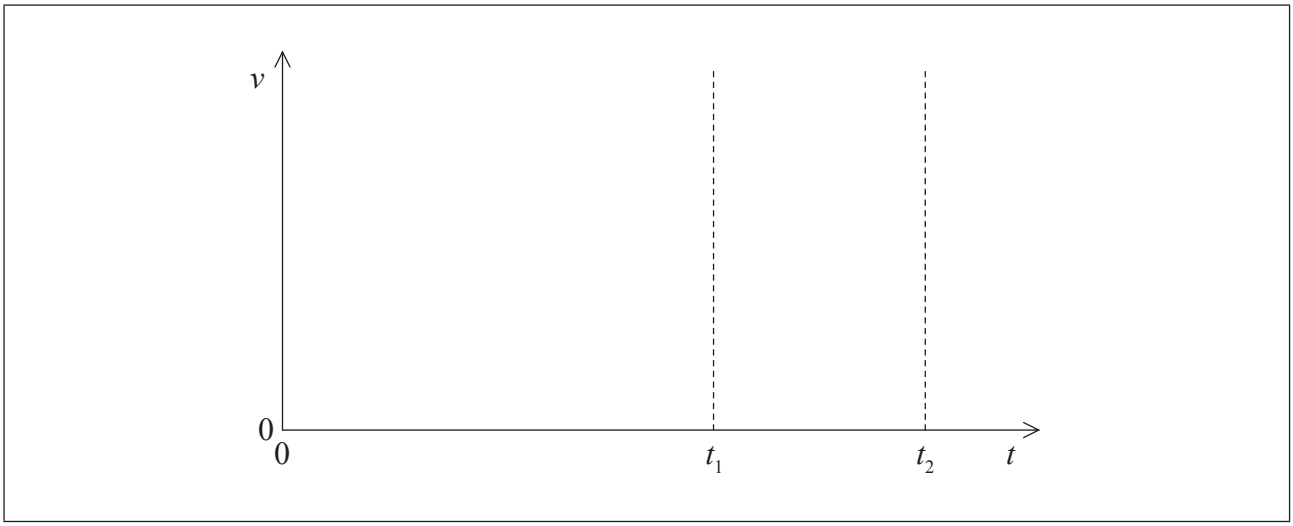
(Question A2 continued)

(b) After the stone in (a) hits the water surface it rapidly reaches a terminal speed as it falls through the water. The stone leaves Fiona's hand at time $t=0$. It hits the water surface at t_1 and it comes to rest at the bottom of the water at t_2. Using the axes below, sketch a graph to show how the speed v of the stone varies from time $t=0$ to just before $t=t_2$. (There is no need to add any values to the axes.) *[3]*



A3. This question is about thermal concepts.

(a) Distinguish between internal energy and thermal energy (heat). *[2]*

Internal energy:

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Thermal energy:

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(This question continues on the following page)

(Question A3 continued)

(b) A 300 W immersion heater is placed in a beaker containing 0.25 kg of water at a temperature of 18 °C. The heater is switched on for 120 s, after which time the temperature of the water is 45 °C. The thermal capacity of the beaker is negligible and the specific heat capacity of water is $4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$.

(i) Estimate the change in internal energy of the water. *[2]*

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(ii) Determine the rate at which thermal energy is transferred from the water to the surroundings during the time that the heater is switched on. *[2]*

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A4. This question is about nuclear reactions and radioactive decay.

(a) The isotope tritium (hydrogen-3) has a radioactive half-life of 12 days.

(i) State what is meant by the term isotope. *[1]*

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(ii) Define *radioactive half-life*. *[1]*

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(Question A4 continued)

(b) Tritium may be produced by bombarding a nucleus of the isotope lithium-7 with a high-energy neutron. The reaction equation for this interaction is

$$^{7}_{3}\text{Li} + ^{1}_{0}\text{n} \rightarrow ^{3}_{1}\text{H} + ^{4}_{Z}\text{X} + ^{1}_{0}\text{n}.$$

(i) Identify the proton number Z of X. *[1]*

$Z =$ . . . . . .

(ii) Use the following data to show that the minimum energy that a neutron must have to initiate the reaction in (b)(i) is about 2.5 MeV. *[2]*

Rest mass of lithium-7 nucleus = 7.0160 u
Rest mass of tritium nucleus = 3.0161 u
Rest mass of X nucleus = 4.0026 u

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(c) A nucleus of tritium decays to a nucleus of helium-3. Identify the particles X and Y in the nuclear reaction equation for this decay. *[2]*

$$^{3}_{1}\text{H} \rightarrow ^{3}_{2}\text{He} + \text{X} + \text{Y}$$

X: . . . . . .

Y: . . . . . .

A5. This question is about electric potential and electric field.

(a) Define *electric potential at a point* in an electric field. *[3]*

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(b) A metal sphere of radius 0.080 m is charged to a potential of 300 V.

(i) Show that the magnitude of the electric charge on the sphere is 2.7 nC. *[2]*

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(ii) Determine, giving an appropriate unit, the magnitude of the electric field strength at a distance of 0.16 m from the centre of the sphere. *[2]*

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(This question continues on the following page)

(Question A5 continued)

(iii) State the value of the magnitude of the gradient of electric potential at a distance of 0.16 m from the centre of the sphere. *[1]*

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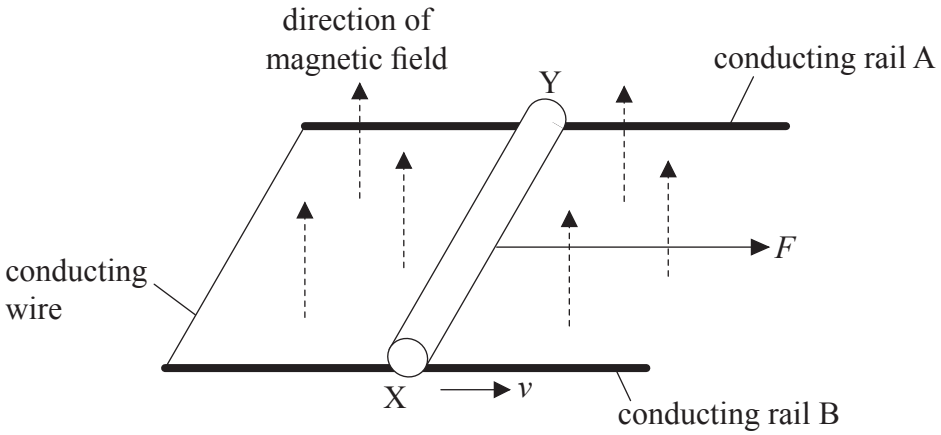
A6. This question is about the motion of a copper rod in a magnetic field.

A copper rod XY is able to move freely along two horizontal, parallel conducting rails A and B. The conducting rails are in a region of uniform magnetic field that is in a direction perpendicular to the plane of the rails. The rails are connected together at one end by a conducting wire.



In the situation shown, the rod is moved along the rails at a constant speed v by a constant horizontal force of magnitude F.

(a) Explain why a constant force is required to move the rod at constant speed. *[4]*

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(Question A6 continued)

(b) Outline how your answer to (a) relates to Lenz's law. *[2]*

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(c) There is a potential difference of 2.4 mV between the ends of the copper rod. The distance between the conducting rails is 0.16 m. Determine the magnetic force on a free electron in the copper rod. *[2]*

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SECTION B

*This section consists of four questions: B1, B2, B3 and B4. Answer **two** questions. Write your answers in the boxes provided.*

B1. This question is in **two** parts. **Part 1** is about electric charge and electric circuits. **Part 2** is about a thermodynamic cycle.

Part 1 Electric charge and electric circuits

(a) State Coulomb's law. *[2]*

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(b) In a simple model of the hydrogen atom, the electron can be regarded as being in a circular orbit about the proton. The radius of the orbit is 2.0×10^{-10} m.

(i) Determine the magnitude of the electric force between the proton and the electron. *[2]*

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(Question B1, part 1 continued)

(ii) Calculate the magnitude of the electric field strength E and state the direction of the electric field due to the proton at a distance of 2.0×10^{-10} m from the proton. *[2]*

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(iii) The magnitude of the gravitational field due to the proton at a distance of 2.0×10^{-10} m from the proton is H.

Show that the ratio $\frac{H}{E}$ is of the order $10^{-28}\,\text{C kg}^{-1}$. *[2]*

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(iv) The orbital electron is transferred from its orbit to a point where the potential is zero. The gain in potential energy of the electron is 5.4×10^{-19} J. Calculate the value of the potential difference through which the electron is moved. *[1]*

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(This question continues on the following page)

(Question B1, part 1 continued)

(c) An electric cell is a device that is used to transfer energy to electrons in a circuit. A particular circuit consists of a cell of emf ε and internal resistance r connected in series with a resistor of resistance $5.0\,\Omega$.

(i) Define *emf of a cell*. *[1]*

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(ii) The energy supplied by the cell to one electron in transferring it around the circuit is 5.1×10^{-19} J. Show that the emf of the cell is 3.2 V. *[1]*

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(iii) Each electron in the circuit transfers an energy of 4.0×10^{-19} J to the $5.0\,\Omega$ resistor. Determine the value of the internal resistance r. *[4]*

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(Question B1 continued)

Part 2 Thermodynamic cycle

(a) State **two** macroscopic differences between a real gas and an ideal gas. *[2]*

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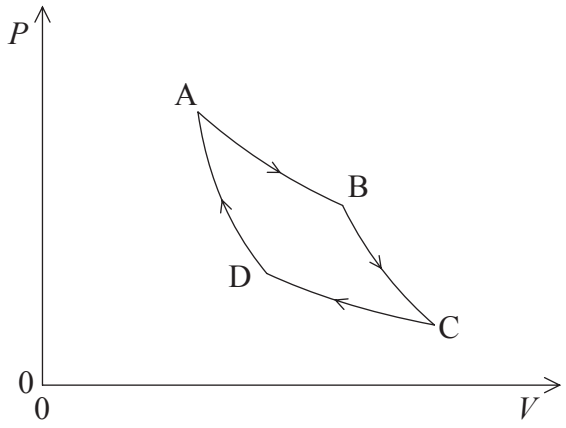
(Question B1, part 2 continued)

(b) A fixed mass of an ideal gas undergoes a thermodynamic cycle ABCD. The diagram shows how the pressure P of the gas varies with volume V.



The changes of state from A to B and C to D are isothermal whereas the changes of state from B to C and D to A are adiabatic.

Describe how the work done on or by a gas relates to the changes of internal energy of the gas for an

(i) adiabatic change. *[2]*

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(ii) isothermal change. *[2]*

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(Question B1, part 2 continued)

(c) State and explain in which part of the cycle there is a transfer of non-mechanical energy from the gas to the surroundings. *[4]*

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B2. This question is in **two** parts. **Part 1** is about power production and the greenhouse effect. **Part 2** is about optical resolution and polarization.

Part 1 Power production and the greenhouse effect

(a) The Drax coal-fired power plant has a power output of 4.0 GW. The efficiency of the plant is 40 %. The energy density of the coal used is $24\,\text{MJ kg}^{-1}$. Estimate the minimum mass of coal that is burned each year (1 year $= 3.2 \times 10^7$ s). *[3]*

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(b) Discuss **one** advantage and **one** disadvantage of using nuclear power production compared to using coal-fired power production. *[4]*

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Disadvantage: . . . . . .
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(Question B2, part 1 continued)

(c) It has been suggested that a wind farm could replace the Drax power station. Using the data below, determine the area that the wind farm would occupy in order to meet the same power output as the Drax power station. *[4]*

Radius of wind turbine blades = 42 m
Area required by each turbine = 5.0×10^4 m^2
Efficiency of a turbine = 30 %
Average annual wind speed = 12 m s^{-1}
Average annual density of air = 1.2 kg m^{-3}

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(d) Wind power does not involve the production of greenhouse gases. Outline why the surface temperature of the Earth is higher than would be expected without the greenhouse effect. *[3]*

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(Question B2, part 1 continued)

(e) The average solar intensity incident at the surface of the Earth is $238\,\text{W}\,\text{m}^{-2}$. Assuming that the emissivity of the surface of the Earth is 1.0, estimate the average surface temperature if there were no greenhouse effect. *[2]*

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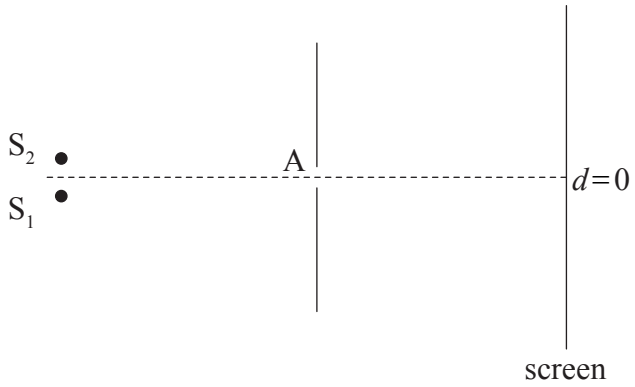
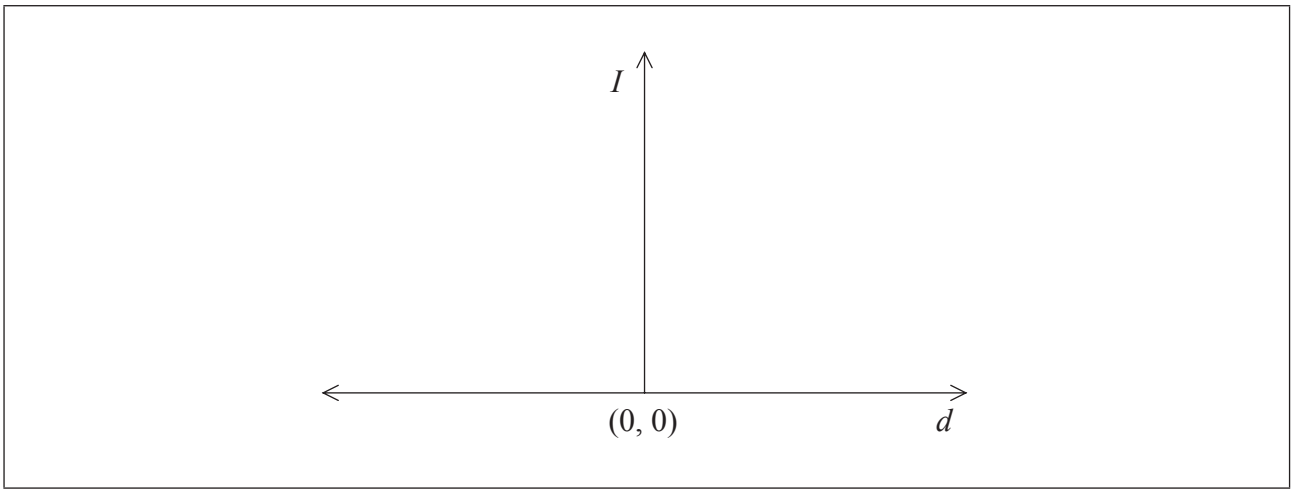
(Question B2 continued from page 22)

Part 2 Optical resolution and polarization

(a) Light from two monochromatic point sources S_1 and S_2 is incident on a circular aperture A.



After passing through the aperture the light is incident on a distant screen. The images of S_1 and S_2 formed on the screen are just resolved according to the Rayleigh criterion. Sketch, using the axes below, the variation with distance d of the intensity I of the light from S_1 and S_2 on the screen. Label the two distributions S_1 and S_2 respectively. *[3]*



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(Question B2, part 2 continued)

(b) The Moon is gradually moving away from the Earth. To the unaided eye, the full Moon appears as a disc. When the Moon is a distance d from the Earth the eye would see the Moon as a single point source of light and not a disc. Show, using the data below, that d is about 3×10^{10} m. *[3]*

Diameter of the Moon $= 3.5\times10^{6}$ m
Diameter of the eye pupil $= 4.0$ mm
Average wavelength of light emitted by Moon $= 4.2\times10^{-7}$ m

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(c) Moonlight reflected from the surface of water is partially polarized.

(i) State what is meant by polarized light. *[1]*

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(ii) Moonlight reflected at a certain angle from the surface of the Mediterranean Sea is completely polarized. Calculate the value of the angle between the reflected light and the surface of the water at which this occurs. The average refractive index of the Mediterranean Sea for moonlight is 1.4. *[2]*

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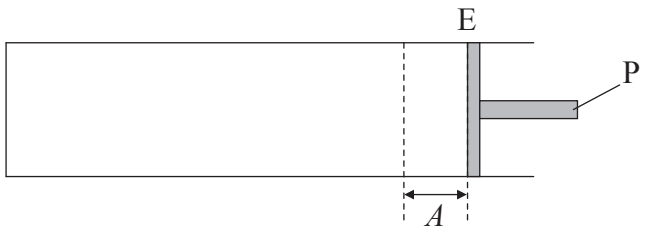
B3. This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and waves. **Part 2** is about a charge-coupled device (CCD).

Part 1 Simple harmonic motion (SHM) and waves

(a) A gas is contained in a horizontal cylinder by a freely moving piston P. Initially P is at rest at the equilibrium position E.



The piston P is displaced a small distance A from E and released. As a result, P executes simple harmonic motion (SHM).

Define *simple harmonic motion* as applied to P. *[2]*

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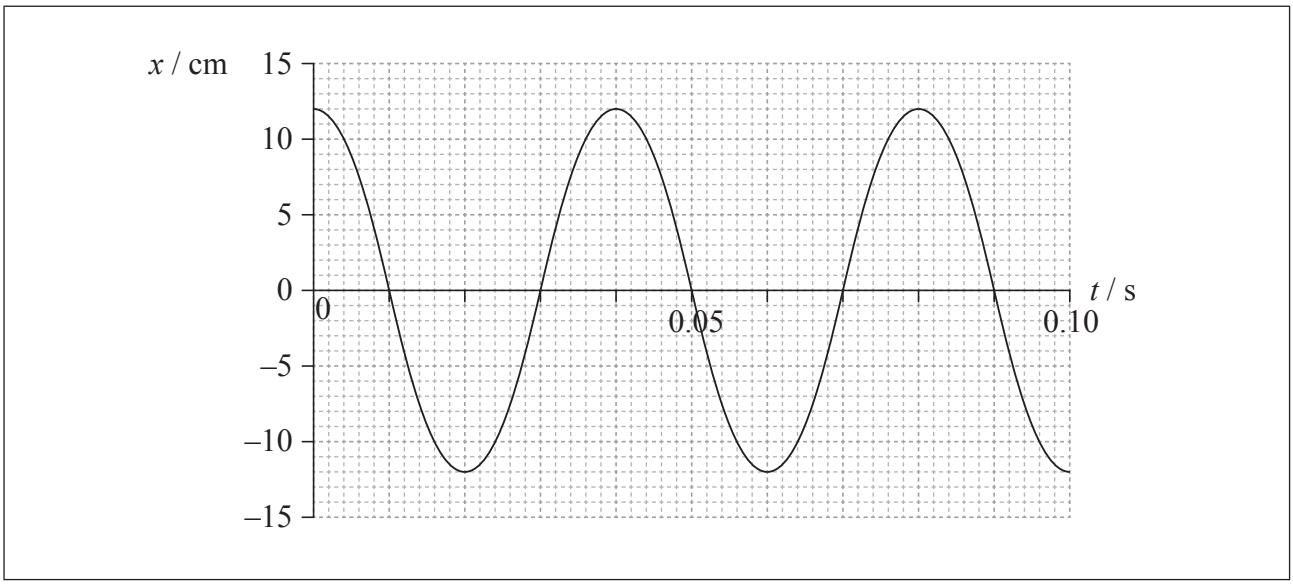
(Question B3, part 1 continued)

(b) The graph shows how the displacement x of the piston P in (a) from equilibrium varies with time t.



(i) State the value of the displacement A as defined in (a). *[1]*

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(ii) On the graph identify, using the letter M, a point where the magnitude of the acceleration of P is a maximum. *[1]*

(iii) Determine, using data from the graph and your answer to (b)(i), the magnitude of the maximum acceleration of P. *[3]*

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(Question B3, part 1 continued)

(iv) The mass of P is 0.32 kg. Determine the kinetic energy of P at $t = 0.052$ s. *[2]*

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(c) The oscillations of P initially set up a longitudinal wave in the gas.

(i) Describe, with reference to the transfer of energy, the difference between a longitudinal wave and a transverse wave. *[3]*

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(ii) The speed of the wave in the gas is 340 m s^{-1}. Calculate the wavelength of the wave in the gas. *[2]*

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(Question B3 continued)

Part 2 Charge-coupled device (CCD)

(a) A charge-coupled device (CCD) consists of a silicon chip divided into small areas called pixels. Each pixel has a property called capacitance.

(i) Define *capacitance*. *[1]*

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(ii) Explain how light incident on a pixel causes a build-up of electric charge on the pixel. *[3]*

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(iii) Outline what information is retrieved from the pixel in order to produce an image on the CCD. *[2]*

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(Question B3, part 2 continued)

(b) Each pixel of a particular CCD has an area of $1.5\times10^{-10}\,m^2$ and a capacitance of 1.2 nF. Light of frequency $5.8\times10^{14}\,Hz$ and intensity $4.0\times10^{2}\,W\,m^{-2}$ is incident on a CCD for a time of 3.0 ms. Assuming that the quantum efficiency of the pixel is 70%, determine the potential difference developed across the pixel. *[5]*

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B4. This question is in **two** parts. **Part 1** is about momentum and energy. **Part 2** is about the de Broglie hypothesis and radioactive decay.

Part 1 Momentum and energy

(a) Define *linear momentum*. *[1]*

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(b) State the law of conservation of momentum. *[2]*

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(c) Far from any massive object, a space rocket is moving with constant velocity. The engines of the space rocket are turned on and it accelerates by burning fuel and ejecting gases. Discuss how the law of conservation of momentum relates to this situation. *[3]*

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(Question B4, part 1 continued)

(d) Jane and Joe are two ice skaters initially at rest on a horizontal skating rink. They are facing each other and Jane is holding a ball. Jane throws the ball to Joe who catches it. The speed at which the ball leaves Jane, measured relative to the ground, is $8.0\,m\,s^{-1}$. The following data are available.

Mass of Jane = 52 kg
Mass of Joe = 74 kg
Mass of ball = 1.3 kg

Use the data to calculate the

(i) speed v of Jane relative to the ground immediately after she throws the ball. *[2]*

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(ii) speed V of Joe relative to the ground immediately after he catches the ball. *[2]*

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(Question B4, part 1 continued)

(e) Jane and Joe are initially separated by 4.0 m. The average frictional force between their skates and the ice is 0.12 N. Show that the separation of Jane and Joe after the ball is thrown and they are at rest again is about 20 m. *[5]*

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Part 2 The de Broglie hypothesis and radioactive decay

(a) Describe the de Broglie hypothesis. *[2]*

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(This question continues on the following page)

(Question B4, part 2 continued)

(b) A positron has a de Broglie wavelength of 1.8×10^{-10} m. Determine the frequency of a gamma (γ) photon that has the same energy as the positron. *[3]*

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(c) Positrons and gamma photons are emitted in the decay of the radioactive isotope potassium-40 (K-40) to the stable isotope argon (Ar).

(i) Outline the origin of gamma photons in this decay. *[2]*

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(ii) At the time that the Earth was formed rocks contained K-40. In a particular sample of rocks it is found that 90 % of the original K-40 nuclei have decayed. The half-life of K-40 is 1.3×10^{9} yr. Determine the age of the Earth. *[3]*

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