# X069/13/01

NATIONAL QUALIFICATIONS 2014

THURSDAY, 22 MAY
1.00 PM – 3.30 PM

# PHYSICS
## ADVANCED HIGHER

Reference may be made to the Physics Data Booklet.

Answer **all** questions.

Any necessary data may be found in the Data Sheet on *Page two*.

Care should be taken to give an appropriate number of significant figures in the final answers to calculations.

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

SA

**DATA SHEET**

COMMON PHYSICAL QUANTITIES

| *Quantity* | *Symbol* | *Value* | *Quantity* | *Symbol* | *Value* |
|---|---|---|---|---|---|
| Gravitational acceleration on Earth | $g$ | $9{\cdot}8\,\text{m s}^{-2}$ | Mass of electron | $m_e$ | $9{\cdot}11 \times 10^{-31}$ kg |
| Radius of Earth | $R_E$ | $6{\cdot}4 \times 10^{6}$ m | Charge on electron | $e$ | $-1{\cdot}60 \times 10^{-19}$ C |
| Mass of Earth | $M_E$ | $6{\cdot}0 \times 10^{24}$ kg | Mass of neutron | $m_n$ | $1{\cdot}675 \times 10^{-27}$ kg |
| Mass of Moon | $M_M$ | $7{\cdot}3 \times 10^{22}$ kg | Mass of proton | $m_p$ | $1{\cdot}673 \times 10^{-27}$ kg |
| Radius of Moon | $R_M$ | $1{\cdot}7 \times 10^{6}$ m | Mass of alpha particle | $m_\alpha$ | $6{\cdot}645 \times 10^{-27}$ kg |
| Mean Radius of Moon Orbit | | $3{\cdot}84 \times 10^{8}$ m | Charge on alpha particle | | $3{\cdot}20 \times 10^{-19}$ C |
| Universal constant of gravitation | $G$ | $6{\cdot}67 \times 10^{-11}\,\text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$ | Planck's constant | $h$ | $6{\cdot}63 \times 10^{-34}$ J s |
| Speed of light in vacuum | $c$ | $3{\cdot}0 \times 10^{8}\,\text{m s}^{-1}$ | Permittivity of free space | $\varepsilon_0$ | $8{\cdot}85 \times 10^{-12}\,\text{F m}^{-1}$ |
| Speed of sound in air | $v$ | $3{\cdot}4 \times 10^{2}\,\text{m s}^{-1}$ | Permeability of free space | $\mu_0$ | $4\pi \times 10^{-7}\,\text{H m}^{-1}$ |

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

| *Substance* | *Refractive index* | *Substance* | *Refractive index* |
|---|---|---|---|
| Diamond | 2·42 | Glycerol | 1·47 |
| Glass | 1·51 | Water | 1·33 |
| Ice | 1·31 | Air | 1·00 |
| Perspex | 1·49 | Magnesium Fluoride | 1·38 |

SPECTRAL LINES

| *Element* | *Wavelength*/nm | *Colour* | *Element* | *Wavelength*/nm | *Colour* |
|---|---|---|---|---|---|
| Hydrogen | 656 | Red | Cadmium | 644 | Red |
| | 486 | Blue-green | | 509 | Green |
| | 434 | Blue-violet | | 480 | Blue |
| | 410 | Violet | *Lasers* | | |
| | 397 | Ultraviolet | *Element* | *Wavelength*/nm | *Colour* |
| | 389 | Ultraviolet | Carbon dioxide | 9550 } 10590 } | Infrared |
| Sodium | 589 | Yellow | Helium-neon | 633 | Red |

PROPERTIES OF SELECTED MATERIALS

| *Substance* | *Density*/ kg m$^{-3}$ | *Melting Point*/ K | *Boiling Point*/K | *Specific Heat Capacity*/ J kg$^{-1}$ K$^{-1}$ | *Specific Latent Heat of Fusion*/ J kg$^{-1}$ | *Specific Latent Heat of Vaporisation*/ J kg$^{-1}$ |
|---|---|---|---|---|---|---|
| Aluminium | $2{\cdot}70 \times 10^3$ | 933 | 2623 | $9{\cdot}02 \times 10^2$ | $3{\cdot}95 \times 10^5$ | .... |
| Copper | $8{\cdot}96 \times 10^3$ | 1357 | 2853 | $3{\cdot}86 \times 10^2$ | $2{\cdot}05 \times 10^5$ | .... |
| Glass | $2{\cdot}60 \times 10^3$ | 1400 | .... | $6{\cdot}70 \times 10^2$ | .... | .... |
| Ice | $9{\cdot}20 \times 10^2$ | 273 | .... | $2{\cdot}10 \times 10^3$ | $3{\cdot}34 \times 10^5$ | .... |
| Glycerol | $1{\cdot}26 \times 10^3$ | 291 | 563 | $2{\cdot}43 \times 10^3$ | $1{\cdot}81 \times 10^5$ | $8{\cdot}30 \times 10^5$ |
| Methanol | $7{\cdot}91 \times 10^2$ | 175 | 338 | $2{\cdot}52 \times 10^3$ | $9{\cdot}9 \times 10^4$ | $1{\cdot}12 \times 10^6$ |
| Sea Water | $1{\cdot}02 \times 10^3$ | 264 | 377 | $3{\cdot}93 \times 10^3$ | .... | .... |
| Water | $1{\cdot}00 \times 10^3$ | 273 | 373 | $4{\cdot}19 \times 10^3$ | $3{\cdot}34 \times 10^5$ | $2{\cdot}26 \times 10^6$ |
| Air | 1·29 | .... | .... | .... | .... | .... |
| Hydrogen | $9{\cdot}0 \times 10^{-2}$ | 14 | 20 | $1{\cdot}43 \times 10^4$ | .... | $4{\cdot}50 \times 10^5$ |
| Nitrogen | 1·25 | 63 | 77 | $1{\cdot}04 \times 10^3$ | .... | $2{\cdot}00 \times 10^5$ |
| Oxygen | 1·43 | 55 | 90 | $9{\cdot}18 \times 10^2$ | .... | $2{\cdot}40 \times 10^4$ |

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^5$ Pa.

Marks

**1.** An HS1000 tidal powered electricity generator is installed on the sea bed close to Orkney. The generator is shown in Figure 1.

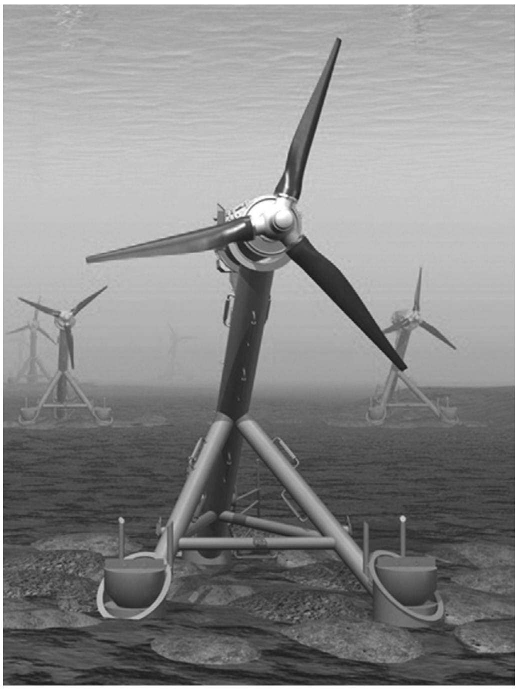

Figure 1

The blades of the turbine are 7·8 m long. The moving tidal water spins the twin turbines to generate electricity. The maximum power output of the HS1000 is 1·0 MW.

(*a*) (i) When operating, the tangential velocity of the tip of the blades is $8{\cdot}2\,m\,s^{-1}$.

Calculate the angular velocity of the blades. **2**

(ii) When the blades are rotating at this angular velocity, the rotational kinetic energy is 100 M J.

Calculate the total moment of inertia of the rotating parts of the HS1000. **2**

(iii) State **one** assumption made in the calculation(s). **1**

(*b*) Starting from rest it takes 42 seconds for the turbine to reach the angular velocity calculated in (*a*)(i).

Calculate the torque acting on the turbines. **3**

**(8)**

**[Turn over**

*Marks*

**2.** A student uses two methods to calculate the moment of inertia of a solid cylinder about its central axis.

(*a*) In the first method the student measures the mass of the cylinder to be 0·115 kg and the diameter to be 0·030 m.

Calculate the moment of inertia of the cylinder. **2**

(*b*) In a second method the student allows the cylinder to roll down a slope and measures the final speed at the bottom of the slope to be 1·60 m $s^{-1}$. The cylinder has a diameter of 0·030 m and the slope has a height of 0·25 m, as shown in Figure 2.

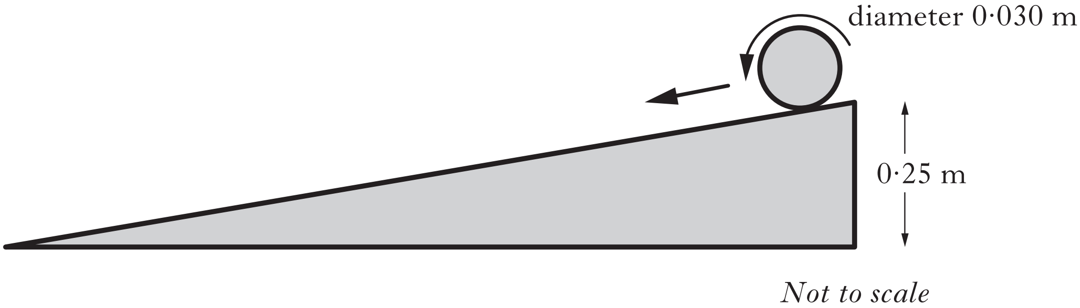


Figure 2

Using the conservation of energy, calculate the moment of inertia. **4**

(*c*) Explain why the moment of inertia found in part (*b*) is greater than in part (*a*). **1**

**(7)**

*Marks*

**3.** A team of astrophysicists from a Scottish University has discovered, orbiting a nearby star, an exoplanet with the same mass as Earth.

By considering the escape velocity of the exoplanet, the composition of its atmosphere can be predicted.

(*a*) (i) Explain the term *escape velocity*. **1**

(ii) Derive the expression for escape velocity in terms of the exoplanet's mass and radius. **2**

(iii) The radius of this exoplanet is 1·7 times that of the Earth.

Calculate the escape velocity of the exoplanet. **3**

(*b*) Astrophysicists consider that a gas will be lost from the atmosphere of a planet if the typical molecular velocity ($v_{rms}$) is $\frac{1}{6}$ or more of the escape velocity for that planet.

The table below gives $v_{rms}$ for selected gases at 273 K.

| *Gas* | $v_{rms}$ ($m\,s^{-1}$) |
|---|---|
| Hydrogen | 1838 |
| Helium | 1845 |
| Nitrogen | 493 |
| Oxygen | 461 |
| Methane | 644 |
| Carbon dioxide | 393 |

The atmospheric temperature of this exoplanet is 273 K.

Predict which of these gases could be found in its atmosphere. **2**

**(8)**

**[Turn over**

*Marks*

**4.** Car engines use the ignition of fuel to release energy which moves the pistons up and down, causing the crankshaft to rotate.

The vertical motion of the piston approximates to simple harmonic motion.

Figure 4 shows different positions of a piston in a car engine.

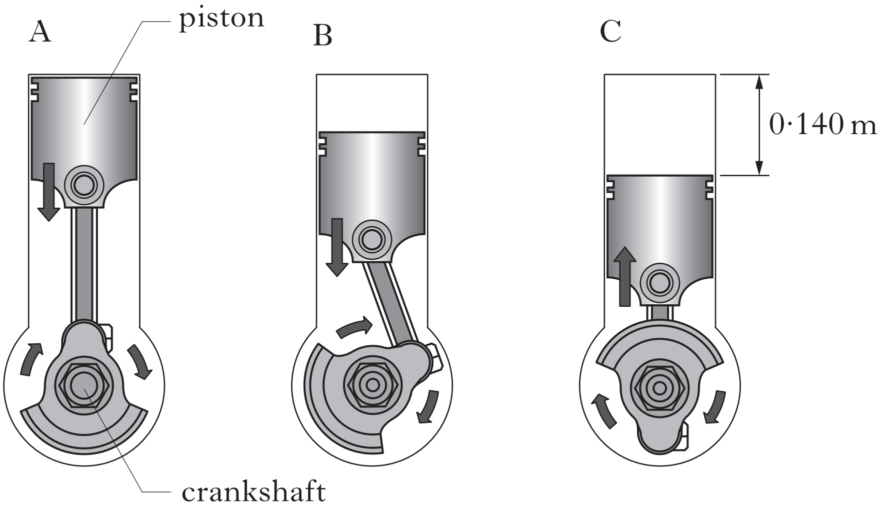


Figure 4

(*a*) Define *simple harmonic motion*. **1**

(*b*) Determine the amplitude of the motion. **1**

(*c*) In this engine the crankshaft rotates at 1500 revolutions per minute and the piston has a total mass of 1·40 kg.

(i) Calculate the maximum acceleration of the piston. **3**

(ii) Calculate the maximum kinetic energy of the piston. **2**

**(7)**

*Marks*

**5.** In 1928, Davisson and Germer fired a beam of electrons through a very thin layer of nickel in a vacuum, which resulted in the production of a diffraction pattern.

(*a*) (i) What did they conclude from the results of their experiment? **1**

(ii) Give **one** example of experimental evidence that photons of light exhibit particle properties. **1**

(*b*) Calculate the de Broglie wavelength of an electron travelling at $4{\cdot}4 \times 10^6\,\mathrm{m\,s^{-1}}$. **2**

(*c*) A 20 g bullet travelling at $300\,\mathrm{m\,s^{-1}}$ passes through a 500 mm gap in a target.

Using the data given, explain why no diffraction pattern is observed. **2**

(*d*) (i) Describe the Bohr model of the hydrogen atom. **2**

(ii) Calculate the angular momentum of an electron in the third stable orbit of a hydrogen atom. **2**

**(10)**

**[Turn over**

**6.** Four point charges P, Q, R and S are fixed in a rectangular array. Point charge A is placed at the centre of the rectangle, 2·5 mm from each of the fixed charges, as shown in Figure 6A.

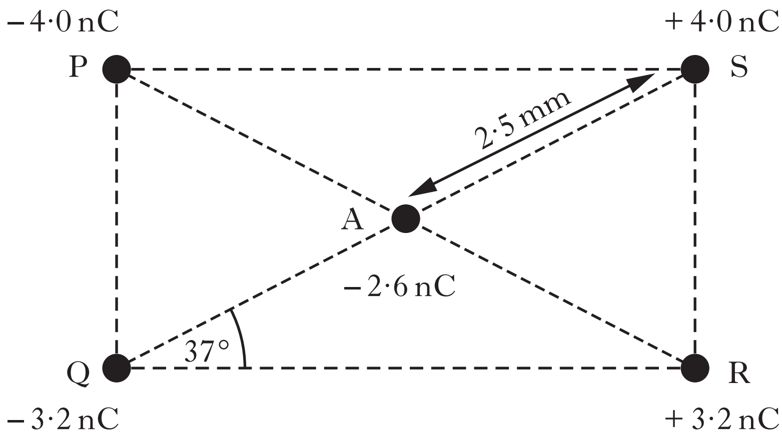


Figure 6A

(*a*) (i) Calculate the magnitude of the force exerted on charge A due to charge P. **2**

(ii) The magnitude of the force exerted on charge A due to charge Q is 0·012 N.

Calculate the **resultant force** exerted on charge A due to all the fixed charges. **3**

(*b*) The four fixed charges are removed and charge A is now fixed. Position B is at a distance $r$ from charge A as shown in Figure 6B.

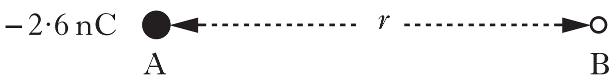


Figure 6B

(i) The electrostatic potential at B is −37 V.

Calculate the distance $r$. **2**

**6. (*b*) (continued)**

(ii) A charge may be moved from B to position C along two possible paths, 1 and 2, shown in Figure 6C.

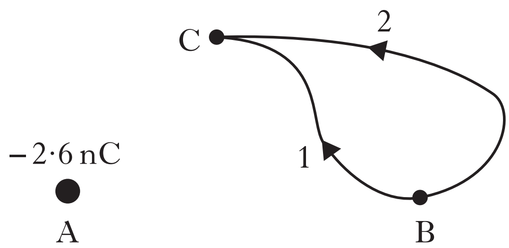


Figure 6C

Compare the work done in moving the charge by the two different routes. **1**

**(8)**

**[Turn over**

7. A student investigates the behaviour of electrons in electric fields. In one experiment the student uses the equipment shown in Figure 7A to investigate the charge to mass ratio for an electron. *Marks*

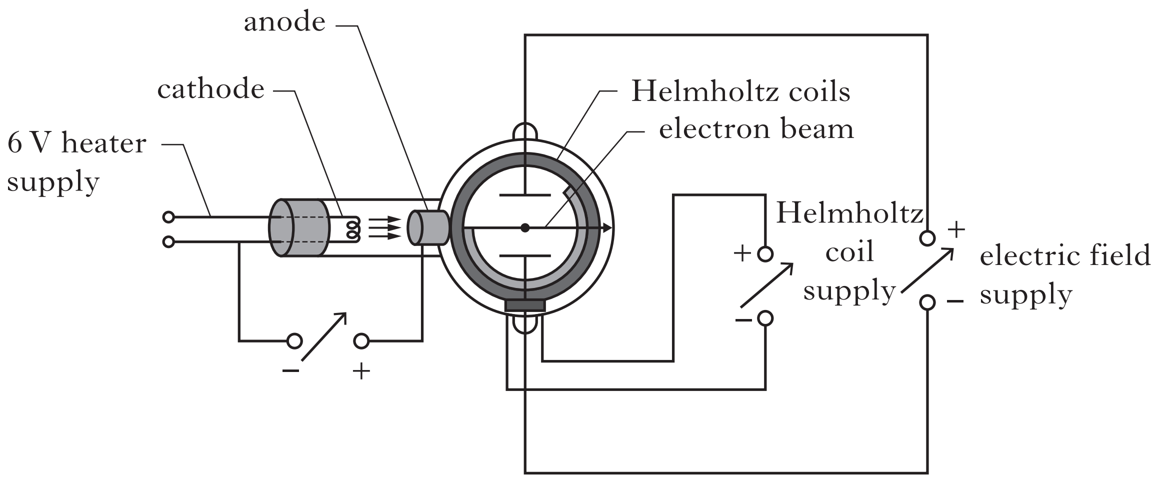


Figure 7A

(*a*) An electron of mass $m$ and charge $q$ is accelerated from rest between a cathode and anode by a potential difference $V$. Electron velocity $v$ is measured using the interaction between electric and magnetic fields.

(i) Show that the charge to mass ratio $q/m$ is given by

$$\frac{q}{m} = \frac{v^2}{2V}.$$ **1**

(ii) The student obtained the following data.

| *Electron velocity* ($\times 10^7$ m s$^{-1}$) | *Potential difference* (kV) |
|---|---|
| 2·92 | 2·48 |
| 2·73 | 2·15 |
| 2·61 | 2·00 |
| 2·47 | 1·75 |
| 2·26 | 1·56 |

(A) The student decides to calculate $q/m$ individually for each pair of results. Calculate the values obtained. **2**

(B) The student then suggests that the mean of these values is the best estimate of $q/m$. Calculate this mean value. **1**

(C) Another student correctly explains that this is an inappropriate method for calculating $q/m$ and that a more appropriate method is to draw a graph.

Explain in detail how a graphical approach could be used to determine a value for $q/m$. **2**

**7. (continued)**

(*b*) In a second experiment the potential difference between cathode and anode is set at 2·08 kV as shown in Figure 7B.

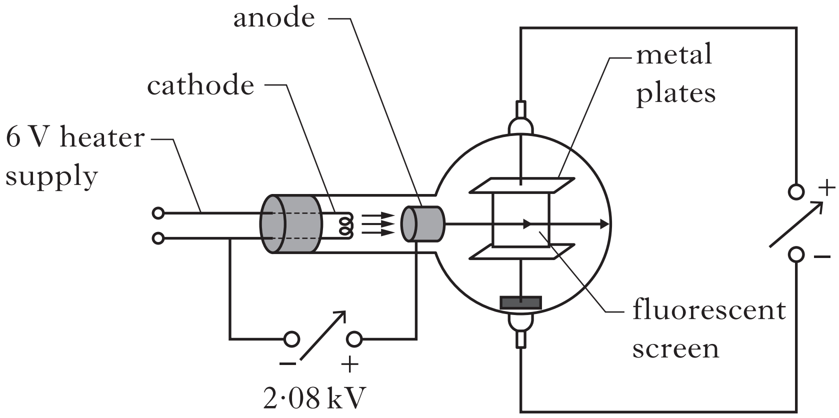


Figure 7B

(i) Show that the speed of an electron on reaching the anode is $2{\cdot}70 \times 10^{7}\,\mathrm{m\,s^{-1}}$. **1**

(ii) The electron then passes through the uniform electric field produced between parallel plates. The path of this electron between the parallel plates is shown in Figure 7C.

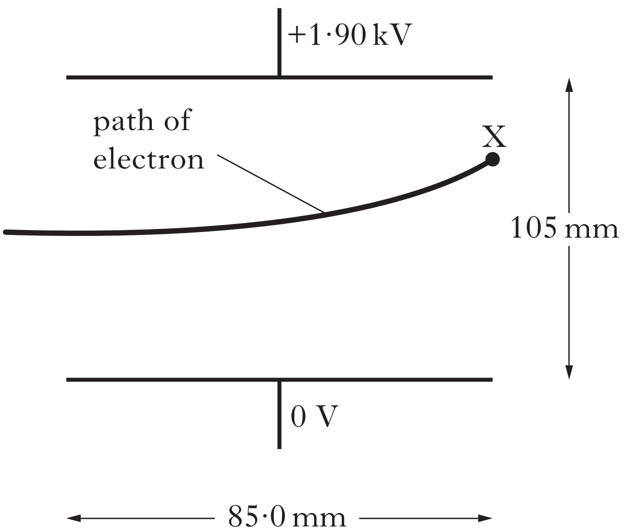


Figure 7C

Calculate the vertical displacement of the electron at point X. **3**

(iii) The potential difference between the cathode and the anode is now increased to 2·40 kV.

Will electrons exit the field at the same position, higher or lower than point X as shown in Figure 7C. Justify your answer. **2**

**(12)**

*Marks*

**8.** Research is currently being carried out into nuclear fusion as a future source of energy. One approach uses a magnetic field to contain ionised gas, known as plasma, in a hollow doughnut-shaped ring. A simplified design is shown in Figure 8A.

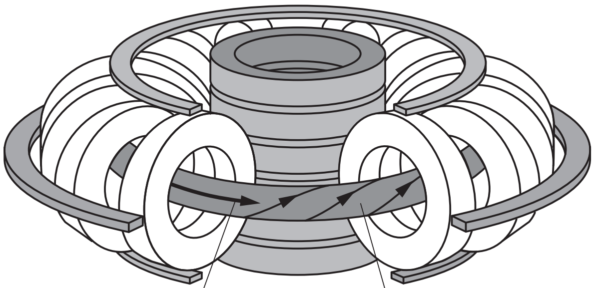


Figure 8A

The motion of a charged gas particle is determined by the angle $\theta$ between its velocity $v$ and the magnetic induction $B$ as shown in Figure 8B.

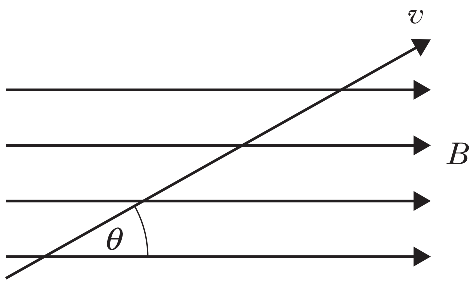


Figure 8B

(*a*) In the case where $\theta = 90°$ the particles undergo circular motion, perpendicular to the magnetic field.

(i) Show that for a charged particle of mass $m$, charge $q$ and velocity $v$ in a field of magnetic induction $B$ the radius of rotation is given by

$$r = \frac{mv}{qB}$$ **1**

**8. (*a*) (continued)**

(ii) A deuterium ion is moving with a velocity of $2{\cdot}4 \times 10^7\,\mathrm{m\,s^{-1}}$ perpendicular to the magnetic field. The maximum diameter of the circular motion, permitted by the design, is 0·50 m.

Properties of ions present in the plasma are given in the table below.

| *Ion* | *Symbol* | *Mass* ($\times 10^{-27}$ kg) | *Charge* ($\times 10^{-19}$ C) |
|---|---|---|---|
| Hydrogen | $H^+$ | 1·686 | 1·60 |
| Deuterium | $D^+$ | 3·343 | 1·60 |
| Tritium | $T^+$ | 5·046 | 1·60 |

Calculate the magnetic induction *B* required to constrain the deuterium ion within the maximum permitted diameter. **2**

(iii) Calculate the maximum period of rotation for this deuterium ion. **2**

(*b*) Another deuterium ion is travelling at $2{\cdot}4 \times 10^7\,\mathrm{m\,s^{-1}}$ at an angle of 40° to the direction of magnetic induction. This results in the ion undergoing helical motion as shown in Figure 8C.

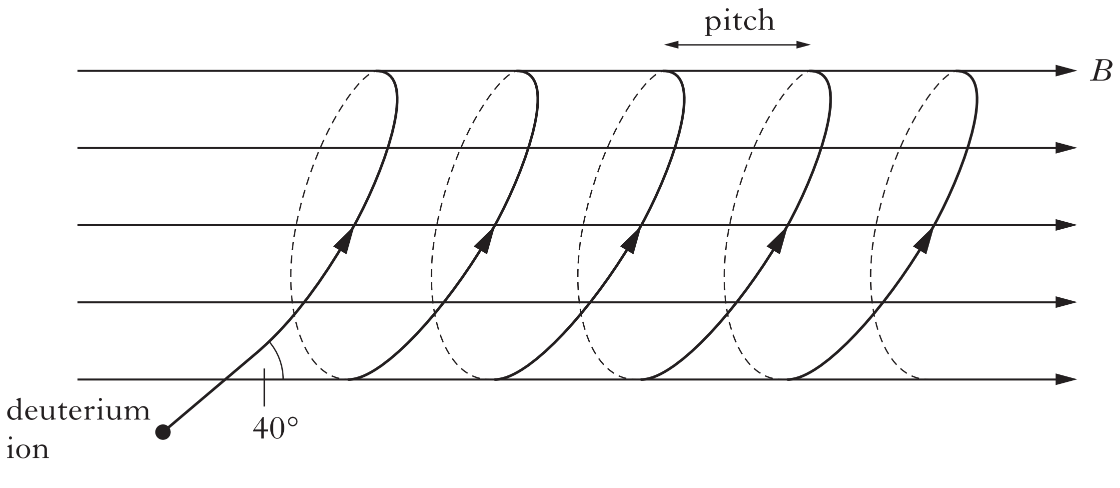


Figure 8C

(i) Explain why the period of rotation for this deuterium ion is the same as in (*a*)(iii). **1**

(ii) The distance between adjacent loops in the helix is called the pitch.

Calculate the pitch of the helical motion. **2**

**(8)**

**[Turn over**

**9.** Cyclotrons consist of two D shaped regions, known as Dees, separated by a small gap. An electric field between the Dees accelerates the charged particles. A magnetic field in the Dees causes the particles to follow a circular path. Negatively charged hydrogen ions ($H^-$) are released from point A and follow the path as shown in Figure 9A.

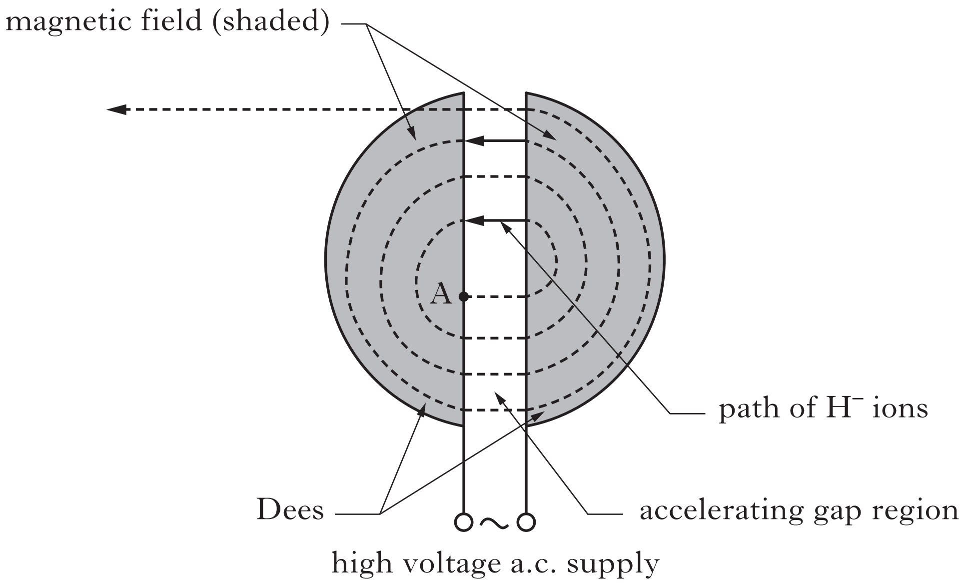


Figure 9A

(*a*) (i) State the direction of the magnetic induction *B*. **1**

(ii) Explain why an a.c. supply must be used to provide the electric field. **1**

(*b*) The energy gained by the $H^-$ ion for one transit of the gap region is $1 \cdot 5 \times 10^{-14}$ J.

(i) How many transits of the gap would occur before relativistic effects should be taken into account? **2**

(ii) When relativistic effects are taken into account, the magnitude of the magnetic induction must increase as the radius of the particle path increases.

Explain why this is the case. **2**

**9. (continued)**

(*c*) The diagram shown in Figure 9B represents the paths of particles A, B and C in a perpendicular magnetic field.

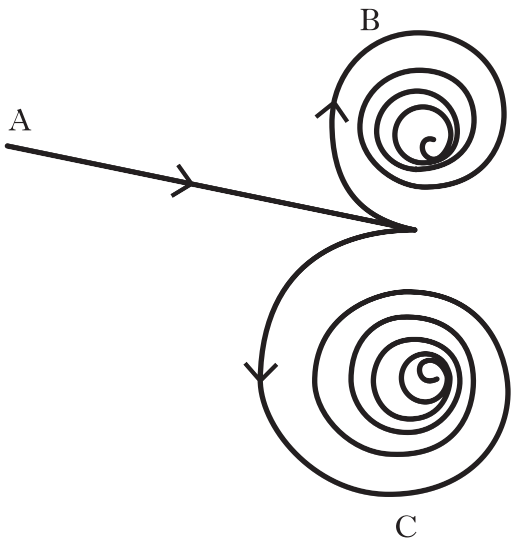


Figure 9B

(i) What information can be deduced about the particles A, B and C? **2**

(ii) Why do the radii of paths B and C decrease? **1**

**(9)**

**[Turn over**

**10.** An inductor of inductance 4·0 H with negligible resistance is connected in series with a 48 Ω resistor shown in Figure 10A.

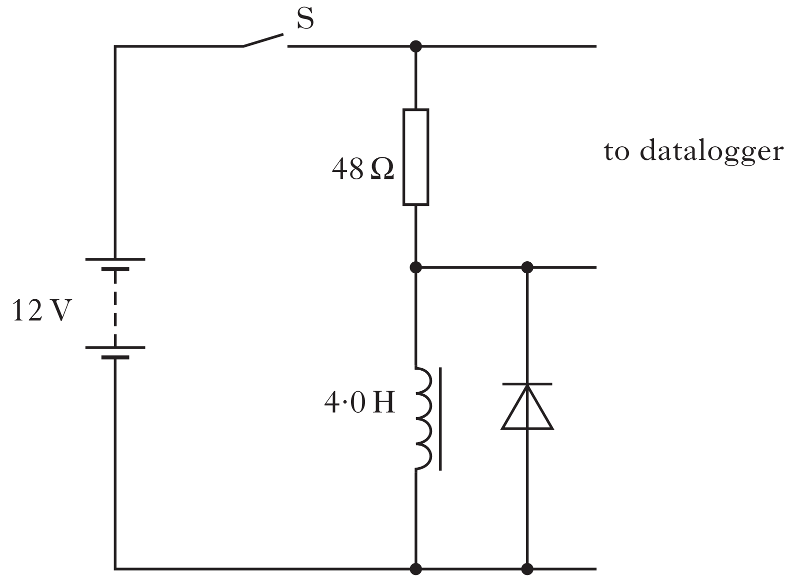


Figure 10A

The datalogger is set to display a graph of current against time.

(*a*) Sketch the graph obtained from the time the switch S is closed until the current reaches a maximum. Numerical values are required on the current axis only. **2**

(*b*) Calculate the initial rate of change of current in the 4·0 H inductor. **2**

(*c*) The 4·0 H inductor is now connected in the circuit shown in Figure 10B.

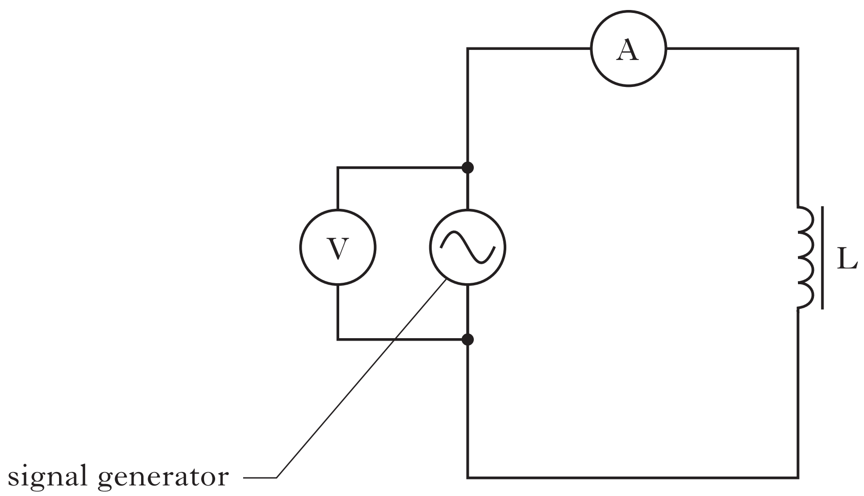


Figure 10B

The frequency of the signal generator is varied and the potential difference across the inductor is kept constant.

Explain what happens to the current in the inductor as the frequency of the signal generator is increased. **1**

**(5)**

**11.** (*a*) When sunlight hits a thin film of oil floating on the surface of water, a complex pattern of coloured fringes is observed.

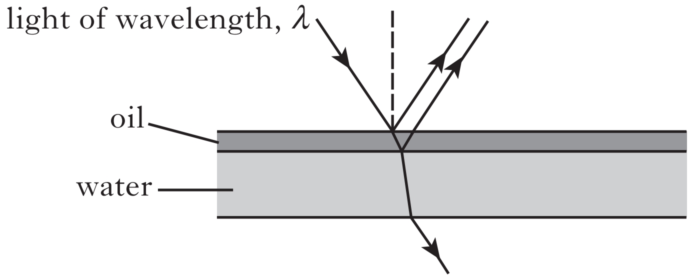


Figure 11

Explain how these fringes are formed. **2**

(*b*) The surface of a lens is coated with a thin film of magnesium fluoride.

Calculate the minimum thickness required to make the lens non-reflecting at a wavelength of 555 nm. **2**

(*c*) The lens of a digital camera appears to be purple in white light.

Explain this observation. **2**

**(6)**

**[Turn over**

**12.** A series of coloured LEDs are used in the Young's slit experiment as shown in Figure 12. The distance from the slits to the screen is (2·50 ± 0·05)m. The slit separation is $(3{\cdot}0 \pm 0{\cdot}1) \times 10^{-4}$ m.

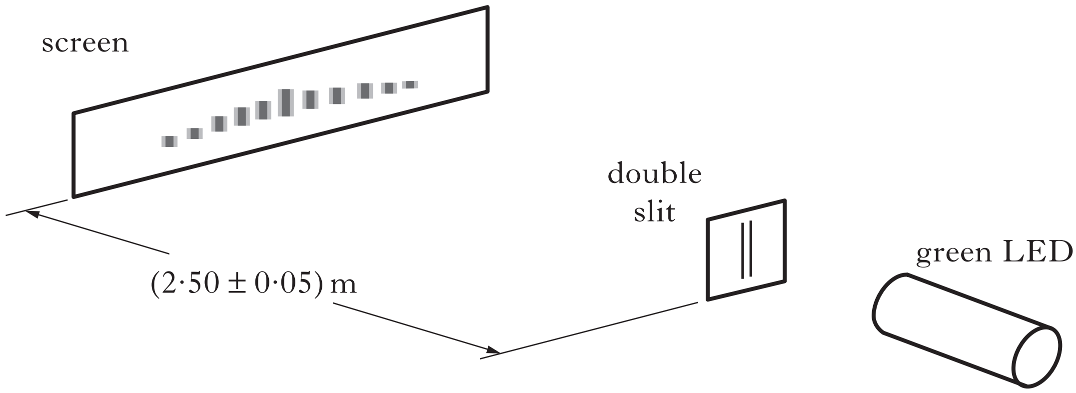


Figure 12

| *Colour of LED* | *Wavelength* (nm) |
|---|---|
| Red | 650 ± 2 |
| Green | 510 ± 2 |
| Blue | 470 ± 2 |

(*a*) State whether the pattern on the screen is caused by the division of wavefront or the division of amplitude. **1**

(*b*) (i) Calculate the fringe separation observed on the screen when the green LED is used. **2**

(ii) Calculate the absolute uncertainty in the fringe separation. **3**

(iii) Which measurement has the most significant impact on the absolute uncertainty?

Justify your answer. **1**

**(7)**

Marks

**13.** A student, wearing polarising sunglasses, is using a tablet computer outdoors. The orientation of the tablet seems to affect the image observed by the student.

Two orientations are shown in Figure 13A.

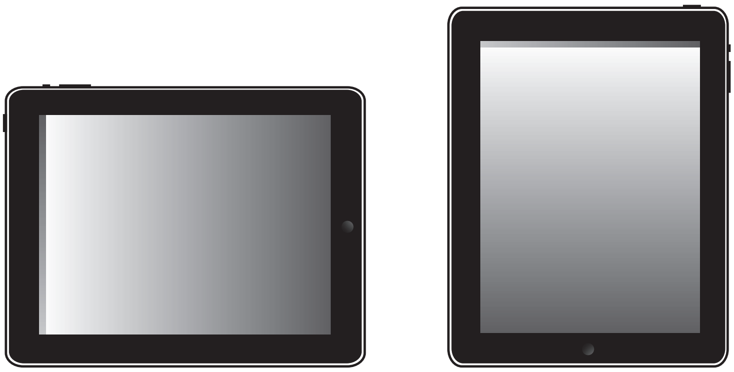


Figure 13A

(*a*) In landscape mode the image appears bright and in portrait mode it appears dark.

(i) What may be concluded about the light emitted from the tablet screen? **1**

(ii) The student slowly rotates the tablet. Describe the change in brightness observed by the student as it is rotated through 180°. **2**

(*b*) Unpolarised sunlight is incident on a water surface as shown in Figure 13B.

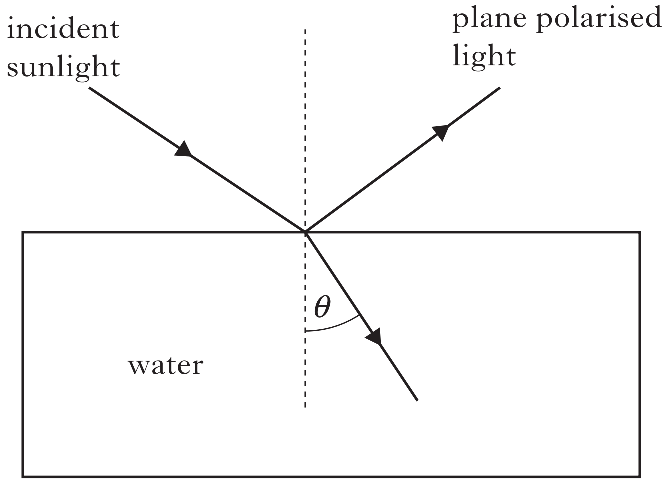


Figure 13B

The light is 100% plane polarised on reflection.

Calculate the angle of refraction $\theta$. **2**

**(5)**

[*END OF QUESTION PAPER*]

ACKNOWLEDGEMENT

Question 1 – Image of Tidal Turbine Technology HS1000 is reproduced by kind permission of Andritz Hydro Hammerfest.