

X069/13/01

NATIONAL
QUALIFICATIONS
2012

MONDAY, 28 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.



DATA SHEET
COMMON PHYSICAL QUANTITIES

| Quantity | Symbol | Value | Quantity | Symbol | Value |
|-------------------------------------|--------|---|----------------------------|--------------|---|
| Gravitational acceleration on Earth | g | 9.8 m s^{-2} | Mass of electron | m_p | $9.11 \times 10^{-31} \text{ kg}$ |
| Radius of Earth | R_E | $6.4 \times 10^6 \text{ m}$ | Charge on electron | e | $-1.60 \times 10^{-19} \text{ C}$ |
| Mass of Earth | M_E | $6.0 \times 10^{24} \text{ kg}$ | Mass of neutron | m_n | $1.675 \times 10^{-27} \text{ kg}$ |
| Mass of Moon | M_M | $7.3 \times 10^6 \text{ kg}$ | Mass of proton | m_p | $1.673 \times 10^{-27} \text{ kg}$ |
| Radius of Moon | R_M | $1.7 \times 10^6 \text{ m}$ | Mass of alpha particle | m_a | $6.645 \times 10^{-27} \text{ kg}$ |
| Mean Radius of Moon Orbit | | $3.84 \times 10^8 \text{ m}$ | Charge on alpha particle | | $3.20 \times 10^{-19} \text{ C}$ |
| Universal constant of gravitation | G | $6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$ | Planck's constant | h | $6.63 \times 10^{-34} \text{ J s}$ |
| Speed of light in vacuum | c | $3.0 \times 10^8 \text{ m s}^{-1}$ | Permittivity of free space | ϵ_0 | $8.85 \times 10^{-12} \text{ F m}^{-1}$ |
| Speed of sound in air | v | $3.4 \times 10^2 \text{ m s}^{-1}$ | Permeability of free space | μ_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 | <i>Lasers</i> | | |
| | 397 | Ultraviolet | <i>Element</i> | <i>Wavelength/nm</i> | <i>Colour</i> |
| | 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/ $\text{J kg}^{-1} \text{ K}^{-1}$ | Specific Latent Heat of Fusion/ J kg^{-1} | Specific Latent Heat of Vaporisation/ J kg^{-1} |
|-----------|--------------------------------|---------------------|-----------------|--|---|---|
| Aluminium | 2.70×10^3 | 933 | 2623 | 9.02×10^2 | 3.95×10^5 | .... |
| Copper | 8.96×10^3 | 1357 | 2853 | 3.86×10^2 | 2.05×10^5 | .... |
| Glass | 2.60×10^3 | 1400 | .... | 6.70×10^2 | .... | .... |
| Ice | 9.20×10^2 | 273 | .... | 2.10×10^3 | 3.34×10^5 | .... |
| Glycerol | 1.26×10^3 | 291 | 563 | 2.43×10^3 | 1.81×10^5 | 8.30×10^5 |
| Methanol | 7.91×10^2 | 175 | 338 | 2.52×10^3 | 9.9×10^4 | 1.12×10^6 |
| Sea Water | 1.02×10^3 | 264 | 377 | 3.93×10^3 | .... | .... |
| Water | 1.00×10^3 | 273 | 373 | 4.19×10^3 | 3.34×10^5 | 2.26×10^6 |
| Air | 1.29 | .... | .... | .... | .... | .... |
| Hydrogen | 9.0×10^{-2} | 14 | 20 | 1.43×10^4 | .... | 4.50×10^5 |
| Nitrogen | 1.25 | 63 | 77 | 1.04×10^3 | .... | 2.00×10^5 |
| Oxygen | 1.43 | 55 | 90 | 9.18×10^2 | .... | 2.40×10^4 |

The gas densities refer to a temperature of 273 K and a pressure of $1.01 \times 10^5 \text{ Pa}$.

1. (a) A beta particle travelling at high speed has a relativistic mass 1.8 times its rest mass.
- (i) Calculate the speed of the beta particle. 2
 - (ii) Calculate the relativistic energy of the beta particle at this speed. 2
 - (iii) Name the force associated with beta decay. 1
- (b) Electrons exhibit both wave-like and particle-like behaviour.
- (i) Give **one** example of experimental evidence which suggests an electron exhibits wave-like behaviour. 1
 - (ii) Give **one** example of experimental evidence which suggests an electron exhibits particle-like behaviour. 1
- (7)**

[Turn over

2. (a) The acceleration of a particle moving in a straight line is given by

$$a = \frac{dv}{dt}$$

where the symbols have their usual meaning.

- (i) Show, by integration, that when a is constant

$$v = u + at.$$

2

- (ii) Show that when a is constant

$$v^2 = u^2 + 2as.$$

1

- (b) The path taken by a short track speed skater is shown in Figure 2A. The path consists of two straights each of length 29.8 m and two semicircles each of radius 8.20 m.

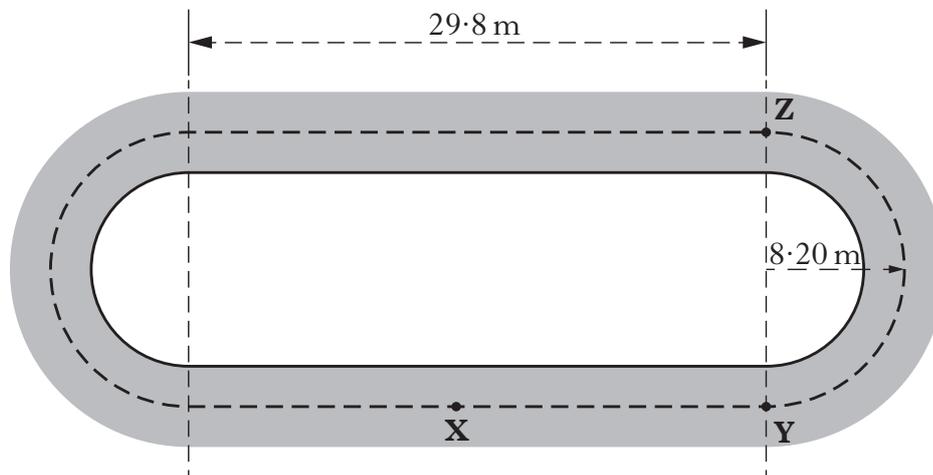


Figure 2A

Starting at point **X**, half way along the straight, the skater accelerates uniformly from rest. She reaches a speed of 9.64 m s^{-1} at point **Y**, the end of the straight.

- (i) Calculate the acceleration of the skater.

2

- (ii) The skater exits the curve at point **Z** with a speed of 10.9 m s^{-1} .

Calculate the average **angular** acceleration of the skater between **Y** and **Z**.

3

2. (continued)

Marks

- (c) When this speedskater reaches a curve she leans inwards and digs the blade of the skate into the ice as shown in Figure 2B. Force F indicates the reaction of the ice on the skater.

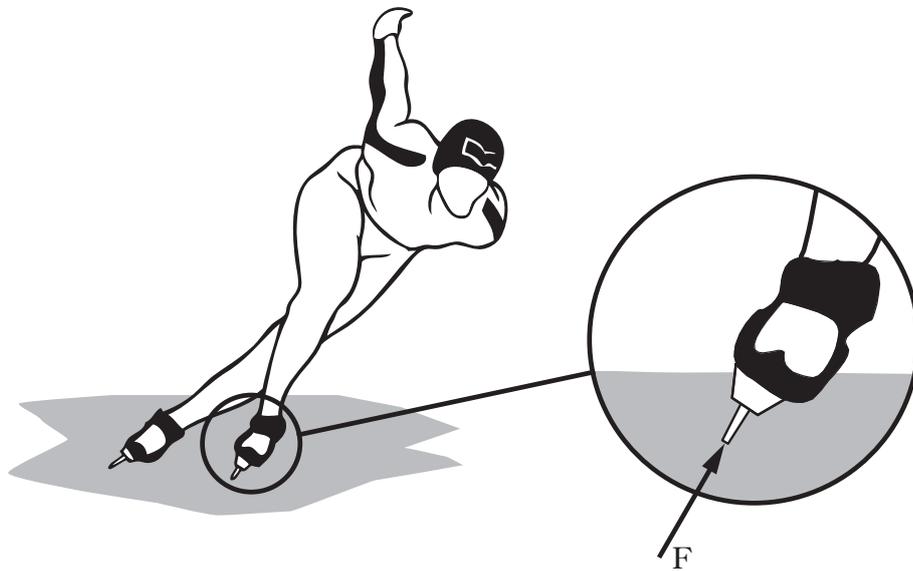


Figure 2B

- (i) Explain how force F allows her to maintain a curved path. 2
- (ii) The skater approaches the next curve at a greater speed and slides off the track. Explain, **in terms of forces**, why this happens. 1
- (11)

[Turn over

3. To test a springboard a diver takes up a position at the end of the board and sets up an oscillation as shown in Figure 3A. The oscillation approximates to simple harmonic motion. The board oscillates with a frequency of 0.76 Hz . The end of the board moves through a vertical distance of 0.36 m .

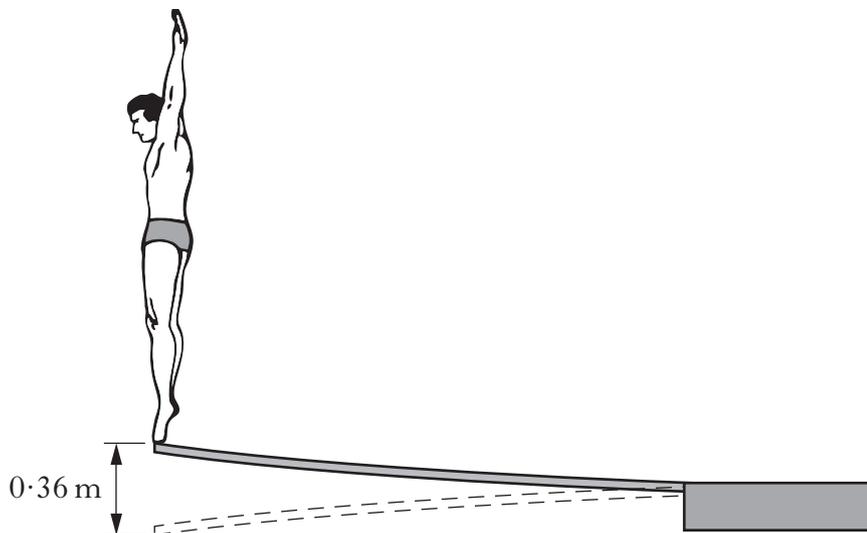


Figure 3A

- (a) (i) Write an expression for the vertical displacement y of the end of the board as a function of time t . Include appropriate numerical values. 2
- (ii) The diver increases the amplitude of the oscillation. The frequency remains constant. Show that the amplitude when the diver just loses contact with the board is 0.43 m . 1

3. (continued)

Marks

- (b) A sport scientist analyses a dive. At one point during the dive, shown in Figure 3B, he approximates the diver's body to be two rods of equal mass rotating about point G. One rod has a length of 0.94 m the other of 0.90 m. The diver has a mass of 66.0 kg

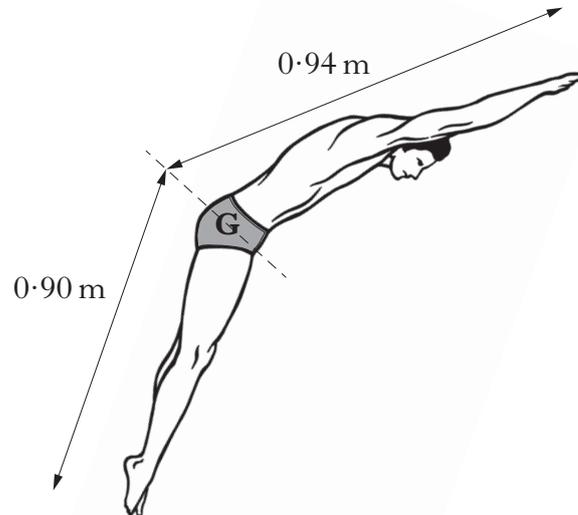


Figure 3B

- (i) Calculate the approximate moment of inertia of the diver. 3
- (ii) The diver's true moment of inertia about point G is found to be 10.25 kg m^2 . Account for any difference between the value calculated in part (i) and the true value. 1
- (iii) In the position shown in Figure 3B, the diver has an initial angular velocity of 0.55 rad s^{-1} . He changes his position to that shown in Figure 3C. The diver now has a moment of inertia of 7.65 kg m^2 . Calculate the angular velocity of the diver in this new position. 2

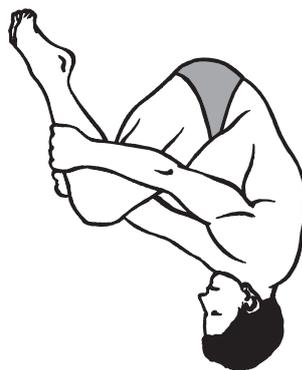


Figure 3C

- (c) (i) Calculate the change in rotational kinetic energy between these two positions. 2
- (ii) Account for the difference in rotational kinetic energy. 1
- (12)**

4. (a) Show that the gravitational field strength at the surface of Pluto, mass M_p , is given by

$$g = \frac{GM_p}{r^2}$$

where the symbols have their usual meanings.

1

- (b) Figure 4A shows how the gravitational potential varies with distance from the centre of Pluto.

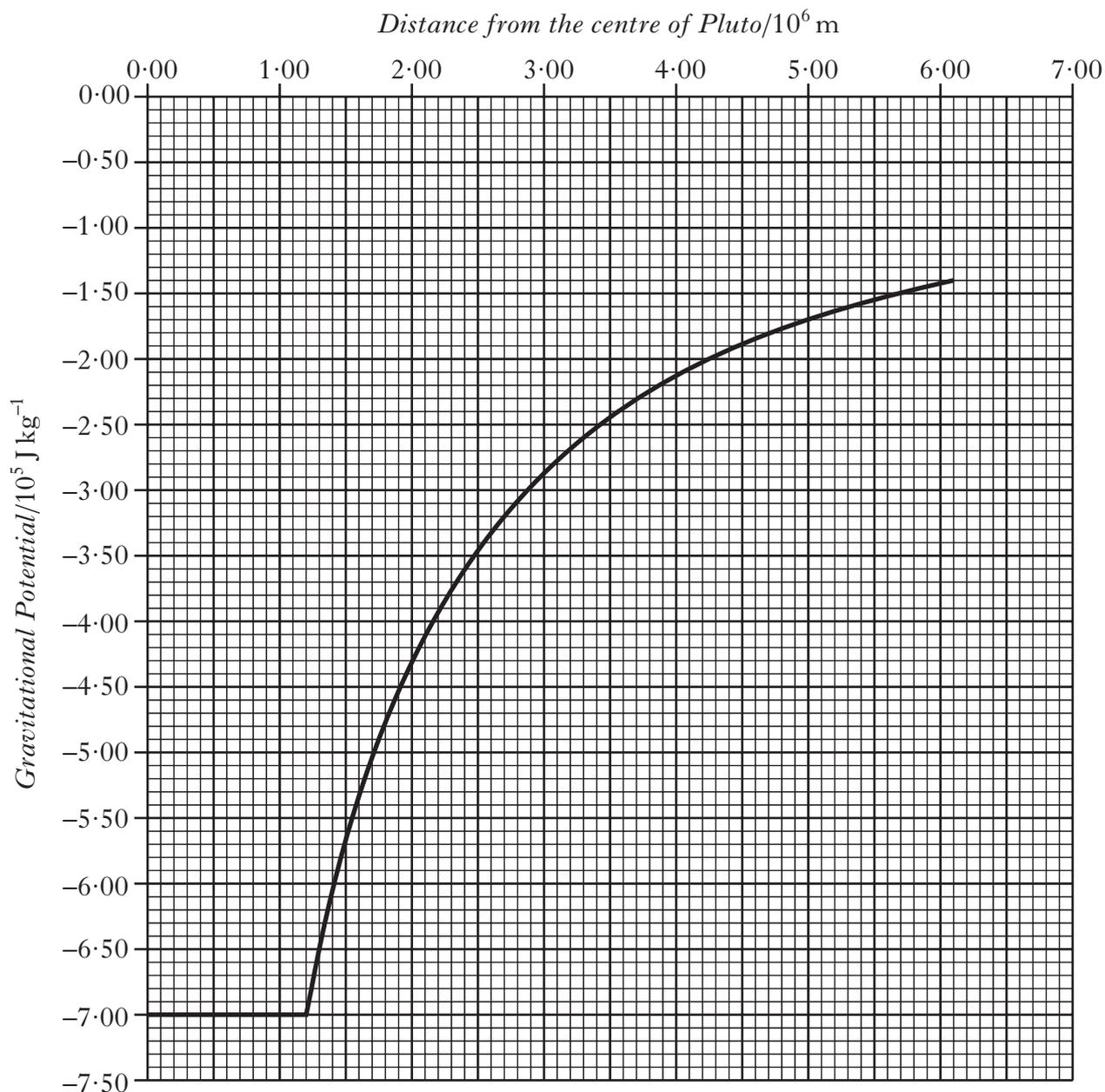


Figure 4A

- (i) The mass of Pluto is 1.27×10^{22} kg. Calculate the gravitational field strength at the surface of Pluto.
- (ii) A meteorite hits the surface of Pluto and ejects a lump of ice of mass 112 kg. The ice is captured in an orbit 1.80×10^6 m from the centre of Pluto. Calculate the gravitational potential energy of the ice at this height.

2

2

4. (continued)

Marks

- (c) In 2015 the New Horizons space probe is due to arrive at Pluto. The space probe will move between Pluto and its moon, Charon, as shown in Figure 4B. Pluto has a mass seven times that of Charon and their average separation is 1.96×10^7 m.

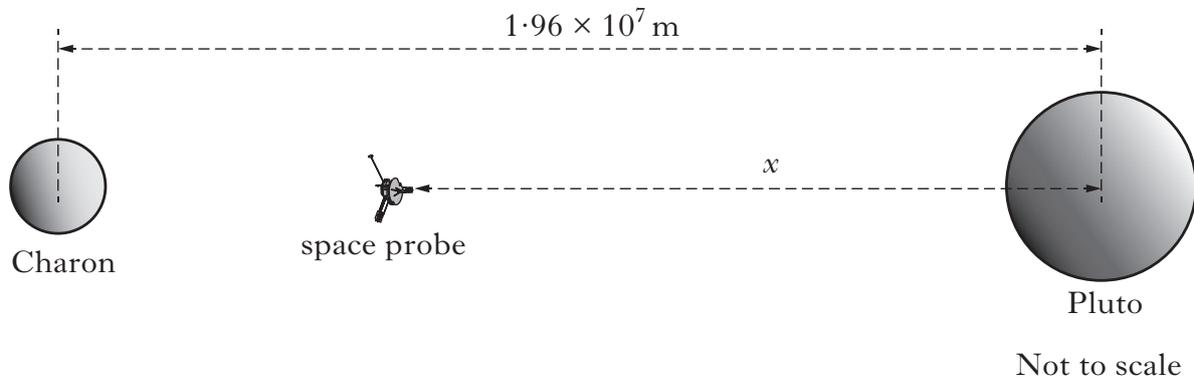


Figure 4B

Calculate the distance x from the centre of Pluto where the resultant gravitational force acting on the probe is zero. Ignore any orbital motion of the two objects.

3

(8)

[Turn over

5. (a) An uncharged conducting sphere is suspended from a fixed point X by an insulating thread of negligible mass as shown in Figure 5A. A charged plate is then placed close to the sphere as shown in Figure 5B.

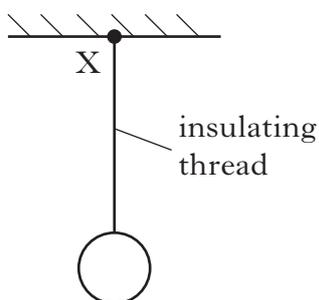


Figure 5A

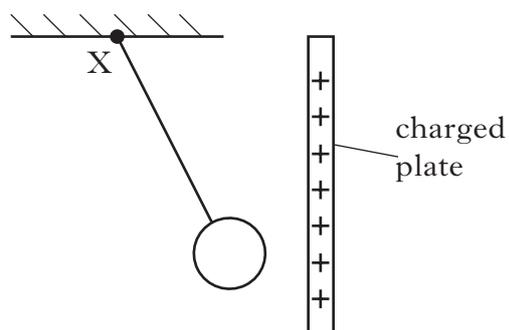


Figure 5B

Explain why the uncharged sphere is attracted to the charged plate. You may use a diagram to help explain your answer.

1

- (b) The sphere is now given a negative charge of 140 nC and placed between a pair of parallel plates with a separation of 42 mm as shown in Figure 5C.

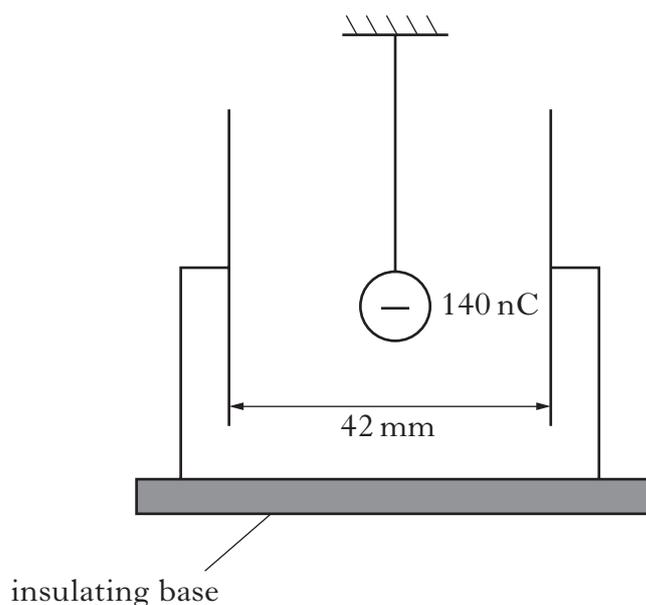


Figure 5C

5. (b) (continued)

Marks

When a potential difference is applied to the plates the sphere is deflected through an angle θ as shown in Figure 5D.

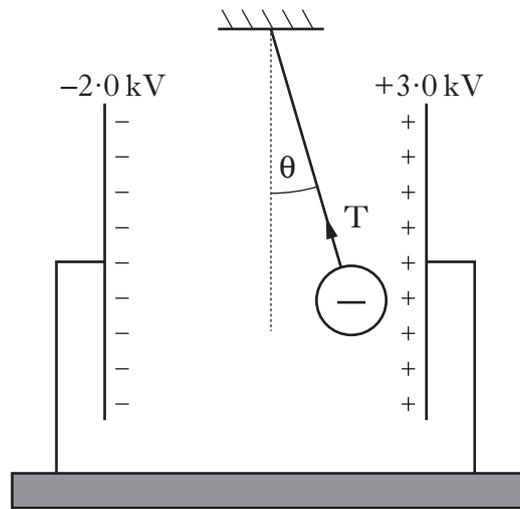


Figure 5D

- (i) Calculate the electric field strength between the plates. 2
- (ii) Calculate the electrostatic force acting on the sphere due to the electric field. 2
- (iii) The mass of the sphere is $4.0 \times 10^{-3} \text{ kg}$.
 Calculate the magnitude and direction of the tension T in the supporting thread. 3
- (c) The plates are now moved a short distance to the right without touching the sphere. The distance between the plates is unchanged.
 Does the angle θ increase, decrease or stay the same? Justify your answer. 2
- (10)**

[Turn over

6. A positively charged particle travelling at $2.29 \times 10^6 \text{ m s}^{-1}$ enters a magnetic field of uniform magnetic induction 2.50 T as shown in Figure 6A.

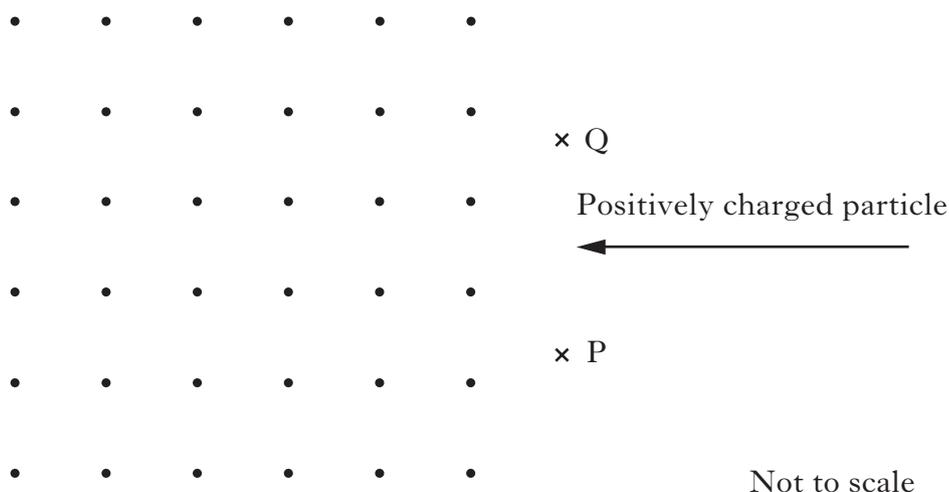


Figure 6A

The direction of the magnetic field is out of the page. The particle follows a semicircular path before exiting the field.

- (a) (i) State whether the particle will exit the field at point P or point Q. 1

- (ii) Show that the charge to mass ratio of the particle is given by

$$\frac{q}{m} = \frac{v}{rB}$$

where the symbols have their usual meaning. 1

- (iii) The radius of the path taken by the particle is 19.0 mm .

Use information from the data sheet to identify the charged particle. You must justify your answer by calculation. 3

- (iv) Calculate the time between the particle entering and leaving the magnetic field. 2

- (v) An identical particle travelling at twice the speed of the original particle enters the field at the same point.

How does the time spent in the magnetic field by this particle compare with the original? Justify your answer. 2

6. (continued)

Marks

- (b) An unknown particle also travelling at $2.29 \times 10^6 \text{ m s}^{-1}$ enters the field as shown in Figure 6B. The path taken by this particle is shown.

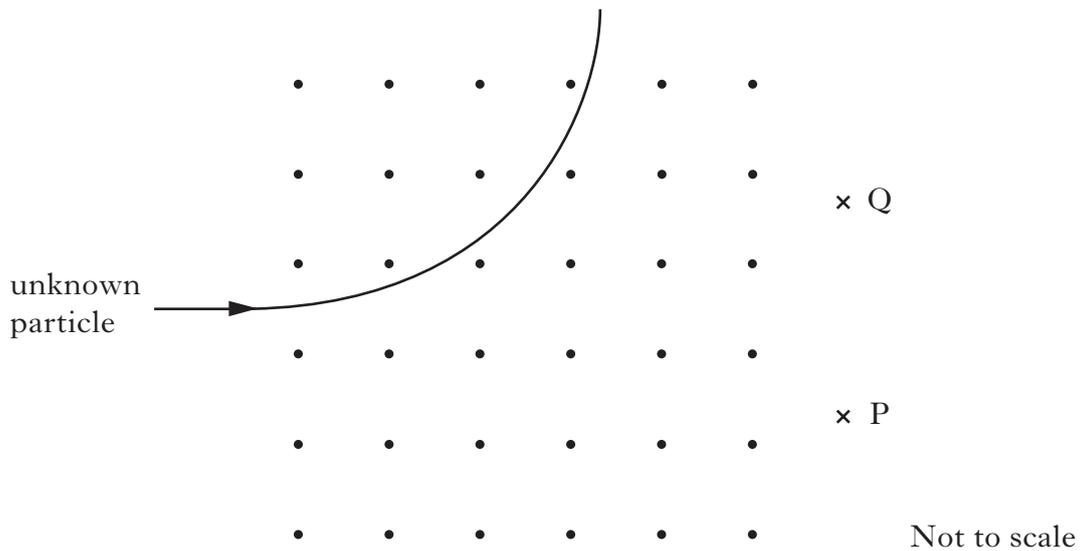


Figure 6B

What can you conclude about:

- | | |
|--|-------------|
| (i) the charge of the unknown particle; | 1 |
| (ii) the charge to mass ratio of the unknown particle? | 1 |
| | (11) |

[Turn over

7. Precision inductors can be produced using laser technology.

A thin film of copper is deposited on a ceramic core. A carbon dioxide laser is then used to cut the copper to form a coil as shown in Figure 7A.

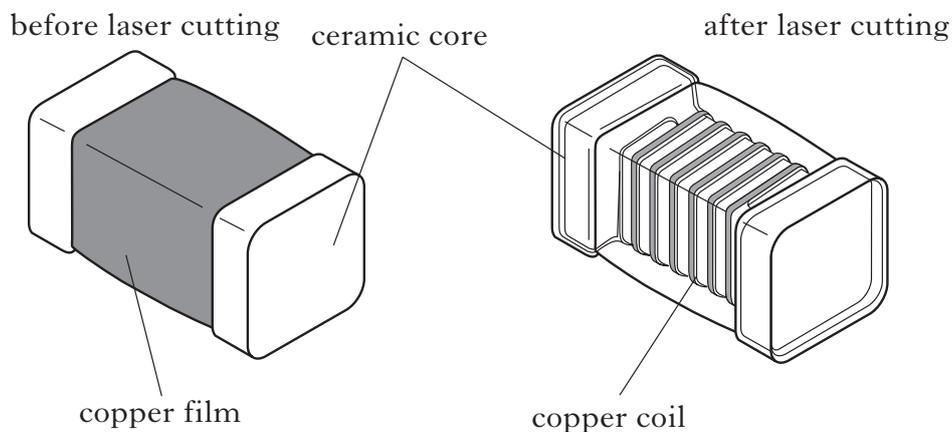


Figure 7A

(a) Each photon from the laser has a momentum of $6.26 \times 10^{-29} \text{ kg m s}^{-1}$.

(i) Calculate the wavelength of each photon.

2

(ii) The inductor has an inductance of 0.1 H.

Explain what is meant by an inductance of 0.1 H.

1

(b) The rate of change of current for a **different inductor** is investigated using a datalogger as shown in Figure 7B. This inductor has inductance L and a resistance of 2Ω .

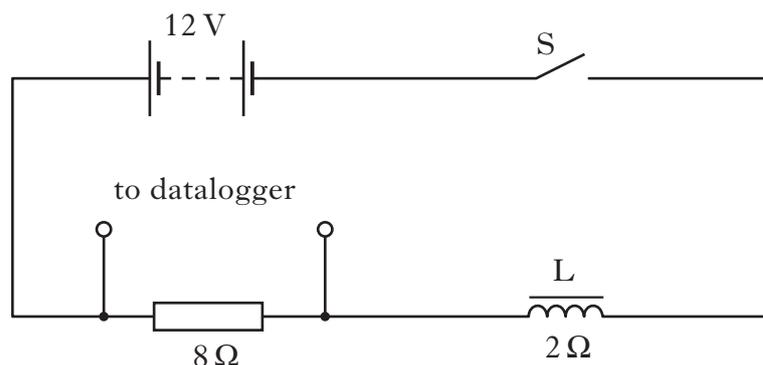


Figure 7B

The graph shown in Figure 7C shows how the rate of change of current dI/dt in the circuit varies with time from the instant switch S is closed.

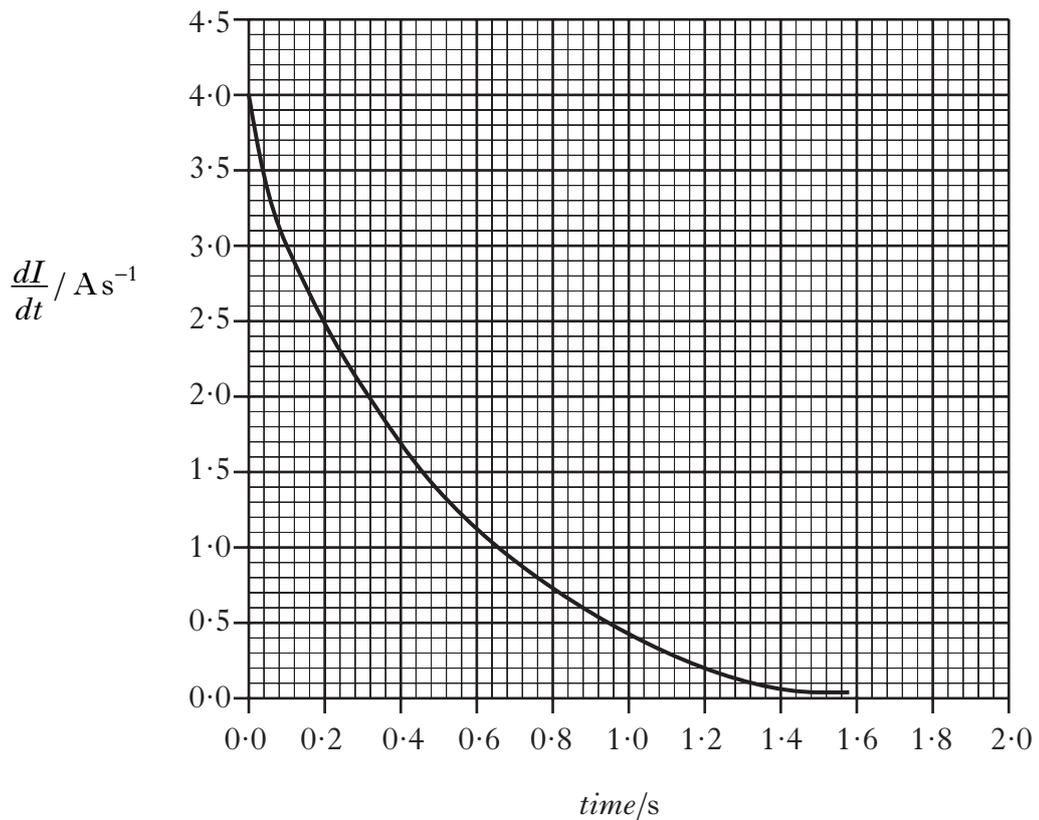


Figure 7C

- (i) Describe what happens to the magnetic field strength associated with the inductor between 0 and 1.6 s. 1
- (ii) Use information from the graph to determine the inductance L. 2
- (iii) Sketch a graph to show how the voltage across the $8\ \Omega$ resistor varies during this time. Numerical values are required on both axes. 2
- (iv) Calculate the maximum energy stored by the inductor in this circuit. 2

[Turn over

7. (continued)

Marks

- (c) A student sets up the circuit shown in Figure 7D to investigate the relationship between current and frequency for a capacitor and for an inductor.

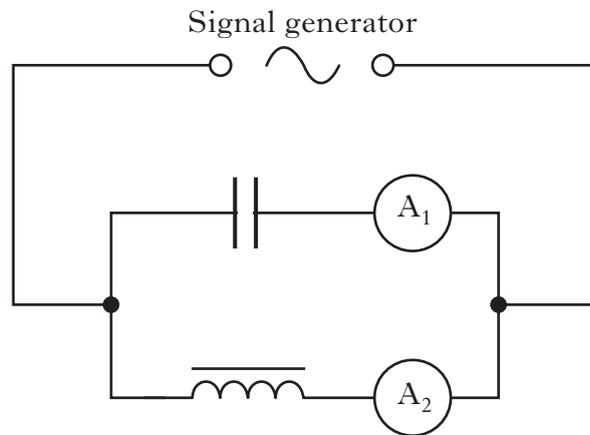


Figure 7D

At frequency of 75 Hz the readings on A_1 and A_2 are the same.

Explain what happens to the readings on each ammeter as the frequency is increased from 75 Hz to 150 Hz.

Assume that the supply voltage remains constant.

2

(12)

8. A long thin horizontal conductor AB carrying a current of 25 A is supported by two fine threads of negligible mass. The tension in each supporting thread is T as shown in Figure 8A.

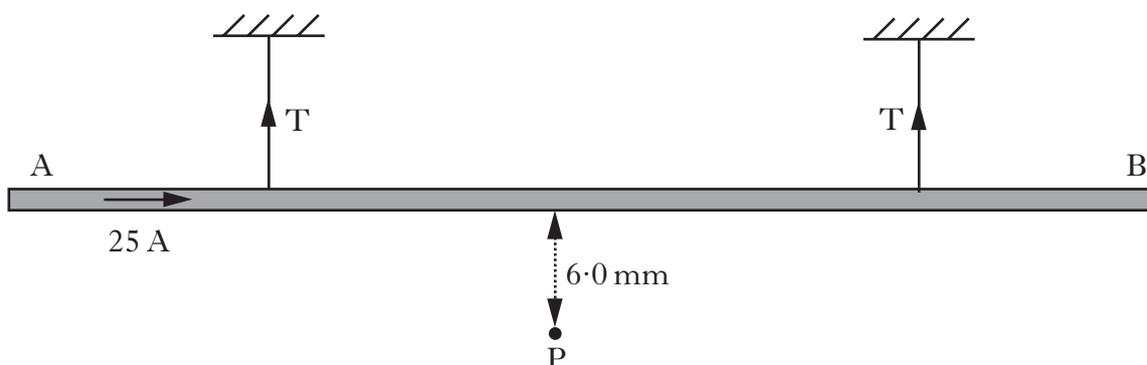


Figure 8A

- (a) Calculate the magnetic induction at a point P, 6.0 mm directly below conductor AB. 2
- (b) A second conductor CD carrying current I is now fixed in a position a distance r directly below AB as shown in Figure 8B. CD is unable to move.

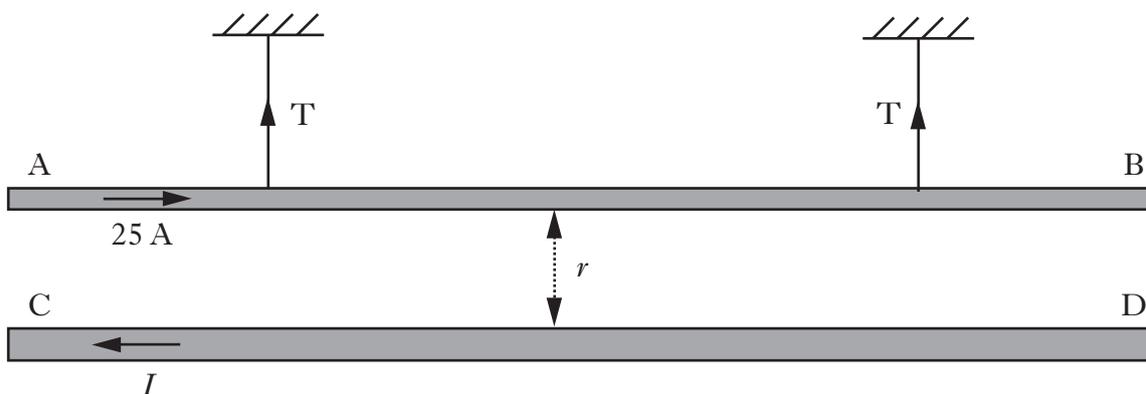


Figure 8B

- (i) Explain why there is a force of repulsion between conductors AB and CD. 2
- (ii) Show that the force per unit length acting on each conductor can be written as

$$\frac{F}{l} = \frac{5.0 \times 10^{-6} I}{r}.$$

1

- (iii) The mass per unit length of the conductor AB is $5.70 \times 10^{-3} \text{ kg m}^{-1}$. When the conductors are separated by 6.0 mm, the current I in conductor CD is gradually increased. Calculate the value of I which reduces the tension in the supporting threads to zero. 3

(8)

9. A travelling wave moves from left to right at a speed of 1.25 m s^{-1} .

Figure 9A represents this wave at a time t . P and Q are particles on the wave.

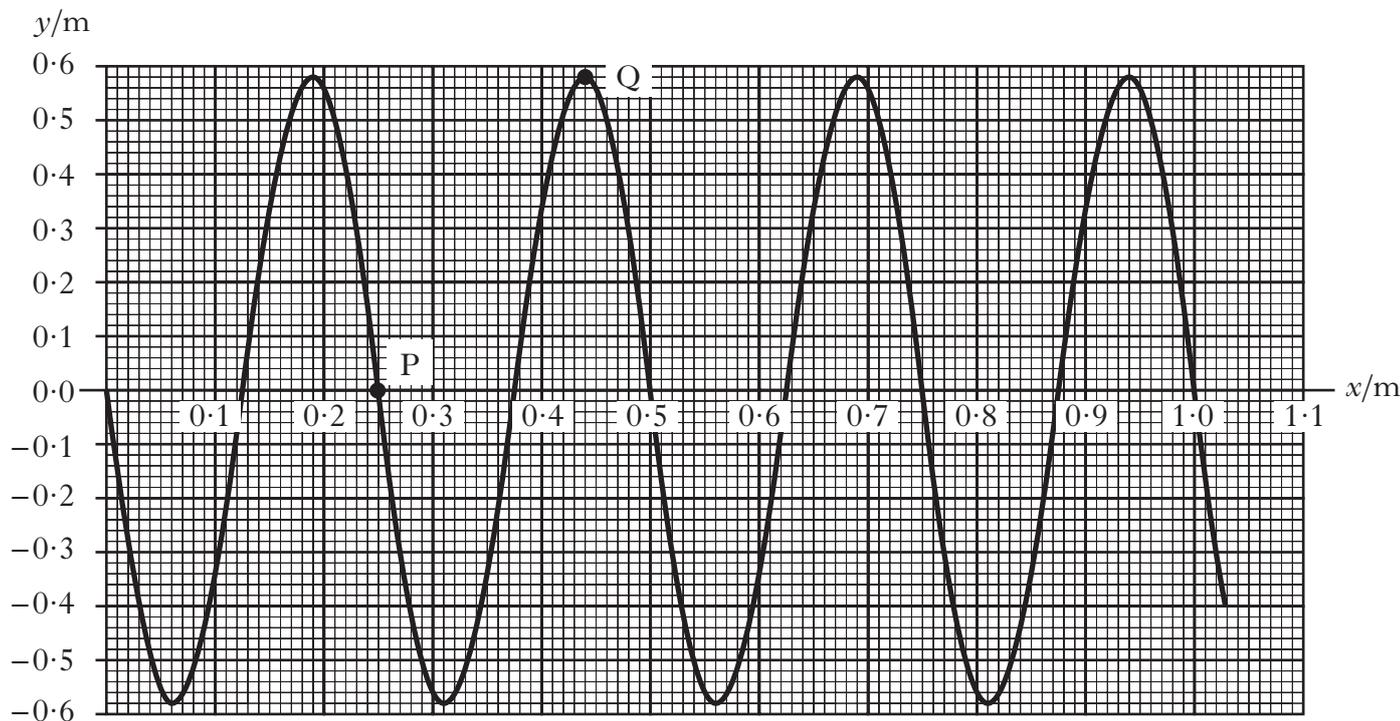


Figure 9A

- | | |
|--|------------|
| (a) (i) Determine the wavelength of the wave. | 1 |
| (ii) State the amplitude of the wave. | 1 |
| (iii) Calculate the frequency of the wave. | 1 |
| (iv) What is the phase difference, in radians, between particles P and Q? | 2 |
| | |
| (b) Write an equation for this travelling wave in terms of y , x and t . Numerical values are required. | 2 |
| | |
| (c) State the equation for a wave of half the amplitude travelling in the opposite direction. | 1 |
| | (8) |

10. Figure 10 shows a model helicopter flying in a straight horizontal path from student A to student B.

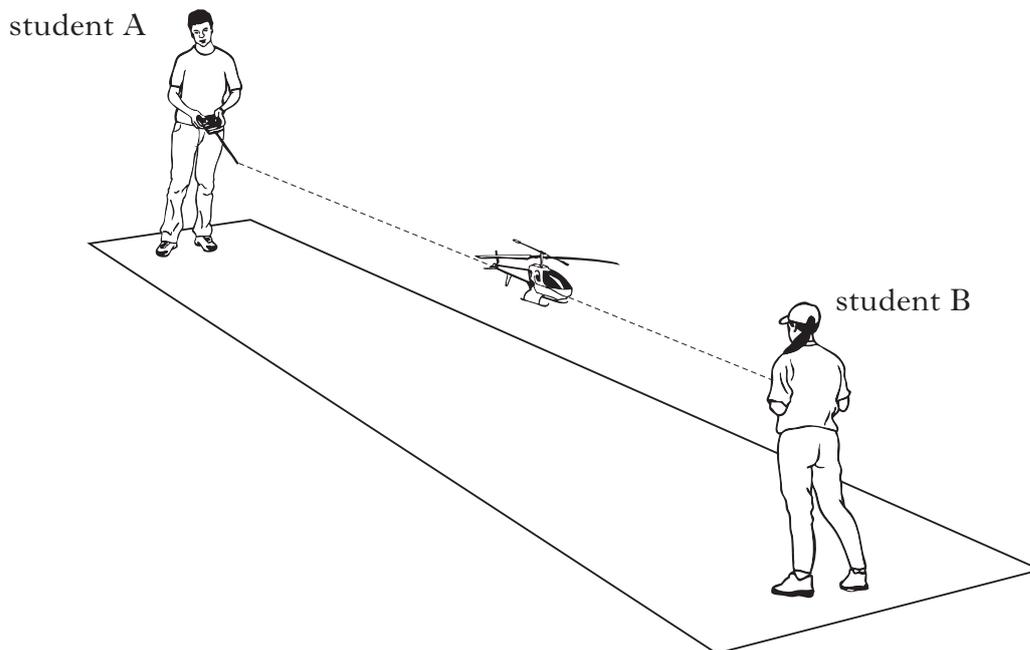


Figure 10

The helicopter has a siren that emits sound of frequency 595 Hz.

- (a) For the first two seconds the displacement of the helicopter relative to student A is described by the equation

$$s = 4.1 t^2.$$

- (i) Calculate the velocity of the helicopter when $t = 2.0$ s. 2
- (ii) Suggest what happens to the frequency of the sound heard by student B as the helicopter accelerates towards her. 2

Justify your answer. 2

- (b) After 2.0 s the helicopter continues towards student B with a constant velocity. Calculate the frequency of the sound heard by student B. 2

(6)

[Turn over

11. A student uses laser light of wavelength of 529 nm to determine the separation of the slits in a Young's double slit arrangement as shown in Figure 11A.

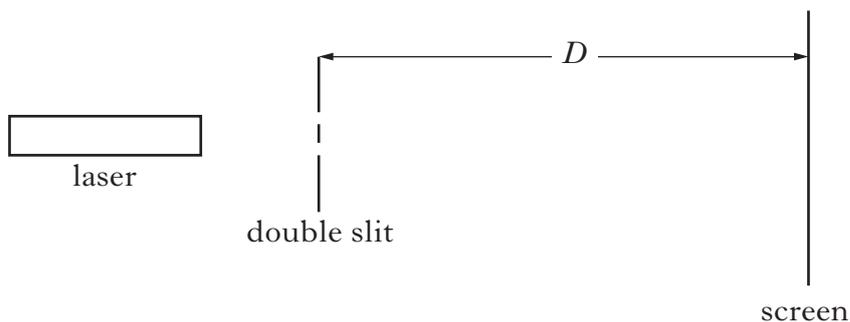


Figure 11A

A pattern of bright green dots is observed on the screen. The distance between the central maximum and the next bright dot is Δx as shown in Figure 11B.

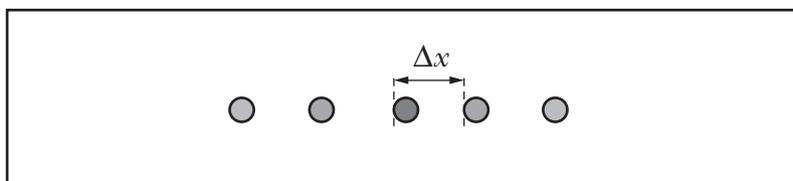


Figure 11B

The distance Δx is measured with a metre stick. The distance D is measured with a tape measure.

The screen is moved and Δx and D are measured for six positions of the screen. Each pair of measurements is repeated five times.

The student uses the results to plot the graph shown in Figure 11C.

11. (continued)

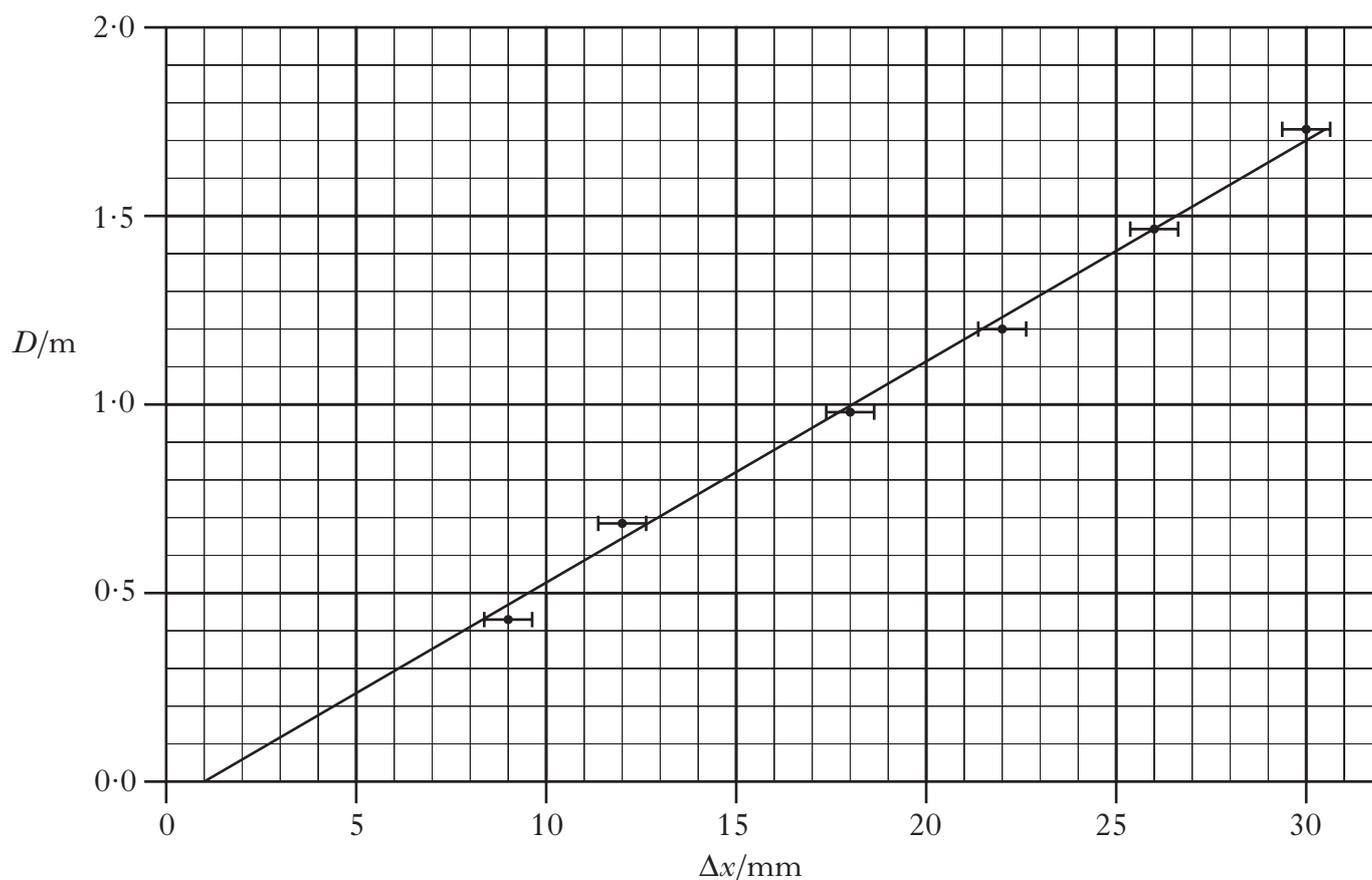


Figure 11C

- (a) (i) Using the gradient of the graph, calculate the separation of the double slits. 2
- (ii) Suggest a reason why no error bars are shown for the slit to screen distance, D . 1
- (iii) Other than repeating the measurements, suggest **two** improvements to the student's experimental technique. 2
- (b) The experiment is repeated using a very bright LED in place of the laser. The LED emits light in the wavelength range 535 to 555 nm.
- Other than a slight colour change, state **two** differences in the pattern observed on the screen compared to the pattern shown in Figure 11B. 2

(7)

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