| Centre Number | Index Number | Name | Class |
| --- | --- | --- | --- |
| 3016 | | | |

**RAFFLES INSTITUTION**
**2017 Preliminary Examination**

**PHYSICS** **9749/02**
**Higher 2**

**14 September 2017**
Paper 2 Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions. The number of marks is given in brackets [ ] at the end of each question or part question.

| For Examiner's Use | |
| --- | --- |
| **1** | / 10 |
| **2** | / 10 |
| **3** | / 10 |
| **4** | / 10 |
| **5** | / 10 |
| **6** | / 10 |
| **7** | / 20 |
| **Deduction** | |
| **Total** | / 80 |

 

**Data**

| | |
|---|---|
| speed of light in free space | $c = 3.00 \times 10^{8}$ m s$^{-1}$ |
| permeability of free space | $\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$ |
| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}$ F m$^{-1}$ |
| | $= (1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ |
| elementary charge | $e = 1.60 \times 10^{-19}$ C |
| the Planck constant | $h = 6.63 \times 10^{-34}$ J s |
| unified atomic mass constant | $u = 1.66 \times 10^{-27}$ kg |
| rest mass of electron | $m_e = 9.11 \times 10^{-31}$ kg |
| rest mass of proton | $m_p = 1.67 \times 10^{-27}$ kg |
| molar gas constant | $R = 8.31$ J K$^{-1}$ mol$^{-1}$ |
| the Avogadro constant | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| the Boltzmann constant | $k = 1.38 \times 10^{-23}$ J K$^{-1}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}$ N m$^{2}$ kg$^{-2}$ |
| acceleration of free fall | $g = 9.81$ m s$^{-2}$ |

**Formulae**

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| work done on / by a gas | $W = p\Delta V$ |
| hydrostatic pressure | $p = \rho gh$ |
| gravitational potential | $\phi = -Gm/r$ |
| temperature | $T$/K = $T$/°C + 273.15 |
| pressure of an ideal gas | $p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$ |
| mean translational kinetic energy of an ideal gas molecule | $E = \dfrac{3}{2}kT$ |
| displacement of particle in s.h.m. | $x = x_0 \sin \omega t$ |
| velocity of particle in s.h.m. | $v = v_0 \cos \omega t = \pm\omega\sqrt{x_0^2 - x^2}$ |
| electric current | $I = Anvq$ |
| resistors in series | $R = R_1 + R_2 + \ldots.$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots.$ |
| electric potential | $V = Q/(4\pi\varepsilon_0 r)$ |
| alternating current / voltage | $x = x_0 \sin\omega t$ |
| magnetic flux density due to a long straight wire | $B = \dfrac{\mu_0 I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil | $B = \dfrac{\mu_0 NI}{2r}$ |
| magnetic flux density due to a long solenoid | $B = \mu_0 nI$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$ |

**1** A sphere is projected with velocity $u$ from the bottom of a ramp which is inclined at an angle $\theta$ to the horizontal as shown in Fig. 1.1.

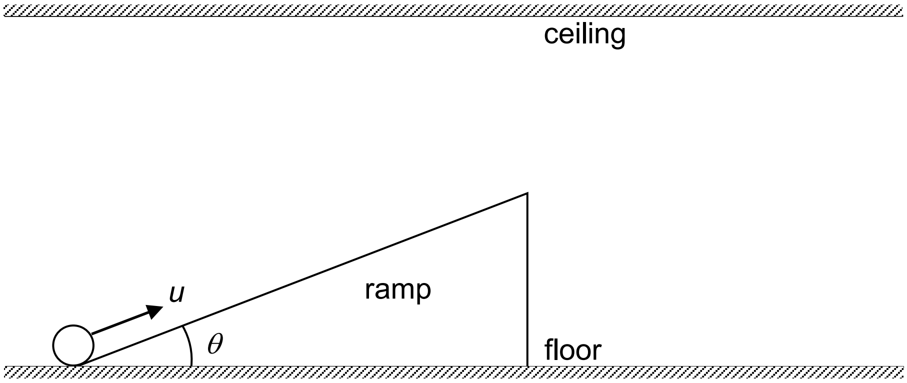


**Fig. 1.1 (not to scale)**

**(a)** Define *acceleration*.

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........................................................................................................................................... [1]

**(b) (i)** When $u$ = 9.0 m s$^{-1}$ and $\theta$ = 26°, the sphere leaves the ramp after 0.70 s.

Show that the sphere leaves the ramp at a speed of 6.0 m s$^{-1}$.

[1]

**(ii)** Determine the height of the ramp.

height = ............................... m [2]

**(c)** After the sphere leaves the ramp, it continues to travel upwards until it hits the ceiling at an angle of 5.0° to the horizontal as shown in Fig. 1.2.

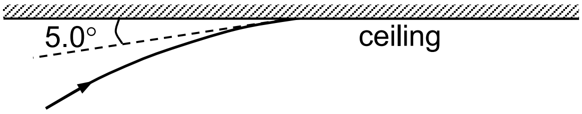


**Fig. 1.2 (not to scale)**

**(i)** Show that the vertical component of velocity of the sphere just before hitting the ceiling is 0.47 m $s^{-1}$.

[1]

**(ii)** Calculate the vertical displacement of the sphere from the instant it leaves the ramp to the instant it hits the ceiling.

vertical displacement = ............................... m [2]

**(iii)** State and explain whether the momentum of the sphere is conserved in the collision with the ceiling.

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.................................................................................................................................. [1]

**(c)** Using answers in **(b)(ii)** and **(c)(ii)**, sketch on Fig. 1.3 the variation with the horizontal displacement $x$ of the vertical displacement $y$ of the sphere from the instant it is projected up the ramp to the instant it hits the floor.


**Fig. 1.3**

[2]

**2** A car travels at 50.0 km h$^{-1}$ due north for 25.0 minutes, after which it travels at 65.0 km h$^{-1}$ in the north-east direction for another 30.0 minutes.

**(a)** Distinguish between *vector* and *scalar* quantities.

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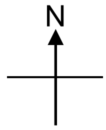
.................................................................................................................................... [1]

**(b)** **(i)** Using a scale of 1.0 cm to represent a speed of 10 km h$^{-1}$, draw a vector diagram to show the change in velocity $\Delta v$ of the car. The direction of north is indicated.




[2]

**(ii)** Hence, or otherwise, determine the magnitude of the average acceleration of the car if it takes 30.0 seconds to change its velocity.

average acceleration = .............................. m s$^{-2}$ [2]

**(c)** **(i)** Calculate the total distance travelled by the car.

total distance = ............................... km [1]

**(ii)** The uncertainty of each velocity measurement is 0.5 km $h^{-1}$, and that of each time measurement is 0.5 minute.

Determine the actual uncertainty in the total distance travelled.

actual uncertainty = ............................... km [3]

**(iii)** Hence, express the total distance travelled with its associated uncertainty.

total distance = ............................. ± ............................... km [1]

**3** **(a)** State *the principle of conservation of linear momentum*.

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**(b)** A block X of mass 2.2 kg travelling at a speed of 6.0 m s$^{-1}$ on a smooth floor collides head-on and sticks together with a block Y of mass 1.0 kg which is travelling at a speed of 2.0 m s$^{-1}$ in the opposite direction, as shown in Fig. 3.1. The collision lasts for 0.35 s.

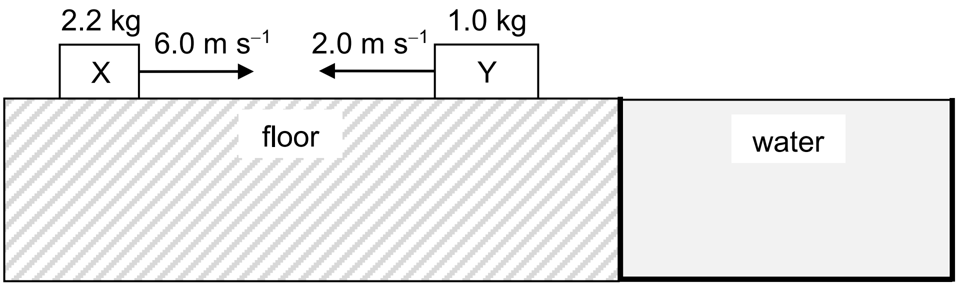


**Fig. 3.1**

**(i)** Show that the blocks move with a speed of 3.5 m s$^{-1}$ to the right after the collision.

[2]

**(ii)** Determine the magnitude of the average force acting on either block during the collision.

average force = .............................. N [2]

**(iii)** The blocks then slide off the edge of the floor and into a tank of water as shown in Fig 3.1. The density of water is 1000 kg m$^{-3}$.

The blocks have uniform densities and their dimensions are shown in Fig. 3.2.

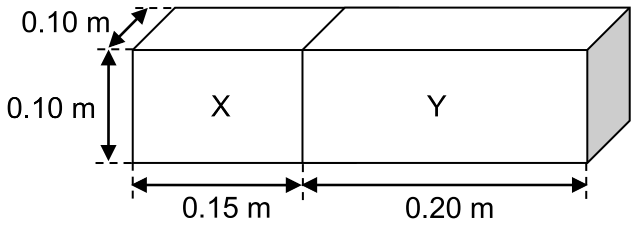


**Fig. 3.2**

**1.** The blocks eventually achieved equilibrium when they are submerged at depth *h* as shown in Fig. 3.3.

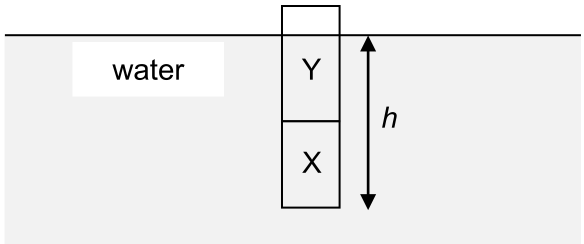


**Fig. 3.3**

Explain how the blocks achieved this final position. You may draw a diagram if you wish.

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**2.** Calculate *h*.

*h* = .............................. m [2]

**4 (a)** Define *work*.

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....................................................................................................................................... [1]

**(b)** Using your definition in **(a)**, derive an expression for the increase in gravitational potential energy $\Delta E_p$ when an object of mass $m$ is raised vertically through a distance $\Delta h$ near the Earth's surface. The acceleration of free fall near the Earth's surface is $g$.

[2]

**(c)** Fig. 4.1 shows a block P of mass 1.0 kg and a block Q of mass 3.0 kg connected by a light inextensible cord passing over a frictionless pulley. Block P starts from rest and moves up a rough slope inclined at an angle of 30° to the horizontal, while block Q falls from a height of 0.45 m above a spring. The frictional force between block P and the slope is 6.3 N.

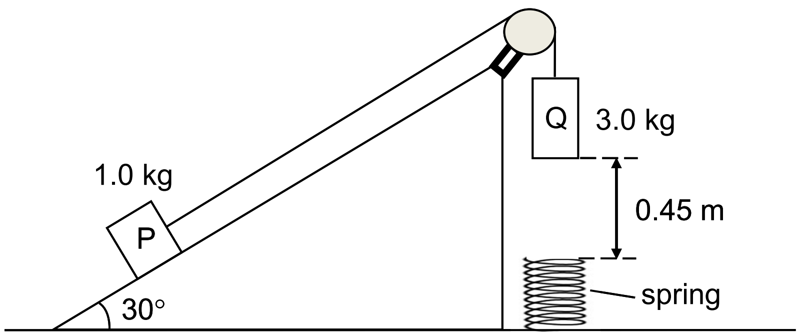


**Fig. 4.1**

**(i)** State the energy changes that take place from the time the blocks are released to the instant just before block Q makes contact with the spring.

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....................................................................................................................................... [1]

**(ii)** Show that the loss in gravitational potential energy of the blocks just before block Q makes contact with the spring is 11 J.

[1]

**(iii)** Determine the total kinetic energy of the blocks just before block Q makes contact with the spring.

total kinetic energy = .............................. J [2]

**(iv)** Show that the maximum compression of the spring when the blocks first come to rest is 0.168 m. The spring has a force constant of 800 N $m^{-1}$ and the string remains taut at all times.

[2]

**(v)** Use your answers in **(ii)** and **(iii)** to explain why the maximum compression in **(iv)** decreases when the angle of the slope is larger.

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.................................................................................................................... [1]

**5** An ideal gas A is contained in an insulated cylinder to prevent the loss of heat, while an ideal gas B is contained in a cylinder without any insulation, as shown in Fig. 5.1.

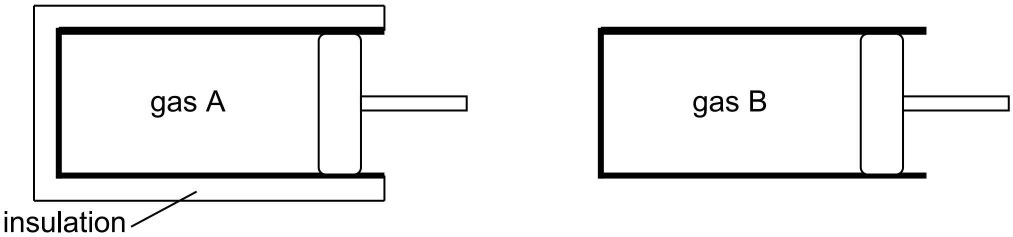


**Fig. 5.1**

Initially, the two gases have the same volume of $2.90 \times 10^{-4}$ m$^3$, the same pressure of $1.05 \times 10^5$ Pa and the same temperature of 303 K.

**(a)** Explain what is meant by the *internal energy* of an ideal gas.

..........................................................................................................................................

.......................................................................................................................................... [1]

**(b)** Determine the number of molecules in gas A.

number of molecules = ................................ [2]

**(c)** Determine the mean translational kinetic energy of a molecule of gas A.

mean translational kinetic energy = ................................ J [1]

**(d)** When gas A is compressed to a volume of $2.10 \times 10^{-4}$ m$^3$, its temperature rises to 357 K. Gas B is compressed very slowly to the same volume of $2.10 \times 10^{-4}$ m$^3$.

**(i)** Determine the change in internal energy of gas A during the compression.

change in internal energy = ................................ J [2]

**(ii)** Determine the work done on gas A during the compression.

work done on the gas = ................................ J [1]

**(iii)** On Fig. 5.2, sketch the variation with volume of the pressure of gas A and gas B. Include appropriate labels, and values of pressure and volume.


**Fig. 5.2**

[3]

**6** A variable resistor R is connected between the terminals of a battery of e.m.f. $E$ and internal resistance $r$, as shown in Fig. 6.1.

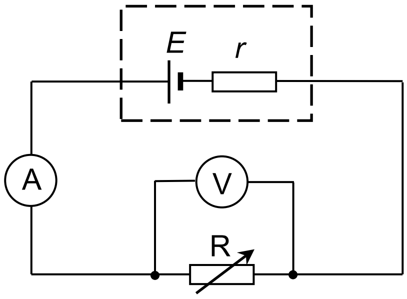


**Fig. 6.1**

As the resistance of R is varied from its maximum to minimum value, the variation of the potential difference $V$ across R with the current $I$ through R is shown in Fig. 6.2.

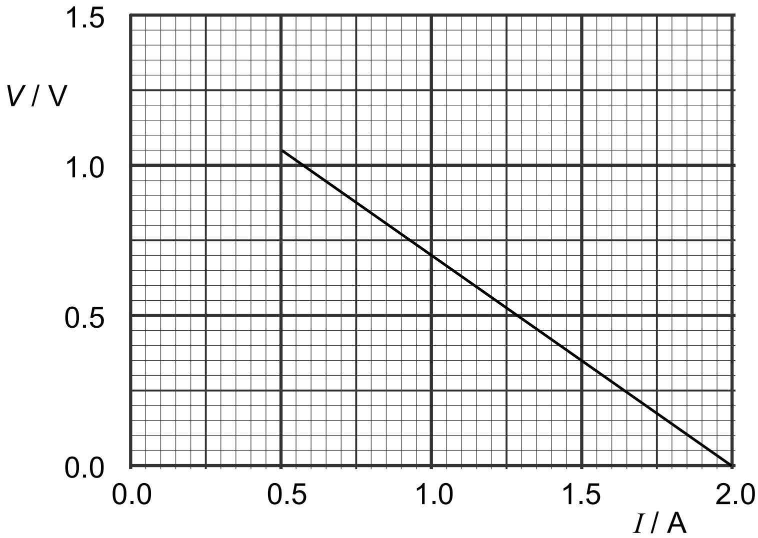


**Fig. 6.2**

**(a)** **(i)** Use Fig. 6.2 to determine the values of $E$ and $r$.

$E$ = ................................ V

$r$ = ................................ Ω [3]

**(ii)** Explain why, in the circuit of Fig. 6.1, the current $I$ through R cannot be varied from 0 to 0.5 A.

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.................................................................................................................................. [1]

**(b)** When the power dissipated in R is the maximum,

**(i)** state the value of the resistance of R in terms of $r$,

resistance = ................................ [1]

**(ii)** calculate the value of the current $I$ through R,

$I$ = ................................ A [2]

**(iii)** calculate the efficiency of transfer of power from the supply to R.

efficiency = ................................ % [1]

**(c)** Determine the maximum efficiency of transfer of power to R of the circuit in Fig. 6.1.

maximum efficiency = ................................ % [2]

**7** A bubble chamber is a vessel filled with a superheated liquid (usually hydrogen) used for detecting charged particles moving through it. It was invented in 1952 by Donald A. Glaser, for which he was awarded the 1960 Nobel Prize in Physics.

Typically, the charged particles possess very high energies and move at speeds close to that of light. They create ionization tracks (ionization causes the particle to lose energy), around which the liquid vaporizes to form microscopic bubbles. As the bubbles grow in size, they become large enough to be seen or photographed.

The entire bubble chamber is subjected to a constant magnetic field that causes charged particles to travel in circular paths. The radius of the path is dependent on the charge and momentum of the particle.

By analyzing one such track, a substantial amount of information can be obtained about the charged particle, such as its momentum, energy, charge, mass and identity. The energies of the charged particles are usually expressed in MeV and their momentum in MeV $c^{-1}$, where $c$ is the speed of light in vacuum.

Fig 7.1 shows a life-size photograph of a track of a charged particle moving in the plane of the paper in a particular bubble chamber where a uniform magnetic field is acting perpendicularly into the paper.

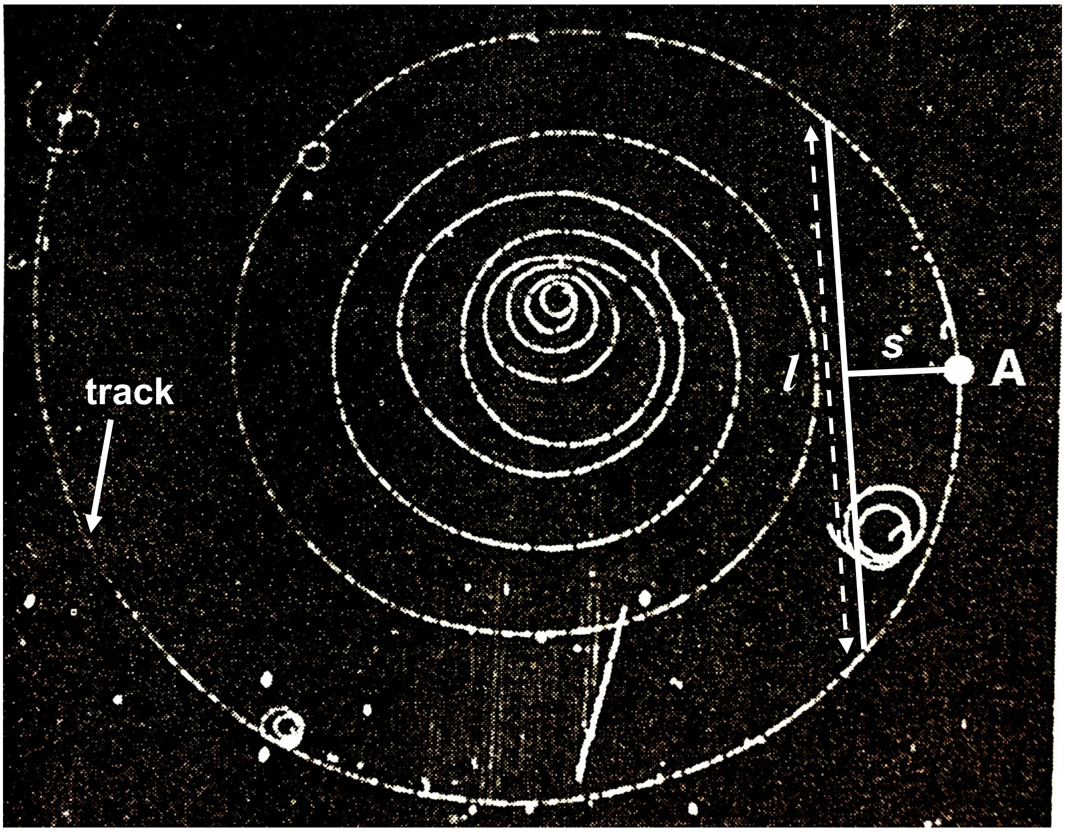


**Fig 7.1 (to scale)**

**(a)** **(i)** Show that the momentum $p$ of the charged particle in Fig. 7.1 is related to its charge $q$, the radius $r$ of the track and the magnetic flux density $B$ of the magnetic field by

$$p = Bqr\ .$$

[2]

**(ii)** For the track indicated in Fig 7.1, state and explain whether the charged particle is moving in a clockwise or anti-clockwise direction.

..........................................................................................................................................

..........................................................................................................................................

.......................................................................................................................................... [2]

**(iii)** State whether the particle is positively or negatively charged.

.......................................................................................................................................... [1]

**(b)** **(i)** By measuring the lengths $l$ and $s$ in Fig 7.1, the radius $r$ of the path at point A can be determined from

$$r = \frac{l^2}{8s} + \frac{s}{2}\ .$$

**1.** Using a ruler, measure and record the lengths $l$ and $s$.

$l$ = .............................. cm

$s$ = .............................. cm [2]

**2.** Calculate the value of $r$.

$r$ = .............................. cm [1]

**(ii)** **1.** Show that a momentum of 1.0 MeV $c^{-1}$ is equal to $5.3 \times 10^{-22}$ kg m s$^{-1}$

[1]

**2.** The magnetic field in the bubble chamber has a magnetic flux density of 0.50 T. The magnitude of the charge of the charged particle is $1.6 \times 10^{-19}$ C.

Use the expression in **(a)(i)** and your answer in **(b)(i)(2)** to determine the momentum of the particle in MeV $c^{-1}$.

$p$ = .......................... MeV $c^{-1}$ [2]

**(iii)** At a momentum of 1.0 MeV $c^{-1}$, the speed $v$ of the charged particle is 0.89 $c$. It is known that at such a high speed, the momentum $p$ of the charged particle is related to its velocity $v$ and rest mass $m_0$ by

$$p = \frac{m_0 v}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

where all quantities are in SI units.

Determine the rest mass $m_0$ of the charged particle, and hence identify it.

$m_0$ = ............................... kg

identity : ............................... [2]

**(c)** In instances when it is not possible to determine the momentum of a charged particle from the radius of its track, it can be found from its range. The range $d$ is the total distance travelled by the charged particle before it comes to rest.

Theory suggests that the range $d$ of a charged particle is related to its initial momentum $p$ by the equation

$$\lg d = n \lg p + \lg k$$

where $n$ and $k$ are constants.

Some of the values of lg ($d$ / cm) and lg ($p$ / MeV c$^{-1}$) are plotted in Fig. 7.2 for a charged particle.

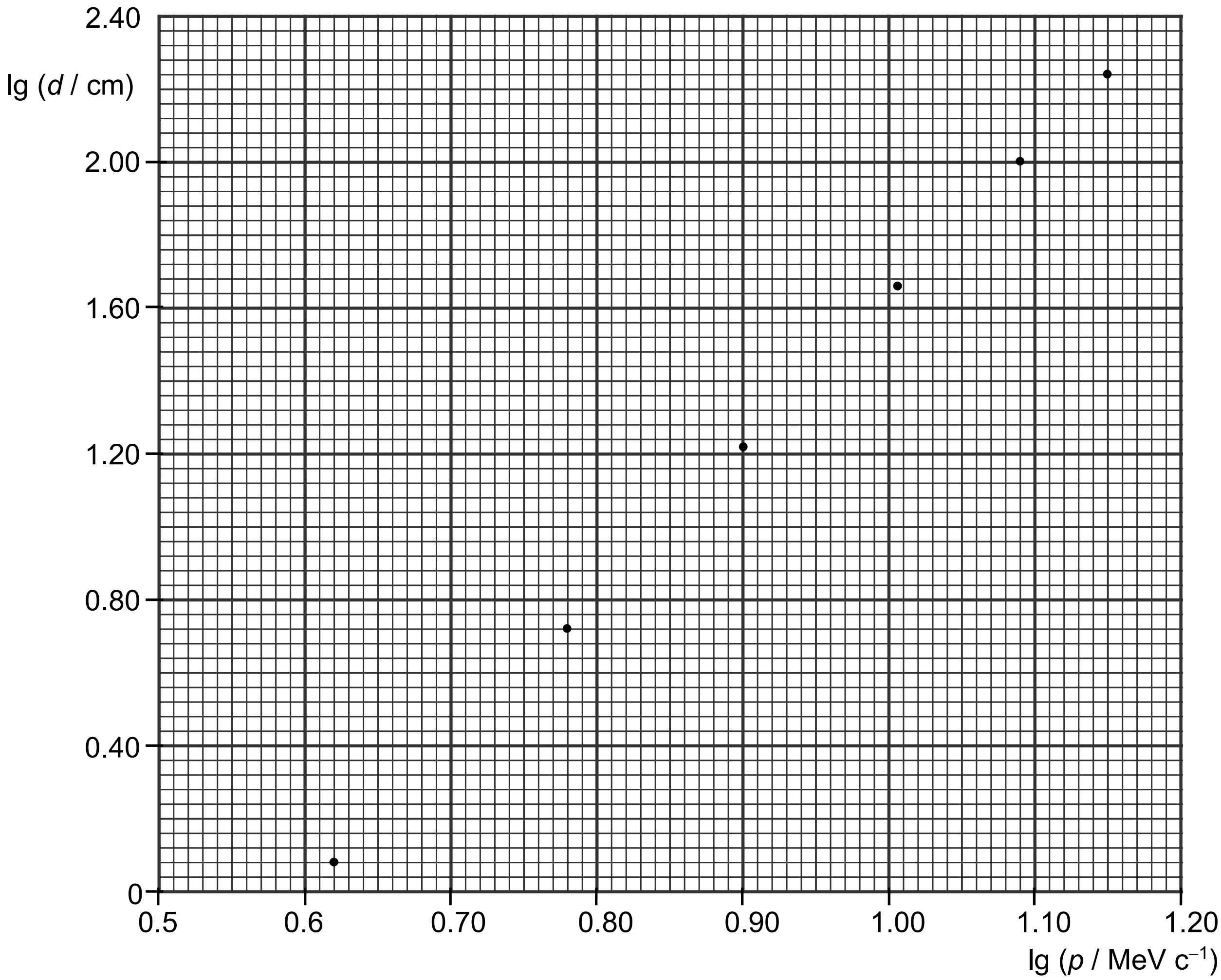


**Fig. 7.2**

**(i)** Draw the line of best-fit for all the points. [1]

**(ii)** Use Fig. 7.2 to determine the values of $n$ and $k$. Express $n$ to the nearest integer.

$n$ = ..........................................

$k$ = .......................................... [4]

**(iii)** Express $p$ in terms of $d$.

[1]

**(iv)** Suggest an example of when it is not possible to determine the radius directly from the track of a particle in a photograph.

..........................................................................................................................................

.......................................................................................................................................... [1]

**End of Paper 2**