* 0012469810501 *

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 3

CANDIDATE NAME

| CENTRE NUMBER | S | | | | | INDEX NUMBER | | | | |
|---|---|---|---|---|---|---|---|---|---|---|

# PHYSICS

**9814/01**

Paper 1

**October/November 2020**

**3 hours**

Candidates answer on the Question Paper.

No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

Write your Centre number, index number and name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE ON ANY BARCODES.

The use of an approved scientific calculator is expected, where appropriate.

**Section A**
Answer **all** questions.
You are advised to spend about 1 hour and 50 minutes on Section A.

**Section B**
Answer **two** questions only.
You are advised to spend about 35 minutes on each question in Section B.

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

This document consists of **28** printed pages.

Singapore Examinations and Assessment Board

Cambridge Assessment International Education



DC (LK/SG) 188647/6

**Data**

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

**Formulae**

| | | | |
|---|---|---|---|
| uniformly accelerated motion | $s$ | = | $ut + \frac{1}{2}at^2$ |
| | $v^2$ | = | $u^2 + 2as$ |
| moment of inertia of rod through one end | $I$ | = | $\frac{1}{3}ML^2$ |
| moment of inertia of hollow cylinder through axis | $I$ | = | $\frac{1}{2}M\left(r_1^{\,2} + r_2^{\,2}\right)$ |
| moment of inertia of solid sphere through centre | $I$ | = | $\frac{2}{5}MR^2$ |
| moment of inertia of hollow sphere through centre | $I$ | = | $\frac{2}{3}MR^2$ |
| work done on/by a gas | $W$ | = | $p\Delta V$ |
| hydrostatic pressure | $p$ | = | $\rho gh$ |
| gravitational potential | $\phi$ | = | $-Gm/r$ |

| | | | |
|---|---|---|---|
| Kepler's third law of planetary motion | $T^2$ | = | $\dfrac{4\pi^2 a^3}{GM}$ |
| temperature | $T/\text{K}$ | = | $T/^\circ\text{C} + 273.15$ |
| pressure of an ideal gas | $p$ | = | $\dfrac{1}{3}\dfrac{Nm}{V} < c^2 >$ |
| mean translational kinetic energy of an ideal gas molecule | $E$ | = | $\frac{3}{2}kT$ |
| 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 | $1/R$ | = | $1/R_1 + 1/R_2 + \ldots$ |
| capacitors in series | $1/C$ | = | $1/C_1 + 1/C_2 + \ldots$ |
| capacitors in parallel | $C$ | = | $C_1 + C_2 + \ldots$ |
| energy in a capacitor | $U$ | = | $\frac{1}{2}CV^2$ |
| electric potential | V | = | $\dfrac{Q}{4\pi\varepsilon_0 r}$ |
| electric field strength due to a long straight wire | $E$ | = | $\dfrac{\lambda}{2\pi\varepsilon_0 r}$ |
| electric field strength due to a large sheet | $E$ | = | $\dfrac{\sigma}{2\varepsilon_0}$ |
| 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 | $B$ | = | $\mu_0 nI$ |
| energy in an inductor | $U$ | = | $\frac{1}{2}LI^2$ |
| RL series circuits | $\tau$ | = | $\dfrac{L}{R}$ |
| RLC series circuits (underdamped) | $\omega$ | = | $\sqrt{\dfrac{1}{LC} - \dfrac{R^2}{4L^2}}$ |
| radioactive decay | $x$ | = | $x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda$ | = | $\dfrac{\ln 2}{t_{\frac{1}{2}}}$ |

## Section A

Answer **all** questions in this section.

You are advised to spend about 1 hour 50 minutes on this section.

1 A thorium nucleus decays by the emission of an α-particle to form a radium nucleus. This is represented by the nuclear equation:

$$^{232}_{90}\text{Th} \rightarrow ^{228}_{88}\text{Ra} + \alpha$$

The thorium nucleus is initially stationary.

**(a)** **(i)** Show that $\dfrac{\text{speed of radium nucleus}}{\text{speed of }\alpha\text{-particle}} = \dfrac{1}{57}$.

[1]

**(ii)** Show that $\dfrac{\text{kinetic energy of radium nucleus}}{\text{kinetic energy of }\alpha\text{-particle}} = \dfrac{1}{57}$.

[1]

**(b)** The total energy released in the decay is 4.08 MeV. Assume that all this energy goes into the kinetic energies of the α-particle and the radium nucleus.

The specific charge (charge per unit mass) of an α-particle is $4.81 \times 10^{7}\,\text{C kg}^{-1}$.

Calculate the speed of the α-particle.

speed = ............................................... $\text{m s}^{-1}$ [4]

[Total: 6]

2 A point mass $m$ is held at the centre of a circular plate of radius $r$ = 20 cm attached to a fixed board. The board is tilted at an angle of 30° to the horizontal, as shown in Fig. 2.1.

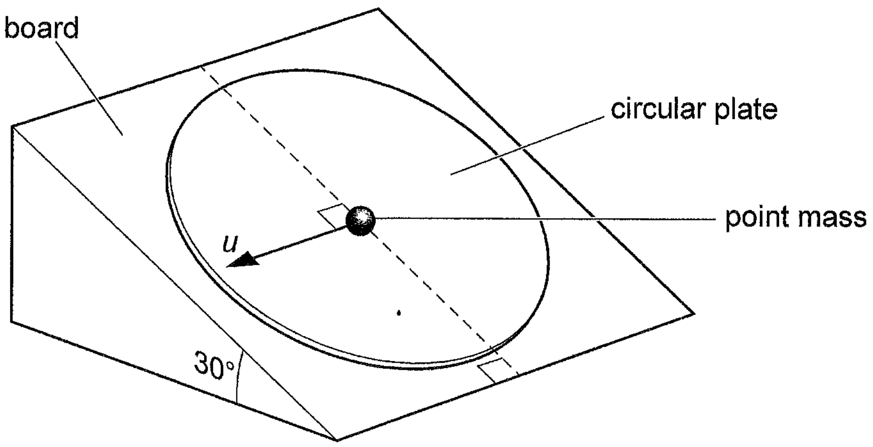



**Fig. 2.1** (not to scale)

The point mass is given an initial velocity $u = 0.50\,\text{m}\,\text{s}^{-1}$ in the direction shown in Fig. 2.1.

**(a)** Determine the time taken for the point mass to fall off the edge of the circular plate.

Ignore the effects of friction.

time = ........................................................ s [5]

**(b)** The circular plate is removed.

A solid ball of mass *m* is released at the top of the sloping face of the board. The ball rolls down the sloping board without slipping, as shown in Fig. 2.2.

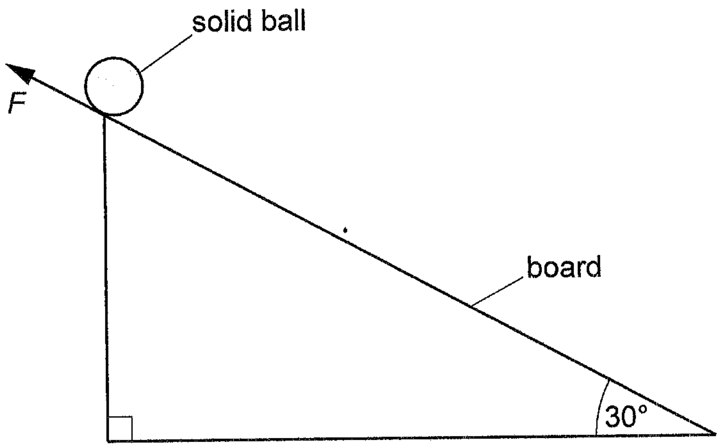



**Fig. 2.2** (not to scale)

A constant frictional force *F* exerts a torque $\tau$ on the ball.

By considering the forces on the ball, show that the linear acceleration *a* of the ball down the slope is 3.5 m s$^{-2}$.

[6]

**(c)** A solid cylinder of mass 80 g is released from rest at the top of the board. It rolls down the slope without slipping, with its central axis perpendicular to the slope, as shown in Fig. 2.3.

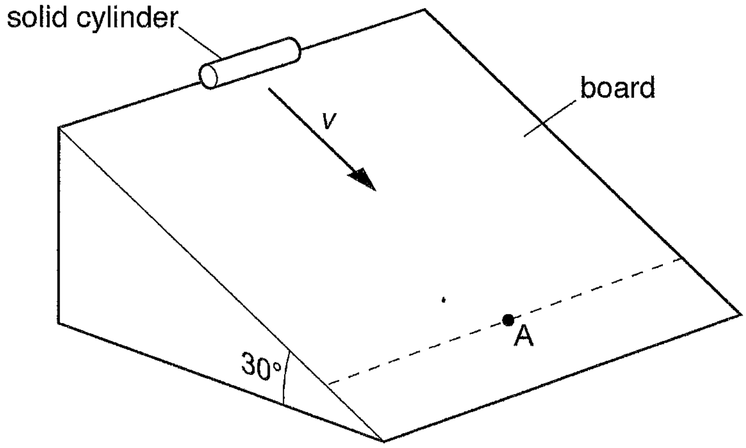



**Fig. 2.3** (not to scale)

When the cylinder reaches point A, the linear speed $v$ of the cylinder is $1.84\,m\,s^{-1}$.

Calculate the rotational kinetic energy of the rolling cylinder as it passes point A.

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

[Total: 13]

3 A power supply provides a square wave voltage that cycles between +230 V and –230 V with a frequency of 50 Hz, as shown on the oscilloscope display in Fig. 3.1.

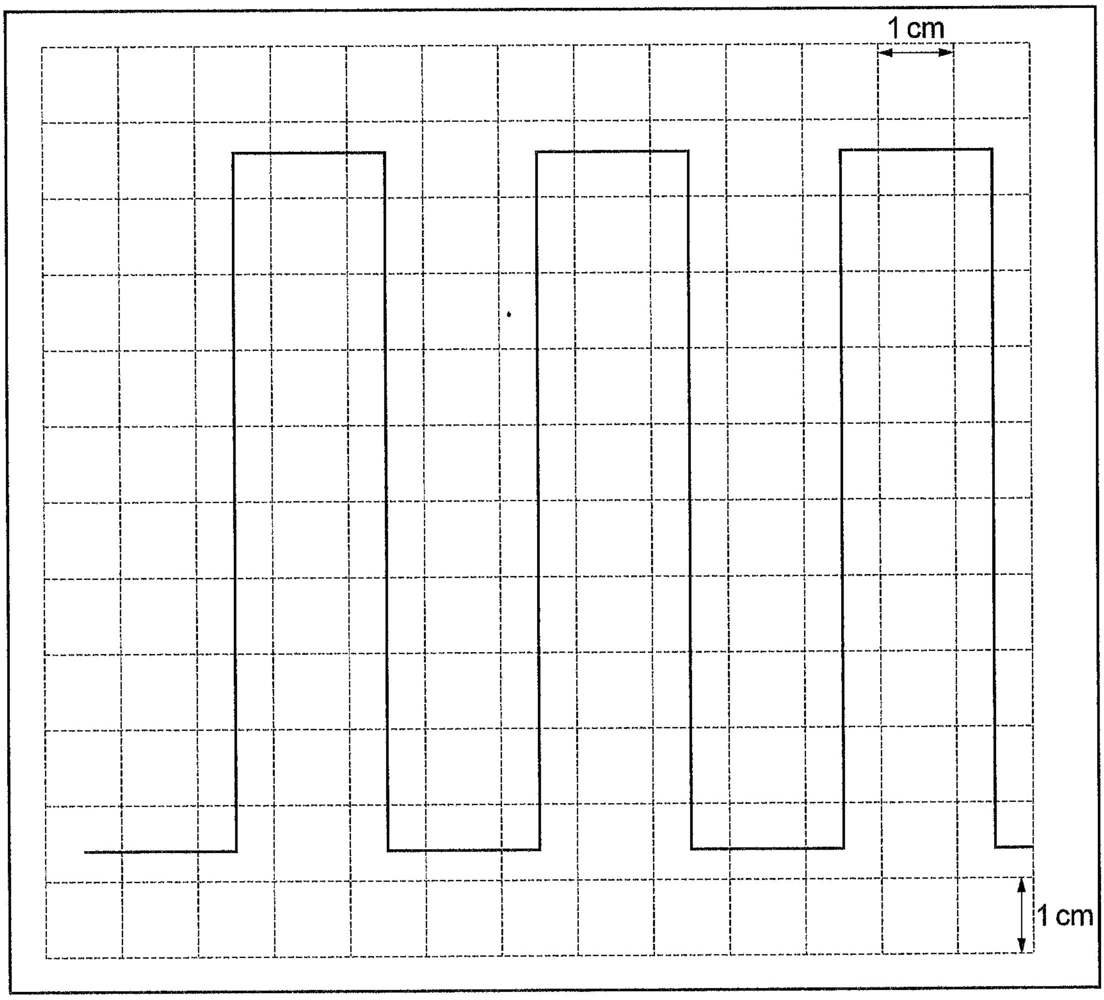



**Fig. 3.1**

**(a)** Determine the Y-gain and time-base in Fig. 3.1.

Y-gain = ........................................... $V\,cm^{-1}$

time-base = ........................................... $s\,cm^{-1}$

[2]

**(b)** Many electrical devices require a constant supply of current, even though they are connected to sources of alternating current.

The circuit shown in Fig. 3.2 is a type of *rectifier*, which is used to produce a near constant supply of direct current. The output of the power supply gives the waveform shown in Fig 3.1.

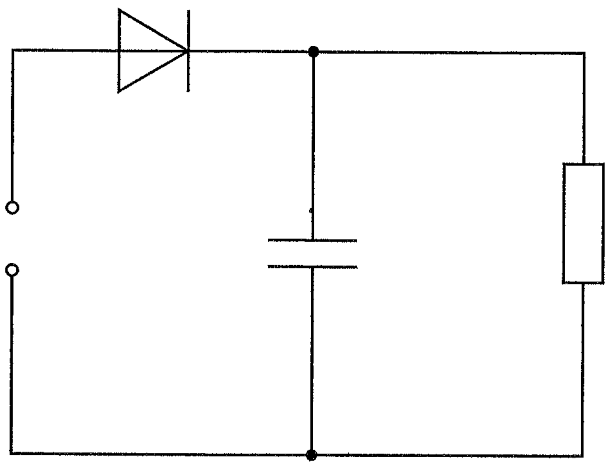
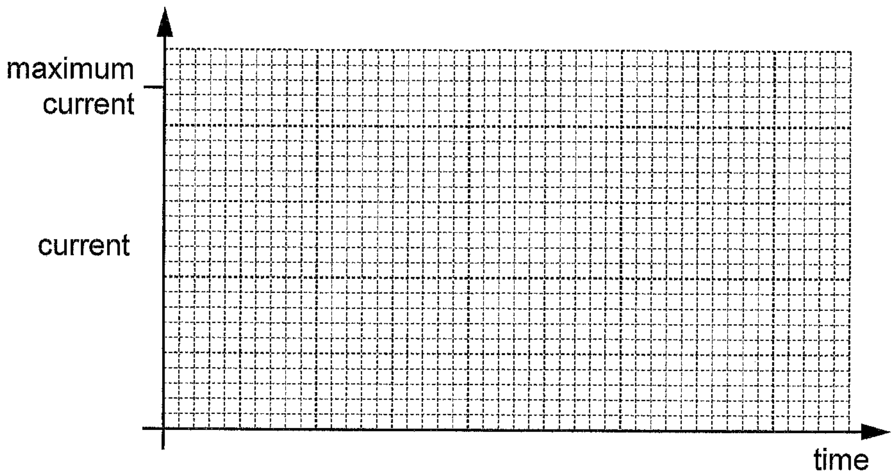


**Fig. 3.2**

**(i)** Sketch a graph on the axes below to show how the current through the resistor varies with time for **two** complete cycles. Use the same scale for time as in Fig. 3.1.




[2]

**(ii)** An electrical component is connected in place of the resistor in Fig. 3.2. It has a resistance of 1.5 kΩ and requires a minimum current of 130 mA to function properly.

Calculate the minimum capacitance of the capacitor that could be used in this circuit.

minimum capacitance = .................................................... μF [4]

**(iii)** A student suggests that adding a second capacitor in series with the minimum capacitance capacitor in **(b)(ii)** would make the component less likely to malfunction. Explain whether the student is correct.

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

[Total: 10]

**4** A parallel plate capacitor has circular parallel plates. The capacitance $C$ of a parallel plate capacitor is given by the equation:

$$C = \varepsilon_0 \frac{A}{d}$$

where $\varepsilon_0$ is the permittivity of free space, $A$ is the surface area of each capacitor plate and $d$ is the separation of the capacitor plates.

**(a)** **(i)** Express the volt in SI base units.

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

**(ii)** Express the units for the permittivity of free space in SI base units.

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

**(b)** The diameter of the circular capacitor plates is measured to be 6.50 cm and their separation is measured to be 5.42 mm.

State and explain which instruments are used for making these measurements.

instrument for measuring diameter ........................................................................................

instrument for measuring separation ........................................................................................

explanation ........................................................................................................................

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

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

**(c)** Air is usually an insulator, but if the electric potential gradient is large enough, arcing (sparks) can occur between the capacitor plates. The voltage at which arcing first occurs is known as the breakdown voltage $V_b$.

The capacitor in **(b)** is connected to a power supply that is designed to deliver a constant current of $I = 4.0\,\mu A$ when charging. A student records a time $T = 12$ minutes 14 seconds for $N = 200$ sparks to occur.

Assume that each sparking event causes the capacitor to fully discharge and the value of the permittivity of air is approximately equal to the permittivity of free space.

**(i)** Show that an expression for the breakdown voltage of air is given by

$$V_b = \frac{ITd}{N\varepsilon_0 A}.$$

[3]

**(ii)** Use the expression in **(c)(i)** to determine the value of the breakdown voltage of air.

$V_b$ = ...................................................... V [3]

**(iii)** Suggest how the breakdown voltage would change if the experiment is done in a vacuum chamber. Refer to the measurements for $T$ and $N$ in your answer.

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

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

[Total: 14]

**5** In 1849, Hippolyte Fizeau made measurements to determine the speed of light using the apparatus shown in Fig. 5.1.

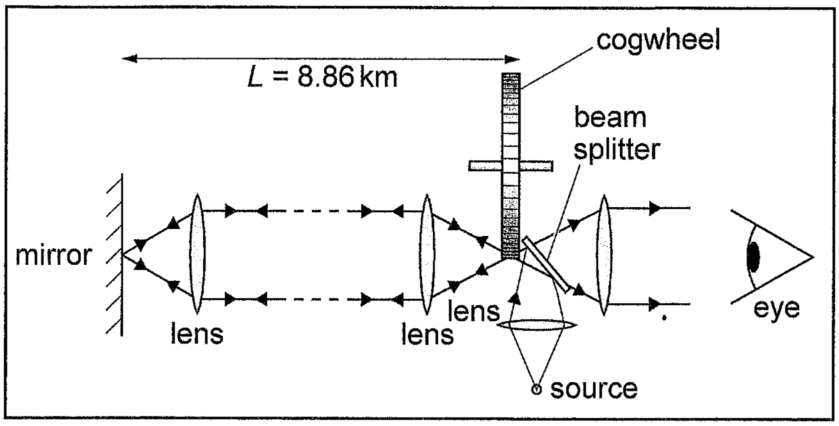


**Fig. 5.1**

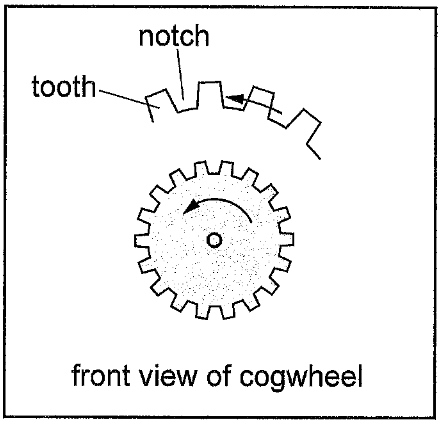


**Fig. 5.2**

The apparatus included a cogwheel (toothed wheel) containing 720 notches that could be rotated several hundred times per second. A simpler cogwheel with fewer notches is shown in Fig. 5.2.

A beam of light was focused through a notch of the cogwheel, as shown in Fig. 5.1. This created a strobing (flashing) effect. This light beam was directed at a mirror 8.86 km away. The beam of light was reflected and the light returning back through the cogwheel was monitored.

Fizeau adjusted the angular velocity of the cogwheel until light passing through one notch of the cogwheel was, on returning after reflecting at the mirror, completely blocked by the adjacent tooth. No reflected light reached his eye with this adjustment.

**(a)** **(i)** Determine an expression for the speed of light $c$ in terms of the angular velocity $\omega$ of the cogwheel and the distance to the mirror $L$.

[3]

**(ii)** Fizeau determined a value for the speed of light of $3.15 \times 10^5\,\text{km}\,\text{s}^{-1}$.

Calculate the value he measured for the angular velocity $\omega_0$.

$\omega_0$ = ............................................ rad $s^{-1}$ [1]

**(iii)** Fizeau then increased the rotation rate and recorded the angular velocity when blocking occurred for a second, third and fourth time.

State, in terms of $\omega_0$, the expected angular velocities for these three measurements.

measurements ...................... , ...................... , ...................... [1]

**(iv)** Suggest why Fizeau took the additional measurements described in **(iii)**.

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

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

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

**(b)** A university researcher wishes to re-enact Fizeau's experiment on a smaller scale and will use a separation between mirror and cogwheel of 88.6 m. He plans to make a cogwheel with 18 notches.

Show that he must spin the cogwheel at about three million revolutions per minute (rpm).

[2]

**(c)** The metal cogwheel shown in Fig. 5.3 is made by cutting out 18 'teeth' from a piece of 2 mm thick aluminium sheet metal.

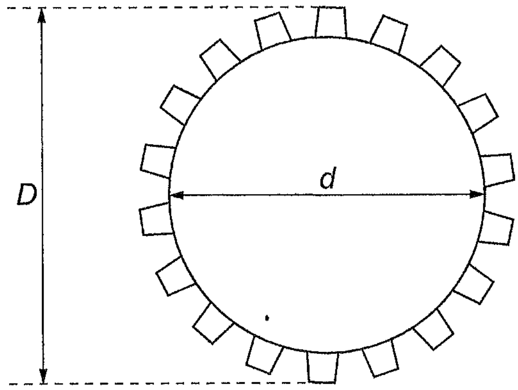


**Fig. 5.3**

The inner diameter $d$ of the cogwheel is 5.5 cm. The outer diameter $D$ is 6.0 cm. The density $\rho$ of aluminium is $2.7\,\text{g cm}^{-3}$.

**(i)** Derive an expression to approximate the cross-sectional area of the cogwheel in terms of the diameters $d$ and $D$.

[2]

**(ii)** Hence show that the mass of the cogwheel is approximately 14 g.

[1]

**(iii)** An approximation for the moment of inertia of the cogwheel can be found by modelling it as a disc with diameter 5.75 cm.

Suggest and explain whether this approximation will lead to a larger or smaller value than the true value for the moment of inertia.

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

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

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

**(iv)** The cogwheel in **(c)(iii)** is connected to a central axle. The mass of the axle can be ignored.

The axle is rotated by a motor connected to a 9.0 V battery. The cogwheel is accelerated in 4.2 seconds to a speed of 15 000 revolutions per minute.

Calculate the minimum current in the motor.

minimum current = ........................................................ A [4]

**(v)** Explain why your answer to **(c)(iv)** is a minimum.

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

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

[Total: 17]

## Section B

Answer **two** questions from this section.

You are advised to spend about 35 minutes on each question.

**6** A uniformly charged thin disc of radius $R$ lies in the $x$–$y$ plane as shown in Fig. 6.1.

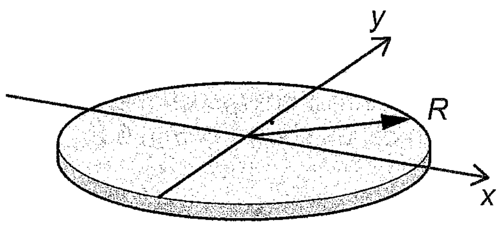


**Fig. 6.1**

The total amount of charge on the disc is $Q$.

**(a)** **(i)** State an expression for the surface charge density $\sigma$ in terms of $Q$ and $R$.

[1]

**(ii)** Use your answer in **(a)(i)** and apply Gauss's law with an appropriately chosen Gaussian surface to show that an approximation for the electric field at the position $(0,0,z)$, where $z \ll R$, is given by

$$E_z = 2\pi k\sigma$$

where $k$ is a constant you will need to determine.

You may wish to draw a diagram to help your answer.

[6]

**(iii)** Determine an expression for the electric potential at the point (0,0,$z$) relative to the origin.

[2]

**(b)** The electric field can be determined more accurately than determined in **(a)** by superimposing the point charge fields of infinitesimal charge elements. This can be done by summing the fields of charged rings of width d$r$, as shown in Fig. 6.2.

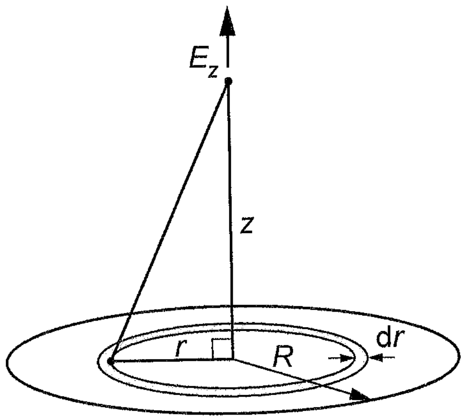


**Fig. 6.2**

**(i)** Show that the electric field at position (0,0,$z$) is given by:

$$E_z = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{z}{\sqrt{z^2 + R^2}}\right]$$

[5]

**(ii)** Determine an expression for $E_z$ when $z \ll R$.

[2]

**(iii)** Determine an expression for $E_z$ when $z \gg R$.

You may wish to use the approximation shown when $x$ is small.

$$(1 + x)^n \approx 1 + nx$$

[2]

**(iv)** Comment on the form of the expressions in **(b)(ii)** and **(b)(iii)**.

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

[Total: 20]

7 **(a)** Fig. 7.1 shows the Earth is not a perfect sphere.

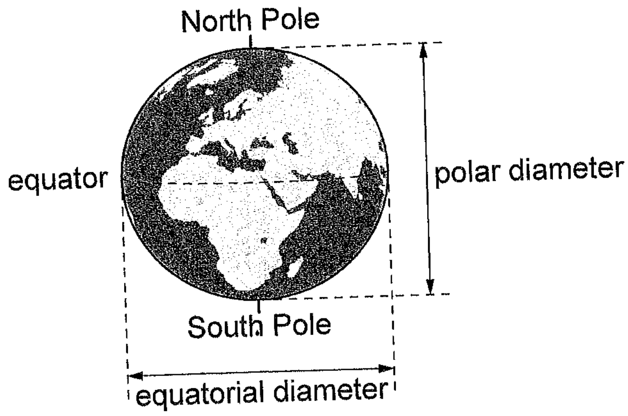


**Fig. 7.1** (not to scale)

The equatorial diameter is slightly greater than the polar diameter.

A person at the North Pole measures his weight by standing on a weighing scale. He will measure a different weight if he is at the equator.

The dominant reasons for this are the shape of the Earth and the rotation of the Earth.

**(i)** State and explain how the shape of the Earth will affect his measured weight.

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

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

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

**(ii)** State and explain how the rotation of the Earth will affect his measured weight.

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

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

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

**(b)** In a spherical Earth model, the Earth is considered a uniform sphere of fixed radius 6380 km.

The rotational period of the Earth is 24 hours.

**(i)** The weight of the person measured at the North Pole is 775 N.

Calculate the difference between this weight and his measured weight at the equator due to the rotation of the Earth.

difference = .................................................... N [3]

**(ii)** Calculate the rotational period required, in hours, for a person to experience the sensation of 'weightlessness' at the equator.

rotational period = ............................................... hours [2]

**(c)** **(i)** State the principle of conservation of angular momentum.

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

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

**(ii)** Explain why an ice-skater spinning with her arms extended can rotate faster by pulling her arms inwards to her chest.

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

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

**(iii)** A student watches a chef making a pizza base by spinning the pizza dough with his hands. The student notices how a ball of pizza dough spreads out into a flat disc.

The student hypothesises that the fast-rotating spherical Earth in **(b)(ii)** could become flatter and flatter until it can be modelled as a uniform rotating disc of radius $r_2$ and thickness $h$.

Show that to satisfy conservation of angular momentum the thickness of the disc-Earth is given by

$$h = \frac{5T_1}{3T_2} r_1$$

where $T_1$ is the period for the fast-rotating spherical Earth model, $r_1$ is the radius for the fast-rotating spherical Earth model and $T_2$ is the period for the disc-Earth model.

[4]

**(iv)** The student assumes that $h = \frac{r_1}{3}$ and the gravitational field strength at the equator of the disc-Earth is $g = \frac{GM}{r^2}$.

Show that these assumptions lead to the following condition for 'weightlessness' at the equator of the disc-Earth:

$$T_2^{\,2} \leqslant \frac{32\pi^2 r_1^{\,3}}{GM}$$

where $M$ is the mass of the Earth and G is the gravitational constant.

[3]

**(v)** The density of the Earth is 5510 kg m$^{-3}$.

Determine whether a person at the equator of the disc-Earth will experience 'weightlessness'.

[2]

**(vi)** Explain without calculation how the measured weight of the person would be affected, if at all, as he moved from the equator directly upwards to point A on Fig. 7.2.

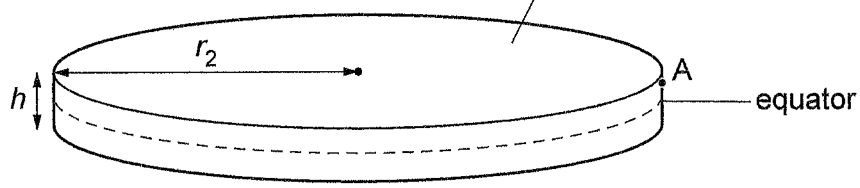


**Fig. 7.2** (not to scale)

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

[Total: 20]

8 **(a)** Explain what is meant by an *inertial frame of reference* and describe its state of motion.

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

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

**(b)** Explain what is meant by the *zero momentum frame* (centre of mass frame) and describe how it is used to simplify the analysis of elastic collisions.

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

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

**(c)** A ball of mass $m$ travels with a velocity $v$ to the right and goes on to collide elastically with a stationary ball of mass $5m$ in free space as shown in Fig. 8.1.

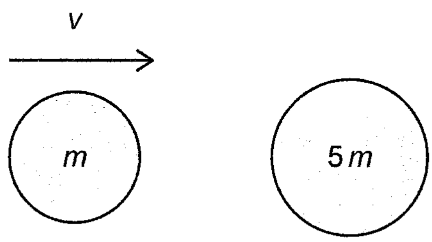


**Fig. 8.1**

By using the zero momentum frame, or otherwise:

**(i)** Show that the ball of mass $m$ rebounds with a velocity of $\frac{2}{3}v$ to the left.

[2]

**(ii)** Determine the **velocity** of the ball of mass $5m$ after the collision.

velocity = ........................................................ [1]

**(iii)** The ball of mass $m$ now moves to the left following the first collision, as shown in Fig. 8.2, and collides elastically with a second stationary ball of mass $5m$.

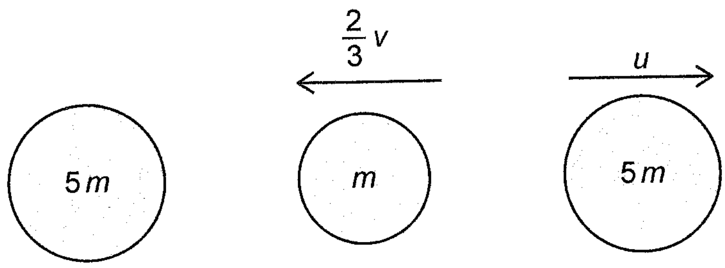


**Fig. 8.2**

Show that there will be a third collision but **not** a fourth.

You may wish to draw sketches of reference frames to help your answer.

[6]

**(iv)** Calculate the percentage of kinetic energy that the ball of mass $m$ loses during the whole process.

kinetic energy lost = .................................................... % [1]

**(d)** A 'Gaussian Gun' is a type of magnetic accelerator, as shown in Fig. 8.3.

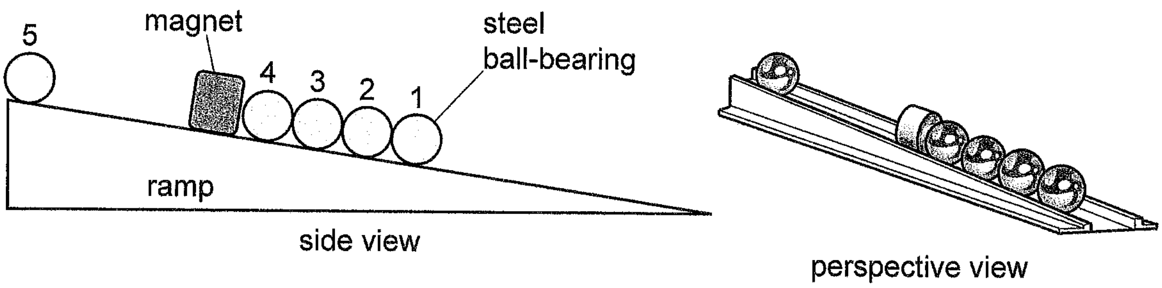


**Fig. 8.3**

The Gaussian Gun consists of a shallow ramp, five steel ball-bearings and a strong neodymium cylindrical magnet.

The magnet holds four ball-bearings in place, and the fifth ball-bearing is released from the top of the ramp, as shown in Fig. 8.3.

What happens next appears to defy conservation laws. Ball-bearing 5 collides with the magnet. This causes ball-bearing 1 to be 'fired' away at a surprisingly high speed. This is illustrated in Fig. 8.4.

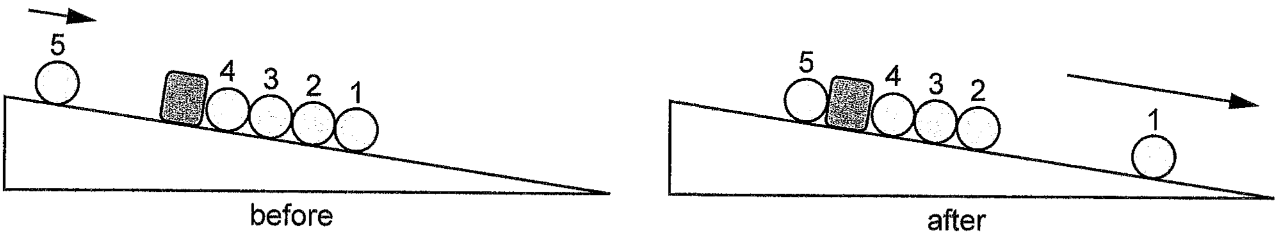


**Fig. 8.4**

**(i)** Describe the energy and momentum transfers that take place in Fig. 8.4. Assume that the magnet does not move from its position on the ramp.

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(ii) The Gaussian Gun experiment is repeated with the initial configuration of the ball-bearings changed, as shown in Fig. 8.5.

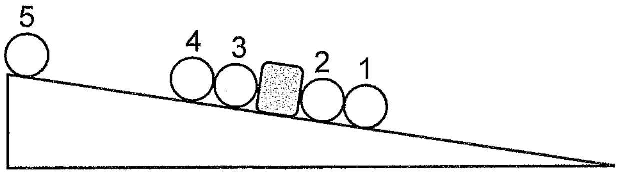


**Fig. 8.5**

Suggest and explain the effect, if any, that this change in configuration has on the motion of ball-bearing 1.

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[Total: 20]