Cambridge Pre-U

UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
Cambridge International Level 3 Pre-U Certificate
Principal Subject

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

9269331796

PHYSICS **9792/03**

Paper 3 Part B Written Paper **May/June 2013**

3 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use a pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Section A
Answer **all** questions.
You are advised to spend about 1 hour 30 minutes on this section.

Section B
Answer any **three** questions. All six questions carry equal marks.
You are advised to spend about 1 hour 30 minutes on this section.

Electronic calculators may be used.
You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	
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11	
12	
13	
Total	

This document consists of **40** printed pages.

DC (NF/JG) 66325/6

UNIVERSITY *of* CAMBRIDGE
International Examinations

Data

gravitational field strength close to Earth's surface	$g = 9.81\,\text{N}\,\text{kg}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
speed of light in vacuum	$c = 3.00 \times 10^{8}\,\text{m}\,\text{s}^{-1}$
Planck constant	$h = 6.63 \times 10^{-34}\,\text{J}\,\text{s}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F}\,\text{m}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\text{N}\,\text{m}^{2}\,\text{kg}^{-2}$
electron mass	$m_\text{e} = 9.11 \times 10^{-31}\,\text{kg}$
proton mass	$m_\text{p} = 1.67 \times 10^{-27}\,\text{kg}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\,\text{kg}$
molar gas constant	$R = 8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Avogadro constant	$N_\text{A} = 6.02 \times 10^{23}\,\text{mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\,\text{J}\,\text{K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\,\text{W}\,\text{m}^{-2}\,\text{K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
	$s = \left(\frac{u+v}{2}\right)t$
heating	$\Delta E = mc\Delta\theta$
change of state	$\Delta E = mL$
refraction	$n = \frac{\sin\theta_1}{\sin\theta_2}$
	$n = \frac{v_1}{v_2}$

diffraction single slit, minima	$n\lambda = b \sin\theta$
grating, maxima	$n\lambda = d \sin\theta$
double slit interference	$\lambda = \dfrac{ax}{D}$
Rayleigh criterion	$\theta \approx \dfrac{\lambda}{b}$
photon energy	$E = hf$
de Broglie wavelength	$\lambda = \dfrac{h}{p}$
simple harmonic motion	$x = A\cos\omega t$
	$v = -A\omega\sin\omega t$
	$a = -A\omega^2\cos\omega t$
	$F = -m\omega^2 x$
	$E = \tfrac{1}{2}mA^2\omega^2$
energy stored in a capacitor	$W = \tfrac{1}{2}QV$
electric force	$F = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \dfrac{Q_1Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = -\dfrac{Gm_1m_2}{r^2}$
gravitational potential energy	$E = -\dfrac{Gm_1m_2}{r}$
magnetic force	$F = BIl\sin\theta$
	$F = BQv\sin\theta$

electromagnetic induction	$E = -\dfrac{d(N\Phi)}{dt}$
Hall effect	$V = Bvd$
time dilation	$t' = \dfrac{t}{\sqrt{1-\dfrac{v^2}{c^2}}}$
kinetic theory	$\tfrac{1}{2}m\langle c^2\rangle = \tfrac{3}{2}kT$
work done on/by a gas	$W = p\Delta V$
radioactive decay	$\dfrac{dN}{dt} = -\lambda N$
	$N = N_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \dfrac{\ln 2}{\lambda}$
attenuation losses	$I = I_0 e^{-\mu x}$
mass-energy equivalence	$\Delta E = c^2\Delta m$
hydrogen energy levels	$E_n = \dfrac{-13.6\,\text{eV}}{n^2}$
Heisenberg uncertainty principle	$\Delta p\Delta x \geqslant \dfrac{h}{2\pi}$
	$\Delta E\Delta t \geqslant \dfrac{h}{2\pi}$
Wien's law	$\lambda_{max} \propto \dfrac{1}{T}$
Stefan's law	$L = 4\pi\sigma r^2 T^4$
electromagnetic radiation from a moving source	$\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

Section A

Answer **all** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

For Examiner's Use

1 **(a)** The International Space Station is travelling in a circular orbit at a distance of 3.90×10^5 m from the surface of the Earth.

Radius of the Earth (assumed to be spherical) = 6.37×10^6 m.
Mass of the Earth = 5.98×10^{24} kg.

An astronaut of mass 83.0 kg is inside the International Space Station, but is not touching its structure.

Calculate,

(i) the gravitational force on the astronaut,

force = ... N [3]

(ii) the acceleration of the astronaut,

acceleration = ... $m s^{-2}$ [1]

(iii) the speed of the astronaut,

speed = ... $m s^{-1}$ [2]

(iv) the time taken for the astronaut to complete one orbit of the Earth.

time = ... s [3]

For Examiner's Use

(b) Suggest an everyday situation where, for a short time, the gravitational force from the Earth is the **only** large force acting on you.

....

.... [1]

(c) A journalist writes that the astronaut in **(a)** is 'weightless'.

Discuss whether or not the astronaut is weightless and compare the astronaut's situation with the situation you have described in **(b)**.

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.... [3]

[Total: 13]

For Examiner's Use

2 The period T of a simple pendulum is given by the formula

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where l is the length of the pendulum and g is the gravitational field strength.

(a) A simple pendulum consists of a ball of mass 0.87 kg supported on a string of length $l = 2.6$ m.

Calculate

(i) the period T,

T = ... s [1]

(ii) the angular frequency ω.

ω = ... rad s^{-1} [1]

(iii) The pendulum oscillates with a maximum angle of swing of 2.3° from the vertical.

Calculate the maximum kinetic energy of the ball.

kinetic energy = ... J [2]

(b) The formula quoted for the period of a simple pendulum is only valid for small angles.

For Examiner's Use

The relationship between the period and the angle is to be investigated over a large range of different angles.

Explain, using a diagram, how the time period T and the angle of swing θ could be measured to get accurate and precise results. In your account suggest how you would cope with the problem of the maximum angle decreasing during any sequence of oscillations.

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.... [6]

[Total: 10]

3 The network of capacitors shown in Fig. 3.1 is charged from a 12V supply. X is a capacitor of capacitance *X*.

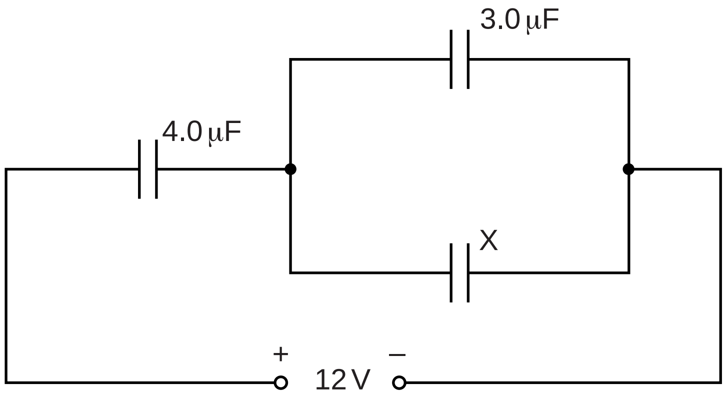

Fig. 3.1

(a) Complete the following table to show the capacitance, the potential difference, the charge and the energy stored by each of three capacitors.

capacitance / μF	potential difference / V	charge / μC	energy / μJ
4.0			
3.0			
X = ...	3.0		

[7]

For Examiner's Use

(b) (i) Determine

1. the charge that flows through the 12 V supply during the charging process,

charge = ... μC [1]

2. the energy supplied by the 12 V supply.

energy = ... μJ. [1]

(ii) Suggest why the energy supplied by the 12 V supply is not equal to the total energy stored by the three capacitors.

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.... [2]

[Total: 11]

4 A coil of wire with 20 turns is wound on to an iron ring as illustrated in Fig. 4.1.

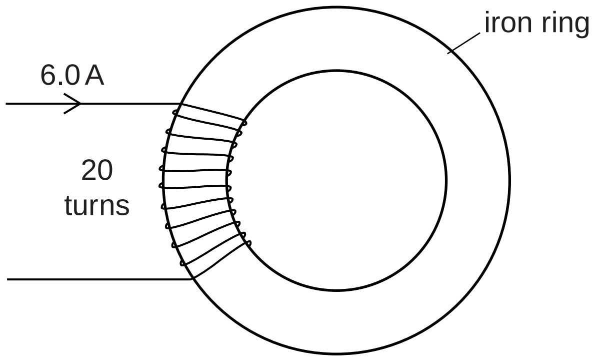

Fig. 4.1

A current of 6.0 A in the coil causes a magnetic flux of 3.8×10^{-5} Wb in the ring.

(a) Calculate

(i) the flux linkage through the coil,

flux linkage = ... Wb [1]

(ii) the emf across the coil when the current through the coil changes uniformly from 6.0 A to zero in a time of 0.0050 s.

emf = ... V [2]

(b) A second coil of 800 turns is now placed on the ring together with the first coil, as shown in Fig. 4.2.

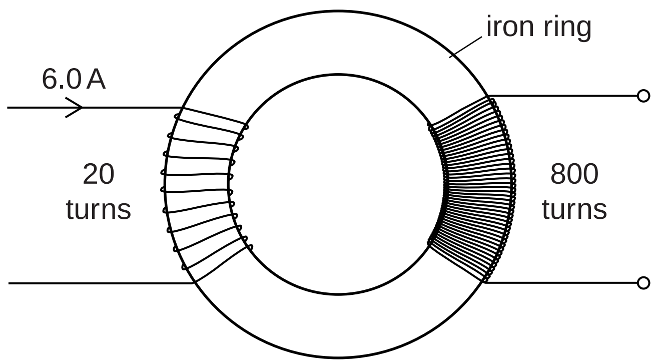

Fig. 4.2

For Examiner's Use

(i) Calculate the emf generated across this second coil when the current through the first coil changes uniformly from 6.0 A to zero in the time of 0.0050 s.

emf = ... V [2]

(ii) The emf across the 20 turn coil is different from the emf across the 800 turn coil. The 800 turn coil is not connected to any component.

Explain how the law of conservation of energy applies in this situation.

....

....

.... [2]

(iii) Suggest a practical application of this arrangement of coils.

....

.... [2]

[Total: 9]

For Examiner's Use

5 **(a)** State three assumptions on which the **kinetic theory model** is based.

1. ....

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2. ....

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3. ....

.... [3]

(b) Describe Brownian motion and explain it in terms of the **particle model** of matter.

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.... [3]

(c) An oxygen molecule has a mass of 5.31×10^{-26} kg.

Calculate

(i) the average kinetic energy of an oxygen molecule at a temperature of 23 °C,

average kinetic energy = ... J [2]

(ii) the root mean square speed of oxygen molecules at a temperature of 23 °C.

root mean square speed = ... $m\,s^{-1}$ [2]

For Examiner's Use

(d) **(i)** Describe what is meant by the *internal energy* of a gas.

....

....

.... [1]

(ii) Air in the cabin of an airliner is usually kept at a constant temperature and pressure.

State, with a reason, the change, if any, to the internal energy of the air in the cabin,

1. as a result of travelling at high speed,

change ....

reason ....

....

2. as a result of travelling at high altitude,

change ....

reason ....

....

3. if the temperature were allowed to decrease.

change ....

reason ....

....

[5]

[Total: 16]

For Examiner's Use

6 Beta-minus decay occurs when a neutron decays into a proton and an electron. The nuclear equation for this is

$${}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{\ 0}_{-1}\text{e}.$$

The masses of the three particles are

neutron	1.6744×10^{-27} kg
proton	1.6730×10^{-27} kg
electron	9.1134×10^{-31} kg.

(a) Calculate the energy released when this nuclear reaction takes place.

energy = ... J [3]

(b) The electron, because it has a much smaller mass than the proton, receives almost all of the energy released in this nuclear reaction. The electron then loses 2.3×10^{-14} J of its energy in escaping from the electrical attraction of the proton.

Calculate for the electron, when it is far removed from the proton,

(i) its kinetic energy,

kinetic energy = ... J [1]

(ii) its momentum.

momentum = ... kg m s^{-1} [2]

For Examiner's Use

(c) Sketch a vector diagram to illustrate directions and speeds for the proton and the electron after the reaction has occurred.

[1]

(d) The decay of a neutron into two particles, a proton and an electron, suggests that all the electrons from this reaction should have the same energy.

However, experiments show that the electrons have a range of energies.

Describe the three particle solution that explains the experimental results. Include an equation for the three particle solution.

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.... [5]

[Total: 12]

For Examiner's Use

7 **(a)** Define, for a star, the terms

(i) *luminosity*, ...

.... [1]

(ii) *luminous flux*. ....

.... [1]

(b) All the information gained by astronomers about stars, apart from the Sun, is gained from their electromagnetic radiation.

Describe the principal information gained from,

(i) the colour of a star,

....

.... [1]

(ii) the absorption spectrum of a star.

....

....

....

....

.... [2]

(c) A green spectral line viewed in a laboratory has a wavelength of 516.7 nm. The same spectral line viewed in the radiation from a distant galaxy has a wavelength of 543.2 nm.

(i) Calculate the velocity of recession of the galaxy.

velocity = ... $m\,s^{-1}$ [2]

(ii) Estimate the distance of the galaxy from the Earth.
The Hubble constant $\approx 2.3 \times 10^{-18}\,s^{-1}$.

distance = ... m [2]

[Total: 9]

End of Section A

Section B

Answer any **three** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

8 **(a)** An object moving in a circular path of radius *r* experiences an acceleration *a* even when travelling at constant speed *v*.

(i) Explain how it is possible for the object to accelerate and yet at the same time have constant speed.

....

....

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....

.... [3]

(ii) State an expression for this acceleration.

....

.... [1]

(b) Fig. 8.1 shows the forces acting on a child who is riding backwards and forwards on a swing that follows a circular arc of radius *r*.

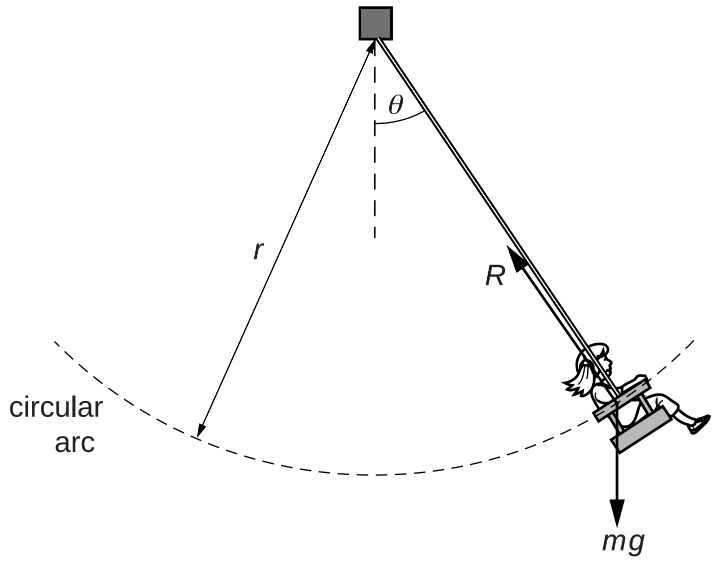


Fig. 8.1 (not to scale)

The child's weight is *mg*. *R* is the force of the seat on the child. As the instantaneous speed *v* of the child changes, *R* also varies.

As the child swings through the lowest point on the circular arc, $\theta = 0°$, her instantaneous speed is 4.7 m s^{-1}. The child weighs 200 N and the radius *r* is 2.8 m.

Calculate the value of *R* at this instant.

R = ... N [2]

(c) Fig. 8.2 shows a roundabout.

For Examiner's Use

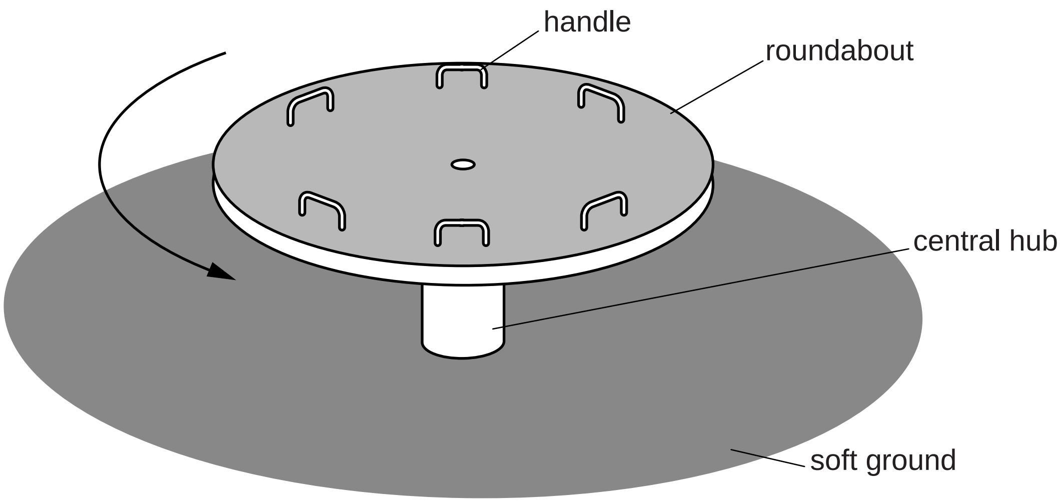


Fig. 8.2

The roundabout consists of a solid disc of mass *M* supported on a central hub.

(i) Use integration to derive an expression for the moment of inertia *I* of a thin uniform disc of radius *R* about its centre. You may annotate the diagram of the disc in Fig. 8.3 to define the terms you use.

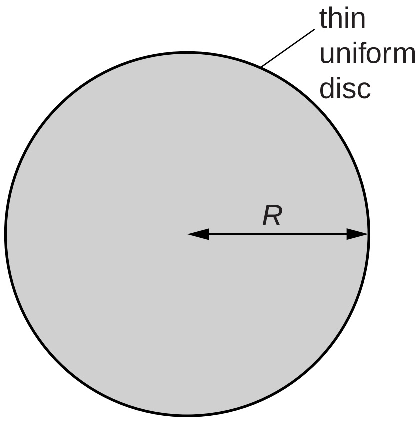


Fig. 8.3

[4]

(ii) The moment of inertia of the roundabout in Fig. 8.2 is 44.8 kg m^2. A torque of 10.1 N m is applied.

Show that the time taken to accelerate the disc from rest to 1.40 rad s^{-1} is approximately 6 s.

time = ... s [2]

(iii) Two teenagers of equal mass sit directly opposite each other on the roundabout. The moment of inertia of the roundabout and the teenagers is now 118 kg m^2.

Calculate how much longer than the time determined in **c(ii)** it will now take to accelerate from rest to 1.40 rad s^{-1}. Assume the same torque is applied as in **c(ii)**.

time increase = ... s [2]

(iv) The roundabout continues to rotate at 1.40 rad s^{-1}. The teenagers then lean outwards.

1. Explain why the period of rotation of the roundabout increases.

....

....

....

....

....

.... [3]

2. The period of rotation increases by 0.66 s.

Calculate the new moment of inertia.

For Examiner's Use

new moment of inertia = ... kg m^2 [3]

[Total: 20]

For Examiner's Use

9 Space rockets require thrust forces to change their motion in space. The thrust is exerted on the rocket by the fast moving exhaust gases that are ejected downwards.

(a) State Newton's second law of motion in terms of momentum.

....

....

.... [2]

(b) The mass of a rocket decreases as fuel is used up. The thrust F on a rocket of instantaneous mass m is given by the expression

$$F = V\frac{\mathrm{d}m}{\mathrm{d}t}$$

where V is the steady velocity of the exhaust gases, relative to the rocket.

The thrust on the rocket is 34.7 MN. The gas exhaust velocity is $2.6 \times 10^3\,\mathrm{m\,s^{-1}}$.

Calculate the rate of change of mass of the rocket.

rate of change of mass = ... $\mathrm{kg\,s^{-1}}$ [2]

(c) The rocket fires its engine and its mass decreases from its initial mass m_o to a mass m. The change in velocity Δv_r of the rocket depends upon the exhaust velocity V of the gases, m_o and m.

The ideal rocket equation gives the relationship as:

$$\Delta v_r = V \ln\left(\frac{m_o}{m}\right)$$

(i) Show that the ratio $\left(\frac{m}{m_o}\right)$ is equal to $e^{-(\Delta v_r/V)}$.

[1]

(ii) Use the relationship in **(c)(i)** to complete the table below.

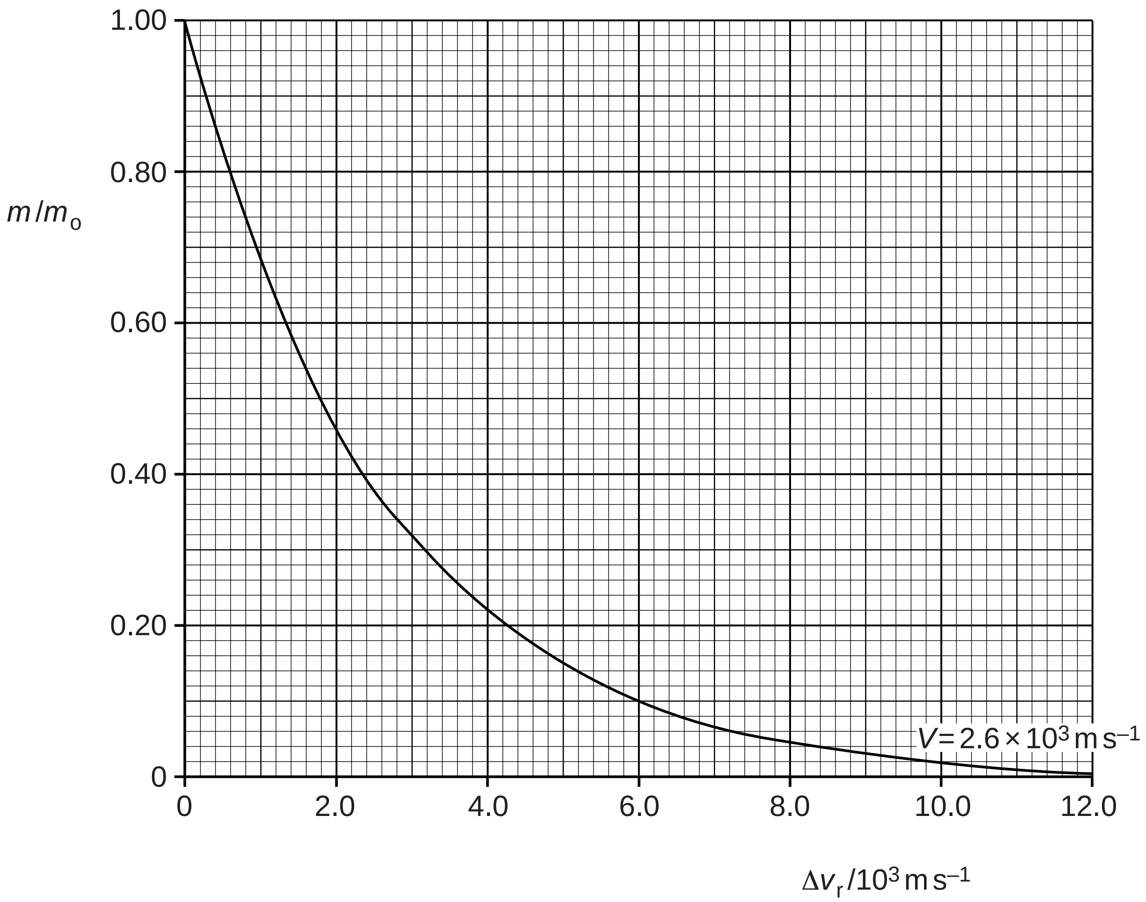
In this case V is $8.0 \times 10^3\,\mathrm{m\,s^{-1}}$.

$\Delta v_r / 10^3\,\mathrm{m\,s^{-1}}$	$\left(\frac{m}{m_o}\right)$
1.0	
2.0	0.78
3.0	0.69
5.0	0.54
6.0	0.47
	0.38
10.0	0.29
12.0	0.22

[2]

(iii) Fig. 9.1 is a graph of the mass ratio $\left(\frac{m}{m_o}\right)$ against the change in velocity Δv_r for a gas exhaust velocity V of $2.6 \times 10^3\,\mathrm{m\,s^{-1}}$.

On Fig. 9.1, draw a second graph plotting all the data from the table in **(c)(ii)**.



[3]

Fig. 9.1

For Examiner's Use

(iv) The initial mass m_o of the rocket, including the fuel, is 2.04×10^6 kg.
The first burn of fuel gives $\Delta v_r = 5.0 \times 10^3\,\mathrm{m\,s^{-1}}$.

Use information from the graphs in **(c)(iii)** to calculate the difference in the mass of fuel used to accelerate the rocket by the same change in velocity Δv_r if its gas exhaust velocity V is $8.0 \times 10^3\,\mathrm{m\,s^{-1}}$ rather than $2.6 \times 10^3\,\mathrm{m\,s^{-1}}$.

difference in mass = ... kg [3]

(d) A rocket launches a satellite, which orbits at a height h above the Earth's surface as shown in Fig. 9.2.

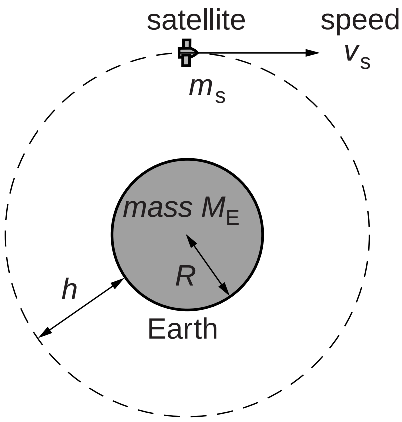


Fig. 9.2 (not to scale)

The satellite of mass m_s has speed v_s. The mass of the Earth is M_E and its radius is R.

(i) State the relationship for the gravitational potential energy E of the satellite in terms of relevant quantities given in Fig. 9.2.

[1]

(ii) Explain what is meant by the term *gravitational potential energy* of a mass such as a satellite.

....

....

.... [2]

(iii) Use the information given below to determine the height h of the satellite above the Earth's surface.

For Examiner's Use

total energy of satellite	E_T	=	-4.5×10^9 J
mass of satellite	m_s	=	152 kg
speed of satellite	v_s	=	7.70×10^3 m s^{-1}
mass of the Earth	M_E	=	5.98×10^{24} kg
radius of Earth	R	=	6.36×10^6 m
gravitational constant	G	=	6.67×10^{-11} N m^2 kg^{-2}

height above Earth = ... m [4]

[Total: 20]

For Examiner's Use

10 A defibrillator is a device used to restart a heart that has stopped beating. It contains a capacitor that, as it discharges, delivers a short pulse of energy to the patient's heart.

The capacitor in the defibrillator is charged by a 2000 V d.c. supply in a circuit of constant resistance.

(a) Fig. 10.1 shows the relationship between the potential difference *V* across the capacitor and the charge *Q* stored on its plates.

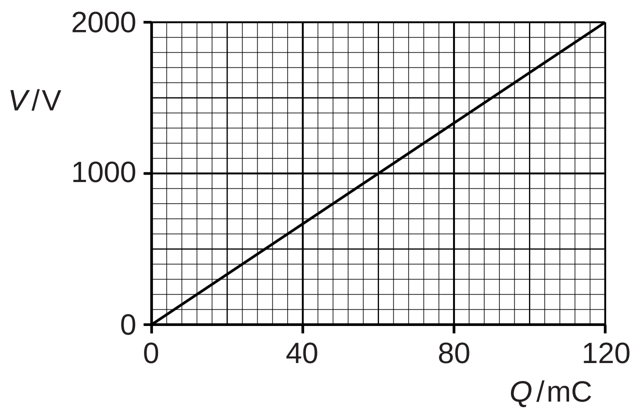


Fig. 10.1

(i) State what is represented by the gradient of the graph.

.... [1]

(ii) The capacitor in Fig. 10.1 is charged to a p.d. of 2000 V in 2.4 s.

Calculate the average current during charging.

average current = ... A [2]

(iii) Explain why the rate of flow of charge to the capacitor decreases during the charging process.

....

....

.... [2]

For Examiner's Use

(b) Fig. 10.2 is a graph of charge Q against time t for the defibrillator capacitor as it discharges through the patient's heart.

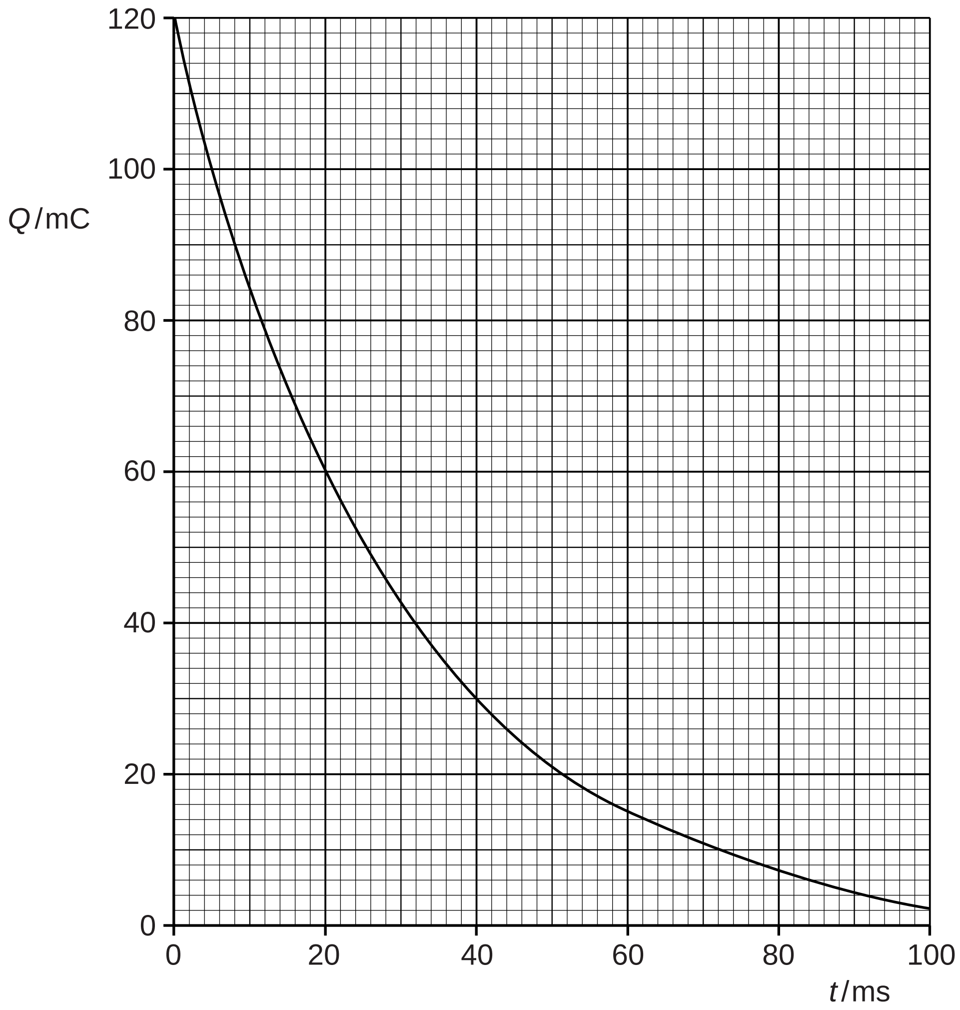


Fig. 10.2

(i) Use the graph to determine the instantaneous rate of flow of charge through the heart at time $t = 30\,\text{ms}$. Show clearly on the graph how you obtained the relevant information.

rate of flow of charge = ... C s^{-1} [3]

(ii) The equation for the curve in Fig. 10.2 is given by the expression

$$Q = Q_0\, e^{-t/CR}$$

where Q_0 is the initial charge and R is the resistance of the patient's heart.

1. Show that the unit of *CR* is s.

For Examiner's Use

[1]

2. Use data from the graph to determine a value for the product *CR*.

CR = ... [2]

3. Hence, determine a value for the resistance of the patient's heart.

resistance = ... Ω [1]

4. Differentiate the expression given for *Q* with respect to time in order to derive an expression for the instantaneous current *I*.

[2]

Question 10 continues on the next page

For Examiner's Use

(c) A point charge, of charge $+Q_2$, is brought from infinity to a distance *r* from a fixed point charge, of charge $+Q_1$, as shown in Fig. 10.3.

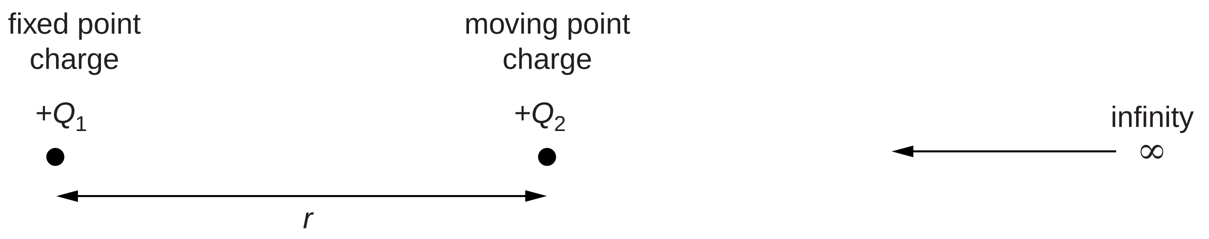


Fig. 10.3

(i) By considering the force *F* on the moving charge, use integration to derive an expression for the electrical potential energy *W* when the two charges are a distance *r* apart. Explain your working fully.

[5]

(ii) Explain the significance of the limits of integration you used in **(i)**.

....

....

.... [1]

[Total: 20]

For Examiner's Use

11 **(a)** Explain in detail what is meant by *time dilation* in special relativity.

....

....

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....

....

.... [3]

(b) Explain why relativistic time dilation does not have to be taken into account when calculating the time for a round trip of 300 km by train. Assume the speed of the train is constant at $30\,\text{m}\,\text{s}^{-1}$. Support your answer with a calculation.

You may use the approximation:

$$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \approx 1 + \frac{v^2}{2c^2}$$

....

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.... [3]

(c) In 1940 George Gamow, the nuclear physicist, published a book called 'Mr Tompkins in Wonderland'. In this story, Mr Tompkins dreams he is in a world in which the speed of light is much slower than its usual $3.0 \times 10^8\,\mathrm{m\,s^{-1}}$ and relativistic effects are obvious even in everyday life.

Consider a train moving at $30\,\mathrm{m\,s^{-1}}$ in a world in which the speed of light is only $100\,\mathrm{m\,s^{-1}}$.

(i) Calculate the time dilation factor γ for the train.

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

γ = ... [2]

(ii) The clock on board the train is synchronised with the station clock when the train leaves the station. It goes on a return journey of 300 km at a steady speed of $30\,\mathrm{m\,s^{-1}}$ and returns to the same station. The total distance travelled is 300 km.

When the train returns, its clock has to be re-synchronised with the station clock.

Calculate the size of the adjustment that must be made and state in what direction the train clock must be adjusted.

size of adjustment = ...

direction of clock adjustment: ....

[4]

(iii) A man who travelled on the journey on the train in **(ii)** claims that relativistic effects have resulted in him travelling in time.

State and explain whether you agree or disagree with him.

....

....

....

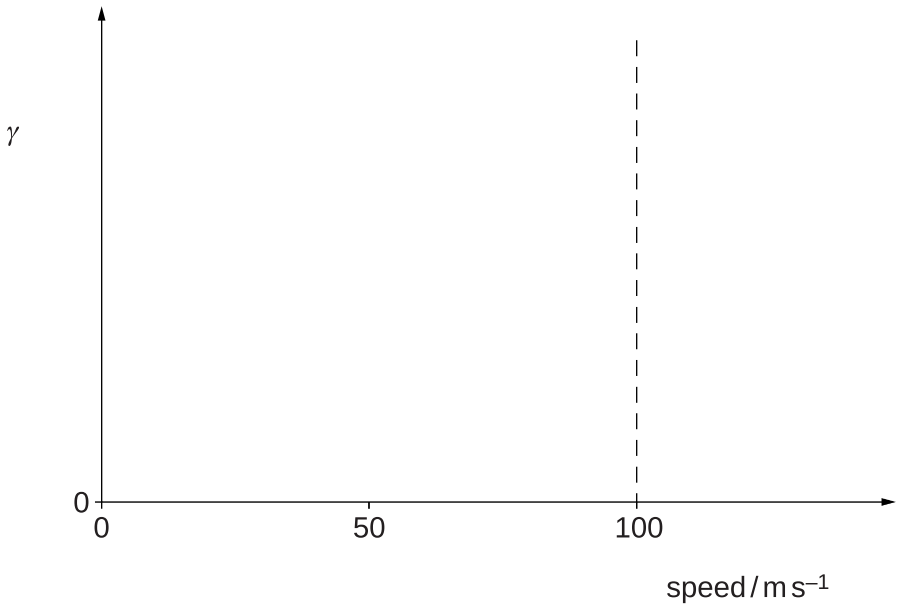
....

.... [2]

(d) The size of relativistic effects is controlled by the time dilation factor γ.

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

On Fig. 11.1, sketch a graph to show how this factor varies with speed in a world in which the speed of light is 100 m s^{-1}. Add a scale to the γ-axis.



[4]

Fig. 11.1

(e) We have considered a world in which the speed of light is less than $3.0 \times 10^8\,m\,s^{-1}$.

Now imagine a world in which the speed of light is infinite. State two consequences of this.

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2. ....

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[2]

[Total: 20]

For Examiner's Use

For Examiner's Use

12 **(a)** Explain how the nuclear model of the atom (the 'Rutherford model') differs from the 'common sense' view held historically that atoms are tiny uniform spheres of matter.

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.... [2]

(b) The nucleus of the atom contains protons and neutrons.

(i) Calculate the electrostatic force between two protons assuming they are about 10^{-15} m apart. Comment on your answer.

force = ... N

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[3]

(ii) Explain why nucleons in the nucleus must be bound together by a nuclear interaction that is

1. strong and attractive,

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.... [1]

2. short range.

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.... [1]

(c) In the 1930s, the physicist Hideki Yukawa suggested a theoretical model for the strong nuclear force between nucleons. He thought that the force was carried by subatomic particles called mesons that were exchanged between the nucleons. These mesons are created from the field between nucleons but can only exist for a time limited by the Heisenberg Uncertainty Principle

$$\Delta E\,\Delta t \approx \frac{h}{2\pi}.$$

One way to understand this is to assume that the energy needed to create a meson of rest mass *m* is 'borrowed' for the time that the meson exists and then 'paid back'. This means that the mesons can only have a limited lifetime.

(i) The energy ΔE needed to create a meson of rest mass m is given by $\Delta E = mc^2$.

Express the lifetime of the meson in terms of the rest mass of the meson.

[1]

(ii) According to Einstein's theory of special relativity, no particle with mass can travel at or above the speed of light.

Explain how this limits the range of the strong nuclear force.

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.... [2]

(iii) The range of the strong nuclear force is about 10^{-15} m.

Use this to estimate the mass of the meson. Assume that the exchanged mesons travel at very close to the speed of light.

For Examiner's Use

mass = ... kg [3]

(iv) Compare this quantitatively to the mass of the proton and to the mass of the electron. Suggest what this implies about the nature of the meson.

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.... [2]

(d) Electromagnetic forces are also thought to be carried by exchange particles. These are called photons. Unlike the strong nuclear force, the electromagnetic force is thought to have infinite range.

(i) Use the Uncertainty Principle to explain what this implies about the lifetime and rest mass of the photon.

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.... [3]

(ii) Suggest why the electrostatic attraction between a proton and an electron gets stronger as they approach one another.

For Examiner's Use

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.... [2]

[Total: 20]

For Examiner's Use

13 Read the four extracts below.

Extract 1 (Rudolph Clausius, 1865)

The energy of the world is constant. Its entropy tends to a maximum.

Extract 2 (from 'Kinetic Theory of the Dissipation of Energy', Lord Kelvin 1874)

If, then, the motion of every particle of matter in the universe were precisely reversed at any instant, the course of nature would be simply reversed for ever after. The bursting bubble of foam at the foot of a waterfall would reunite and descend into the water; the thermal motions would reconcentrate their energy and throw the mass up the fall in drops reforming into a close column of ascending water.

Extract 3 (from 'The Nature of the Physical World', Sir Arthur Stanley Eddington, 1927)

Let us draw an arrow arbitrarily. If as we follow the arrow we find more and more of the random element in the state of the world, then the arrow is pointing towards the future; if the random element decreases the arrow points towards the past … I shall use the phrase "time's arrow" to express this one-way property of time.

Extract 4 (Feynman Lectures on Physics volume 1, Richard Feynman, 1963)

Are all the laws of physics reversible? Evidently not! Just try to unscramble an egg! Run a moving picture backwards, and it takes only a few minutes for everybody to start laughing. The most natural characteristic of all phenomena is their obvious irreversibility. Where does this irreversibility come from? It does not come from Newton's laws.

(a) Name the law referred to in Extract 1 by the statement

(i) the energy of the world is constant,

....

(ii) its entropy tends to a maximum,

....
[1]

(b) State which of the two laws identified in **(a)** is irreversible and explain why.

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.... [1]

For Examiner's Use

(c) **(i)** In Extract 4, Richard Feynman refers to the process of scrambling an egg (breaking the egg into a bowl and mixing up its contents by stirring it).

Use this example to explain what is meant by entropy and entropy change.

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.... [3]

(ii) Explain why continuous stirring never unscrambles the egg.

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.... [3]

(d) Explain what is meant by the *Thermodynamic Arrow of Time*.

For Examiner's Use

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.... [2]

(e) (i) Imagine a universe which just consists of an empty closed box.

Explain why it would not be possible to define a thermodynamic arrow of time in such a universe.

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.... [2]

(ii) Now imagine a universe which just consists of a closed box containing 50 gas particles.

Discuss whether it would be possible to define an arrow of time in such a universe.

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.... [3]

For Examiner's Use

(iii) Explain whether the arrow of time could ever reverse in the imagined universe of **(ii)**.

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.... [2]

(f) Collisions between individual molecules at a microscopic level are governed by time-reversible laws (e.g. Newton's Laws).

Explain how irreversible large-scale behaviour (such as that described in Extract 2) can arise from these underlying reversible laws.

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.... [3]

[Total: 20]

End of Section B