Cambridge Pre-U

Cambridge International Examinations
Cambridge Pre-U Certificate

CANDIDATE NAME			
CENTRE NUMBER		CANDIDATE NUMBER	

7076115222

PHYSICS (PRINCIPAL) **9792/03**

Paper 3 Written Paper **May/June 2016**

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 an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

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

Section 2
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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12	
13	
Total	

The syllabus is approved for use in England, Wales and Northern Ireland as a Cambridge International Level 3 Pre-U Certificate.

This document consists of **42** printed pages and **2** blank pages.

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Data

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

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	$\lambda = \frac{ax}{D}$
Rayleigh criterion	$\theta \approx \frac{\lambda}{b}$
photon energy	$E = hf$
de Broglie wavelength	$\lambda = \frac{h}{p}$
simple harmonic motion	$x = A\cos\omega t$
	$v = -A\omega\sin\omega t$
	$a = -A\omega^2\cos\omega t$
	$F = -m\omega^2 x$
	$E = \frac{1}{2}mA^2\omega^2$
energy stored in a capacitor	$W = \frac{1}{2}QV$
capacitor discharge	$Q = Q_0 e^{-\frac{t}{RC}}$
electric force	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = -\frac{Gm_1 m_2}{r^2}$
gravitational potential energy	$E = -\frac{Gm_1 m_2}{r}$
magnetic force	$F = BIl\sin\theta$
	$F = BQv\sin\theta$

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

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Section 1

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

1 **(a)** **(i)** In Napoleonic times the original definition of the metre was one ten millionth (1/10 000 000) of the distance from the equator to the poles, along the Earth's surface. Use this value to calculate the average value for the radius of the Earth.

radius of the Earth = ... m [1]

(ii) The accepted value for the polar radius of the Earth is currently 6357 km. Calculate the percentage error in the value you obtained in **(a)(i)**.

error = ... % [2]

(b) A satellite of mass 95.0 kg is placed in a circular geostationary orbit around the Earth. The mass of the Earth is 5.97×10^{24} kg.

(i) Calculate the orbital period of a geostationary satellite.

period = ... s [1]

(ii) A geostationary satellite remains above the same point on the Earth. Explain why it must orbit the Earth from west to east directly above the equator.

....

....

....

....

....[2]

(c) The radius R of the orbit of the geostationary satellite is 4.23×10^7 m. Gravitational potential energy E_p of the satellite in **(b)** is given by

$$E_p = -\frac{GMm}{R}.$$

(i) Calculate the gravitational potential energy E_p of the satellite.

E_p = ... J [1]

(ii) **1.** Calculate the kinetic energy E_k of the satellite.

E_k = ... J [2]

2. Comment on the relationship between the values of E_p and E_k.

....

....[1]

(iii) Values calculated in **(c)(i)** and **(c)(ii)** apply to stable, circular orbits of radius *R*.

Put the values you obtained in **(c)(i)** and **(c)(ii)** into the table and complete it for stable orbits of different radii.

radius of orbit	gravitational potential energy / 10^8 J	kinetic energy / 10^8 J	total energy / 10^8 J
geostationary orbit *R*			
2*R*		+2.25	−2.25
10*R*			
infinity			

[4]

(iv) A probe of mass 95.0 kg could be launched from a geostationary orbit with an additional kinetic energy of 4.50×10^8 J.

Explain why such a probe would not be very effective for a journey to Mars, even if pointing in the correct direction.

....

....

....[2]

[Total: 16]

2 **(a)** **(i)** The natural frequency of an oscillating system is f_o. The oscillating system is lightly damped.

On Fig. 2.1, sketch a graph to show how the amplitude of a forced oscillation changes with the driver frequency. Label this graph A. [2]

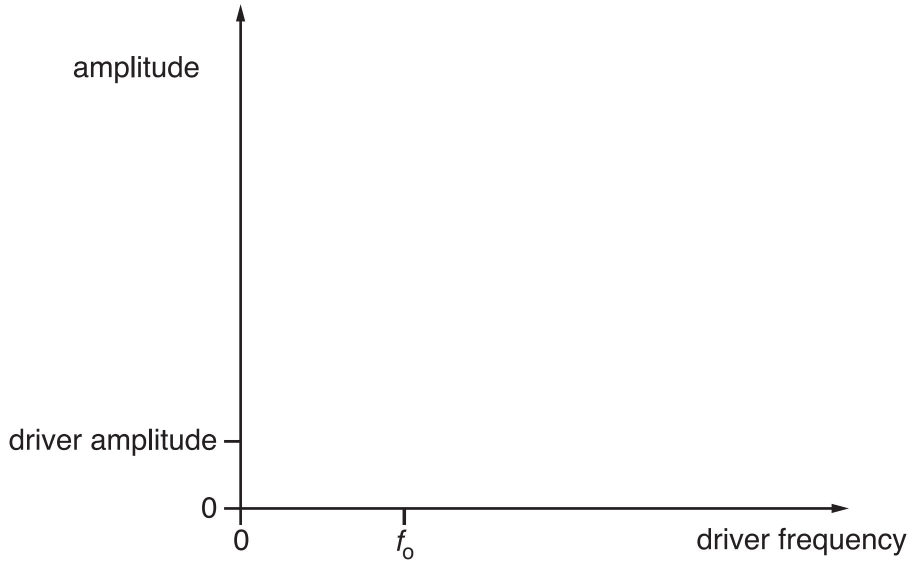

Fig. 2.1

(ii) On Fig. 2.1, sketch a second graph to illustrate the effects of increased damping. Label this graph B. [2]

(b) Suggest why the amplitude of the forced oscillation tends towards zero as the frequency of the driver increases.

....

....

....[2]

(c) Resonant oscillations are used in many electronic circuits. Tuning a radio to a particular frequency is one such use. These circuits use the transference of energy backwards and forwards between a capacitor and a coil of wire. When a capacitor with a capacitance C is connected to a coil, the frequency of resonance f is given by

$$f = \frac{1}{2\pi\sqrt{LC}}.$$

The symbol L represents a property of the coil called its inductance. The SI unit of inductance is the henry, H.

(i) Calculate the capacitance of a capacitor required for resonance at a frequency of 5.2 MHz when the inductance of the coil is 8.6 μH.

capacitance = ... F [3]

(ii) Calculate the wavelength of a radio wave of frequency 5.2 MHz.

wavelength = ... m [1]

[Total: 10]

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3 **(a)** **(i)** State what is meant by an *electric field*.

....

....[1]

(ii) Show that the electric field strength at a point in a uniform electric field is equal to the size of the potential gradient at the point.

[2]

(b) Fig. 3.1 shows a positively charged metal sphere surrounded on three sides by an earthed metal shield at zero potential.

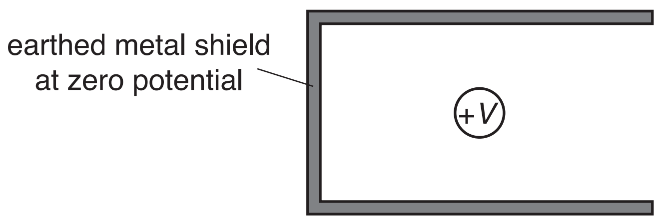

Fig. 3.1

(i) On Fig. 3.1, illustrate the shape of the field (in the plane of the paper) within and beyond the shield by drawing field lines from the sphere to the shield and in the space beyond the open end. [4]

(ii) The electrical potential of the metal sphere in Fig. 3.1 is $+V$.

On Fig. 3.1, draw **three** labelled equipotential lines at approximate potentials of $\frac{1}{4}V$, $\frac{1}{2}V$ and $\frac{3}{4}V$. [2]

(c) At a large distance from the shield, the charge and shield system could be considered as a point charge of 7.2×10^{-8} C. This value is lower than the charge on the sphere.

(i) Calculate the electric field strength at a large distance of 2.8 m from this point charge.

electric field strength = ... N C^{-1} [2]

(ii) The shield is maintained at zero potential by connecting it to earth. Explain why the effective point charge of 7.2×10^{-8} C is less than the charge on the sphere.

....

....[1]

[Total: 12]

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4 A nylon cord is used in a parachute between the parachute canopy and the parachutist. Samples of the cord material, of circular area of cross-section and different lengths, are available for testing.

(a) Describe a suitable experiment to determine the Young modulus of the nylon. Draw a diagram of the set-up.

....

....

....

....[5]

(b) When a rapidly falling parachutist opens the parachute canopy the nylon cord must be strong enough not to break.

Outline a method for determining the maximum energy that can be stored in a sample length of the cord before it breaks, when the cord is subjected to a sudden force. You may draw a diagram to illustrate your method.

....

....

....

....[4]

[Total: 9]

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5 A heat engine, such as a car engine, is a device that converts thermal energy into mechanical work. The efficiency of a heat engine in converting thermal energy into work is of huge commercial importance. A French physicist, named Sadi Carnot, showed in 1810 that any heat engine working between a high temperature T_1 and a low temperature T_2 has a maximum possible efficiency given by

$$\text{efficiency} = \frac{T_1 - T_2}{T_1}.$$

(a) **(i)** Calculate the maximum possible percentage efficiency of an ideal heat engine working between a high temperature of 900 K (627 °C) and a low temperature of 300 K (27 °C).

efficiency = ...% [1]

(ii) Show that a typical diesel engine, with a high temperature of 1500 K, is more efficient than a typical petrol engine with a high temperature of 1250 K.

[2]

(iii) For a car engine, suggest one factor that limits the maximum value of T_1, and one that limits the minimum value of T_2.

T_1 ....

....

T_2 ....

....[2]

(b) A heat engine operates when a fixed amount of gas repeatedly expands and contracts. The cycle of expansion and contraction that gives the maximum possible efficiency for an engine is called the Carnot cycle. It is illustrated graphically, for a fixed quantity of an ideal gas, in Fig. 5.1.

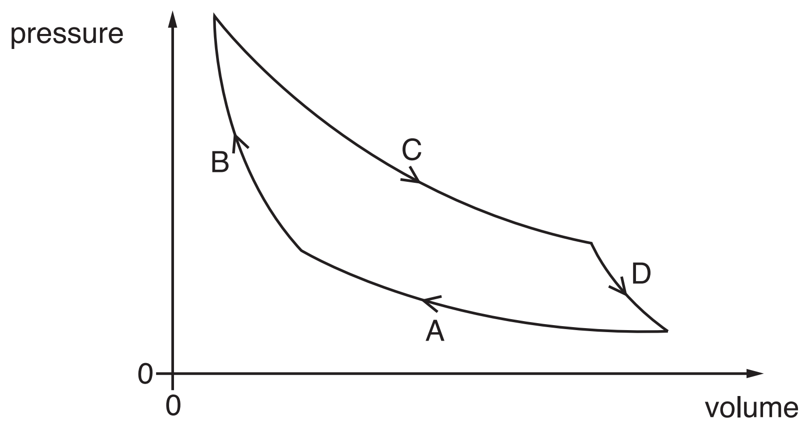

Fig. 5.1 (not to scale)

The cycle for the heat engine consists of four stages, A, B, C and D.

A	a slow compression of gas at a constant temperature
B	a sudden compression of the gas causing a rise in temperature
C	a slow expansion of the gas at a constant temperature
D	a sudden expansion back to its original pressure, volume and temperature

(i) Explain the following facts about the cycle of changes in Fig. 5.1.

1. At the end of all four stages in one cycle the change in the internal energy of the gas must be zero.

....

....[2]

2. During stage A there is no change in the internal energy of the gas.

....

....[1]

3. During stage C the work done on the gas is negative.

....

....[1]

(ii) Complete the table for the four stages of the Carnot cycle represented in Fig. 5.1.

stage	thermal energy supplied **to** gas /J	work done **on** gas /J	**increase** in internal energy of gas /J
A		+702	0
B		+844	+844
C		−936	
D	0		

[4]

(iii) Deduce the percentage efficiency of this cycle.

efficiency = ... % [2]

[Total: 15]

6 **(a)** Sketch a graph showing how the relative intensity of light from a hot body varies with the wavelength of the light.

[1]

(b) **(i)** The Sun has a surface temperature of 5800 K and the wavelength of light of maximum intensity occurs at a wavelength of 520 nm. A distant star has its wavelength of maximum intensity at a wavelength of 210 nm.

Calculate the surface temperature of the distant star.

temperature = ... K [1]

(ii) Using data from similar stars it is estimated that the surface area of the distant star is $6.3 \times 10^{17}\,m^2$. From your answer in **(b)(i)** calculate the approximate luminosity of the star.

luminosity = ... W [2]

(iii) The intensity of radiation incident on the Earth from the distant star is $1.60 \times 10^{-9}\,W\,m^{-2}$. Estimate the distance of the star from the Earth.

distance = ... m [2]

[Total: 6]

7 **(a)** **(i)** Write an equation for the decay of uranium $^{238}_{92}U$ by the emission of an alpha particle to form a thorium (Th) nucleus.

[1]

(ii) Write an equation for the decay of this thorium nucleus by the emission of a beta particle to form a protactinium (Pa) nucleus.

[2]

(b) The proton number of radon is 86. Radon-222 is a radioactive gas that can be formed by radioactive decay from uranium-238.

State the number of alpha decays and the number of beta decays that are needed for radon-222 to be formed.

number of alpha decays ....

number of beta decays ....
[2]

(c) **(i)** Radon-222 decays by emitting an alpha particle of energy 5.48 MeV. Express the mass equivalent of this energy in unified atomic mass units.

mass = ... u [3]

(ii) The half-life of radon-222 is 3.83 days. A sample of radon-222 has an initial activity A_0. After 20 days the activity of the sample is A.

Determine the ratio $\frac{A}{A_0}$.

$\frac{A}{A_0}$ = ... [2]

(d) Radon-222 gas poses a health hazard in various parts of the UK by being emitted from certain types of rock. The radioactive gas could build up in houses and be breathed in by the residents.

Suggest how people living in the areas concerned might be protected from radon gas seeping into their houses.

....

....

....

....[2]

[Total: 12]

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Section 2 starts on the next page.

Section 2

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

8 A pacemaker is an electrical device that delivers short pulses of energy to the heart.

(a) The emf E of a pacemaker battery is 2.80 V. Explain what is meant by an *emf of 2.80 V*.

....

....[2]

(b) A student uses a circuit to determine the internal resistance r of a pacemaker battery of emf E. The circuit contains a milliammeter, a fixed resistor of resistance R_F and a set of known resistors of different resistance, R. These are connected using switch S, as shown in Fig. 8.1.

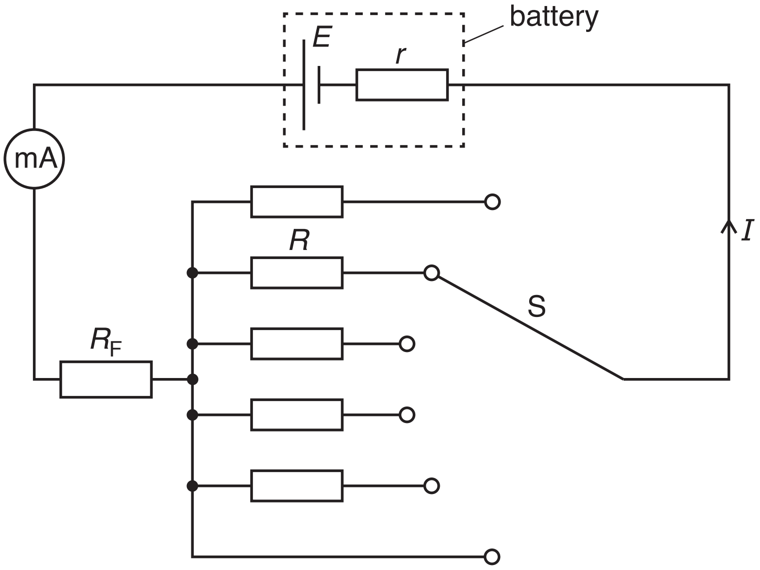

Fig. 8.1

(i) State an expression for the emf E in terms of R_F, R, r and the current, I.

....[1]

(ii) The student measures the p.d. V_F across the fixed resistor of resistance R_F and the p.d. V across the selected resistor of 180 Ω as shown in Fig. 8.2.

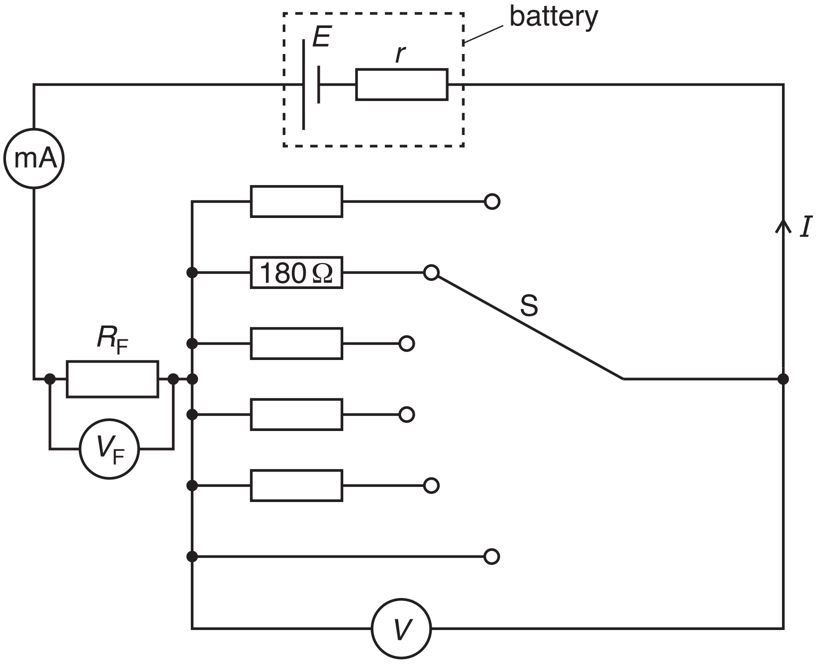

Fig. 8.2

The table shows a selection from the student's results.

resistance	R / Ω	180
emf of battery	E / V	2.80
potential difference across R	V / V	1.63
potential difference across R_F	V_F / V	0.45

Select values from the table to determine the value of the fixed resistor R_F and a value for the internal resistance r.

R_F = ... Ω

r = ... Ω

[3]

(iii) The student records the current I for each value of R. He plots a graph of R against $\frac{1}{I}$. Fig. 8.3 shows the shape of his graph.

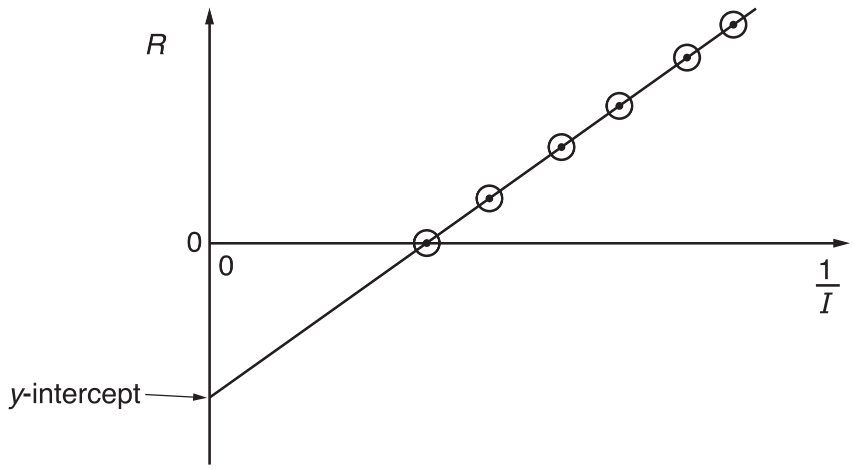

Fig. 8.3

State the physical significance of the gradient **and** the *y*-intercept on the graph.
You may use the space below to do any necessary working.

gradient ....

y-intercept ....
[2]

(c) The pacemaker battery charges a capacitor which then discharges, delivering a short pulse of energy to the heart.

The specifications required of the pacemaker are that it produces regular pulses with a maximum value of 2.80 V, with each pulse delivering a total energy of 18.2 μJ in about 1.0 ms. Assume that all of this energy comes from the complete discharge of a 4.20 μF capacitor.

(i) Calculate the mean current delivered during each pulse.

current = ... A [2]

(ii) The pacemaker delivers 60 pulses each minute and the battery has an energy capacity of 5900 J.

Show that the maximum battery life of the pacemaker battery is about 10 years.

[1]

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[Turn over

(d) The student uses a pacemaker battery to fully charge a capacitor of capacitance C to an initial voltage V_0. He then discharges the capacitor through a sample of heart tissue of resistance R. His data-logger records the instantaneous voltage V across the tissue against time t. Fig. 8.4 shows the student's results.

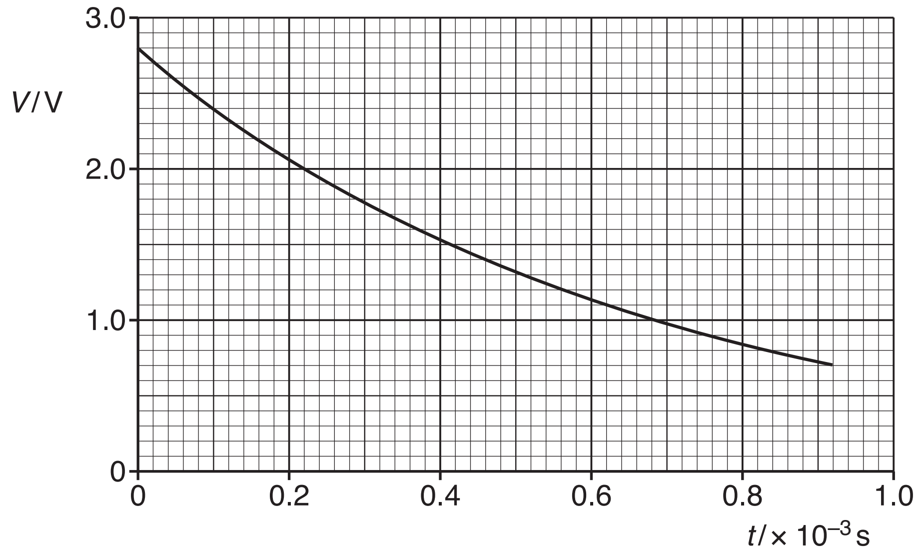

Fig. 8.4

The voltage V and the time t are related by the expression

$$V = V_0 e^{-t/CR}.$$

(i) Show that the expression $V = V_0 e^{-t/CR}$ is a solution to the differential equation $\frac{dV}{dt} = -\frac{V}{CR}$.

[1]

(ii) Deduce the expression for the time $t_{\frac{1}{2}}$ taken for the voltage V to fall from V_0 to $\frac{V_0}{2}$.

[2]

(iii) The emf of the battery is 2.80 V and the capacitor has a capacitance of 4.40 μF.

1. Use values from the graph in Fig. 8.4 and your expression in **(d)(ii)** to determine the resistance of the heart tissue.

resistance = ... Ω [2]

2. The capacitor had an initial stored energy of 18.2 μJ. Determine the time taken for the discharging capacitor to deliver 99 % of this energy, leaving 0.182 μJ in the capacitor.

time = ... s [4]

[Total: 20]

9 A theme-park ride consists of two cages. They are moving in a circular path at constant speed *v* about a horizontal axis. Fig. 9.1 shows the ride at one instant when cage A is vertically above cage B.

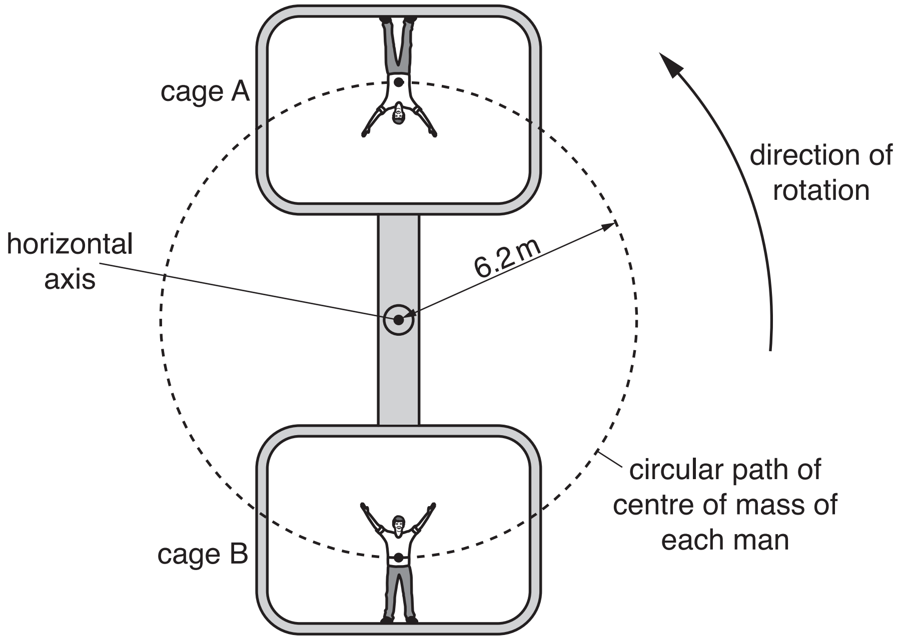

Fig. 9.1 (not to scale)

(a) A man is riding in each cage. The mass of each man is 75 kg. The centre of mass of each man is 6.2 m from the horizontal axis. The time period of one rotation is 4.1 s.

(i) Determine the speed *v* of the centre of mass of each man.

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

(ii) Calculate the magnitude of the acceleration of the centre of mass of each man.

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

(b) Fig. 9.2 shows the forces acting on the man in cage B at the instant the cages are in the positions shown. It shows the man in cage A at that same instant.

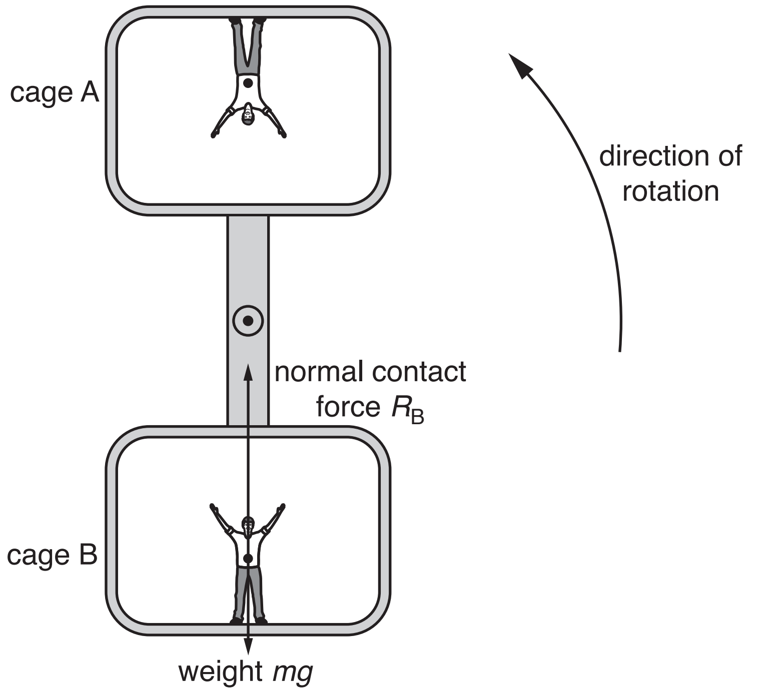

Fig. 9.2 (not to scale)

(i) On Fig. 9.2, mark labelled arrows to represent the magnitude and direction of the forces acting on the man in cage A. [2]

(ii) Calculate the magnitude of the normal contact force R_A on the man in cage A at this instant.

R_A = ... N [2]

(c) **(i)** Explain why a minimum value for the speed is needed for the man in cage A to maintain contact with the floor of his cage.

....

....

....

....[2]

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(ii) Derive an expression for this minimum speed and calculate its value.

minimum speed = ... $m\,s^{-1}$ [3]

(d) When several more people ride in each of the cages it is found that this ride takes longer to accelerate from rest to the same final angular velocity.

By considering the moment of inertia I of the ride and the torque T on the system, discuss why this should be the case.

State and make reference to any relevant formulae.

....

....

....

....

....

....

....

....

....[4]

(e) Fig. 9.3 shows another theme-park ride called the pirate ship. It consists of a gondola that oscillates about a horizontal axis.

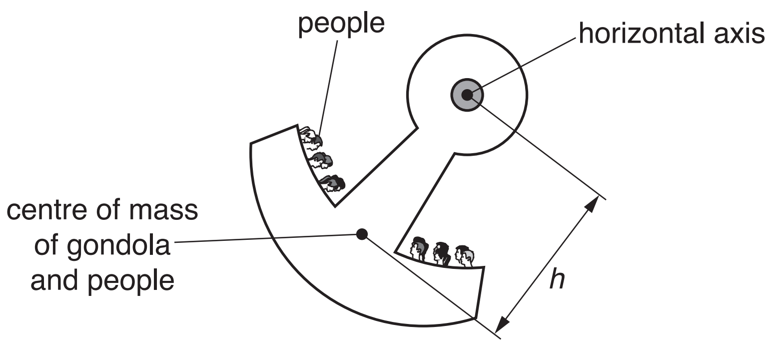

Fig. 9.3 (not to scale)

The gondola (with people) is a compound pendulum with moment of inertia I_P and a period P where

$$P = 2\pi\sqrt{\frac{I_P}{Mgh}}\ .$$

The meaning of some of the terms in this expression and values are listed in the table.

period of oscillation P	12.6 s
mass of gondola and people M	1.72×10^4 kg
moment of inertia about horizontal axis I_p	3.04×10^6 kg m^2

The distance from the centre of mass to the horizontal axis is h.
Determine the value of h.

h = ... m [3]

[Total: 20]

10 **(a)** **(i)** State Kepler's first two laws of planetary motion.

1. ....

....

2. ....

....
[2]

(ii) Kepler's third law of planetary motion states that T^2 is proportional to r^3, where T is the orbital period of a planet, r is the mean distance of the planet from the Sun and G is the gravitational constant.

1. Use Newton's law of gravity and centripetal force to show that

$$T^2 = \frac{4\pi^2 r^3}{GM}.$$

[2]

2. Kepler's third law can be verified by plotting a graph of ln T against ln r.

State an expression for the intercept on the ln T axis and a value for the gradient for such a graph.

[3]

(b) The moons of Uranus move round the planet in near-circular orbits. The mean orbital distance and period of four of the moons of Uranus are given in the table below.

moon	period T/hours	mean orbital distance from Uranus r/km	ln (T/hours)	ln (r/km)
Ariel	60.5	192 000	4.10	12.165
Umbriel	99.5	266 000	4.60	12.491
Titania	209	436 000	5.34	12.985
Oberon	323	582 000	5.78	13.274

(i) Use the values in the table and the axes given in Fig. 10.1 to plot a graph of ln (T/hours) against ln (r/km) for the four moons of Uranus. [2]

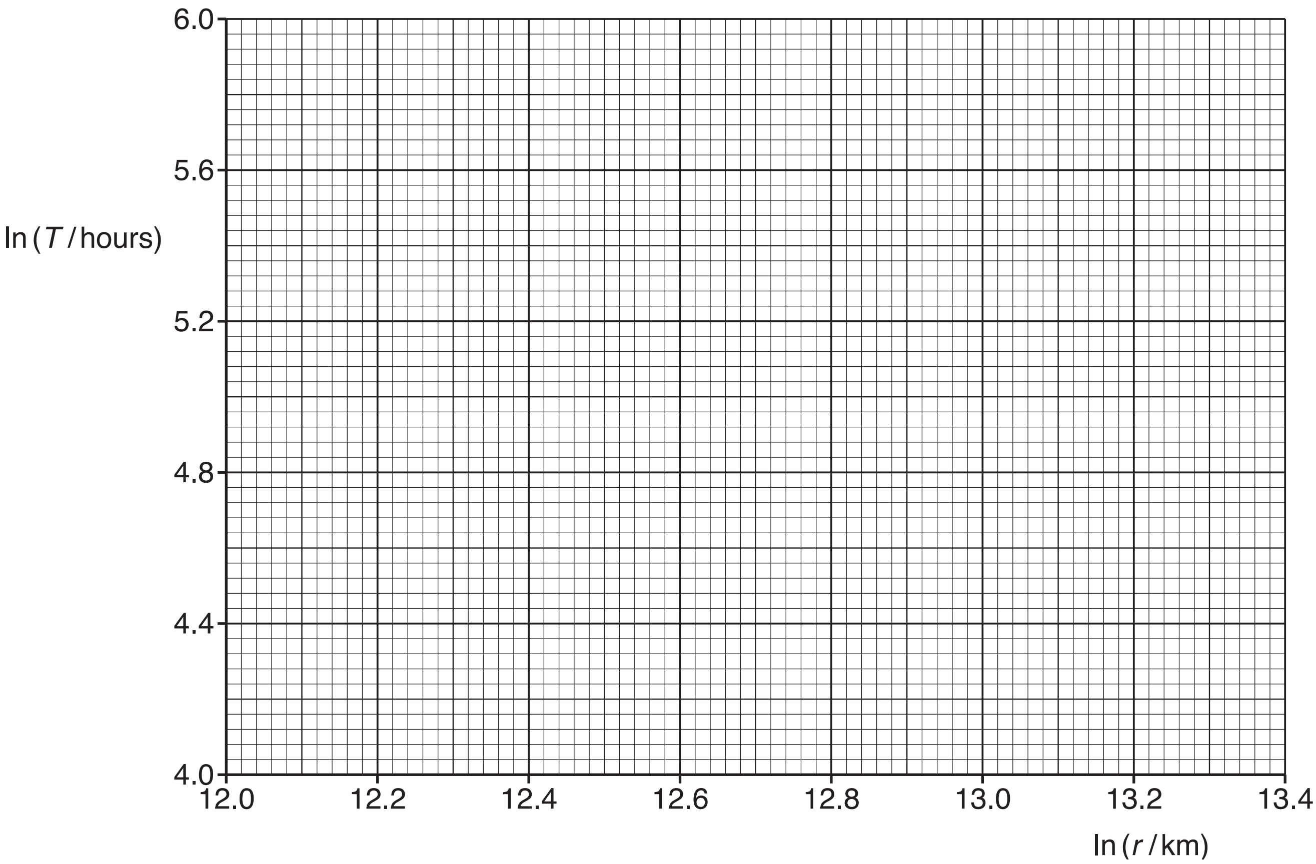

Fig. 10.1

(ii) **1.** Determine an accurate value for the gradient of your graph in Fig 10.1.

gradient ....[2]

2. Explain how your graph supports the suggestion that T^2 is proportional to r^3 for the moons of Uranus.

....

....

....[1]

(iii) Another moon of Uranus has a period of 153 hours. Use your graph to determine its mean orbital distance from Uranus.

distance = ... km [1]

(iv) Use the information you have about Oberon and the relationship in **(a)(ii)1** to determine a value for the mass of Uranus.

mass of Uranus = ... kg [3]

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(c) Gravitational fields and electric fields are similar in that they can both be described as regions in which force is applied to an object.

State, in words, two further similarities **and** two differences between gravitational and electric fields.

similarity 1 ....

....

similarity 2 ....

....
[2]

difference 1 ....

....

difference 2 ....

....
[2]

[Total: 20]

11 Fig. 11.1 shows the results of a double-slit experiment using electrons that was carried out by Tonomura in 1980.

$t = 0.10\,\text{s}$		11 electrons
$t = 1.7\,\text{s}$		200 electrons
$t = 51\,\text{s}$		6000 electrons
$t = 5$ minutes $42\,\text{s}$		40 000 electrons
$t = 20$ minutes		140 000 electrons

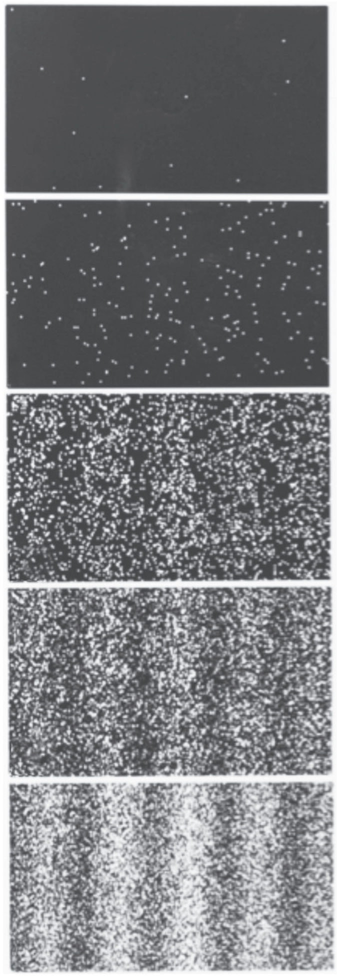

Fig. 11.1

The experiment was set up so that the electrons passed through the apparatus one at a time. Fig. 11.1 shows how the pattern of electrons hitting the screen developed over a period of 20 minutes. Each bright spot represents a place where one electron hit the screen.

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(a) The experimental arrangement used by Tonomura was very similar to the arrangement that could be used to demonstrate the double-slit interference pattern for single photons.

Draw a simplified, labelled diagram to show how such an experiment could be set up with single electrons.

[4]

(b) Explain how the images in Fig. 11.1 show that electrons exhibit both particle-like and wave-like properties.

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(c) The image in Fig. 11.1 shows that after 20 minutes a regular pattern has formed.

(i) State and explain what this regularity implies about the velocities of the electrons used in the experiment.

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(ii) Explain how the Copenhagen Interpretation accounts for the way in which this regular pattern built up.

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(d) The intensity of the electron beam used in this experiment was so low that electrons passed through the apparatus one at a time.

Use the sum-over-histories approach to explain why two successive electrons, approaching the apparatus in exactly the same way, are likely to end up at different positions on the screen.

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(e) Explain what is meant by a *deterministic* theory.

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(f) Explain how this experiment shows that quantum theory is indeterministic.

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[Total: 20]

12 In physics, a variety of different models can be used to represent physical reality and it is always important to be aware of the limitations of our models.

(a) One example is the kinetic theory which treats gases as a collection of tiny particles. The particles are in rapid random motion and they interact only by elastic collisions with each other and with the walls of their container. This model can be used to derive the ideal gas equation $pV = nRT$.

Explain why this model might break down

(i) when gases are under very high pressure,

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(ii) when gases are heated to very high temperatures,

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(iii) when gases are cooled to very low temperatures.

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(b) Newton used a model of absolute time and absolute space as a background for his laws of motion.

(i) Explain why this model breaks down when we use it to explain the meaning of the *speed of light*.

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(ii) We all assume that we share the same absolute time in our everyday lives. Einstein's time dilation equation is given by the expression

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

Use Einstein's time dilation equation to explain quantitatively why the model of absolute time works for everyday life, even when applied to aircraft moving at about 300 m s^{-1}.

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(c) Young used a wave model to explain the observed pattern in the double-slit experiment. Einstein used a particle model to explain the photoelectric effect. Neither model is capable of explaining all aspects of the behaviour of light.

(i) State two aspects of the photoelectric effect that cannot be explained by a **wave** model.

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(ii) State two aspects of Young's double-slit experiment that cannot be explained by a **particle** model.

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(d) The table shows data relating to the Moon orbiting the Earth and an electron orbiting the nucleus of a hydrogen atom.

	Moon orbiting Earth	electron orbiting nucleus
mass / kg	7×10^{22}	9×10^{-31}
speed / m s^{-1}	1×10^{3}	2×10^{7}
orbital radius / m	4×10^{8}	5×10^{-11}

(i) Use the data in the table to determine

1. the de Broglie wavelength of the Moon orbiting the Earth,

wavelength = ... m

2. the de Broglie wavelength of the electron orbiting the nucleus.

wavelength = ... m
[3]

(ii) Use your answers to **(d)(i)** to explain why it is reasonable to treat the Moon in orbit around the Earth as a particle, but it is not reasonable to treat the electron in orbit around the nucleus as a particle.

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[Total: 20]

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13 **(a)** The second law of thermodynamics states that the entropy of an isolated system tends to a maximum and does not decrease. Explain what is meant by an *isolated system* in this context and explain why it is important that the system is isolated.

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(b) State and explain the condition under which a system of interacting bodies obeys the law of conservation of momentum.

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(c) **(i)** Explain why living things **appear** to violate the second law of thermodynamics.

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(ii) Explain why living things do **not** actually violate the second law of thermodynamics.

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(d) **(i)** Explain, in terms of *numbers of ways*, why cooling something down involves decreasing its entropy.

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(ii) Explain how it is possible for a refrigerator to cool things down without violating the second law of thermodynamics.

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(e) Discuss what the second law of thermodynamics implies about the past and future of the universe.

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(f) Energy is conserved and yet governments are concerned that global energy resources are running out. Use the second law of thermodynamics to explain this apparent contradiction.

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[Total: 20]

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