Cambridge Pre-U

CANDIDATE NAME	

CENTRE NUMBER		CANDIDATE NUMBER	

* 2 2 0 2 6 1 4 4 4 4 *

PHYSICS **9792/03**

Paper 3 Written Paper **October/November 2020**

3 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS
- Section 1: answer **all** questions.
- Section 2: answer **three** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION
- The total mark for this paper is 140.
- The number of marks for each question or part question is shown in brackets [ ].

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

DC (LO) 208248

[Turn over

Data

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

Formulae

uniformly accelerated motion

$$s = ut + \tfrac{1}{2}at^2$$

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

$$s = \left(\frac{u+v}{2}\right)t$$

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	$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$
electrostatic potential energy	$W = \frac{Q_1Q_2}{4\pi\varepsilon_0 r}$
gravitational force	$F = -\frac{Gm_1m_2}{r^2}$
gravitational potential energy	$E = -\frac{Gm_1m_2}{r}$
magnetic force	$F = BIl\sin\theta$
	$F = BQv\sin\theta$
electromagnetic induction	$E = -\frac{\mathrm{d}(N\Phi)}{\mathrm{d}t}$
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	$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda N$
	$N = N_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
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	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

Section 1

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

1 In a simple model of the structure of the atom, a hydrogen atom can be thought of as consisting of an electron in circular orbit around a proton, as shown in Fig. 1.1.

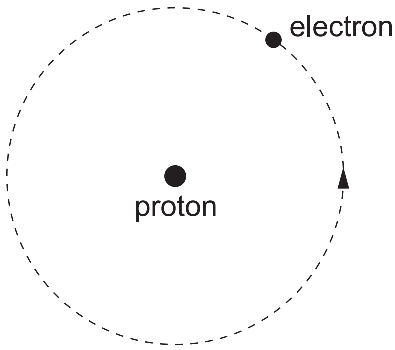

Fig. 1.1

(a) **(i)** Explain why a centripetal force acts on the electron in Fig. 1.1.

....

....

.... [2]

(ii) State the expression, in terms of the elementary charge e and the radius r of the orbit, for the electrostatic force F acting on the electron.

[1]

(iii) State the expression, in terms of the orbital speed v of the electron, the mass m of the electron, and r, for the centripetal force F acting on the electron.

[1]

(iv) Show, using your answers in **(a)(ii)** and **(a)(iii)**, that v is given by

$$v = \frac{e}{\sqrt{4\pi\varepsilon_0 mr}}.$$

[1]

(b) The electric potential energy E_P of the orbiting electron is given by

$$E_P = -\frac{e^2}{4\pi\varepsilon_0 r}.$$

Use this expression, and the answer in **(a)(iv)**, to show that the total energy E_T of the orbiting electron is given by

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r}.$$

[3]

(c) The ground state energy of an electron in a hydrogen atom is –13.6 eV.

Use the expression in **(b)** to calculate the radius of orbit of an electron in its ground state in a hydrogen atom.

radius = ... m [3]

[Total: 11]

2 A student investigates the motion of a small steel ball in a smooth bowl. The bowl can be considered to form part of the surface of a sphere of radius r. The steel ball is initially in its equilibrium position at the lowest part of the bowl, as shown in Fig. 2.1.

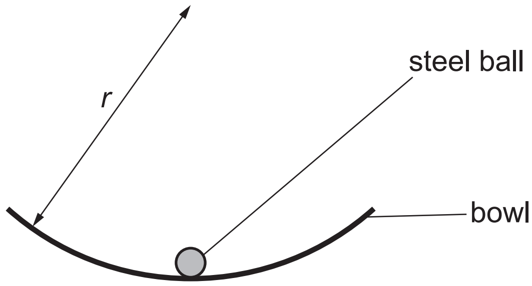

Fig. 2.1

The student displaces the ball along an arc of length x as shown in Fig. 2.2.

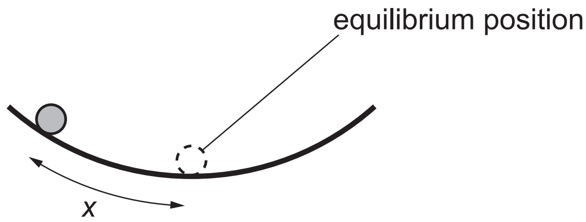

Fig. 2.2

The student now releases the ball and observes it as it oscillates about its equilibrium position.

(a) By considering the forces acting on the ball, show that the ball has an approximate acceleration a towards its equilibrium position given by

$$a = \frac{gx}{r}$$

where g is the gravitational field strength. Ignore any rotation of the ball.

[3]

(b) (i) Explain how the information in **(a)** demonstrates that the motion of the ball is approximately simple harmonic.

....

....

.... [2]

(ii) Show, with reference to the defining equation of simple harmonic motion $a = -\omega^2 x$, that the period T of the oscillations of the ball is given by

$$T = 2\pi\sqrt{\frac{r}{g}}.$$

[2]

(iii) Explain how the motion of the ball makes it possible for the period of the oscillations to be independent of their amplitude.

....

....

.... [1]

(c) The student decides to time 10 complete oscillations of the ball in order to determine *T*. The student takes four sets of measurements.

11.82 s   11.78 s   13.12 s   11.91 s

(i) Identify one precaution that the student can take to ensure that the timing starts and stops at the same point in the motion of the ball.

....

....

.... [1]

(ii) One of the measurements is anomalous.

Suggest an explanation for the anomalous measurement.

....

.... [1]

(iii) Use the measurements of the student to determine the value of *T*. Give your answer to an appropriate number of significant figures.

T = ... s [2]

(d) Explain why, when carrying out the measurements to determine *T*, the student:

(i) measures the time for 10 oscillations rather than for 1 oscillation

....

.... [1]

(ii) repeats these measurements.

....

.... [1]

(e) Use your answer in **(c)(iii)** to calculate the radius *r* of the bowl.

r = ... m [1]

[Total: 15]

3 A capacitor of capacitance C is charged so that it has a potential difference (p.d.) V_0 across its plates. The capacitor is then discharged through a resistor of resistance R.

(a) Describe the transfers of charge and of energy as the capacitor discharges.

....

....

....

....

....

.... [3]

(b) **(i)** On Fig. 3.1, complete the graph to show how the current I in the resistor varies with time t until the capacitor is fully discharged.

Fig. 3.1

[2]

(ii) On Fig. 3.2, complete the graph to show how the current I in the resistor varies with the charge Q on the capacitor until the capacitor is fully discharged.

Fig. 3.2

[1]

(c) Give expressions, in terms of R, C and V_0, for:

(i) the area under the graph of Fig. 3.1

area = ... [2]

(ii) the gradient of the graph of Fig. 3.2.

gradient = ... [2]

[Total: 10]

4 A student investigates the electromotive force (e.m.f.) induced in a small coil. The small coil is fixed near to the end of a solenoid with an iron core. The solenoid is connected to a circuit, as shown in Fig. 4.1.

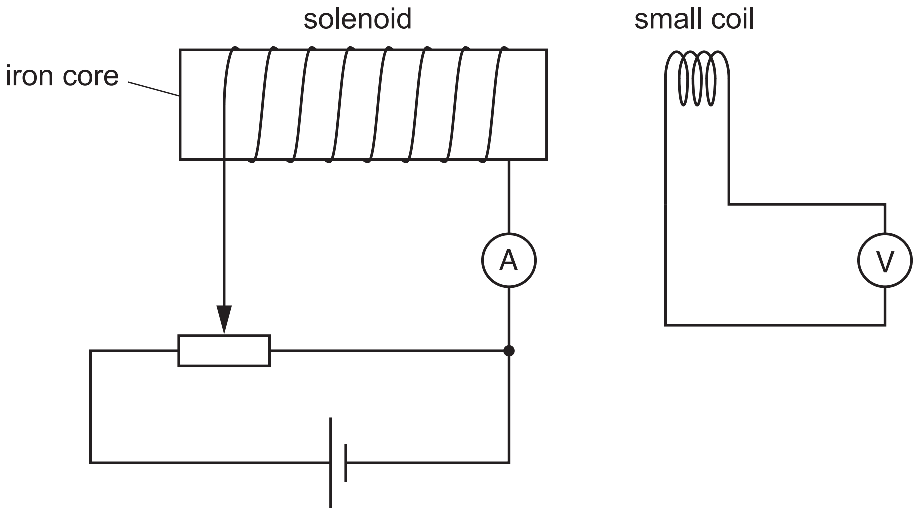

Fig. 4.1

The variable resistor is initially set so that the current in the solenoid is I_0. This current is then decreased to zero, at a constant rate, in measured time t. The e.m.f. E induced in the small coil is measured using the voltmeter.

This procedure is repeated for different values of t, so that there are five pairs of values of E and t. The results are shown in Table 4.1. The value of I_0 is measured, using the ammeter, to be 4.60 A.

Table 4.1

t/s	E/mV	
2.10	36.4	
4.04	18.8	
5.98	12.9	
8.26	9.2	
9.89	7.7	

(a) Explain why the e.m.f. E induced in the small coil is greater when the time t taken for the current to decrease from I_0 to zero is smaller.

....

....

....

....

.... [3]

(b) Calculate values of $\frac{1}{t}$ and record them in the third column of the table. Include an appropriate column heading. [3]

(c) Plot, on Fig. 4.2, a graph of E against $\frac{1}{t}$. Include an axis label for the horizontal axis, and draw a line of best fit.

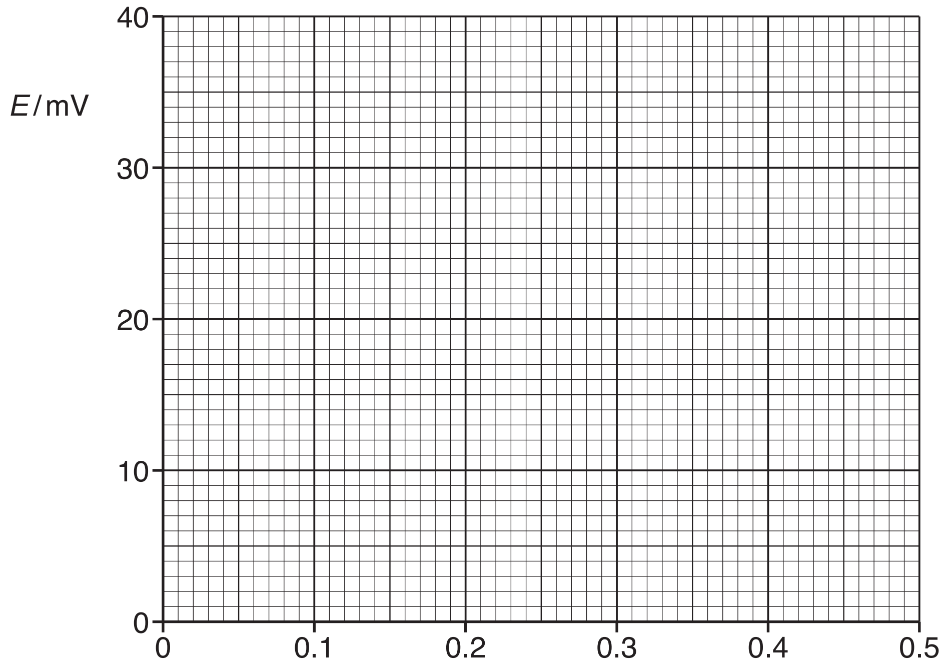

Fig. 4.2

[3]

(d) E and t are related by the equation

$$E = I_0 \frac{k}{t}$$

where k is a constant.

(i) Determine the gradient of your best-fit line in Fig. 4.2.

gradient = ... [2]

(ii) Use your answer in **(d)(i)** to determine the value of k. Include an appropriate unit for k in your answer.

k = ... unit .... [2]

(e) Suggest two modifications to the investigation that would yield a larger value of k.

1. ....

....

2. ....

....

[2]

[Total: 15]

5 (a) (i) State three assumptions made in the kinetic model of an ideal gas.

1. ....

....

2. ....

....

3. ....

....
[3]

(ii) Explain why a real gas approaches ideal behaviour at very low pressure.

....

....

....

....

....

.... [3]

(b) The characteristics of a gas at constant temperature can be displayed using a graph of pV against p, where p is the pressure exerted by the gas and V is the volume of the gas. The characteristics of 1 mole of a real gas at temperature T are shown in Fig. 5.1.

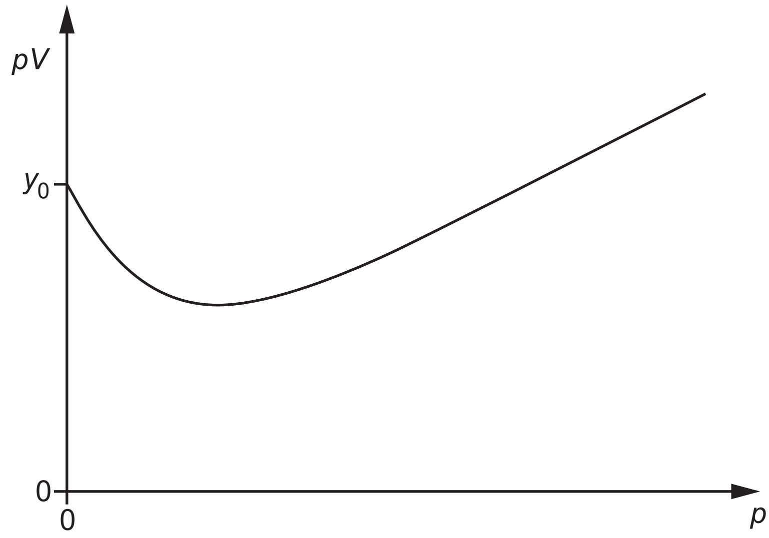

Fig. 5.1

(i) Determine an expression for the temperature T of the real gas in terms of y_0. State the meaning of any other symbols used.

[2]

(ii) Draw, on Fig. 5.1, a line to show the pV–p characteristics of 1 mole of an ideal gas at temperature T. [2]

[Total: 10]

6 **(a)** The masses of the atoms of various nuclides, and of various sub-atomic particles, are shown in Table 6.1.

Table 6.1

atom or particle	atomic number	mass / u
electron	n/a	0.000549
proton	n/a	1.007276
neutron	n/a	1.008664
helium-4	2	4.002603
thallium-205	81	204.974428
lead-209	82	208.981090
bismuth-209	83	208.980399
polonium-209	84	208.982430

(i) Bismuth-209 is radioactive.

Use the data in Table 6.1 to determine which type(s) of radiation (α, β^+, β^-) it is possible for bismuth-209 to emit. Explain your reasoning.

....

....

....

....

.... [5]

(ii) The half-life of bismuth-209 is 1.9×10^{19} years.

Estimate the number of nuclei in a 10 kg sample of bismuth-209 that are likely to disintegrate in the next 100 years.

number = ... [3]

(iii) Polonium-209 is radioactive and decays by β^+ emission.

Calculate, in MeV, the maximum kinetic energy of the β^+ particle that is emitted during the β^+ decay of one nucleus of polonium-209.

kinetic energy = ... MeV [3]

(b) Fig. 6.1 shows concrete shielding for nuclear reactors being tested for defects using a process called gamma radiometry.

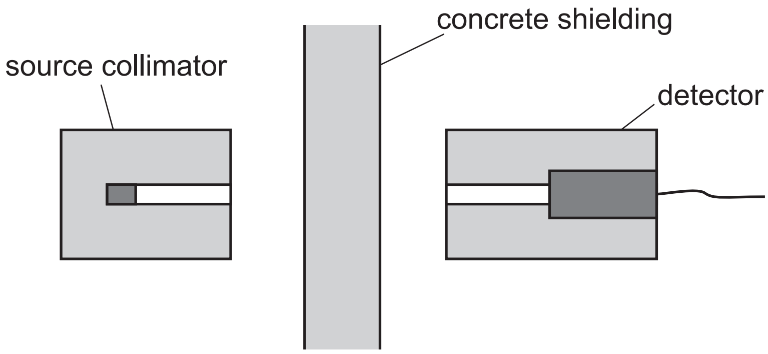

Fig. 6.1

The source collimator produces a beam of gamma radiation which is detected on the other side of the concrete shielding.

The linear attenuation coefficient of the gamma rays in concrete is 0.189 cm^{-1}.

Calculate the thickness of the concrete shielding if the intensity of the gamma ray beam at the detector is 5.00% of the intensity at the source.

thickness = ... m [3]

[Total: 14]

7 A star is observed from the Earth. The Earth is a distance of 6.04×10^{18} m away from the star.

(a) State the name of the term used by cosmologists to describe an object of known luminosity that is used to determine distances to galaxies.

....

.... [1]

(b) The light from the star that is observed from Earth is found to be redshifted.

(i) Explain what is meant by *redshift*.

....

.... [1]

(ii) State what can be deduced, from this observation, about the motion of the star.

....

.... [1]

(c) Explain how the observation of redshift in many galaxies has led to the Big Bang theory.

....

....

....

.... [2]

[Total: 5]

Section 2

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

8 **(a)** There is an analogy between linear mechanics and rotational mechanics.

(i) Complete Table 8.1 to show the rotational quantities and their SI units corresponding to the linear quantities and units. The first row has been completed for you.

Table 8.1

Linear mechanics			Rotational mechanics		
Quantity	symbol	SI unit	Quantity	symbol	SI unit
displacement	s	m	angular displacement	θ	rad
velocity	v	$\mathrm{m\,s^{-1}}$		ω	
acceleration	a	$\mathrm{m\,s^{-2}}$		α	
mass	m	kg		I	
force	F	N		Γ	

[4]

(ii) When a resultant force F acts on an object with constant mass m, the acceleration a of the mass is given by

$$a = \frac{F}{m}.$$

Write down an analogous equation for rotational motion of an object where the quantity I is constant.

[1]

(b) Fig. 8.1 shows a solid uniform disc of mass m and radius R rotating about its central axis.

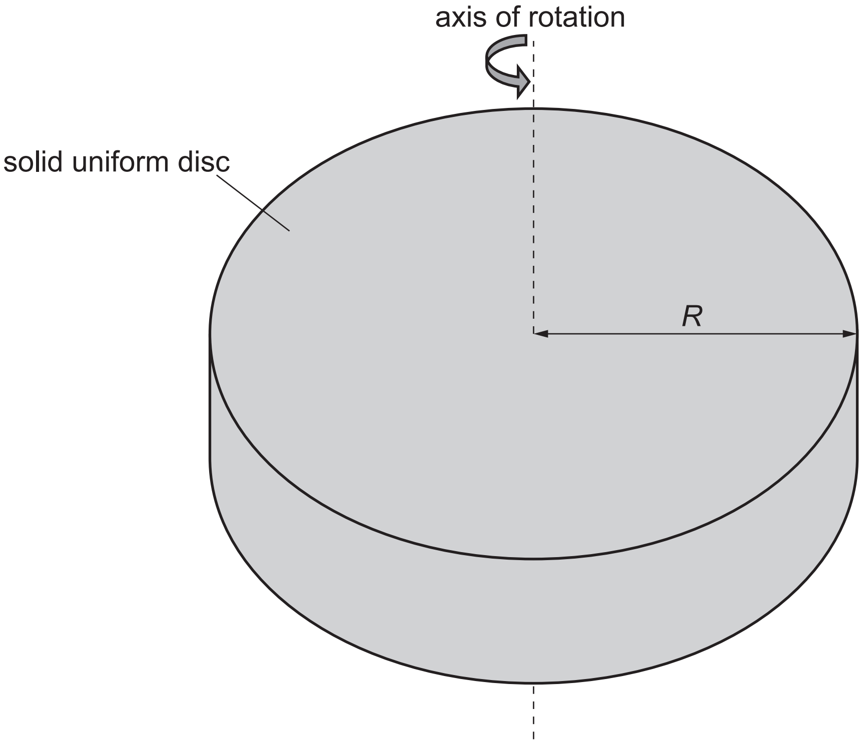

Fig. 8.1

(i) Use integration to show that the moment of inertia of this disc, rotating about its central axis, is equal to $\frac{1}{2}mR^2$. You might find it helpful to add to Fig. 8.1 or to draw your own diagram.

[4]

(ii) A large cylindrical hole of radius r is cut out of the centre of the disc shown in **(b)(i)**, as shown in Fig. 8.2.

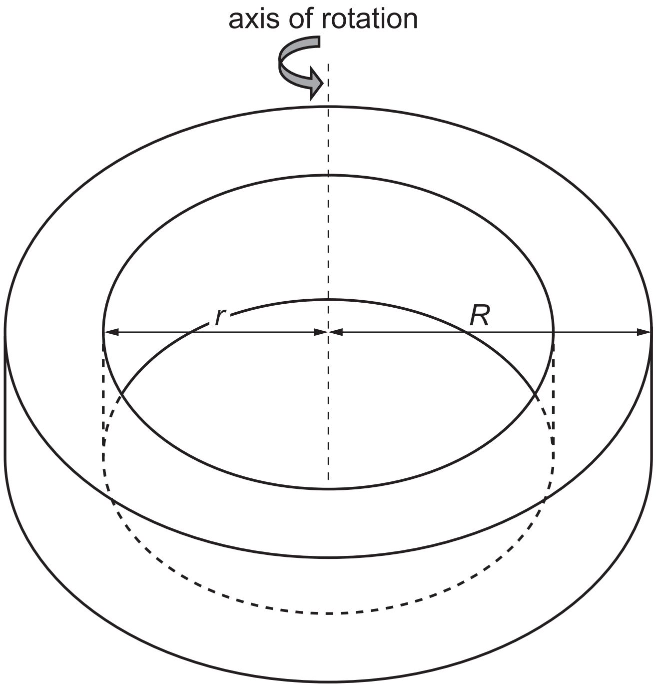

Fig. 8.2

Using your result from **(b)(i)** or otherwise, derive an expression for the moment of inertia of this uniform hollow disc about the same central axis of rotation.

[4]

(c) Towards the end of its life our Sun will lose about 50% of its mass and the remaining core will collapse into a star known as a white dwarf. A simplified model of the collapse of the core treats it as a uniform rotating sphere of mass 10^{30} kg whose radius decreases from 10^{9} m to 10^{7} m with the mass remaining constant.

The moment of inertia I of a uniform sphere of radius r and mass m is $\frac{2}{5}mr^2$.

(i) Explain why the angular momentum of the collapsing star is conserved.

....

.... [1]

(ii) The period of rotation of the core at the start of collapse is 25 days. Calculate the period of rotation in seconds of the white dwarf star.

period of rotation = ... s [3]

(iii) State what happens to the rotational kinetic energy of the star during the collapse. Explain your answer.

....

....

....

....

....

.... [3]

[Total: 20]

9 A communications satellite has a mass of 832 kg. To transport it to a launch site, it is loaded into a lorry as shown in Fig. 9.1.

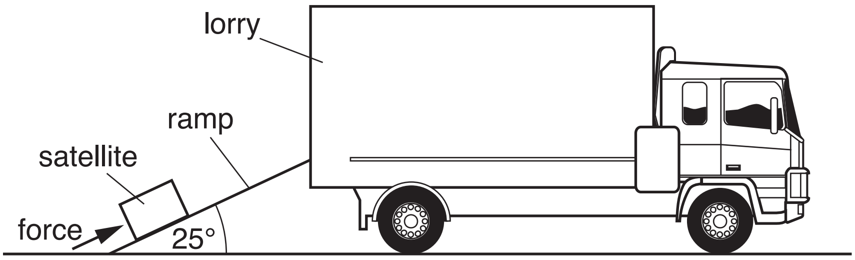

Fig. 9.1

The satellite is pushed along the ramp at a steady speed by a constant force of 3.6×10^3 N until the satellite reaches the top of the ramp. It moves through a vertical distance of 1.45 m above the ground. The ramp is at an angle of 25° with the horizontal.

(a) **(i)** Calculate the distance moved by the satellite along the ramp.

distance = ... m [1]

(ii) On Fig. 9.2, sketch a graph of force applied with distance moved in the direction of the force as the satellite is pushed along the ramp.

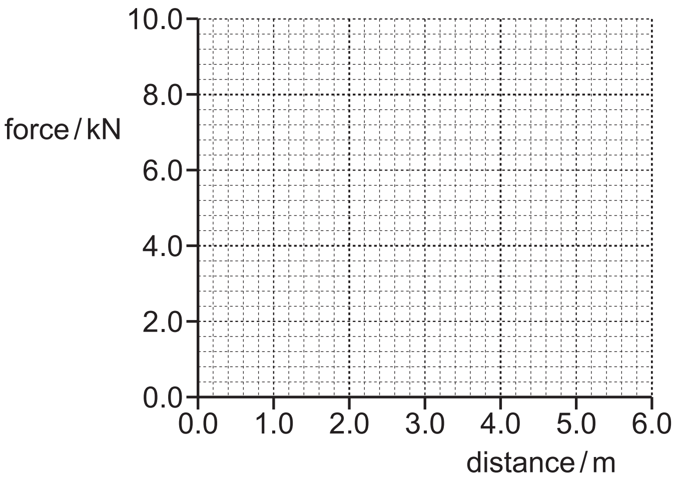

Fig. 9.2

[1]

(iii) State what the area under the graph represents.

.... [1]

(iv) Calculate the frictional force acting between the satellite and the ramp.

force = ... N [3]

(b) When the satellite is being used, it is in a geostationary orbit of radius r_o.

The gravitational potential energy E in this situation is given by

$$E = -\frac{G m_s M_E}{r_o}$$

where m_s is the mass of the satellite, M_E is the mass of Earth and G is the gravitational constant.

(i) Explain why the gravitational potential energy is negative.

....

.... [2]

(ii) Calculate the gravitational potential energy for the satellite in its geostationary orbit, 3.58×10^4 km above the surface of the Earth.

radius of the Earth = 6.37×10^3 km
mass of the Earth = 5.97×10^{24} kg

gravitational potential energy = ... J [1]

(iii) Fig. 9.3 shows the variation with distance r from the centre of the Earth, of the gravitational force F on the satellite.

The radius of the Earth is r_E.
The radius of the geostationary orbit is r_o.

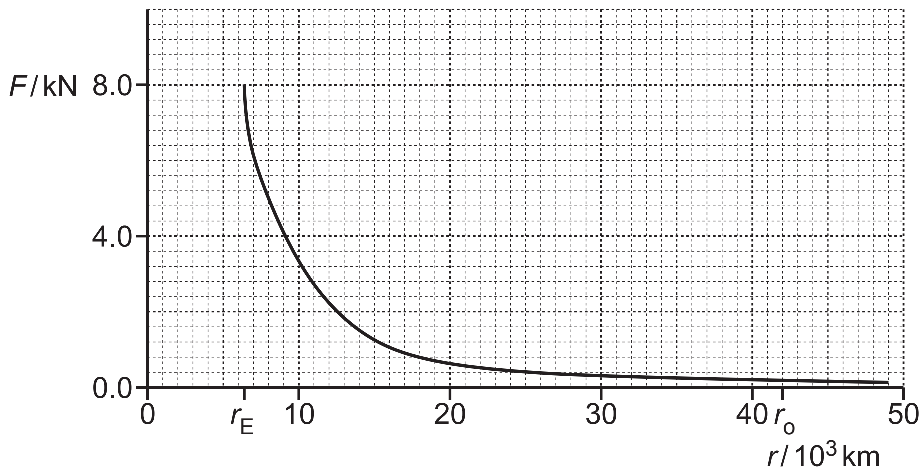

Fig. 9.3

The general equation for the shape of this graph is

$$F = -\frac{GMm}{r^2}.$$

The minimum work done in moving a satellite from the surface of the Earth to a point in the geostationary orbit is W.

Show, using integration of the general equation for F, that W is given by

$$W = GMm\left(\frac{1}{r_o} - \frac{1}{r_E}\right).$$

[2]

(iv) Determine the minimum energy needed to move the satellite from the surface of the Earth to a point in the geostationary orbit.

energy = ... J [2]

(c) **(i)** Calculate the speed of the satellite in the geostationary orbit.

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

(ii) The speed of a satellite in orbit about the Earth is greater when the satellite is closer to the Earth.

Explain what happens to the satellite if it slows down in the geostationary orbit.

....

.... [2]

(iii) In practice, the energy required to launch the satellite into orbit is greater than the value calculated in **b(iv)**.

Suggest two reasons for this difference.

1. ....

....

2. ....

....

[2]

[Total: 20]

10 Astronomers use line spectra to estimate the recessional velocities of galaxies.

(a) Explain in terms of photon emission, how atomic line spectra are produced.

....

....

.... [2]

(b) Electromagnetic radiation from a galaxy is passed through a spectrum analyser and a line spectrum is obtained.

Fig. 10.1 shows a small part of the Sun's spectrum. The absorption lines at wavelengths λ = 393.0 nm and 397.0 nm are caused by calcium atoms absorbing particular wavelengths.

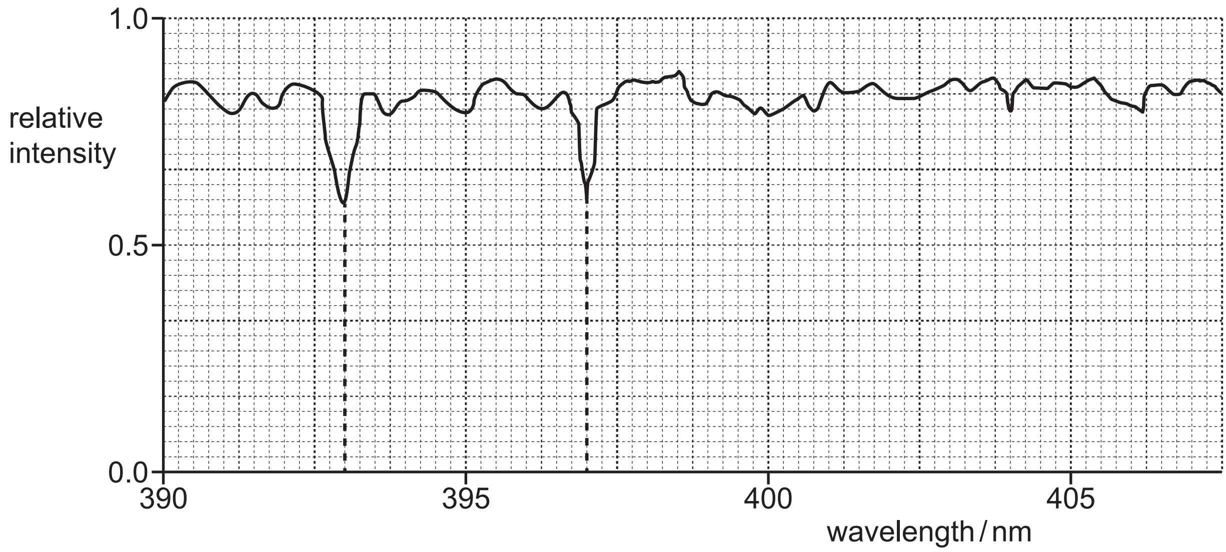

Fig. 10.1

Fig. 10.2 shows the spectrum from a distant galaxy NGC 2276, with a pair of absorption lines that astronomers assume are also caused by calcium atoms.

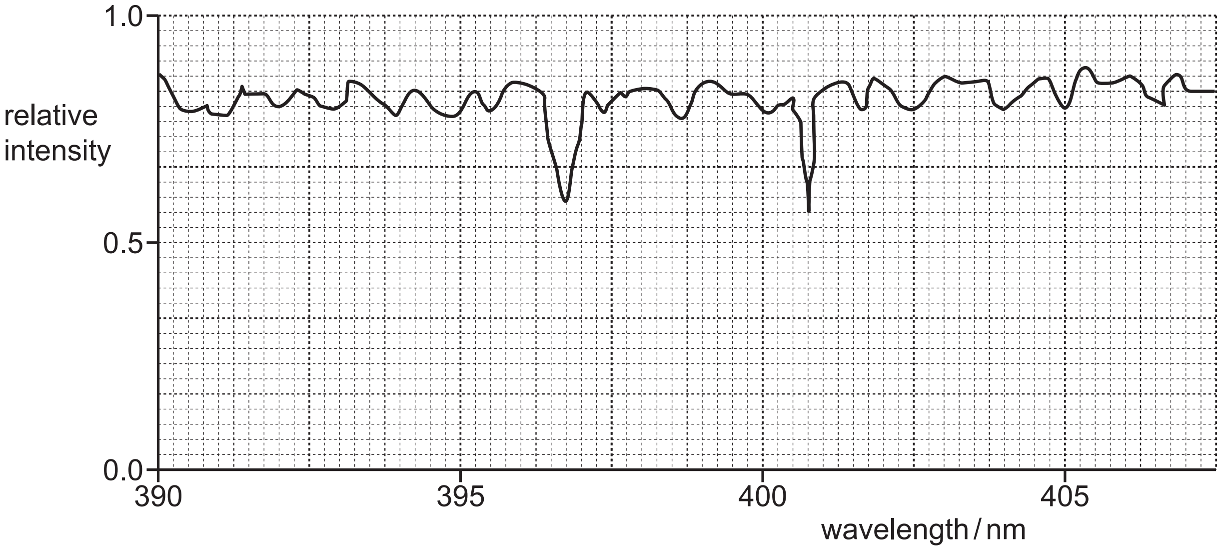

Fig. 10.2

(i) Determine the wavelengths of the two absorption lines shown in Fig. 10.2.

wavelength 1 = ... nm

wavelength 2 = ... nm [1]

(ii) Calculate an estimate for the recessional speed of this galaxy.

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

(iii) Astronomical distances are commonly measured in mega parsecs (Mpc).
1 megaparsec (Mpc) = 3.26 megalight-years = 3.09×10^{19} km.

Estimate the distance of this galaxy from Earth.
$H_0 = 79\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$

distance = ... km [3]

(c) The intensity of the electromagnetic radiation received from space may be analysed to reveal more about the source. Using data from the Sun, the power output of the Sun may be estimated.

Light from the Sun is incident on an area of 1.00 m^2 of the surface of the Earth, making an angle of 20° with the vertical as shown in Fig. 10.3.

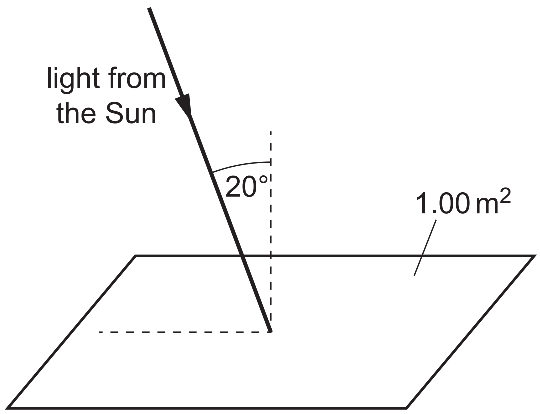

Fig. 10.3

The intensity measured at the 1.00 m^2 area is 1280 W m^{-2}.
Intensity I is the power P incident **normally** per unit area A. ($I = P/A$)

(i) Show that the intensity of the light from the Sun at the Earth's surface is approximately $1400\,W\,m^{-2}$.

[2]

(ii) The radius of the Earth's orbit is 1.50×10^{8} km.

Show that the output power of the Sun is approximately 4×10^{26} W.

[2]

(iii) Suggest two reasons why the true value of the output power of the Sun is likely to be greater than that calculated in **(c)(ii)**.

1. ....

....

2. ....

....
[2]

(d) The relative intensity of the electromagnetic radiation from the Sun at each wavelength is shown in Fig. 10.4.

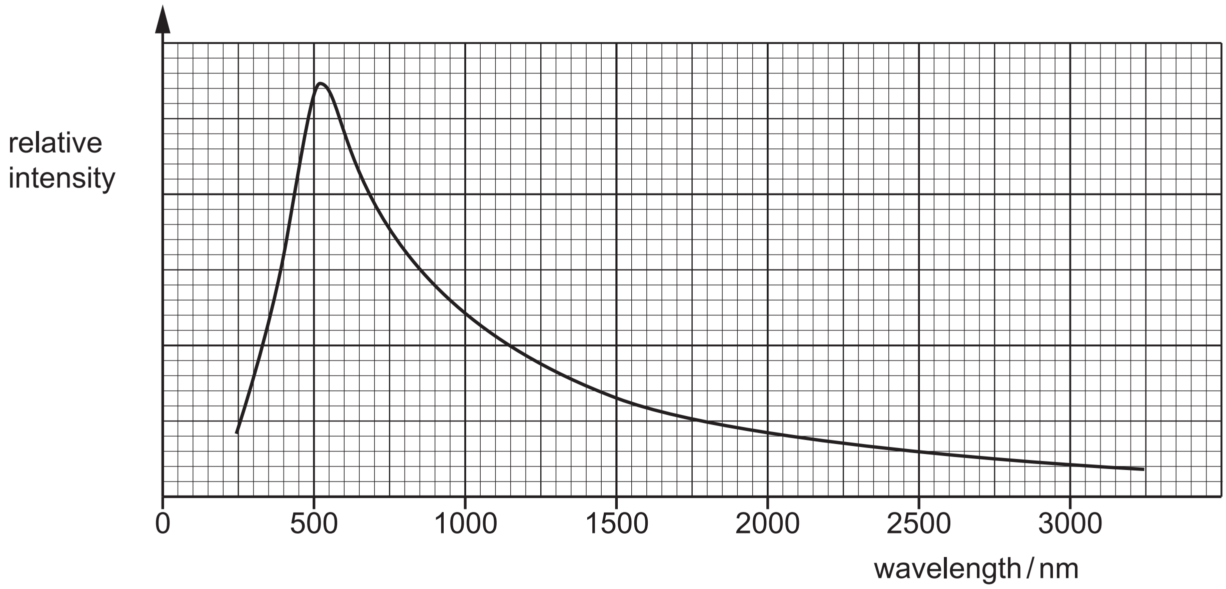

Fig. 10.4

(i) Use the data in Fig. 10.4 to give an estimate of the surface temperature of the Sun.

constant in Wien's displacement law = 2.898×10^{-3} m K

temperature = ... K [2]

(ii) On Fig. 10.4 sketch a graph to the same scale, to show the relative intensity for a star with a lower surface temperature than that of the Sun. [1]

(iii) Use Stefan's Law and your answers to **(c)(ii)** and **d(i)** to estimate a value for the radius of the Sun.

radius = ... m [2]

(iv) Suggest with a reason whether your value is likely to be an under estimation or over estimation of the radius of the Sun.

....

....

.... [1]

[Total: 20]

11 Ludwig Boltzmann's gravestone in Vienna has the following formula engraved on it:

$$S = k \ln W$$

S is the entropy of the system, k is the Boltzmann constant and W is the number of ways of arranging the system. The change in entropy, ΔS, when the number of ways, W, increases by ΔW is given by:

$$\Delta S = k \ln (W + \Delta W) - k \ln (W) = k \ln \left(\frac{W + \Delta W}{W}\right).$$

(a) **(i)** A set of 52 numbered cards is arranged in numerical order. The cards are then shuffled so that they are mixed randomly. The set of cards can be arranged in a large number of different ways which calculation shows to be 8.0658×10^{67}. Calculate the change in entropy when a system that has one way of arranging it is changed to have 8.0658×10^{67} ways.

entropy change = ... $\mathrm{J\,K^{-1}}$ [2]

(ii) A student claims that it is **not** impossible that, on shuffling, the cards could come out in numerical order.

Comment on this statement. You may wish to make a comparison with other numbers such as the Avogadro constant.

....

....

.... [1]

(b) An ideal gas in a cylinder with a piston expands to twice the volume. There are now more ways in which the gas molecules can be arranged. The number of ways increases by a factor of 2^N where N is the number of molecules.

(i) Write an expression for the change in entropy of the gas when it expands.

.... [1]

(ii) The gas initially has a volume of $2.00 \times 10^{-4}\,\text{m}^3$, a pressure of 100 kPa and a temperature of 10 °C.

Calculate the value of N.

N = ... [3]

(iii) Calculate the change in entropy when the gas expands.
You are reminded that $\ln(a^b) = b \ln a$.

change in entropy = ... J K^{-1} [2]

(c) A way of thinking about internal energy in solids is a model called an Einstein solid. Quanta of energy are randomly distributed and exchanged between the atoms of the solid.

Fig. 11.1 shows a two-dimensional version of an Einstein solid, with 16 squares representing the 16 atoms, at two different times.

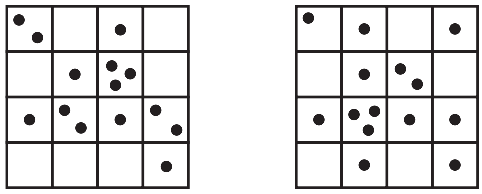

Fig. 11.1

The quanta are represented by 14 black dots. It can be shown that there are 77 558 760 different arrangements of indistinguishable quanta of energy in the 16-square Einstein solid.

(i) Suggest the physical quantity that is proportional to the number of quanta divided by the number of atoms.

.... [1]

(ii) Fig. 11.2 shows two different Einstein solids A and B just before they are placed in thermal contact.

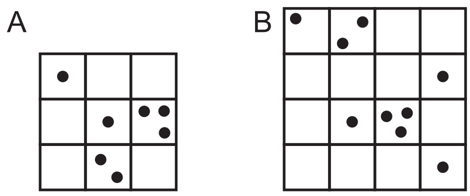

Fig. 11.2

State which solid has the higher internal energy. Explain your reasoning.

....

.... [1]

(iii) Table 11.1 shows the number of ways quanta of energy can be arranged in Einstein solids of two different sizes.

Table 11.1

number of quanta	number of ways, *W*, the quanta can be arranged for solid A with 9 atoms	number of ways, *W*, the quanta can be arranged for solid B with 16 atoms
5	1 287	15 504
6	3 003	54 264
7	6 435	170 544
8	12 870	490 314
9	24 310	1 307 504
10	43 758	3 268 760

Calculate the change in the **total** number of ways of arranging the quanta when solids A and B are placed in thermal contact and one quantum of energy moves from solid A to solid B.

change in the total number of ways = ... [2]

(iv) Explain which solid is at the higher temperature.

....

.... [2]

(d) The change in entropy ΔS of a solid when a quantity of energy is transferred to it by heating at absolute temperature T is given by the formula $\Delta S = +\dfrac{\Delta Q}{T}$.

Fig. 11.3 represents a heat engine, such as a steam engine, transferring energy by heating from a source (the boiler) at 500 K to the sink (the surroundings) at 300 K.

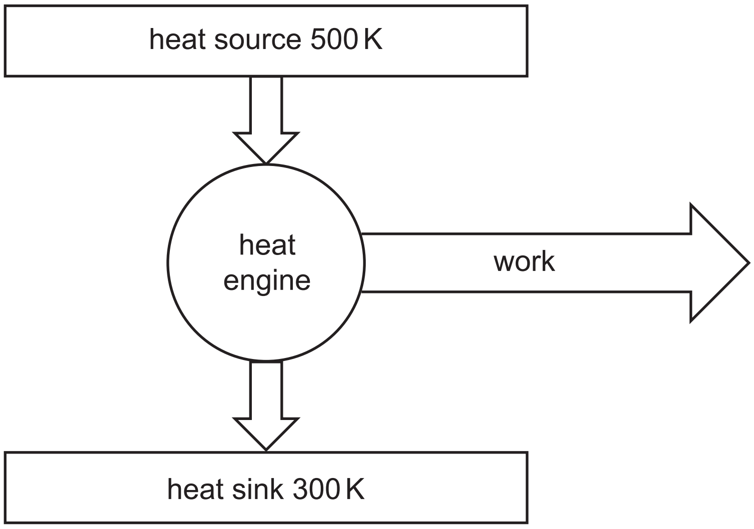

Fig. 11.3

(i) Calculate the change in entropy of the heat source when 3600 kJ of energy is transferred by heating from the source.

change in entropy = ... J K^{-1} [1]

(ii) In the process the engine does 1000 kJ of work. Working does not involve a change in entropy.

Calculate the change in entropy of the sink.

change in entropy = ... J K^{-1} [2]

(iii) Calculate the efficiency with which the engine is converting thermal energy into work.

efficiency = ... % [1]

(iv) Explain, using thermodynamic principles, whether it is possible for the steam engine to operate with this efficiency.

....

....

.... [1]

[Total: 20]

12 This question is about *models* used in Physics.

(a) The range of a projectile is the distance on level ground from where it is launched to where it lands.

A model of projectile motion gives a formula for the range L of a projectile as

$$L = \frac{2v_x v_y}{g}$$

where v_x and v_y are the initial horizontal and vertical velocities and g is the acceleration due to gravity.

(i) Calculate the range of a projectile launched with a speed of $2000\,\text{m}\,\text{s}^{-1}$ at an angle of 30° to the horizontal.

range L = ... m [2]

(ii) Calculate the maximum height reached by the projectile.

maximum height = ... m [2]

(iii) The equation in **(a)** is derived using the kinematic equations of motion for constant acceleration and the assumption that the vertical and horizontal motion may be treated independently. However the behaviour of real projectiles differs from that predicted by the model.

State two reasons for the difference.

1. ....

2. ....
[2]

(b) Newton's laws of motion were once regarded as absolute truth. Because of Einstein's theory of relativity, Newton's laws may now be regarded as a model for when speeds are relatively low.

Show that at a speed of $400\,\text{km}\,\text{s}^{-1}$ the Newtonian model leads to an inaccuracy of approximately 1 part in 1 000 000 (0.0001 %).

[3]

(c) The simplest model of a cell in an electric circuit is a cell with a fixed potential difference across its terminals. A better model could include a potential difference between the terminals that changes with the current in the cell. The change in potential difference is proportional to the current because of internal resistance.

(i) The potential difference across the terminals of a car battery falls from 13.50 V to 13.45 V when the lights are on. The total current in the lights is 8.0 A.

Use the better model to calculate the potential difference across the battery's terminals when the starter motor is on and the current in the battery is 200 A.

potential difference = ... V [2]

(ii) The actual potential difference is 12.00 V when the current is 200 A.

Suggest a problem with the better model when the battery is supplying a high power.

....

.... [1]

(d) A student is investigating a laboratory power source that does not seem to behave like a typical battery. A variable resistor is connected across the terminals of the power supply. The results in Table 12.1 are obtained as the resistance is varied.

Table 12.1

current in variable resistor / A	p.d. across terminals / V
0.00	12.0
0.50	11.9
1.00	11.5
1.50	10.9
2.00	10.0
2.50	8.9
3.00	7.5
3.50	5.8
4.00	3.8
4.50	1.5
5.00	0.0

(i) Use data from Table 12.1 to show that the internal resistance of the power supply is **not** constant.

[2]

(ii) The student suggests a model for the power supply. The model is a source of fixed e.m.f. E in series with a component that has a potential difference across it proportional to the square of the current I according to the formula p.d.= kI^2 where k is a constant.

Write an equation that relates the potential difference V between the power supply terminals and the current I.

.... [1]

(iii) Use data from Table 12.1 for two currents to show the value of k is $0.50\,\mathrm{V\,A^{-2}}$ for smaller currents.

[2]

(iv) Use data from Table 12.1 to show that the model starts to fail in predicting the behaviour with the larger currents.

[1]

(e) A student claims models are useless because they do not always give perfect predictions.

Suggest **two** reasons why models are useful.

1. ....

....

2. ....

....
[2]

[Total: 20]

13 After the huge success of *Principia*, in which Sir Isaac Newton gave his laws of motion and explained the workings of the solar system, he wrote *Opticks*. In this work he developed a theory that light is a stream of *corpuscles* (small particles).

Robert Hooke and the Dutch physicist Christiaan Huygens believed light to be a wave like ripples on a pond.

(a) (i) State what happens to the speed of light as the light passes from air into a sheet of glass.

....

.... [1]

(ii) Newton explained refraction by saying the velocity of the corpuscles normal to a glass surface was affected by the surface and increased on entering the glass.

Describe the motion of the particles as they pass out of a sheet of glass.

....

.... [2]

(b) (i) A hundred years after the publication of *Opticks*, Thomas Young demonstrated effects that suggest light behaves like a wave. These effects could not be explained by a particle theory.

State an effect that **cannot** be explained by a particle theory and explain briefly the principle behind the effect.

....

....

....

.... [2]

(ii) Suggest why, until Young's ideas emerged, many English scientists had been reluctant to accept the wave theory and stuck with the particle theory despite it being less satisfactory.

....

.... [1]

(c) Most waves travel through a medium. Despite not having been discovered, the medium for light was given a name: the *aether*. In 1880 Michelson and Morley devised an experiment to demonstrate the Earth's motion through the aether (the aether wind).

(i) Light travelling through the aether can be illustrated by a canoeist paddling through water. A canoeist paddles 9.0 km upriver and then returns downriver to the starting place at a steady speed of $6.0\,\mathrm{km\,h^{-1}}$ relative to the water. In stationary water the trip takes 3.0 hours.

Calculate how much longer, in hours, the trip will take if there is a current of $3.0\,\mathrm{km\,h^{-1}}$. Show your working.

time difference = ... [2]

(ii) A beam of light is travelling to a mirror and back to the source of the light. The distance from the source to the mirror is L. Without an aether wind the time taken is $\frac{2L}{c}$ where c is the speed of light.

Show that in an aether wind of speed u parallel to the beam, the time taken for the light to travel a distance L to a mirror and return is increased by $\frac{2Lu^2}{c^3}$ when $c >> u$.
You may use the result that $\frac{1}{(1-x)} \sim 1 + x$ when $x << 1$.

[3]

(d) The diagram in Fig. 13.1 shows a simplified version of Michelson and Morley's experiment. At the centre was a half-silvered mirror allowing half the light to be reflected and half to pass straight through. Light and dark fringes were observed through the telescope where the rays travelling by different paths interfered. It was expected that the whole fringe pattern would shift sideways as the equipment was rotated relative to the aether wind.

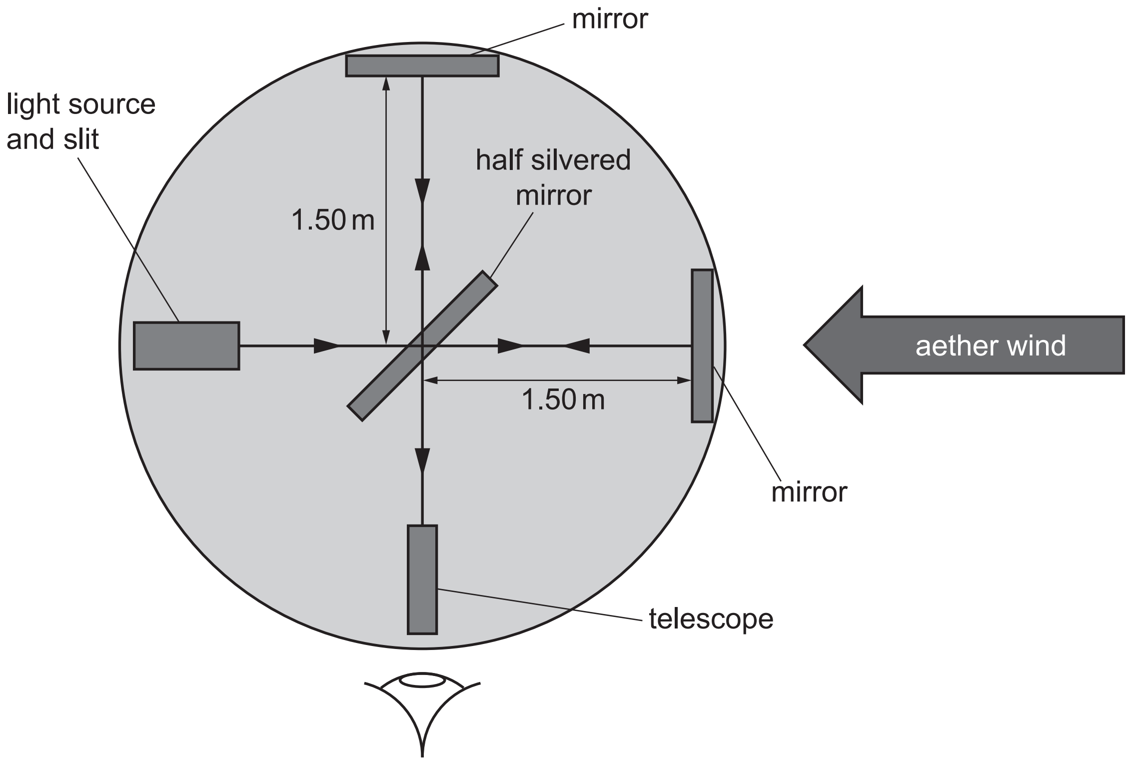

Fig. 13.1

(i) The distance from the centre to each mirror is 1.50 m.

Michelson assumed that the light with a path perpendicular to the aether wind would be unaffected.

Use Michelson's assumption to calculate the extra time taken by the light travelling into the wind if the speed of the aether wind is 30 km s^{-1}.

extra time = ... s [2]

(ii) Calculate the time period of light of wavelength 600 nm.

time period = ... s [2]

(iii) In the actual experiment, multiple mirrors were used and the light reflected back and forth several times to make the two distances travelled 11.0 m instead of the 3.0 m in the simplified version in Fig. 13.1.

Use your numerical answers to **(d)(i)** and **(d)(ii)** to explain why the increase in paths was necessary to be able to observe an effect. Vibrations can affect the fringes so assume it will only be possible to detect a clear fringe shift if the phase difference between the light paths changes by at least 0.5 radian (29°).

....

....

....

.... [2]

(iv) Although their experiment allowed for measurements of sufficient accuracy and precision, Michelson and Morley observed no effect (a null result).

State what conclusion can be drawn from this.

....

.... [1]

(e) Einstein's Nobel Prize was mainly for his explanation of the photoelectric effect using a particle model, not for his work on relativity. A student suggests that relativity proves Newton's *Principia* wrong and the photoelectric effect proves Newton's *Opticks* right. Comment briefly on this suggestion.

....

....

....

.... [2]

[Total: 20]