

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

PHYSICS B (ADVANCING PHYSICS)

2865/01

Advances in Physics

Thursday **26 JANUARY 2006** Morning 1 hour 30 minutes

Candidates answer on the question paper.

Additional materials:

Insert (Advance Notice Article for this question paper)

Data, Formulae and Relationships Booklet

Electronic calculator

Candidate Name	Centre Number	Candidate Number												
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TIME 1 hour 30 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.
- Show clearly the working in all calculations, and give answers to only a justifiable number of significant figures.

FOR EXAMINER'S USE		
Qu	Max.	Mark
1	8	
2	9	
3	11	
4	9	
5	8	
6	12	
7	16	
8	13	
QWC	4	
TOTAL	90	

INFORMATION FOR CANDIDATES

- Section A (questions 1–6) is based on the Advance Notice article, a copy of which is included as an insert. You are advised to spend about 60 minutes on Section A.
- The number of marks is given in brackets [] at the end of each question or part question.
- There are four marks for the quality of written communication on this paper.
- The values of standard physical constants are given in the Data, Formulae and Relationships booklet. Any additional data required are given in the appropriate question.

This question paper consists of 23 printed pages and 1 blank page and an insert.

Answer **all** the questions.

Section A

The questions in this section are based on the Advance Notice article.
You are advised not to spend more than 60 minutes on this section.

- 1 This question is about the physical properties of the polymer PTFE (lines 19–29 and Fig. 1 in the article).
Fig. 1.1 shows a plot of resistivity and cost for a number of materials.

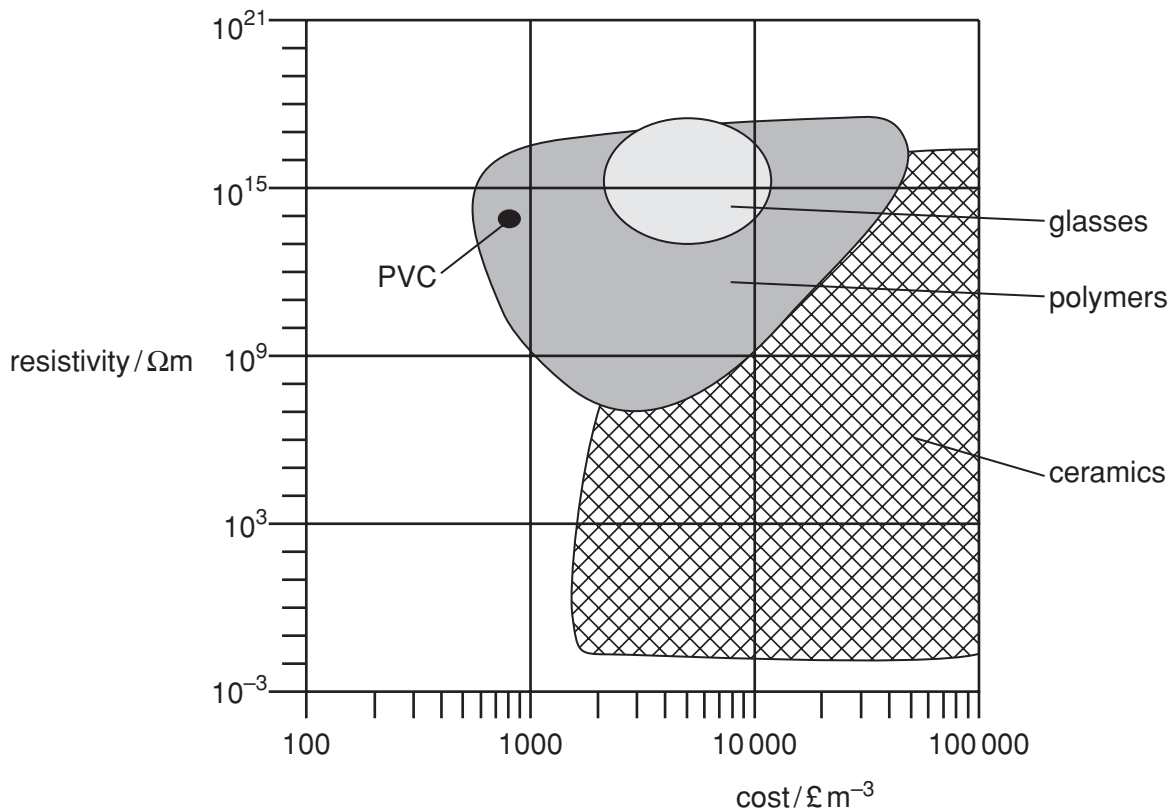


Fig. 1.1

A point for PVC is shown plotted on the graph.
PTFE has a resistivity of $10^{16} \Omega\text{m}$, and costs about $\text{£}20\,000$ per cubic metre.

- (a) Plot PTFE on Fig. 1.1. [2]
- (b) PVC and PTFE are both used as electrical insulators. Use Fig. 1.1 to suggest why
- (i) PVC is used for domestic wiring

[1]

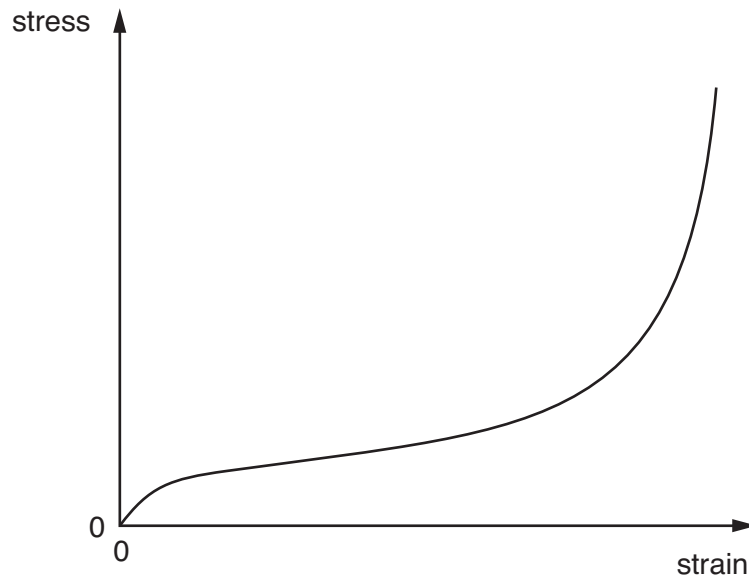
(ii) PTFE is used for the electrical connections to high-voltage equipment.

[1]

(c) The deformation of polythene can be described in terms of the movements of the molecular chains.

- A** bonds rotate
- B** bond angles become deformed

Fig. 1.2 shows the stress-strain graph for polythene.
Circle and label the appropriate sections **A** and **B**.



[2]

Fig. 1.2

(d) Polythene and PTFE are both composed of long chains of carbon atoms. They differ only in the other atoms joined to the carbon atoms. (Fig. 1.3).

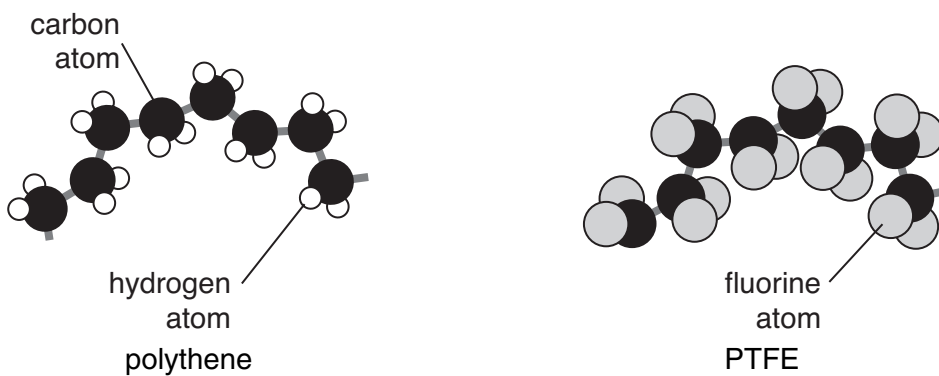


Fig. 1.3

- (i) Use the differences between these two structures to suggest why PTFE is **stiffer** than polythene (lines 19–24 in the article).

[1]

- (ii) Sketch on Fig. 1.2, a possible stress-strain graph for PTFE.

[1]

[Total: 8]

2 This question is about the properties of uranium hexafluoride (lines 39–46 in the article).

- (a) Use the table below to show that a molecule of uranium hexafluoride (UF_6) is more than ten times as massive as an air molecule (lines 39–41 in the article). Most air molecules consist of two nitrogen atoms bonded together.

atom	nucleon number
uranium	238
fluorine	19
nitrogen	14

[2]

- (b) **Equation 1** relates the motion of N molecules each of mass m and mean square speed $\overline{c^2}$ in an ideal gas to the pressure p and volume V of the gas.

$$pV = \frac{1}{3} Nmc^2 \quad \text{equation 1}$$

Equation 1 can be rewritten as
$$pV = \frac{1}{3} Mc^2 \quad \text{equation 2}$$

- (i) State what the quantity $M = Nm$ in **equation 2** represents.

[1]

- (ii) Use **equation 2** to show that the mean-square speed of the molecules in a gas of density ρ is given by

$$\overline{c^2} = \frac{3p}{\rho} \quad \text{equation 3}$$

[2]

- (iii) Use **equation 3** to show that the difference in the r.m.s. speeds ($\sqrt{\overline{c^2}}$) of uranium-238 hexafluoride and uranium-235 hexafluoride at standard pressure is only about 1 m s^{-1} .

standard pressure = $1.01 \times 10^5 \text{ Pa}$

at standard pressure, density of uranium-235 hexafluoride $\rho = 15.5 \text{ kg m}^{-3}$

at standard pressure, density of uranium-238 hexafluoride $\rho = 15.7 \text{ kg m}^{-3}$

[2]

- (iv) Use your answers to parts **(b)(ii)** and **(iii)** to explain why 'the difference in diffusion speeds is very small indeed, so large-scale apparatus with many stages was needed' (lines 45–46 in the article).

[2]

[Total: 9]

3 This question is about keeping charged particles moving around in a ring (lines 64–67 and Fig. 2 in the article).

(a) Fig. 3.1 shows a plan view of Fermilab's Main Ring. The arrows show the path taken by protons moving at a speed $2.97 \times 10^8 \text{ m s}^{-1}$ (99% of the speed of light).

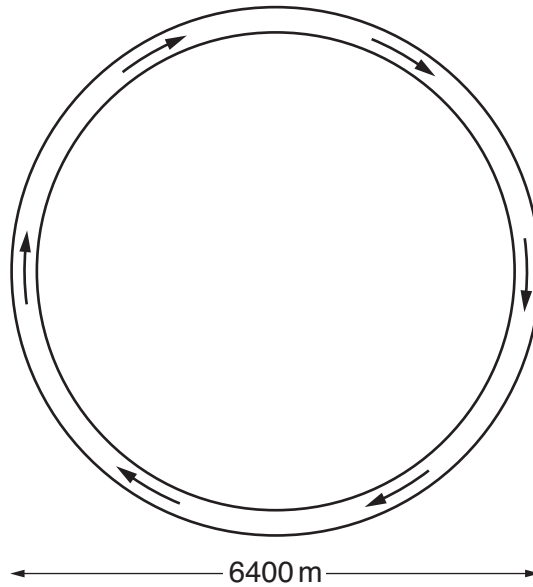


Fig. 3.1

(i) Explain clearly why there must be a force acting on the protons if they are to travel in a circular path.

[1]

(ii) This force is provided by a magnetic field. Here are four directions in which the magnetic field could be acting.

A radially inwards towards the centre of the circle

B radially outwards away from the centre of the circle

C perpendicular to the plane of the diagram

D the same direction as the proton path

Choose the correct direction from the four directions above.

direction [1]

(b) The same ring contains antiprotons (the anti-particles of protons), also moving at a speed of $2.97 \times 10^8 \text{ m s}^{-1}$.

(i) Complete the table below comparing the proton and antiproton.

particle	mass / 10^{-27} kg	charge / 10^{-19} C
proton	1.7	+1.6
antiproton		

[1]

(ii) Draw arrows on Fig. 3.1 above to show the path followed by the antiprotons. [1]

(c) (i) In the article, it states that 'The job of the Tevatron Ring is to accelerate the protons to energies of 1000 GeV (1 TeV), which is about 1000 times their rest energy' (lines 85–86 in the article).

Show that the rest energy of a proton is about 1 GeV.

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$m_p = 1.7 \times 10^{-27} \text{ kg}$$

[3]

(ii) Use the result of (c)(i) to explain why, for a proton of total energy $E = 1000 \text{ GeV}$ (1 TeV), the equation

$$E^2 = (pc)^2 + (\text{rest energy})^2 \quad (\text{Line 82 in the article})$$

can be simplified to

$$E \approx pc.$$

[2]

- (iii) Use the equation $E \approx pc$ and the data from Table 1 in the article to show that the total energy E of a proton travelling at 99.9999% of the speed of light is close to 1 TeV (1.6×10^{-7} J).

[2]

[Total: 11]

4 This question is about superconducting electromagnets (Figs. 3 and 4 and lines 96–109 in the article).

- (a) The magnetic field in the conventional magnets in the Fermilab Main Ring is 1.8 T. In the superconducting Tevatron Ring, the field is 4.5 T.

Explain why it was not possible to use conventional electromagnets to achieve a field of 4.5 T.

[2]

- (b) The cross-section of the wire used in the superconducting electromagnet coils is shown in Fig. 4.1. About half of the cross-section is niobium-titanium, and half is copper.

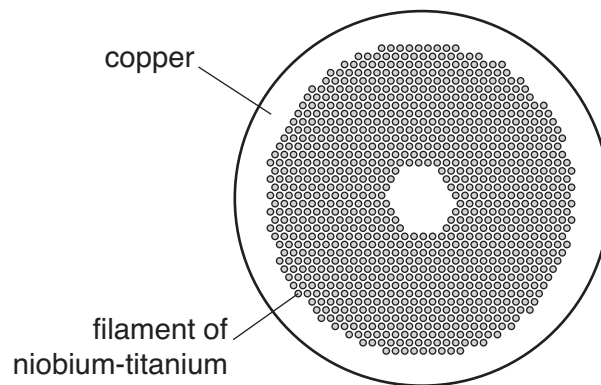


Fig. 4.1

Below a temperature of 10 K, the resistivity of niobium-titanium is zero.

No electrical p.d. is required to maintain the current in the superconducting niobium-titanium. Explain why there is no current in the copper under these circumstances (lines 100–101 in the article).

[2]

(c) The article describes the catastrophic effects of a temperature rise in the superconducting magnets (lines 105–109 in the article).

(i) Explain why a collapse of the magnetic flux leads to a large current in the coil.

[2]

(ii) Explain why this current passes mainly in the copper, not in the niobium-titanium.

[1]

(iii) Explain why the copper could become very hot.

[1]

(d) The large superconducting magnet in an MRI scanner produces a very strong magnetic field inside the scanner.

Suggest why patients must remove any iron or steel objects, such as dental braces, before entering the scanner.

[1]

[Total: 9]

[Turn over

- 5 This question is about medical images of the head (Fig. 5 and lines 122–125 in the article).



Fig. 5.1 X-ray



Fig. 5.2 MRI

- (a) Suggest why X-rays (Fig. 5.1) are better than MRI scans (Fig. 5.2) for investigating possible fractures of the skull.

[2]

- (b) A doctor wishes to study the region of the brain marked X (the cerebellum). The MRI image is enhanced as shown in Fig. 5.3 to make this region clearer.

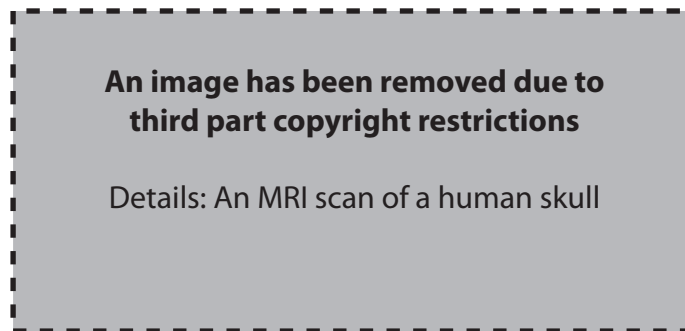


Fig. 5.3 enhanced MRI

- (i) This digital image has been enhanced by the process of inversion, where light areas have become dark and dark ones light. Explain this process.

[3]

- (ii) Describe one **other** way in which the image could be enhanced to make the structure of region **X** clearer.

[2]

- (iii) The scale of the structures in region **X** is small, so an image with high resolution is needed. Explain the meaning of the term *resolution* of an image.

[1]

[Total: 8]

- 6 This question is about the energy needed to put satellites into orbit (lines 128–130 in the article).
The International Space Station (ISS) orbits the Earth with an orbit of mean radius 6.8×10^6 m.

(a) Use **equation 1**

$$V_{\text{grav}} = -\frac{GM}{r} \quad \text{equation 1}$$

to show that the gravitational potential difference between the surface of the Earth and the position of the ISS is given by **equation 2**

$$\Delta V_{\text{grav}} = GM \left(\frac{1}{r_{\text{E}}} - \frac{1}{r} \right) \quad \text{equation 2}$$

where r_{E} is the radius of the Earth, r is the radius of the orbit, G is the gravitational force constant and M the mass of the Earth.

[2]

- (b) (i) Use **equation 2** above to show that the gravitational potential difference ΔV_{grav} between the surface of the Earth and the position of the ISS is about $4 \times 10^6 \text{ J kg}^{-1}$.

$$GM = 4.0 \times 10^{14} \text{ N m}^2 \text{ kg}^{-1}$$

$$r_{\text{E}} = 6.4 \times 10^6 \text{ m}$$

$$r = 6.8 \times 10^6 \text{ m}$$

[2]

- (ii) Calculate the gravitational potential energy gained by the ISS as it is put into orbit.

$$\text{mass of ISS} = 1.9 \times 10^5 \text{ kg}$$

gravitational potential energy J [1]

- (iii) The ISS orbits the Earth once every 90 minutes.
Calculate its kinetic energy in orbit.

kinetic energy J [3]

- (iv) Suggest why the energy required to put the ISS into orbit is much greater than the sum of the two energies in parts (ii) and (iii).

[2]

- (c) The orbit of the ISS is quite low. Satellites are often placed in a geostationary orbit, about $100 \times$ higher above the Earth's surface.

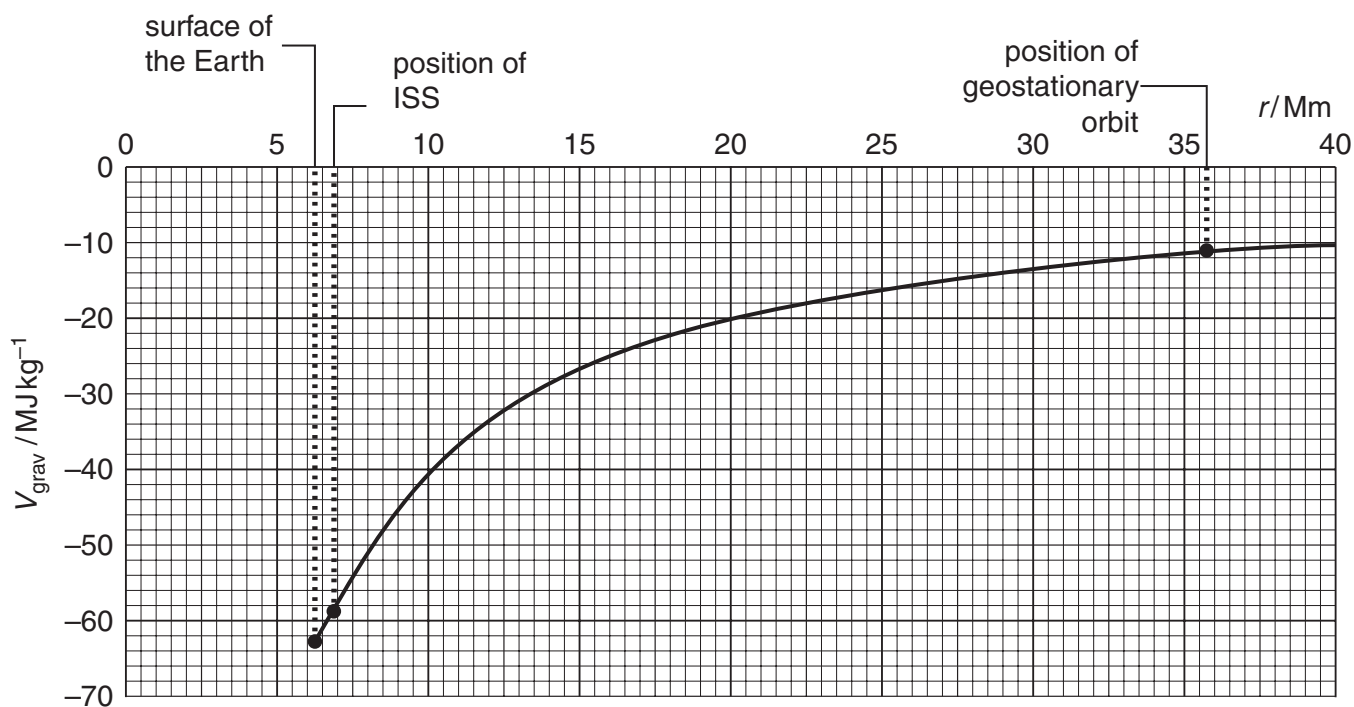


Fig. 6.1

Use the graph of Fig. 6.1 to calculate the gravitational potential energy the ISS would need to gain if it were moved from its present position into a geostationary orbit.

$$\text{mass of ISS} = 1.9 \times 10^5 \text{ kg}$$

[2]

[Total:12]

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Section B

- 7 This question is about light and astronomy.

When an electric current is passed through hydrogen gas in a discharge tube, the hydrogen emits a line spectrum. One of the wavelengths in the visible part of the spectrum is due to the change in the energy levels of the hydrogen atom shown in Fig. 7.1.

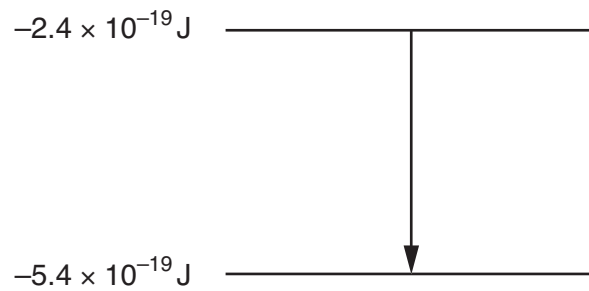


Fig. 7.1

- (a) Show that photons of light of wavelength 660 nm can be produced by this energy level change.

$$h = 6.6 \times 10^{-34} \text{ J s}$$

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

[3]

- (b) Light from a discharge tube containing hydrogen was observed through a diffraction grating having 600 lines per mm.

- (i) Show that the grating spacing d is about $1.7 \times 10^{-6} \text{ m}$.

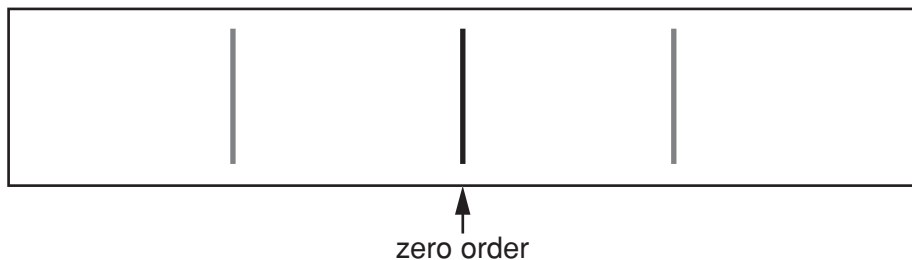
[1]

- (ii) Show that the 660 nm wavelength will be detected at about 23° from the zero order.

[2]

- (c) When stars are moving away from us, their spectral lines are red-shifted.

Indicate on Fig. 7.2 how the position of the lines, originally at 660 nm, would change when viewed through the diffraction grating if the light had been **red-shifted**. The grey lines indicate the position of these lines if there is no red-shift.



[1]

Fig. 7.2

- (d) The wavelengths of light from the star Regulus were found to be red-shifted by 0.0020%.
Use the relationship

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

to calculate the velocity of recession v of Regulus relative to Earth.

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

velocity of recession m s^{-1} [3]

- (e) Two stars A and B have the same actual luminosity (brightness). However, star A appears to be emitting 100 times less energy per second than star B, which is at a distance of 30 parsecs from the Earth. Use the inverse square law to calculate the distance of star A from Earth.

distance parsecs [2]

- (f) For distant galaxies, the cosmological redshift z is given by

$$1 + z = \frac{\lambda + \Delta\lambda}{\lambda}.$$

One particular spectral line of hydrogen has wavelength 122 nm on Earth. In light from the very distant galaxy *Abell 1835 IR1916*, the same spectral line is observed to have a wavelength of 1.34 μm .

- (i) Show that the redshift z of this galaxy is about 10.

[2]

- (ii) Use the cosmological redshift equation above to explain why a cosmological redshift of 10 implies that the Universe is now 11 times larger than when the galaxy emitted that light.

[2]

[Total: 16]

- 8 This question is about the position sensing system shown in Fig. 8.1.

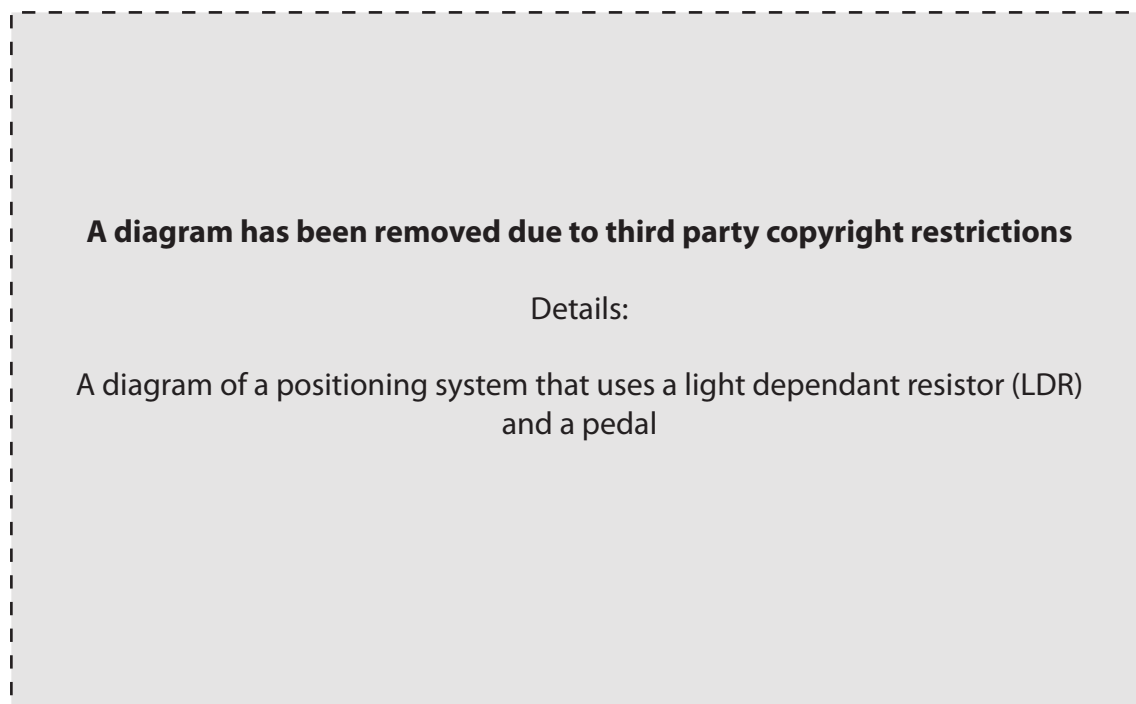


Fig. 8.1

As the pedal is pushed, the shaft moves allowing more light to fall on the LDR. This results in a reduction in the resistance of the LDR.

A +30 D lens, positioned 0.05 m to the right of the lamp, is used to converge light onto the LDR.

- (a) (i) Calculate the separation between the LDR and the lens needed to achieve a sharp image of the lamp filament on the face of the LDR.

[3]

- (ii) State one way in which the lens improves the performance of the system.

[1]

- (b) Fig. 8.2 shows the sensing circuit connected to the LDR. The fixed resistor has a resistance of $1500\ \Omega$. The 12 V battery has negligible internal resistance, and the voltmeter has a very large resistance.

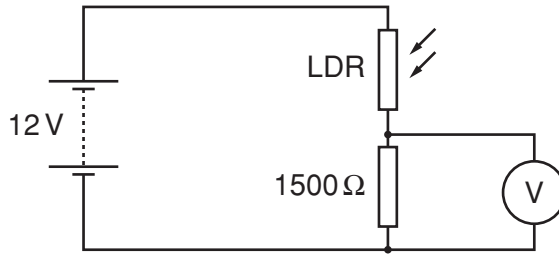


Fig. 8.2

- (i) When the shaft completely covers the LDR it has a maximum resistance of $3000\ \Omega$. Show that in this position the current drawn from the battery is about 3 mA.

[2]

- (ii) Show that the voltmeter reading with the LDR covered would be 4 V.

[2]

- (iii) As the pedal is pushed the voltmeter reading rises to a maximum of 11.3 V. Show that the LDR resistance drops to a minimum of about $100\ \Omega$.

[3]

Question 8 continues on page 24

- (iv) Explain how the performance of the system would be changed if the fixed resistor were replaced with a $1\text{ M } \Omega$ resistor.

[2]

[Total: 13]

Quality of Written Communication [4]

END OF QUESTION PAPER