Sample Examination Questions

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NB. Material covered by the AS papers may also appear in A2 papers.

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1 Fig. 1.1 shows how the displacement of a simple harmonic oscillator varies with time.

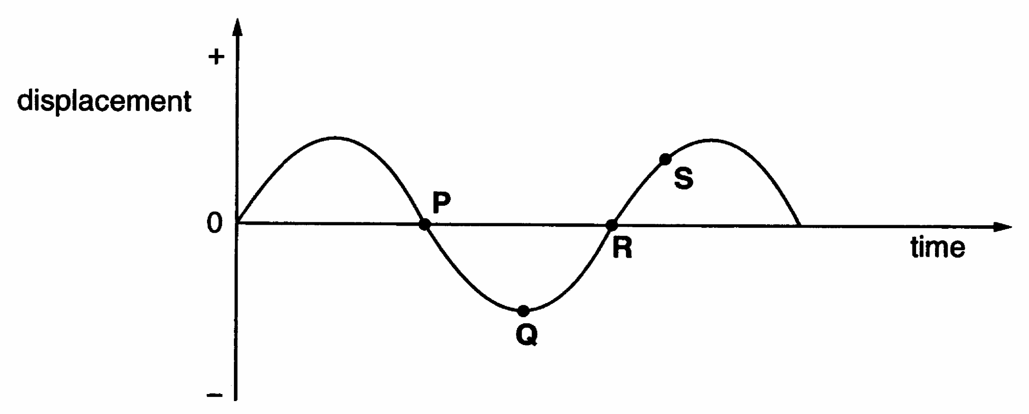


Fig. 1.1

(a) At which point, **P**, **Q**, **R** or **S**, is the acceleration the greatest?

answer ....[1]

(b) At which point, **P**, **Q**, **R** or **S**, is the velocity of the oscillator at its greatest positive value?

answer ....[1]

2 A plastic duck hangs from a long spring as shown in Fig. 2.1. The duck oscillates vertically with a time period of 2.4 s.

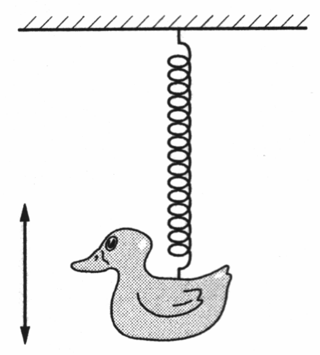


Fig. 2.1

(a) Calculate the frequency, *f*, of the oscillation.

frequency = ... Hz [2]

(b) The displacement *x* of the duck at time *t* is given by the equation

$x = A \cos(2\pi f t)$

where A = 0.20 m.

Calculate the displacement of the duck when t = 2.0 s.

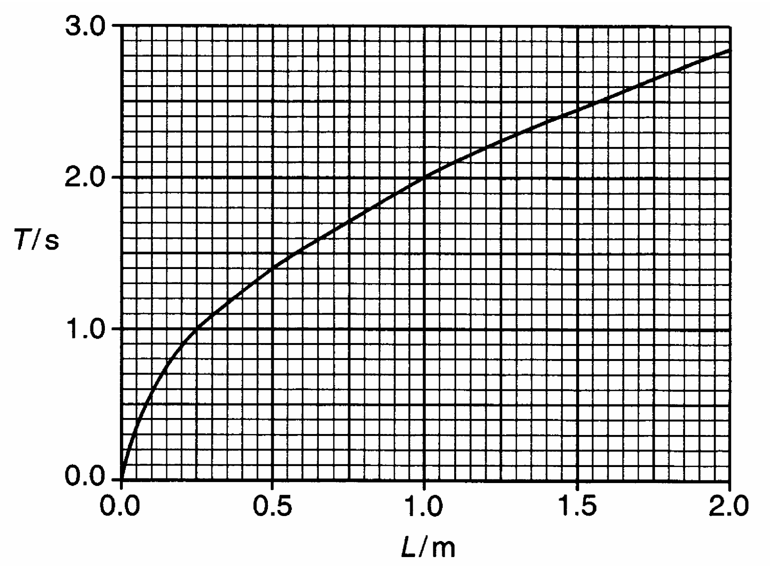
displacement = ... m [2]

3 Accurate timekeeping became a practical possibility when Christiaan Huygens developed the pendulum clock. His design used the fact that the period of a pendulum is independent of its amplitude of swing for small angles.

(a) Explain what is meant by the **period** of a pendulum.

[1]

(b) The graph shows how the period T of a simple pendulum varies with length L.



Early clocks contained a pendulum with a time period of 2 seconds.

Use the graph to find the length of the pendulum that will give a time period of 2 seconds.

length of pendulum = ...m [1]

(c) The period of a pendulum, T, is proportional to $\sqrt{L}$.

(i) What graph could you draw to show that this is true?

[1]

(ii) State the property of your graph that would show that T is proportional to $\sqrt{L}$.

[2]

(d) The amplitude of a pendulum will decrease every oscillation. Early clocks use a mass hanging on a rope to drive the mechanism. This gives the pendulum a push every oscillation which keeps the amplitude constant. The mass falls through a very small distance each oscillation and loses gravitational potential energy, transferring energy to the pendulum. When the mass has reached the bottom of its fall the clock is wound up by lifting the mass back up.

In one such clock a mass of 9 kg drops a distance of 1.2 m in a day. During this time the pendulum makes about 43 000 oscillations.

Assuming that all the energy from the falling mass is given to the pendulum show that about 2.5 mJ of energy is transferred to the pendulum each oscillation.

$g = 9.8 \text{ N kg}^{-1}$

[3]

(e) The clocks are called `long case clocks' and they stand about 2 metres high because of the length of the pendulum and the height through which the mass falls. Discuss the advantage in using

(i) a large drop height through which the mass can fall

[2]

(ii) a long pendulum with a large, massive bob.

[2]

[Total: 12]

4 A student makes and calibrates the simple water clock shown in Fig. 4.1.

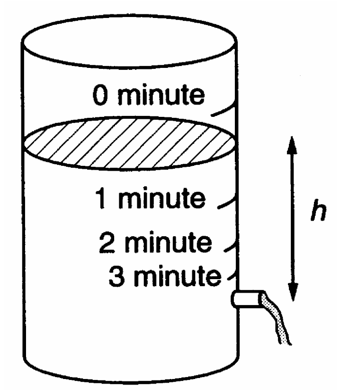


Fig. 4.1

(a) Explain how the marked time scale shows that the relationship between level of water and time passed is not linear.

[1]

(b) The rate of change of height of water $\frac{dh}{dt}$ is related to the instantaneous height h of water by the equation

$$\frac{dh}{dt} = -kh$$

where k is a constant.

(i) Describe in words the meaning of the equation $\frac{dh}{dt} = -kh$.

[2]

(ii) Suggest a physical factor that might affect the value of k.

[1]

5 This question is about calculating the age of stars using the radioactive decay of uranium-238.

A sample containing 1.0×10^{-6} kg of uranium-238 contains 2.5×10^{18} uranium-238 atoms.

The activity of the sample is 12 decays s^{-1}.

(a) **(i)** Show that the probability λ of any one atom of uranium-238 decaying in one second is about 5×10^{-18} s^{-1}.

[2]

(ii) Use the relationship, half life = $\dfrac{0.693}{\lambda}$, to find the half life of uranium-238 in years.

1 year = 3.2×10^{7} s

[2]

(iii) Explain why it is not possible to predict the lifetime of one particular atom of uranium-238.

[1]

(b) Astronomers have observed the spectra of a very old nearby star to determine how much uranium-238 it contains. This is compared to the amount that is thought to have been present when the star was formed.

Recent observations suggest that the amount of uranium-238 in the star has fallen to one eighth of its original level.

(i) Use your answer to **(a)(ii)** to calculate the age of the star in years.

[2]

(ii) This technique, called **cosmochronometry** by its inventors, has given a value to the least possible age of the universe.

Explain why this method gives the least possible age of the universe.

[1]

(c) The Hubble law, based on observation of cosmological red shifts, suggests that the universe is much older than the age of the stars measured by cosmochronometry.

The Hubble law suggests that the age of the universe is of the order $\frac{1}{H_0}$ where H_0 is the Hubble parameter.

Estimating the value of H_0 is an extremely important task. Until recently the values ranged from 1.6×10^{-18} s^{-1} to 3.2×10^{-18} s^{-1}.

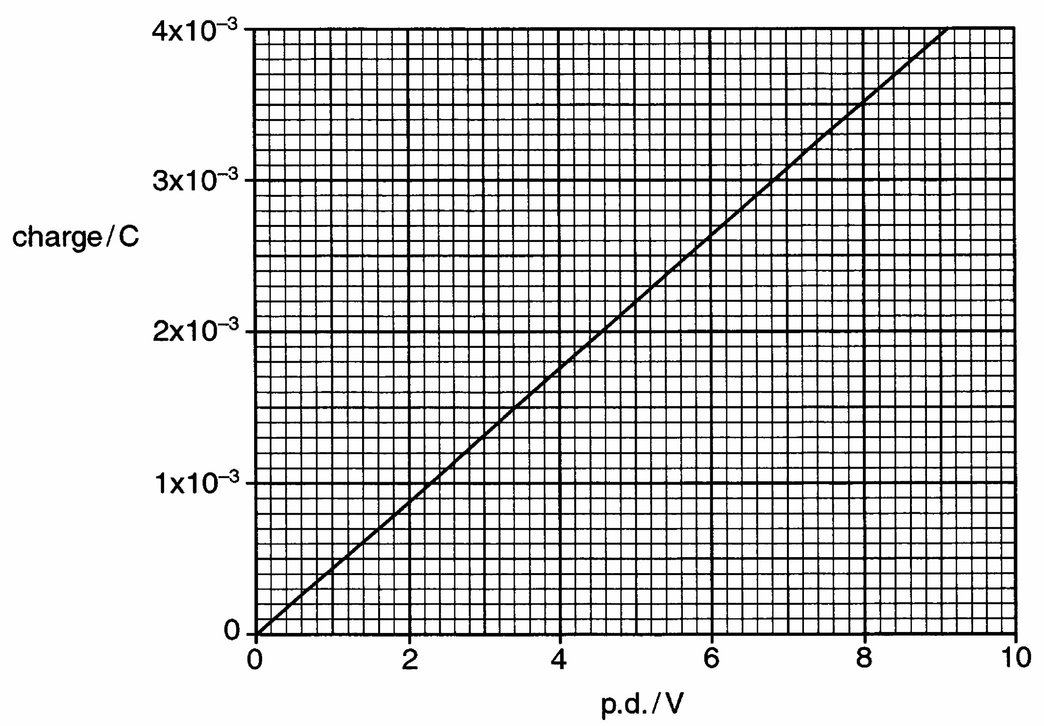
(i) Estimate the minimum and maximum age of the universe in years from the values of H_0.

minimum age = ... years maximum age = ... years [2]

(ii) Explain how data from cosmochronometry can be used to help astronomers choose between these values of H_0.

[2]
[Total: 12]

6 The graph shows how the charge on a capacitor varies with p.d. across the capacitor.



Use the graph to find

(a) the energy stored by the capacitor when charged to a potential difference of 8 V

energy stored = ... J [2]

(b) the capacitance of the capacitor.

capacitance = ... F [2]

7 This question is about using a capacitor to make a light flash on and off at regular intervals. A capacitor is connected in the circuit of Fig. 7.1.

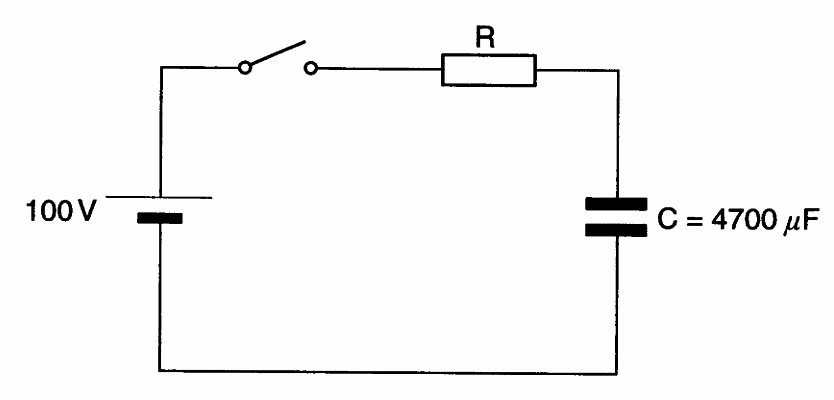


Fig. 7.1

The switch is closed and the capacitor is charged to a potential difference of 100 V.

(a) Calculate the charge on the capacitor.

charge = ... C [2]

(b) The time constant of the circuit is 0.70 s.

Calculate the value of the resistor, R.

resistance = ... Ω [2]

(c) The capacitor is discharged and a fluorescent lamp is connected into the circuit as shown in Fig. 7.2

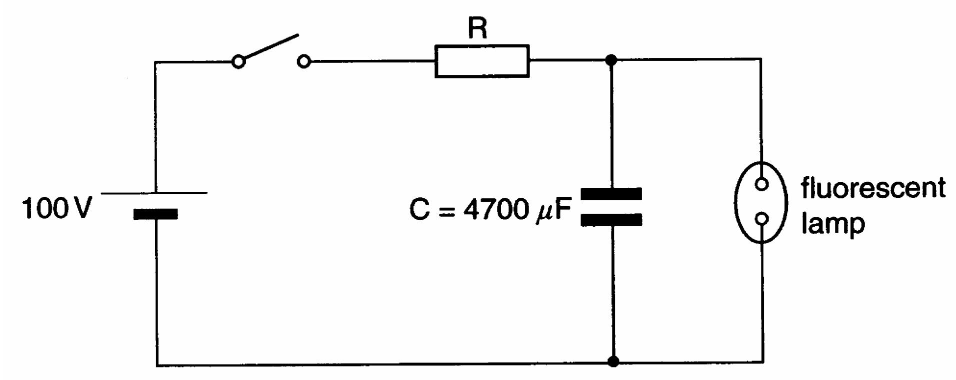


Fig. 7.2

The switch is closed and the capacitor begins to charge. When the p.d. across the capacitor reaches 72 V the lamp conducts. The capacitor discharges through the lamp which emits a flash of light.

(i) Show that the energy stored on the capacitor just before the discharge is about 12 J.

(ii) When the lamp flashes it transfers energy at an average rate of 150 W.

Show that the duration of the flash is about 0.08 s.

(iii) After the flash the lamp stops conducting and the capacitor begins to charge again. When the p.d. across the lamp reaches 72 V the process repeats.

Explain why the time interval between flashes is greater than the duration of the flash.

[6]

8 A tennis ball of mass 0.11 kg travelling at 40 m s^{-1} hits a wall head-on and bounces off, returning along the same path at 30 m s^{-1}.

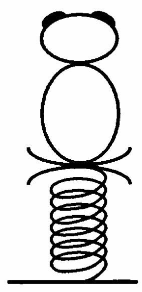
(a) Calculate the change in velocity of the ball.

change in velocity = ... m s^{-1}

(b) Calculate the change in momentum of the ball. Include the unit in your answer.

change in momentum = ... unit ....[3]

9 A novelty toy consists of a plastic frog mounted on a spring. The frog is pushed down and then released. This makes the frog jump into the air.



The stiffness constant of the spring is 220 N m^{-1}. The toy has a mass of 0.080 kg.

(a) Show that when the spring is compressed by 30 mm the energy stored in the spring is about 0.1 J.

[2]

(b) Calculate the maximum height the toy will reach when released, stating any assumption you make.

maximum height = ... m [3]

10 This question is about using airbags and seat belts to improve driver safety.

In a test laboratory, a car travelling at 11.0 m s^{-1} strikes a wall head-on and comes to rest in 0.1 s.

A crash test dummy of mass 75 kg is belted into the driver's seat of the car.

(a) Calculate the change of momentum of the dummy in the crash.

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

(b) In the crash, the dummy is brought to rest by the seat belt from a speed of 11 m s^{-1}, in a time of 0.14 s.

Show that the average force on the dummy is about eight times its weight.

[2]

The seat belt does not stop the head of the dummy moving forward. With no airbag the head could strike the steering wheel. Fig. 10.1 shows how the force on the head of the dummy changes over time if the head strikes a steering wheel.

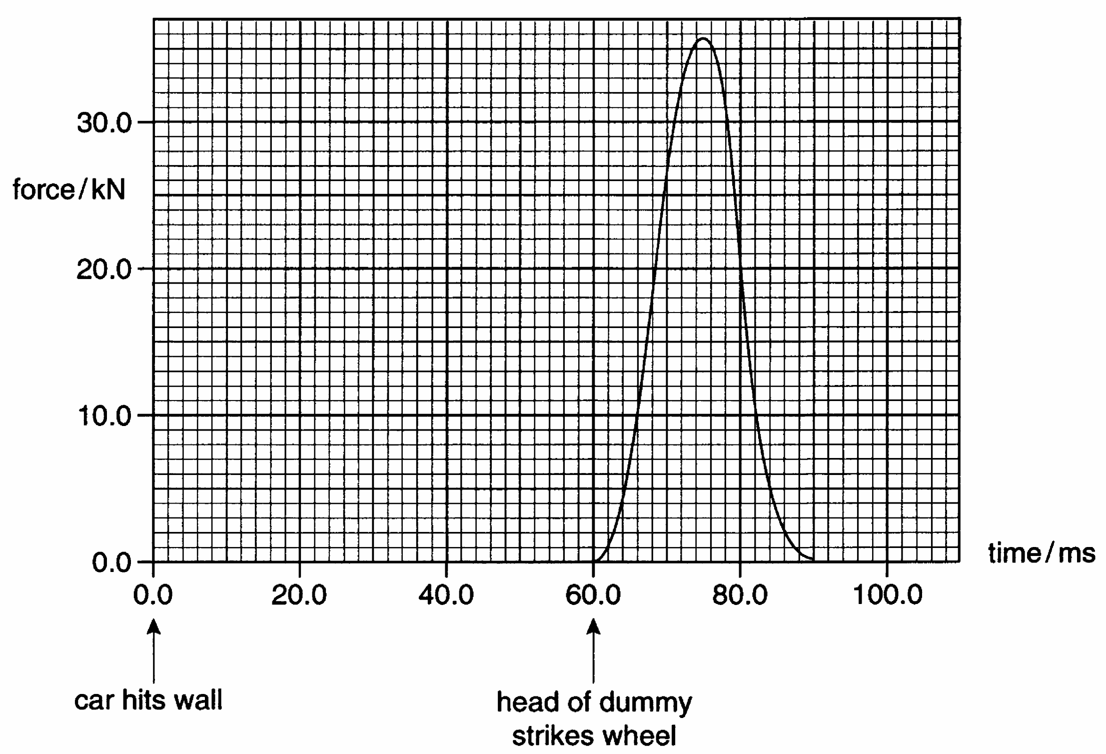


Fig. 10.1

If an airbag is installed it will begin to inflate from the steering wheel about 20 ms after the collision and takes a further 20 ms to fully inflate. 40 ms after the collision the bag begins to deflate.

(c) Suggest why airbags are most helpful if they are already deflating when the head strikes them.

[2]

(d) Draw a second graph on Fig. 10.1 to show how the force on the head changes if an airbag is present.

Explain how your graph shows,

(i) that the average force on the head is lower with an airbag

(ii) that the change of momentum of the head is the same in both cases.

[4]

11 This question is about the gravitational field around the Moon and the absence of any atmosphere around the Moon.

Fig. 11.1 shows lines representing equipotentials at different heights above the surface of the Moon.

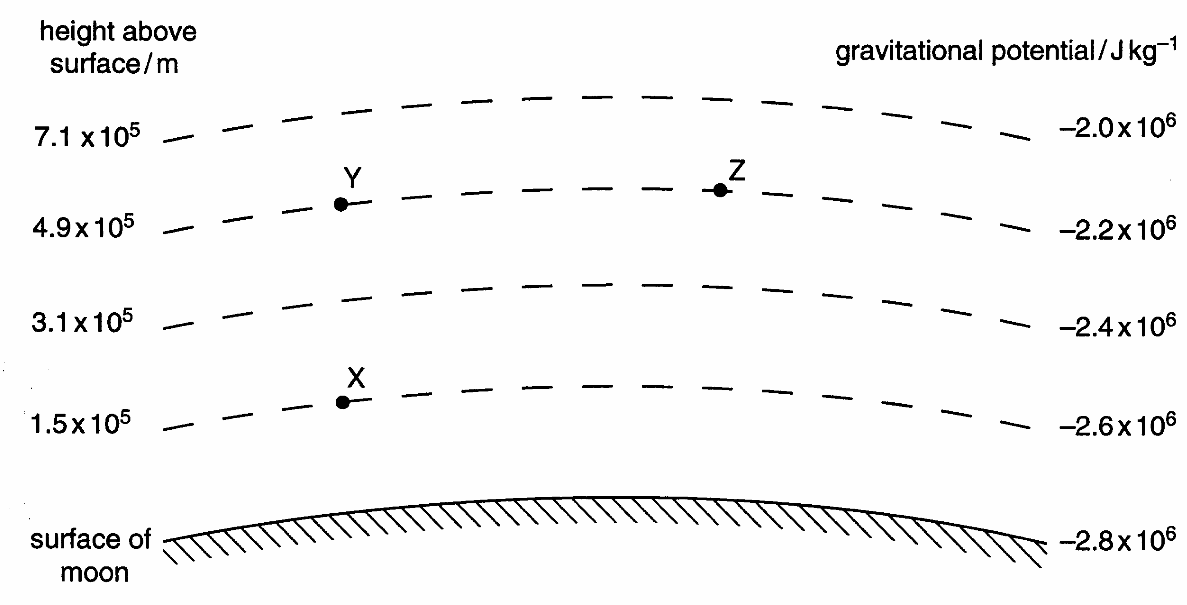


Fig. 11.1

(a) Explain why the energy required to move a mass from X to Y is the same as the energy required to move a mass from X to Z.

[2]

(b) **(i)** Show that about 78,000 J are required to move 28 gram of nitrogen molecules (one mole) from the surface of the Moon to a point far away from the surface.

[2]

Each nitrogen molecule has a mass of 4.7×10^{-26} kg. In one mole there are 6.0×10^{23} nitrogen molecules.

(ii) Show that the speed required for molecules at the surface of the planet to escape is about 2400 m s^{-1}.

[3]

(c) Use the ideal gas law and $pV = \frac{1}{3} Nm\, c^2$ to show that the mean square speed of a molecule of an ideal gas at absolute temperature T is given by:

$$c^2 = \frac{3RT}{M_m}$$

where M_m is the mass of one mole of the gas.

[3]

(d) The mean surface temperature of the Moon is 290 K.

Calculate the root mean square speed of nitrogen molecules at 290 K.

[2]

(e) Explain why the Moon has lost any nitrogen atmosphere it may have once possessed.

[2]

12 The distance from Earth to a comet can be found by firing a pulse of radio waves at the comet and recording the time for the reflected pulse to return. On one occasion the pulse took 500 s to make the round trip.

(a) Show that the distance from Earth to the comet at the time of measurement was 7.5×10^{10} m.

[1]

(b) Describe how this technique could be used to find the speed of a comet which is directly approaching Earth.

[2]

13 This question is about the expansion of the Universe.

(a) The speed of light is 3.0×10^8 m s^{-1}. Show that the distance light will travel through space in one year is about 10^{16} m.
(assume one year = 3.2×10^7 s)

[1]

(b) **(i)** During the past century it has been possible to observe galaxies which are receding from Earth.
One such galaxy is observed in the area of the sky known as Virgo. The distance to this galaxy is 10 000 million light years.
Explain why the galaxy is observed as it was 10 000 million years ago.

(ii) Show that the galaxy is about 1.0×10^{26} m from Earth.

[2]

(c) The light from the galaxy shows 'red-shift'. This is thought to be due to the expansion of space and is called 'cosmological red-shift'.

(i) Explain what is meant by 'red-shift'.

(ii) Explain how the expansion of space causes a cosmological red-shift.

(iii) The cosmological red-shift is greater for galaxies further away from the Earth. Describe how the model of an expanding universe explains this observation.

[6]

14 This question is about measuring distances and velocities in the Universe.

Distances and velocities of planets and asteroids within the Solar System can be measured by radar pulses from Earth reflected from the distant objects.

(a) A radar pulse from Earth was aimed at an asteroid. The time interval between the pulse leaving the transmitter and the detection of the reflected pulse was 40.2 s.

Show that the distance to the asteroid at the time of measurement was about 6×10^9 m. State any assumption you make.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$

[2]

(b) The measurement was repeated 14 minutes later. The time interval was then 40.0 s.

(i) Show that the change in distance between the Earth and the asteroid was about 3×10^7 m during the period the measurements were taken.

[2]

(ii) Calculate the average velocity of approach of the asteroid at the time of the measurements.

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

(c) This radar-ranging method is impractical for measuring the distance or velocity of a star such as Sirius which lies about 7 light years from Earth.
Suggest **two** reasons why this is so.

[2]

(d) Distant galaxies are observed to be receding (moving away) from the Earth at high velocities. The velocity of a galaxy in deep space is calculated from its redshift. The distance d to the object can be determined from its velocity of recession v using the relationship

$v = H_0 d$

where H_0 is the Hubble constant.

(i) Galaxy Y is observed to be receding at a velocity of 1.0×10^6 m s^{-1}.

Show that the distance from the Earth to galaxy Y is about 4.5×10^{23} m.

In the year 2001, $H_0 = 2.2 \times 10^{-18}$ s^{-1}.

[1]

(ii) Observations of distant galaxies show how the galaxies appeared millions of years ago.

Use your answer to **(d)(i)** to explain why this is so.

1 year = 3.2×10^7 s

[2]

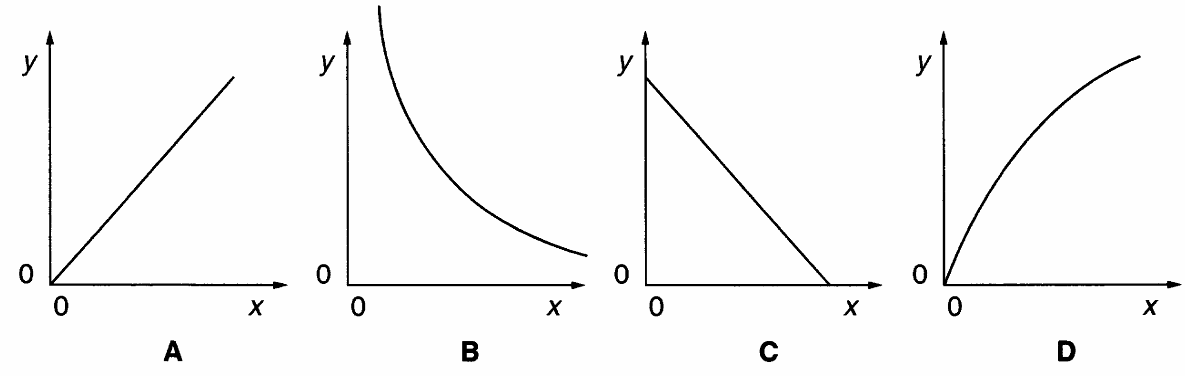
(e) The value of H_0 given in **(d)(i)** as $H_0 = 2.2 \times 10^{-18}$ s^{-1} is often given in the alternative form $H_0 = 70$ km s^{-1} Mpc^{-1}.

One megaparsec (Mpc) is an astronomical unit of distance equal to 3.1×10^{22} m.

Show that the value 70 km s^{-1} Mpc^{-1} is approximately equivalent to 2.2×10^{-18} s^{-1}.

[2]
[Total: 13]

15 Study the graphs **A**, **B**, **C**, **D**.



(a) Which graph shows the variation in **volume** (y) of a fixed mass of ideal gas at constant pressure with **absolute temperature** (x) ?

answer ....

(b) Which graph shows the variation in **pressure** (y) of a fixed mass of ideal gas at constant temperature with volume (x) ?

answer .... [2]

16 A helium balloon has a volume of 5.0 m^3 at ground level on a summer's day. The temperature at ground level is 298 K and the pressure of the helium is 1.0×10^5 Pa.

The balloon rises to a height at which its volume is 10.8 m^3 and the temperature is 257 K.

Calculate the pressure of the helium in the balloon.

Assume that helium behaves as an ideal gas.

pressure =. .... Pa [3]

17 This question is about gases under pressure.

One mole of helium gas is in a sealed container at 300 K and at a pressure of 2.0×10^5 Pa. The gas is slowly compressed to one third of its original volume without a temperature change. It behaves as an ideal gas.

(a) Calculate the new pressure of the gas.

pressure = ... Pa [2]

(b) Calculate the root mean square speed, c_{rms}, of the molecules at this temperature. (molar mass of helium = 4 g mol^{-1})

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

(c) Show that the root mean square speed goes up by a factor of $\sqrt{\frac{4}{3}}$ when the gas is heated to 400 K.

[2]

18 It has been suggested that drinking ice-cold water at 0 °C can help weight loss because the body uses stored energy in the form of fat to warm the water up to body temperature of 37 °C.

0.5 kg of fat stores about 1.6×10^8 J of energy.

(a) Calculate the mass of ice-cold water that a person would need to drink in order to lose 0.5 kg of fat.

specific thermal capacity, $c = 4200 \text{ J kg}^{-1} \text{ K}^{-1}$

mass =.. kg [2]

(b) Give a reason why it is not sensible to drink ice-cold water in order to lose weight.

[1]

19 This question is about a detector for neutrons and other sub atomic particles which works by measuring the temperature rise of a suitable liquid.

When neutrons enter the detector their kinetic energy can be shared amongst the particles within the detector. This results in a temperature rise of the liquid.

(a) Consider using water as the liquid in the detector.

Assume that each neutron passing through the detector transfers 3.5×10^{-16} J of energy to the water.

Show that 1.2×10^{19} neutrons would need to enter the detector to raise the temperature of 1 kg of water by 1 K.

Specific thermal capacity of water = 4.2×10^{3} J kg^{-1} K^{-1}

[2]

(b) Scientists are attempting to use this process to detect a new type of particle. This particle has a kinetic energy of 3.5×10^{-16} J but only interacts with matter very rarely. It is expected that only one of these particles would be absorbed per day by 1 kg of water.

Explain why the temperature rise of water cannot be used to detect such rare happenings.

[2]

(c) A similar type of detector uses the temperature rise of very cold liquid helium-3 to detect the particles. When helium-3 is cooled to 1×10^{-4} K it has a specific thermal capacity of 7.0×10^{-8} J kg^{-1} K^{-1}.

(i) The detector uses 8.0×10^{-6} kg of helium-3 at this temperature. Show that a particle transferring 3.5×10^{-16} J to the helium-3 will give a temperature rise of 6.3×10^{-4} K.

(ii) The smallest temperature change that can be detected is 0.5×10^{-6} K. Explain why it is unlikely that any particles will be detected if helium-3 absorbs the particles at a similar rate to water. Suggest how the apparatus can be adapted to make detection more likely.

[3]

20 At temperature T, the average energy of a particle is of the order kT where k is the Boltzmann constant.

(a) Show that the average energy of a particle, kT, at 300 K is about 4 x 10^{-21} J.

$k = 1.4 \times 10^{-23}$ J K^{-1}

[1]

(b) Water molecules are held to the surface of the liquid by an average of two hydrogen bonds. It requires an energy of about 3.2 x 10^{-20} J to break each bond.

Show that the average energy required for a water molecule to break free from the surface of the liquid at 300 K is about 15 kT.

[1]

(c) Puddles of water can evaporate quickly on a warm summer's day even though the average energy of the molecules is less than that required to break free from the surface. Explain why this happens.

[2]

21 The energy, ε, required for a water molecule to go from the liquid into the vapour is about 3×10^{-20} J.

(a) Calculate the Boltzmann factor, $e^{-\varepsilon/kT}$ for the vaporisation of water at 300 K.

Boltzmann factor = ... [2]

(b) State the units of the quantity kT.

units = ... [1]

22 This question is about oscillations in loaded vehicles.

A small delivery truck can be thought of as a box supported by four springs, one at each wheel (the suspension of the truck). In this question, only the two rear springs will be considered.

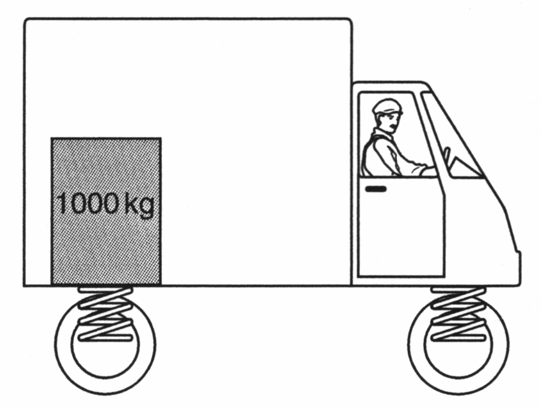


Fig. 22.1

(a) The spring constant k in $F = kx$ of each spring is 2.6×10^4 N m^{-1}.

(i) Explain why the spring constant of the two rear springs together is 5.2×10^4 N m^{-1}.

[2]

(ii) Show that the back of the truck will move down about 20 cm when it is loaded with 1 tonne (1000 kg), placed above the rear wheels as in Fig. 22.1.

[2]

The part of the truck body supported by the rear wheels has a mass of 500 kg.

(b) Show that the period of oscillation of an unloaded truck is about 0.6 s.

[2]

(c) A truck oscillates with a time period exactly double that of an unloaded truck. Is it carrying more than the maximum permitted load of 1 tonne? Show your working.

[3]

`Speed bumps' are put on the road into a large supermarket to slow the traffic (Fig. 22.2).

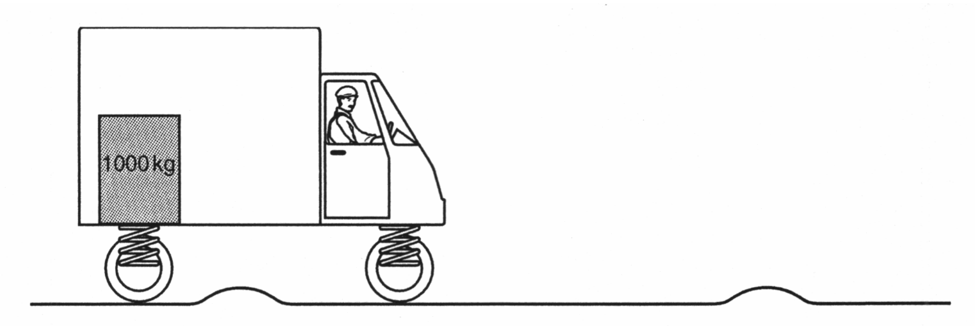


Fig. 22.2

(d) Explain why the truck will oscillate after passing quite rapidly over a speed bump.

[2]

(e) If the truck travels at a certain speed over the set of speed bumps, the vertical oscillations can become very large. Explain why this is so.

[2]

(f) Free oscillations of the suspension, as shown in the graph below, would be uncomfortable, so friction is used to damp them by reducing the amplitude.

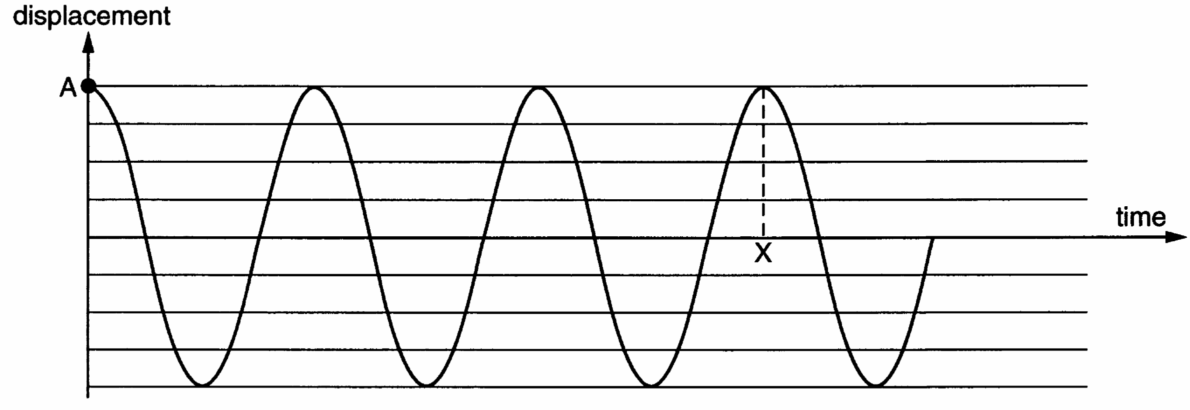


Fig. 22.3

Starting at point A, sketch on Fig. 22.3 a graph showing the displacement–time graph you would get if the oscillation was damped so that the amplitude at point X was about one-quarter of the starting amplitude.

[3]
[Total: 16]

23 This question is about the absorption of gamma photons by different materials.

The half-thickness of a material is the thickness that halves the gamma intensity. This depends on the energy of the gamma photon and the nature of the material.

The table shows some values for the absorption of 1.33 MeV gamma photons emitted in the decay of cobalt-60.

	Lead	**Steel**	**Water**
half-thickness/mm	12	22	178
density/kg m^{-3}	11800	7800	1000

(a) It is suggested that the half-thickness and the density follow the relationship

half-thickness x density = constant

Use the data in the table to check this relationship.

[2]

(b) Suggest and explain one physical property, **other than density**, that would be necessary in a material used for shielding large cobalt-60 sources when they are transported by road to the hospital.

Property:

Explanation:

[2]

(c) Fig. 23.1 shows sixteen 1.33 MeV gamma photons incident on three sheets of lead, each 12 mm thick. Continue the diagram to show how many gamma photons emerge on average from the last sheet.

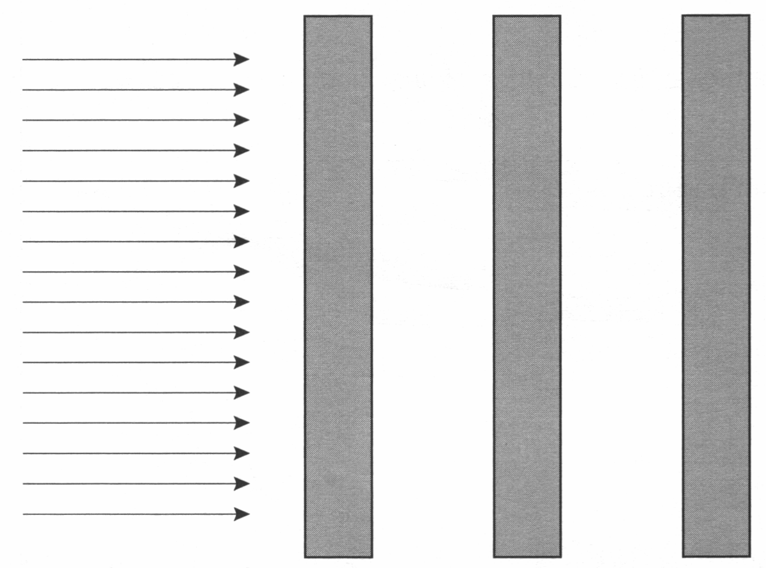


Fig. 23.1

[1]

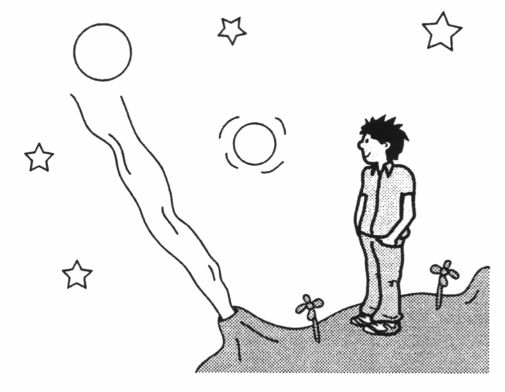
(d) Explain why the word **exponential** is used to describe the absorption of gamma radiation by different thicknesses of absorbing material.

[3]

(e) The lead shield surrounding a cobalt-60 radiotherapy source is 120 mm thick. Show that less than 0.1% of the gamma radiation reaching the shielding escapes.

[3]

24 This question is about the gravitational fields of asteroids and moons in the Solar System. In a children's story, the Little Prince travels from asteroid to asteroid.



(a) (i) One such asteroid is roughly 500 m in radius and has density of 5000 kg m^{-3}. Show that its mass is about 3 x 10^{12} kg.

[2]

(ii) The Little Prince has a mass of 50 kg. Show that he weighs about 0.04 N on this asteroid.

G = 6.7 x 10^{-11} N m^2 kg^{-2}

[3]

(b) The gravitational potential energy E_{grav} of the Little Prince on this asteroid = –18 J.

(i) Explain why this quantity is negative.

[2]

(ii) Explain why the Little Prince should be cautious as he moves on the surface of this asteroid.

[2]

(c) Titan, one of Saturn's moons, is very much larger than this asteroid. It has an atmosphere of nitrogen, while the atmosphere of the planet Saturn is mostly hydrogen. The table below shows the gravitational potential energy that one molecule of each gas would have on the surface of Titan.

molecule	$E_{grav}/10^{-19}$ **J**
nitrogen	–1.7
hydrogen	–0.12

(i) Explain why these two values are different.

[1]

(ii) The temperature T of the surface of Titan is 93 K. Compare the value kT, where k is the Boltzmann constant, with the values of the gravitational potential energy E_{grav} in the table to explain why Titan has an atmosphere of nitrogen but no hydrogen.

$k = 1.4 \times 10^{-23}$ J K^{-1}

[3]
[Total: 13]

This question is based on the advance notice article on 'Probing the early Universe'

25 This question is about the expanding Universe.

Fig. 25.1 shows a popular `balloon model' used to show the expanding Universe.

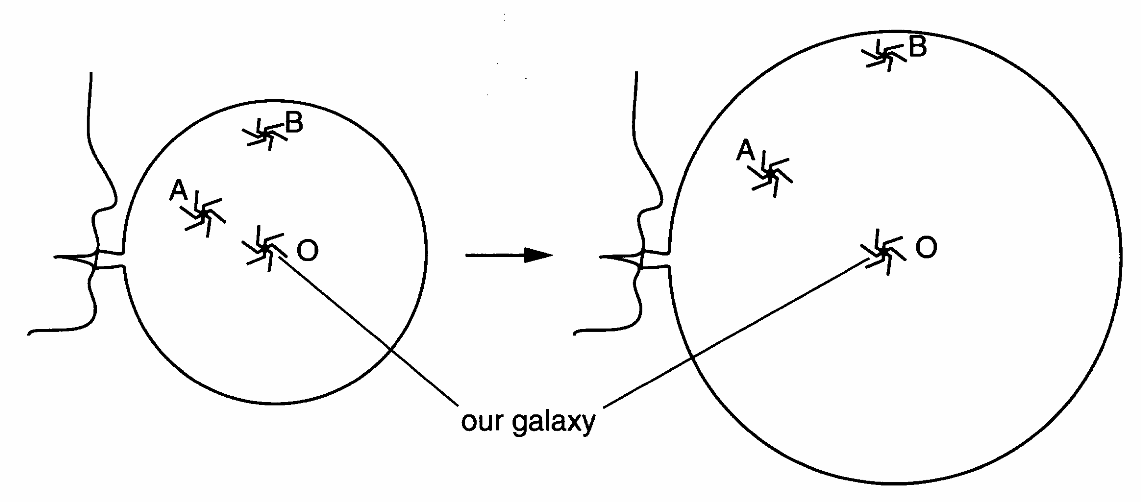


Fig. 25.1

(a) What does the rubber surface of the balloon represent?

[1]

(b) State how the expansion of the Universe is shown in this model.

[1]

(c) Explain how the balloon model shows that galaxy B is receding from our galaxy O at a higher speed than galaxy A.

[1]

(d) Fig. 25.2 shows a recent best-fit graph for the observed speed of recession *v* of different distant galaxies, measured in km s^{-1}, and their distance *d* from us, measured in megaparsec (Mpc).

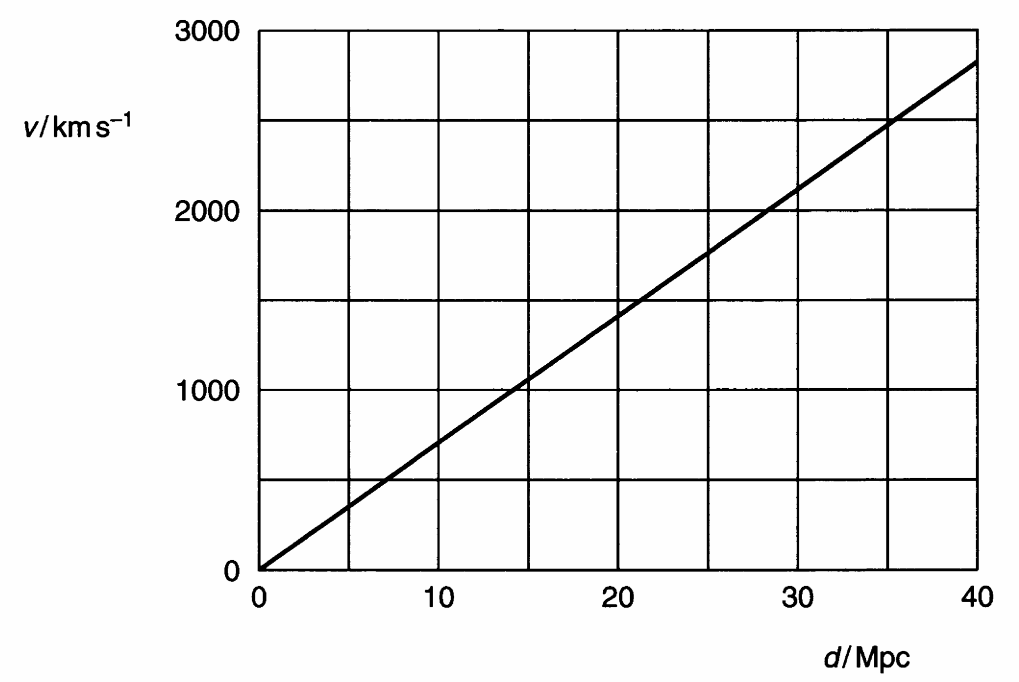


Fig. 25.2

(i) Explain how the graph illustrates Hubble's Law, $v = H_0 d$.

[2]

(ii) Calculate the value of H_0 given by the graph.

H_0 =..................... unit..................... [3]

[Total: 8]

26 This question is about the BOOMERANG helium balloon.

The upward force (upthrust) on the balloon is equal to the weight of the air displaced by the balloon and all its fittings.

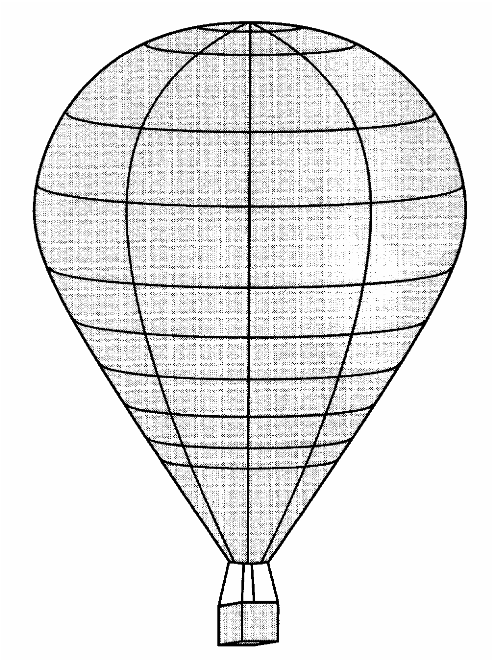


Fig. 26.1

(a) The balloon and all its fittings have a mass of 1.4×10^3 kg. Show that the weight of the balloon is about 14 kN.

[1]

(b) The volume of air displaced at ground level is approximately 1.0×10^4 m^3. The density of this air is 1.2 kg m^{-3}.
Show that the upthrust on the balloon is about 120 kN.

[2]

(c) Calculate the initial upward acceleration of the balloon at the instant of release.

initial acceleration = ... m s^{-2} [3]

(d) As the balloon rises, the pressure, the density and the temperature of the air surrounding the helium balloon all decrease.

Suggest and explain how changes in these three factors will affect the resultant force acting on the balloon.

(i) the decrease in pressure

[2]

(ii) the decrease in density

[2]

(iii) the decrease in temperature

[2]

[Total: 12]