



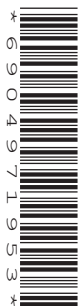
Oxford Cambridge and RSA

A Level Physics A

H556/01 Modelling physics

Monday 4 June 2018 – Afternoon

Time allowed: 2 hours 15 minutes



You must have:

- the Data, Formula and Relationship Booklet (sent with general stationery)

You may use:

- a scientific or graphical calculator
- a ruler (cm/mm)



First name										
Last name	StemUp Model Solution									
Centre number						Candidate number				

INSTRUCTIONS

- Use black ink. You may use an HB pencil for graphs and diagrams.
- Complete the boxes above with your name, centre number and candidate number.
- Answer **all** the questions.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.
- Do **not** write in the barcodes.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **32** pages.

2
SECTION A

You should spend a maximum of 30 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

1 Which of the following units is **not** an S.I. base unit?

- A** ampere
- B** mole
- C** volt
- D** kilogram

Your answer

C

[1]

2 Which set of quantities are all scalar?

- A** acceleration, displacement, velocity
- B** energy, mass, power
- C** extension, force, gravitational potential energy
- D** weight, kinetic energy, work done

Your answer

B

[1]

3 A metal block of mass 0.28 kg has an initial temperature of 82 °C. It is dropped into cold water. The temperature of the block after 1.2 minutes is 20 °C.
The specific heat capacity of the metal is 130 J kg⁻¹ K⁻¹.

What is the average thermal power transferred away from the metal block?

- A** 31 W
- B** 41 W
- C** 1900 W
- D** 2700 W

Your answer

A

[1]

- 4 The acceleration a of a simple harmonic oscillator is related to its displacement x by the equation

$$a = -25x.$$

What is the frequency of the oscillator?

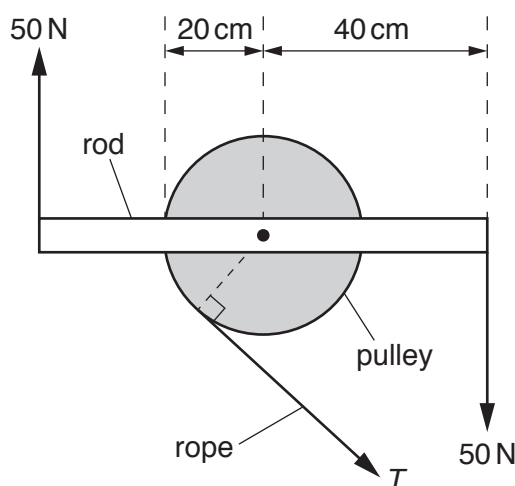
- A 0.80 Hz
- B 1.3 Hz
- C 4.0 Hz
- D 5.0 Hz

Your answer

A

[1]

- 5 A rod is fixed to a pulley. Two 50 N forces are applied to the ends of the rod as shown. The tension in the rope attached to the pulley is T . The system is in equilibrium.



Not to scale

What is the moment of the tension T about the centre of the pulley?

- A 10 Nm
- B 20 Nm
- C 30 Nm
- D 40 Nm

Your answer

D

[1]

- 6 The latent heat of vaporisation of a liquid is 2300 kJ kg^{-1} and it has a molar mass of $0.018 \text{ kg mol}^{-1}$.

What is the energy required to change 30 moles of the liquid to gas?

- A $4.1 \times 10^4 \text{ J}$
B $1.2 \times 10^6 \text{ J}$
C $6.9 \times 10^7 \text{ J}$
D $3.8 \times 10^9 \text{ J}$

Your answer

B

[1]

- 7 One end of a spring is fixed and a force F is applied to its other end. The elastic potential energy in the extended spring is E . The spring obeys Hooke's law.

What is the extension x of the spring?

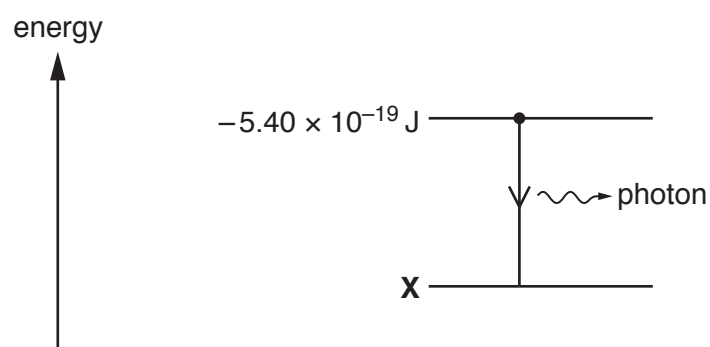
- A $x = \frac{E}{F}$
B $x = \frac{F}{E}$
C $x = \frac{2E}{F}$
D $x = \frac{F}{2E}$

Your answer

C

[1]

- 8 An electron makes a transition between the two energy levels shown below.



This transition produces a photon of frequency $4.10 \times 10^{14} \text{ Hz}$.

What is the value of the energy level **X**?

- A $-2.68 \times 10^{-19} \text{ J}$
- B $-2.72 \times 10^{-19} \text{ J}$
- C $-5.40 \times 10^{-19} \text{ J}$
- D $-8.12 \times 10^{-19} \text{ J}$

Your answer

D

[1]

- 9 A pendulum is oscillating in air and experiences damping.

Which of the following statements is/are correct for the damping force acting on the pendulum?

- 1 It is always opposite in direction to acceleration.
- 2 It is always opposite in direction to velocity.
- 3 It is maximum when the displacement is zero.

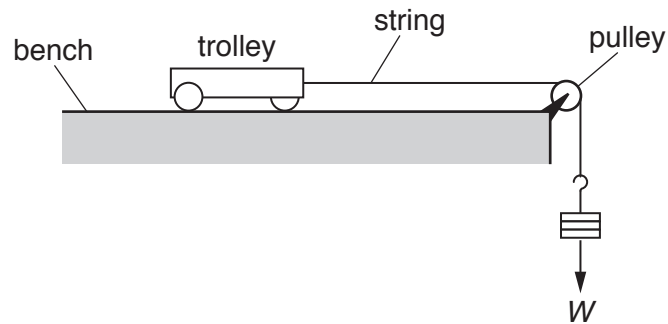
- A Only 1 and 2
- B Only 2 and 3
- C Only 3
- D 1, 2 and 3

Your answer

B

[1]

- 10 A trolley of mass M is pulled along a horizontal table by a force W provided by a mass hanging from the end of a string as shown.



Frictional forces are negligible. The acceleration of free fall is g .

What is the correct equation for the acceleration a of the trolley?

A $a = \frac{W}{M}$

B $a = g$

C $a = \frac{W}{2M}$

D $a = \frac{W}{M + \frac{W}{g}}$

Your answer

D

[1]

- 11 The table below shows some data on two wires **X** and **Y**.

Wire	Young modulus of material / GPa	Cross-sectional area of wire / mm ²
X	120	1.0
Y	200	2.0

The wires **X** and **Y** have the same original length. The tension in each wire is the same. Both wires obey Hooke's law.

What is the value of the ratio $\frac{\text{extension of X}}{\text{extension of Y}}$?

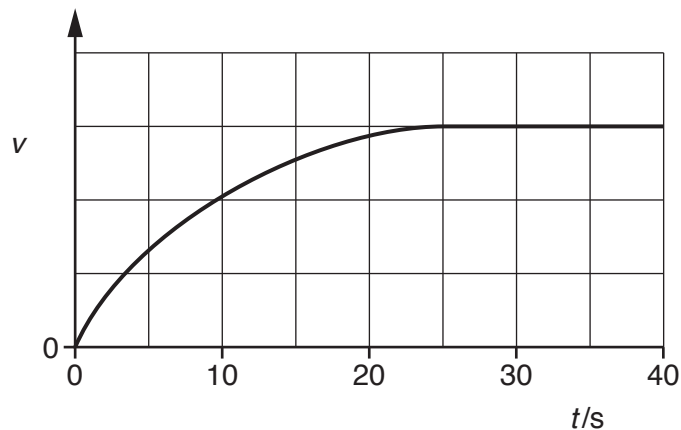
- A** 0.30
B 1.7
C 2.0
D 3.3

Your answer

D

[1]

- 12 An object is dropped from rest at time $t = 0$. It falls vertically through the air. The variation of the velocity v with time t is shown below.



Which statement is correct about this object?

- A** It has constant acceleration.
B It experiences zero drag at $t = 30$ s.
C It has an acceleration of 9.81 ms^{-2} at $t = 0$ s.
D It travels the same distance in every successive 10 s.

Your answer

C

[1]

- 13** Earth has a mass of 6.0×10^{24} kg and a radius of 6400 km.
A satellite of mass 320 kg is lifted from the Earth's surface to an orbit 1200 km above its surface.

What is the change in the gravitational potential energy of the satellite?

- A** 9.1×10^2 J
- B** 9.9×10^6 J
- C** 3.2×10^9 J
- D** 3.8×10^9 J

Your answer

C

[1]

- 14** The volume of one mole of an ideal gas is V . The gas exerts pressure p and has thermodynamic temperature T .

Which of the following has the units $\text{J mol}^{-1} \text{K}^{-1}$?

- A** pV
- B** $\frac{p}{T}$
- C** $\frac{V}{T}$
- D** $\frac{pV}{T}$

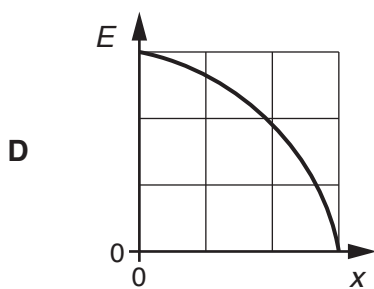
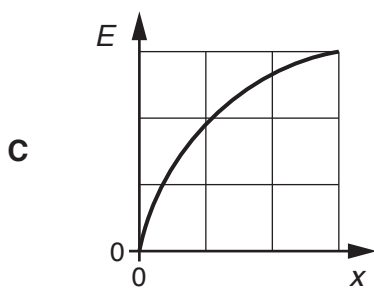
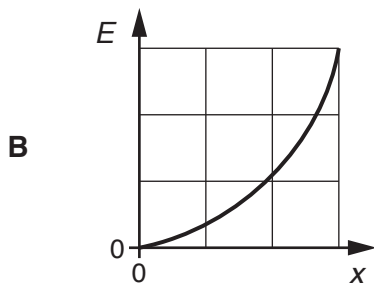
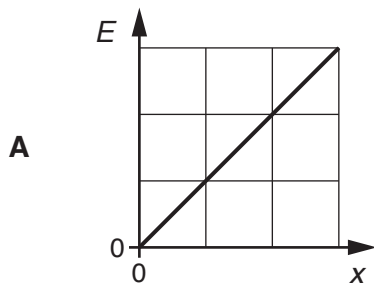
Your answer

D

[1]

15 An object oscillates with simple harmonic motion.

Which graph **best** shows the variation of its potential energy E with distance x from the equilibrium position?



Your answer

B

[1]

10
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SECTION B

Answer **all** the questions.

- 16 (a) A tennis ball is struck with a racket. The initial velocity v of the ball leaving the racket is 30.0 m s^{-1} and it makes an angle of 70° to the horizontal as shown in Fig. 16. Air resistance is negligible

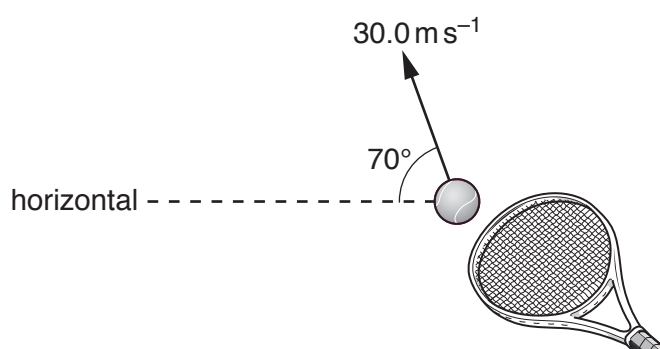


Fig. 16

- (i) Calculate the vertical component of the initial velocity of the ball.

$$\begin{aligned} \text{vertical component} &= 30.0 \sin 70^\circ \\ &= 28.19 \text{ m s}^{-1} \end{aligned}$$

vertical component = ...28.2..... m s^{-1} [1]

- (ii) Use your answer in (i) to show that the ball reaches a maximum height h of about 40 m.

$$\begin{aligned} v^2 &= u^2 + 2as, \text{ with } v = 0 \text{ at maximum height} \\ 0 &= 28.2^2 - 2 \times 9.81 \times h \\ h &= 28.2^2 \div (2 \times 9.81) \\ h &= 40.5 \text{ m, which is about 40 m} \end{aligned}$$

$h =$ 40.5..... m [2]

- (iii) Explain why the kinetic energy of the ball is not zero at maximum height.

At maximum height the vertical velocity is zero, but the ball still has its horizontal velocity (constant, 10.3 m s^{-1}), so its KE is not zero. [1]

- (iv) The mass m of the ball is 57.0g.
Calculate the kinetic energy E_k of the ball when it is at its **maximum** height.

$$\text{horizontal velocity} = 30.0 \cos 70^\circ = 10.26 \text{ m s}^{-1}$$

$$\text{at maximum height } v = 10.26 \text{ m s}^{-1} \text{ (vertical component} = 0)$$

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.0570 \times 10.26^2$$

$$E_k = 3.0 \text{ J}$$

$$E_k = \dots\dots\dots 3.0 \dots\dots\dots \text{ J [2]}$$

- (b)* A metal ball is rolled off the edge of a horizontal laboratory bench. The initial horizontal velocity of the ball is v . The ball travels a horizontal distance x before it hits the level floor.

Use your knowledge of projectile motion to suggest the relationship between v and x . Describe how an experiment can be safely conducted to test this relationship and how the data can be analysed.

Relationship: the ball leaves the bench horizontally, so its initial vertical velocity is zero. The time of fall t depends only on the bench height H : $H = \frac{1}{2}gt^2$, so $t = \sqrt{(2H/g)}$, which is independent of v .

Air resistance is negligible, so there is no horizontal force and the horizontal velocity v stays constant: $x = vt$. Hence $x = v\sqrt{(2H/g)}$, so $x \propto v$. A graph of x against v should be a straight line through the origin.

Method: clamp a curved ramp to the bench so that its end is horizontal at the edge of the bench (check with a spirit level), so the initial velocity is horizontal. Release the ball from rest from different heights up the ramp to vary v ; use the same release point for repeats so v is consistent.

Measure v with a light gate at the end of the ramp connected to a data logger: $v = \text{diameter of ball} \div \text{time the beam is blocked}$ (diameter measured with vernier callipers). (A video with a metre rule in the frame could also be

used.)

Find the landing point with a tray of sand, or carbon paper on white paper on the floor, so the ball leaves a mark; do a trial run first to find roughly where it lands. Measure x with a metre ruler from the point vertically below the bench edge (found with a plumb line) to the mark.

Repeat each release height 3 times and average x ; use at least 6 values of v .

Measure H with a metre ruler.

Safety: catch the ball in the sand tray so it cannot roll across the floor and cause someone to slip or trip, keep the landing area clear of people, and clamp the ramp firmly.

Analysis: plot a graph of x against v . If $x \propto v$ it is a straight line through the origin, confirming the relationship. The gradient = $\sqrt{(2H/g)}$, which can be compared with the value calculated from H (or used to find $g = 2H/(\text{gradient}^2)$).

[6]

- 17 (a) Phobos is one of the two moons orbiting Mars. Fig. 17.1 shows Phobos and Mars.

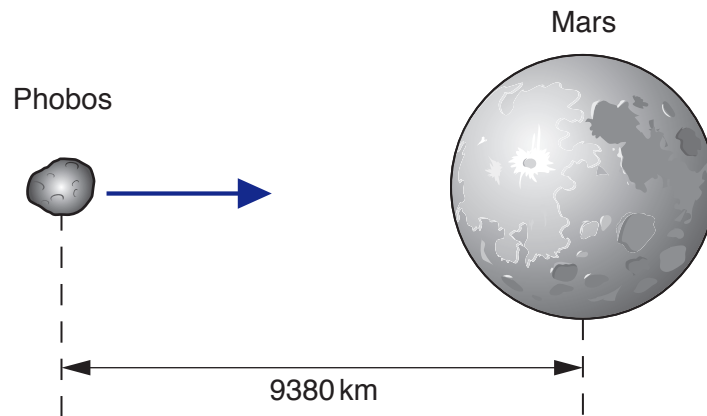


Fig. 17.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed $2.14 \times 10^3 \text{ m s}^{-1}$.

- (i) On Fig. 17.1, draw an arrow to show the direction of the force which keeps Phobos in its orbit. [1]
- (ii) Calculate the orbital period T of Phobos.

$$v = 2\pi r/T, \text{ so } T = 2\pi r/v$$

$$T = (2\pi \times 9380 \times 10^3) \div 2.14 \times 10^3$$

$$T = 2.75 \times 10^4 \text{ s}$$

$$T = 2.75 \times 10^4 \text{ s [2]}$$

- (iii) Calculate the mass M of Mars.

$$GMm/r^2 = mv^2/r, \text{ so } v^2 = GM/r$$

$$M = v^2 r/G$$

$$M = (2.14 \times 10^3)^2 \times 9380 \times 10^3 \div 6.67 \times 10^{-11}$$

$$M = 6.44 \times 10^{23} \text{ kg}$$

$$M = 6.44 \times 10^{23} \text{ kg [3]}$$

(b) The gravitational field strength at a distance r from the centre of Mars is g .

The table below shows some data on Mars.

$g/\text{N kg}^{-1}$	r/km	$\lg(g/\text{N kg}^{-1})$	$\lg(r/\text{km})$
1.19	6 000	0.076	3.78
0.87	7 000	-0.060	3.85
0.67	8 000	-0.174	3.90
0.53	9 000	-0.276	3.95
0.43	10 000	-0.367	4.00

(i) Complete the table by calculating the missing values.

[1]

(ii) Fig. 17.2 shows the graph of $\lg(g/\text{N kg}^{-1})$ against $\lg(r/\text{km})$.

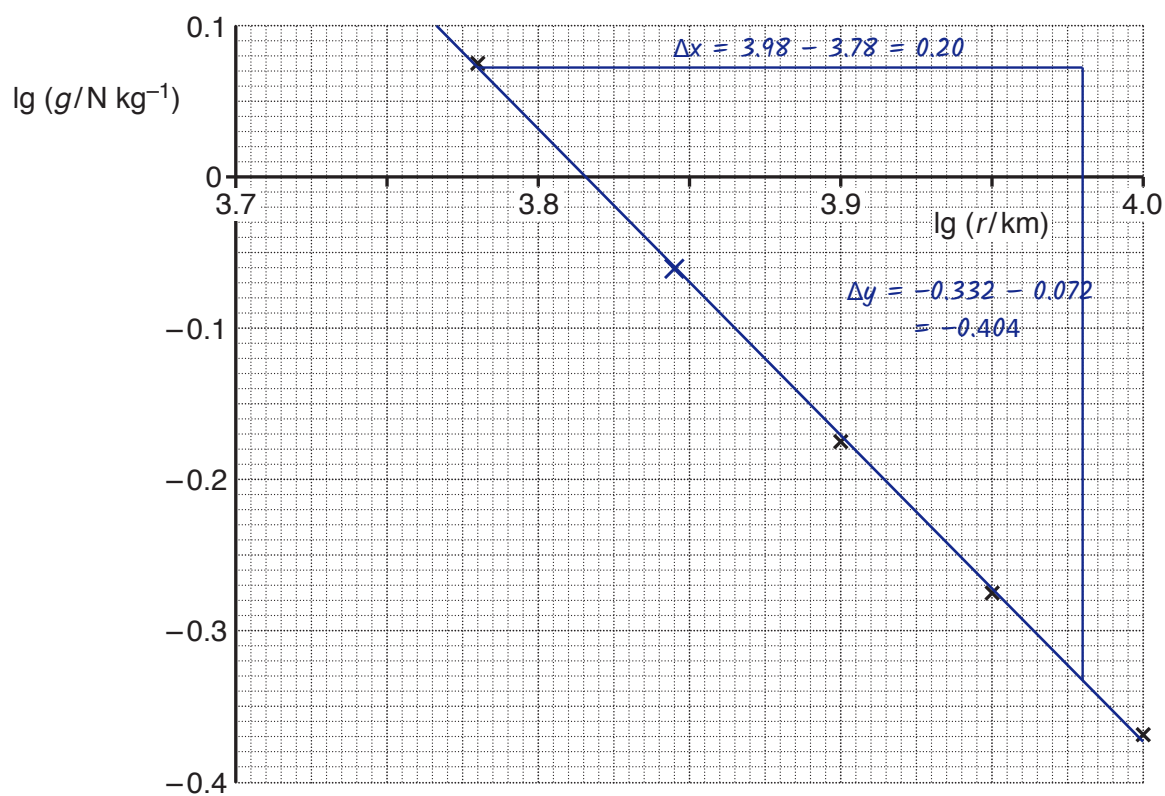


Fig. 17.2

1 Plot the missing data point on the graph and draw the straight line of best fit.

[2]

- 2 Use Fig. 17.2 to show that the gradient of the straight line of best fit is -2 .

From the gradient triangle on Fig. 17.2:

$$\text{gradient} = \Delta y / \Delta x = (-0.332 - 0.072) \div (3.98 - 3.78)$$

$$\text{gradient} = -0.404 \div 0.20 = -2.0 (\approx -2)$$

[1]

- 3 Explain why the gradient of the straight line of best fit is -2 .

$$g = GM/r^2$$

$$\lg g = \lg(GM) - 2 \lg r$$

Compared with $y = mx + c$: $y = \lg g$, $x = \lg r$,

so the gradient $m = -2$ (and $c = \lg(GM)$, a constant).

[2]

- (c) In July 2018, the closest distance between the centre of Mars and the centre of Earth will be 5.8×10^{10} m.

Fig. 17.3 shows the variation of the **resultant** gravitational field strength g between the two planets with distance r from the centre of the **Earth**.

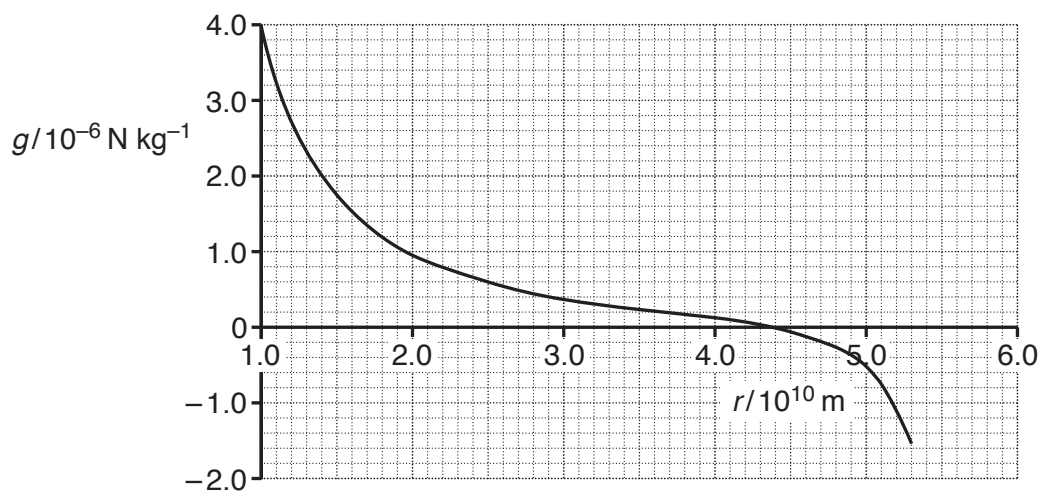


Fig. 17.3

- (i) Explain briefly the overall shape of the graph in Fig. 17.3.

*The fields of Earth and Mars are in opposite directions. For $r < \text{about}$
 $4.4 \times 10^{10} \text{ m}$ Earth's g is greater, so the resultant g is towards Earth;
 beyond this Mars's g is greater (towards Mars). Near each planet g rises
 steeply (inverse square law).*

[2]

- (ii) Use the value of r when $g = 0$ from Fig. 17.3 to determine the ratio

$$\frac{\text{mass of Earth}}{\text{mass of Mars}}.$$

$$\begin{aligned} g &= 0 \text{ at } r = 4.4 \times 10^{10} \text{ m from Earth} \\ \text{distance from Mars} &= 5.8 - 4.4 = 1.4 \times 10^{10} \text{ m} \\ GM_E/r_E^2 &= GM_M/r_M^2 \\ M_E/M_M &= r_E^2/r_M^2 = (4.4/1.4)^2 \\ M_E/M_M &= 9.9 \end{aligned}$$

$$\frac{\text{mass of Earth}}{\text{mass of Mars}} = \dots\dots\dots 9.9 \dots\dots\dots [2]$$

- 18 Wind turbines convert the kinetic energy of the wind into electrical energy. Fig. 18 shows a wind turbine.

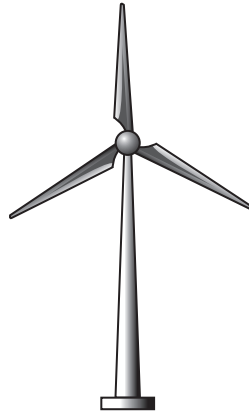


Fig. 18

- (a) When the wind speed is 8.0 ms^{-1} , the kinetic energy of the air incident at the turbine per second is 1.2 MJ s^{-1} .
Calculate the mass of the air incident at the turbine per second.

$$\begin{aligned} KE \text{ per second} &= \frac{1}{2} \times (\text{mass per second}) \times v^2 \\ 1.2 \times 10^6 &= \frac{1}{2} \times (\text{mass per second}) \times 8.0^2 \\ \text{mass per second} &= 2.4 \times 10^6 \div 64 = 3.75 \times 10^4 \end{aligned}$$

$$\text{mass per second} = \dots 3.8 \times 10^4 \dots \text{ kg s}^{-1} \text{ [2]}$$

- (b) A group of engineers are investigating the design of wind turbines.
The maximum **input** power P from the wind is given by the equation

$$P = \frac{1}{2} \rho A v^3$$

where A is the area swept out by the rotating blades, ρ is the density of air and v is the speed of the wind.

- (i) Show that the equation is homogeneous with both sides of the equation having the same base units.

$$A: m^2 \quad \rho: kg \, m^{-3} \quad v^3: (m \, s^{-1})^3 = m^3 \, s^{-3}$$

$$RHS: kg \, m^{-3} \times m^2 \times m^3 \, s^{-3} = kg \, m^2 \, s^{-3} \text{ (}\frac{1}{2} \text{ has no units)}$$

$$LHS: P = \text{work done/t} = Fv = kg \, m \, s^{-2} \times m \, s^{-1} = kg \, m^2 \, s^{-3}$$

Both sides have base units $kg \, m^2 \, s^{-3}$, so the equation is homogeneous.

[3]

- (ii) The input power to the wind turbine is 1.2 MW when the wind speed is $8.0 \, m \, s^{-1}$. The density of air is $1.3 \, kg \, m^{-3}$.

Calculate the length L of the turbine blades.

$$1.2 \times 10^6 = \frac{1}{2} \times 1.3 \times A \times 8.0^3$$

$$A = 2.4 \times 10^6 \div (1.3 \times 512) = 3.6 \times 10^3 \, m^2$$

$$A = \pi L^2, \text{ so } L = \sqrt{(3606 \div \pi)}$$

$$L = 34 \, m$$

$$L = \dots\dots\dots 34 \dots\dots\dots m \text{ [2]}$$

- (iii) A wind farm is required to produce an output power of 50 MW when the average wind speed is $8.0 \, m \, s^{-1}$. The efficiency of each wind turbine is 42%.

Calculate the minimum number N of wind turbines required to meet this demand.

$$\text{output power per turbine} = 0.42 \times 1.2 = 0.504 \, MW$$

$$N = 50 \div 0.504 = 99.2$$

so a minimum of 100 turbines is needed

$$N = \dots\dots\dots 100 \dots\dots\dots \text{ [2]}$$

Turn over

19 Fig. 19 is an incomplete Hertzsprung-Russell (HR) diagram of stars in our galaxy.

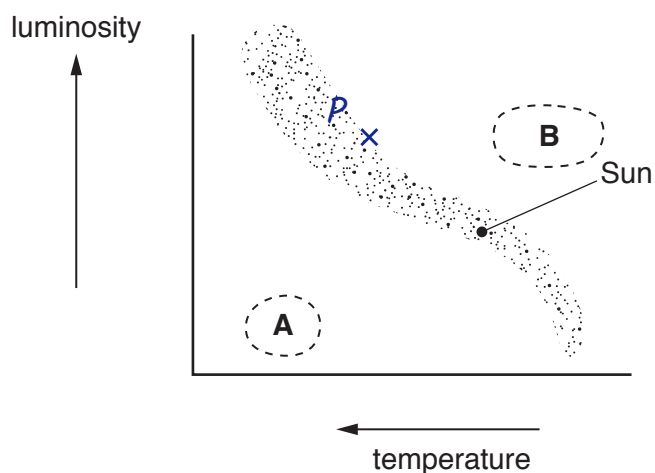


Fig. 19

The position of the Sun on the HR diagram is shown in Fig. 19.

(a) State the type of stars found in regions **A** and **B**.

A white dwarf **B** red giant [1]

(b) The Sun is a main sequence star. Its surface temperature is 5800 K. The wavelength of the emitted light at maximum intensity is 550 nm.

Beta Pictoris is also a main sequence star. The wavelength of the emitted light at maximum intensity from this star is 370 nm.

(i) Calculate the surface temperature of Beta Pictoris.

Wien's law: $\lambda_{\max} T = \text{constant}$

$$550 \times 5800 = 370 \times T$$

$$T = 550 \times 5800 \div 370 = 8620 \text{ K}$$

temperature = 8600 K [2]

(ii) On Fig. 19, mark the likely position of Beta Pictoris with a letter **P**. [1]

- 20 (a) Use the equations for momentum and kinetic energy to derive an expression for the kinetic energy E_k of a particle in terms of its momentum p and mass m .

$$E_k = \frac{1}{2}mv^2 \text{ and } p = mv$$

$$\text{so } v = p/m$$

$$E_k = \frac{1}{2}m(p/m)^2 = \frac{1}{2} \times p^2/m$$

$$E_k = p^2/2m$$

[2]

- (b) Fig. 20.1 shows an electric motor used to lift and lower a load.

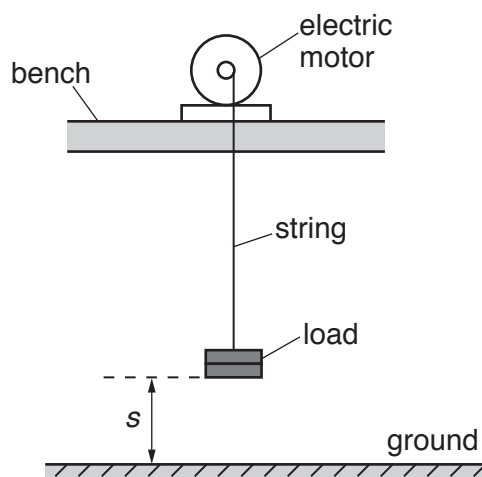


Fig. 20.1

At time $t = 0$ the load is on the ground with displacement $s = 0$.

Fig. 20.2 shows the variation of the displacement s of the load with time t .

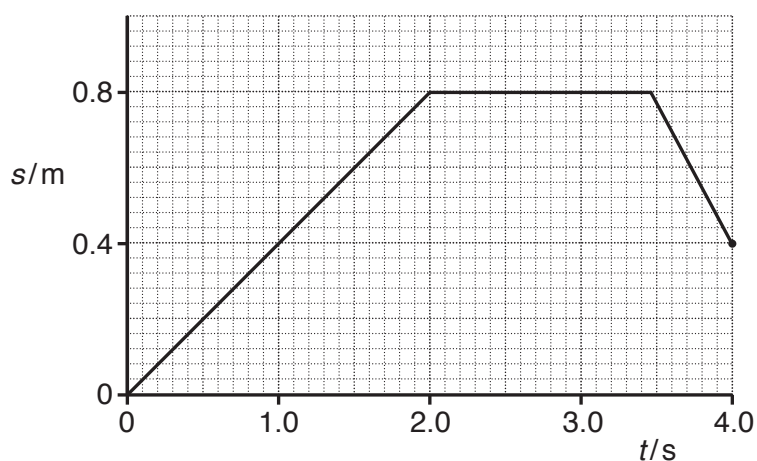


Fig. 20.2

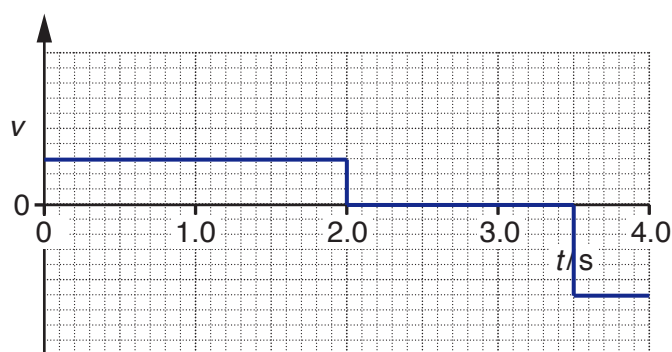


Fig. 20.3

- (i) On Fig. 20.3, sketch a graph to show the variation of the velocity v of the load with time t . You do not need to insert a scale on the v axis. [3]
- (ii) Describe how the kinetic energy and the gravitational potential energy of the load varies from $t = 0$ to $t = 2.0$ s.

The kinetic energy is constant, as the velocity is constant (s-t graph is a straight line).

The GPE increases linearly (at a constant rate, proportional to t) as the height increases at a constant rate. [2]

- (iii) During the **downward** journey of the load, the string breaks at $t = 4.0\text{s}$. It then falls vertically towards the ground. The mass of the load is 120g . Air resistance is negligible.

1 Calculate the velocity V of the load just before it hits the ground.

at $t = 4.0\text{ s}$: $s = 0.40\text{ m}$, $\text{speed} = 0.40 \div 0.50 = 0.80\text{ m s}^{-1}$ (down)

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

$$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40 = 8.49$$

$$V = 2.9\text{ m s}^{-1}$$

$$V = \dots\dots\dots 2.9 \dots\dots\dots \text{ms}^{-1} \text{ [2]}$$

2 The load hits the ground and comes to **rest** in a time interval of 25ms .

Calculate the average force F exerted by the ground on the load.

$$F = \Delta p / \Delta t = m \Delta v / \Delta t$$

$$F = 0.120 \times 2.9 \div 0.025$$

$$F = 14\text{ N}$$

$$F = \dots\dots\dots 14 \dots\dots\dots \text{N [2]}$$

21 Fig. 21 shows the drum of a washing machine.

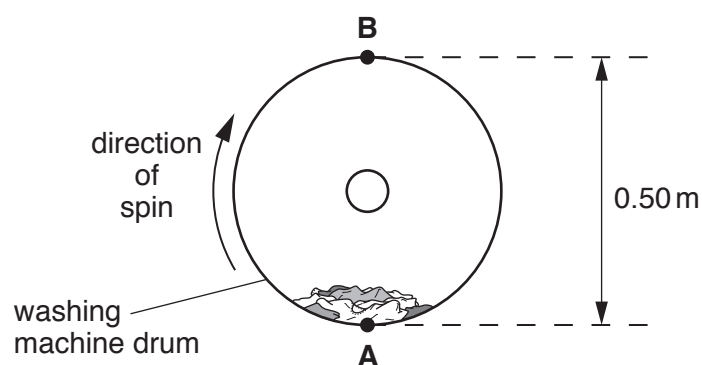


Fig. 21

The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

- (a) When the drum is at rest, the weight of the clothes is equal to the normal contact force on the clothes at point A.

Explain why these two forces are not an example of Newton's Third Law of motion.

Both forces act on the same object (the clothes), whereas a Newton's third law pair acts on two different objects.

They are different types of force: the weight is gravitational and the normal contact force is electrostatic.

..... [2]

- (b) The drum has diameter 0.50 m. The manufacturer of the washing machine claims that the drum spins at 1600 ± 100 revolutions per minute.

Calculate the speed of rotation of the drum and the absolute uncertainty in this value.

$$T = 60 \div 1600 = 3.75 \times 10^{-2} \text{ s}$$

$$v = 2\pi r/T = \pi \times 0.50 \div 3.75 \times 10^{-2} = 41.9 \text{ m s}^{-1}$$

$$\% \text{ uncertainty} = 100 \div 1600 \times 100\% = 6.25\%$$

$$\text{uncertainty} = 0.0625 \times 41.9 = 2.6 \approx 3 \text{ m s}^{-1}$$

$$\text{speed} = \dots\dots 42 \dots\dots \pm \dots\dots 3 \dots\dots \text{ m s}^{-1} \text{ [3]}$$

- (c) The washing machine is switched off and the speed of the drum slowly decreases. The clothes at the top of the drum at point **B** start to drop off at a certain speed v .

At this speed v , the normal contact force on the clothes is zero.

Calculate the speed v .

At B the normal contact force is zero, so the weight alone provides the centripetal force:

$$mv^2/r = mg, \text{ so } v^2 = gr$$

$$v^2 = 9.81 \times 0.25 \text{ (} r = 0.25 \text{ m)}$$

$$v = 1.6 \text{ m s}^{-1}$$

$$v = \dots\dots\dots 1.6 \dots\dots\dots \text{ ms}^{-1} \text{ [3]}$$

- 22 (a) A helium atom **X** travelling at 610 m s^{-1} makes an elastic collision with a stationary helium atom **Y**. The magnitude of the velocity of **X** after the collision is 258 m s^{-1} . The directions of the velocities of **X** and **Y** are as shown in Fig. 22.

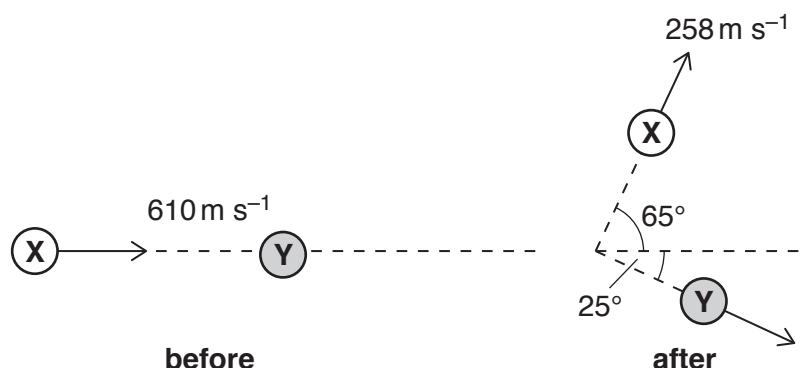


Fig. 22

- (i) Explain what is meant by an *elastic collision*.

The total kinetic energy is conserved (no KE is lost), as well as momentum. [1]

- (ii) The mass of a helium atom is $6.64 \times 10^{-27} \text{ kg}$. Calculate the magnitude of the momentum p of **Y** after the collision.

momentum perpendicular to the initial direction is conserved:

$$p \sin 25^\circ = m \times 258 \sin 65^\circ$$

$$p = 6.64 \times 10^{-27} \times 258 \times \sin 65^\circ \div \sin 25^\circ$$

$$p = 3.67 \times 10^{-24} \text{ kg m s}^{-1}$$

$$p = 3.7 \times 10^{-24} \text{ kg m s}^{-1} \quad [3]$$

- (b)* There is a lot of helium in the Universe. This was also true of the Earth when it was formed billions of years ago. However, only small traces of helium are now found in the atmosphere of the Earth.

Use the kinetic theory of gases to explain why only small amounts of helium are found in the Earth's atmosphere. Use the information below to do suitable calculations to support your answer.

- typical atmospheric temperature = 10°C
- mass of helium atom = $6.64 \times 10^{-27} \text{ kg}$
- escape velocity from the Earth = 11 km s^{-1}

Helium behaves as an ideal gas. At a given temperature all the atoms have the same mean kinetic energy: $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$.

Calculation: $T = 10 + 273 = 283 \text{ K}$. $\langle c^2 \rangle = 3kT/m = (3 \times 1.38 \times 10^{-23} \times 283) \div 6.64 \times 10^{-27} = 1.76 \times 10^6 \text{ m}^2 \text{ s}^{-2}$.

$c_{\text{r.m.s.}} = \sqrt{3kT/m} = \sqrt{1.76 \times 10^6} = 1.3 \times 10^3 \text{ m s}^{-1} = 1.3 \text{ km s}^{-1}$.

This r.m.s. speed is much less than the escape velocity of 11 km s^{-1} (about 8 times smaller), so a typical helium atom cannot escape.

However, the atoms have a range of speeds (Maxwell-Boltzmann distribution), so a small fraction of atoms in the high-speed tail have speeds greater than 11 km s^{-1} . These fastest atoms escape from the Earth's gravitational field.

Collisions then redistribute the energy so more atoms reach escape speed, and over billions of years most of the helium has escaped. Helium atoms have a very small mass, so for the same mean KE they move much faster than heavier N_2 and O_2 molecules, which are kept.

Also the Earth was significantly hotter in the past, so the mean KE and speeds of the atoms were greater and even more helium atoms could escape.

[6]

- 23 (a) According to the Cosmological principle, the Universe is isotropic, homogeneous and the laws of physics are universal.

State what is meant by the term *homogeneous*.

Matter is uniformly distributed (on a large scale), so the density of the Universe is the same everywhere. [1]

- (b) Astronomers often use absorption spectral lines to determine the relative velocity of distant galaxies. The wavelength of a specific absorption spectral line observed in the laboratory is 280 nm.

The galaxy RXJ1242-11 is 200 Mpc away from the Earth and it has a massive black hole at its centre.

- (i) Calculate in nm the wavelength λ of the same spectral line from RXJ1242-11 when **observed** from the Earth. Assume the Hubble constant is $68 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

$$v = H_0 d = 68 \times 200 = 13\,600 \text{ km s}^{-1} = 1.36 \times 10^7 \text{ m s}^{-1}$$

$$\Delta\lambda/\lambda = v/c$$

$$\Delta\lambda = 280 \times 1.36 \times 10^7 \div 3.00 \times 10^8 = 12.7 \text{ nm}$$

$$\lambda = 280 + 12.7 = 293 \text{ nm}$$

$$\lambda = \dots\dots\dots 293 \dots\dots\dots \text{ nm} [3]$$

- (ii) State one of the characteristics of a black hole.

Its escape velocity is greater than the speed of light, so light cannot escape from it. [1]

- (c) The Universe evolved from the Big Bang.

Describe the evolution of the Universe up to the formation of the first nuclei.

At the Big Bang the Universe was a singularity; extremely hot and dense, with the fundamental forces unified.

The Universe then expanded rapidly (inflation) and cooled; at first it contained only high-energy (gamma) photons and no matter.

As it cooled, quarks and leptons (e.g. electrons) formed from the photons: a quark-gluon plasma.

On further cooling the quarks combined to form hadrons, i.e. protons and neutrons.

Finally protons and neutrons (nucleons) fused to make the first nuclei, e.g. helium and deuterium nuclei.

[4]

- 24 A group of students are conducting an experiment to determine the wavelength of monochromatic light from a laser.

Fig. 24.1 shows the laser beam incident normally at a diffraction grating.

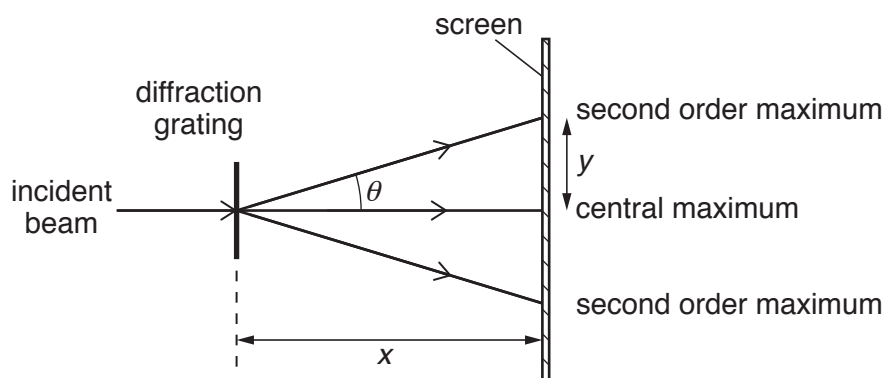


Fig. 24.1

The students use a diffraction grating with $600 \text{ lines mm}^{-1}$. They vary the distance x between the grating and the screen from 1.000 m to 2.000 m . They measure the distance y from the **central** maximum to the **second order** maximum.

- (a) The students decide to plot a graph of y against $\sqrt{x^2 + y^2}$.

Show that the gradient of the graph is equal to $\sin \theta$, where θ is the angle between the central maximum and the **second** order maximum.

$$\sin \theta = y \div \sqrt{x^2 + y^2} \quad (\text{opposite} \div \text{hypotenuse})$$

$$\text{so } y = \sin \theta \times \sqrt{x^2 + y^2}$$

Compared with $y = mx + c$: $c = 0$ and $m = \sin \theta$,

so the gradient of the graph is $\sin \theta$.

[1]

(b) Fig. 24.2 shows the graph plotted by the students.

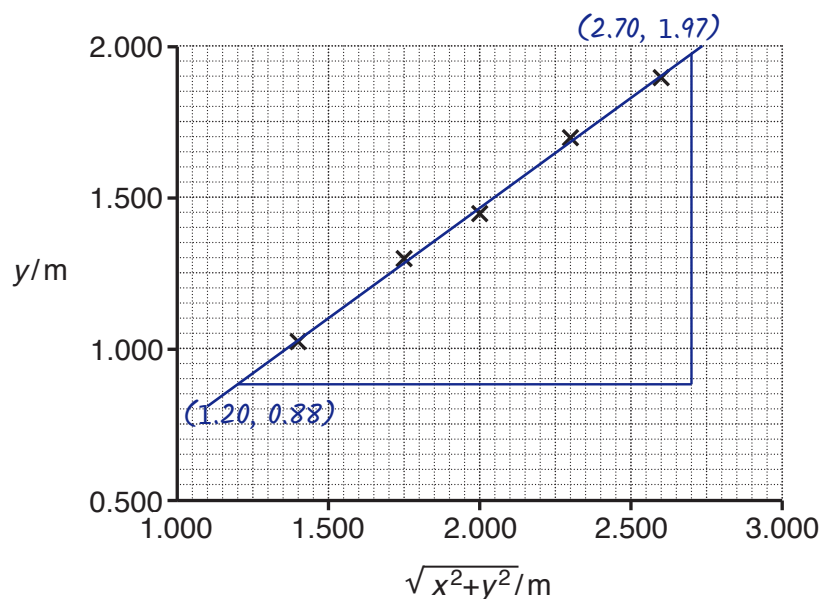


Fig. 24.2

- (i) Use Fig. 24.2 to determine an accurate value of the wavelength λ of the light from the laser.

$$\text{gradient} = (1.97 - 0.88) \div (2.70 - 1.20) = 1.09 \div 1.50 = 0.73$$

$$\sin \theta = 0.73; \quad d = 1 \div 600 \text{ mm} = 1.67 \times 10^{-6} \text{ m}$$

$$d \sin \theta = n\lambda \text{ with } n = 2$$

$$\lambda = 1.67 \times 10^{-6} \times 0.73 \div 2 = 6.1 \times 10^{-7} \text{ m}$$

$$\lambda = 6.1 \times 10^{-7} \text{ m [3]}$$

- (ii) Suggest why there are no error bars shown in Fig. 24.2.

The absolute uncertainties in x and y are too small to be shown on this graph's scale (the distances are large). [1]

- (iii) Suggest how the precision of this experiment may be affected by using a protractor to measure the angle θ .

θ and λ would be less precise: a protractor has poor resolution (1°), so repeat readings are less likely to agree. [1]

END OF QUESTION PAPER

[illegible]

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