OCR
Oxford Cambridge and RSA

Thursday 26 May 2022 – Afternoon

A Level Physics A

H556/01 Modelling physics

Time allowed: 2 hours 15 minutes

A Level Physics Online . com

You must have:
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number 3 1 4 1 5 Candidate number 9 2 6 5

First name(s) Lewis

Last name Matheson

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

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

ADVICE
- Read each question carefully before you start your answer.

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 A student has constructed the table below of possible scalar and vector quantities.

	Scalar	**Vector**
A	~~acceleration~~	momentum
B	~~displacement~~	~~amplitude~~
C	frequency	~~wavelength~~
D	mass	centripetal force

Which row is correct?

Your answer D ✓ **[1]**

2 The diameter of a wire is measured in five different places along its length.
The results are shown below.

1.92 mm 1.88 mm 1.90 mm 1.86 mm 1.89 mm

What is the absolute uncertainty in the diameter of this wire?

A 0.01 mm

B 0.03 mm

C 0.05 mm

D 0.06 mm

$\frac{1}{2}$ range $= \frac{1.92 - 1.86}{2} = 0.03$ mm

Your answer B ✓ **[1]**

3 A student has plotted a velocity against time graph for a trolley moving down a ramp.

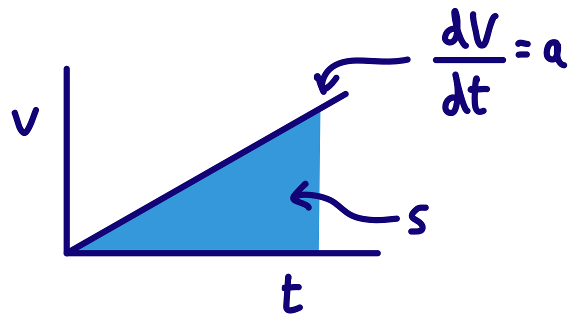
Which of the following pair of quantities can be determined from the gradient of the graph and the area under the graph?

A acceleration, displacement

B acceleration, impulse

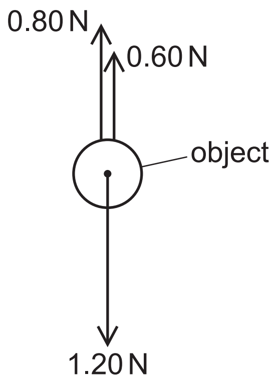
C displacement, kinetic energy

D force, work done



Your answer A ✓ **[1]**

4 The diagram below shows the directions and magnitudes of the three forces acting on an object at a specific time as it moves through water.



v ↓ ↑F Resultant force upwards

∴ decelerating

The weight of the object is 1.20 N, the upthrust on the object is 0.80 N and the drag is 0.60 N.

Which statement is correct about this object at this specific time?

A It has reached its terminal velocity.

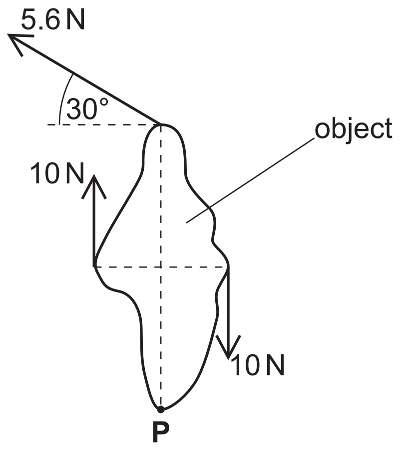
B It is accelerating.

C It is decelerating.

D It is moving upwards.

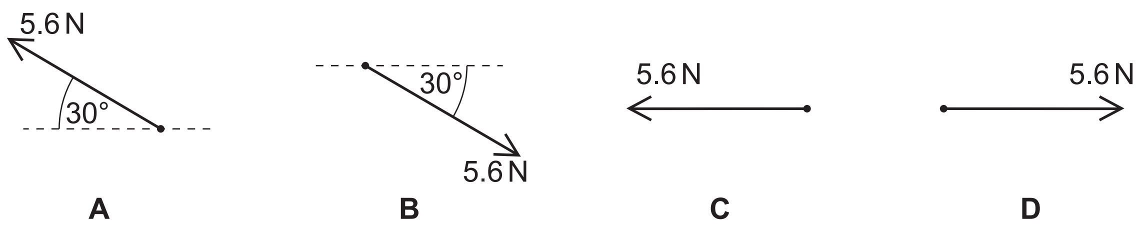
Your answer C ✓ **[1]**

5 The object below is in equilibrium.



A force, not shown on the diagram, also acts on the object at point **P**.

Which of the following shows the correct direction and magnitude of the force acting at point **P**?



Your answer B ✓ Equal and opposite **[1]**

6 A particle **X** of mass m collides with a stationary particle **Y** of mass $4m$.

Immediately after the collision the particle **X** is moving at velocity v_1 at an angle of 60° to its original direction and the particle **Y** is moving with velocity v_2 at 90° to the velocity of particle **X**.

Before collision After collision

Vertical direction

$p = 0$

$p = mv_1 \sin 60 + 4mv_2 \sin 30$

$0 = mv_1 \sin 60 + 4mv_2 \sin 30$

$v_1 \sin 60 = -4 v_2 \sin 30$

$\frac{v_1}{v_2} = \frac{4 \sin 30}{\sin 60} = 2.31$

What is the value of the ratio $\frac{v_1}{v_2}$?

A 2.3

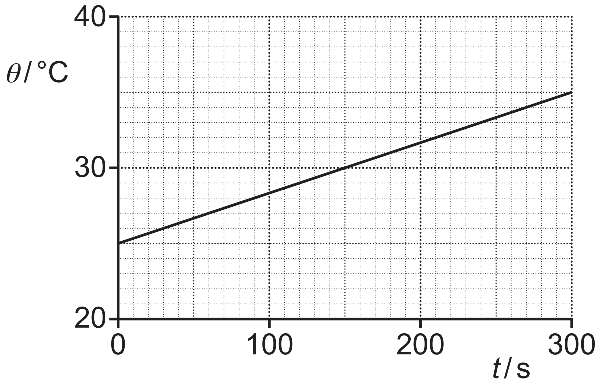
B 3.9

C 4.0

D 6.9

Your answer A ✓ **[1]**

7 A metal block of mass m is heated by an electric heater.
The graph of temperature θ against time t for this block is shown below.



The power of the heater is P. The gradient of the straight-line graph is G.

What is the correct expression for the specific heat capacity c of the metal?

A $c = G$

B $c = \dfrac{PG}{m}$

C $c = \dfrac{mP}{G}$

D $c = \dfrac{P}{mG}$

$E = mc\Delta\theta$ $\quad P = \dfrac{\Delta E}{\Delta t}$ $\quad G = \dfrac{\Delta\theta}{\Delta t}$

$\dfrac{\Delta E}{\Delta t} = mc\dfrac{\Delta\theta}{\Delta t}$

$P = mcG$ $\quad c = \dfrac{P}{mG}$

Your answer D ✓ **[1]**

8 Which statement(s) below are implied by the assumptions of the kinetic theory model of gases?

1 A gas is mostly empty space. ✓
2 Gas particles spend more time between collisions than time during collisions. ✓
3 There are always forces between the gas particles. ✗

A Only 1 and 2

B Only 1 and 3

C Only 2 and 3

D 1, 2 and 3

Your answer A ✓ **[1]**

9 A container has 1.0 mole of gas at pressure 100 kPa.
The root mean square (r.m.s.) speed of the gas particles is 500 m s^{-1}. The mass of each gas particle is 4.7×10^{-26} kg.

What is the volume of the container?

A $3.9 \times 10^{-26}\,m^3$

B $4.7 \times 10^{-5}\,m^3$

C $2.4 \times 10^{-2}\,m^3$

D $4.7 \times 10^{-2}\,m^3$

$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT \quad T = \frac{m\overline{c^2}}{3k}$

$pV = nRT$

$V = \frac{nRm\overline{c^2}}{p\,3k} = \frac{1.0 \times 8.31 \times 4.7 \times 10^{-26} \times 500^2}{100 \times 10^3 \times 3 \times 1.38 \times 10^{-23}}$

$V = 0.0236$

Your answer C ✓ **[1]**

10 A mass is attached to the bottom end of a spring which is fixed at its top end.
The mass is displaced vertically, and then released. The mass oscillates with a simple harmonic motion.

Which row correctly describes the energy of this spring-mass system when the mass is at its **lowest** point in its oscillations?

	Elastic potential energy	Gravitational potential energy	Kinetic energy
A	Maximum	~~Maximum~~	~~Maximum~~
B	Maximum	Minimum	Zero
C	~~Minimum~~	~~Maximum~~	Zero
D	~~Minimum~~	Minimum	~~Maximum~~

x_{max} ∴ EPE_{max}

h_{min} ∴ GPE_{min}

$v = 0$ ∴ $KE = 0$

Your answer B ✓ **[1]**

11 Which pair of quantities do **not** have the same, or equivalent, units?

A acceleration, gravitational field strength — $m s^{-2}$

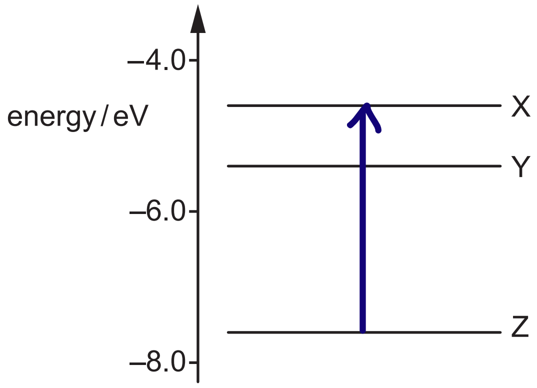
B angular frequency, angular velocity — $rad\,s^{-1}$

C gravitational potential, kinetic energy — $J kg^{-1}$ and J

D impulse, momentum — $kg\,m s^{-1}$

Your answer C ✓ **[1]**

12 The diagram shows three energy levels X, Y and Z of an electron within a gas atom.



Which transition is correct when the electron absorbs a photon with the shortest wavelength?

A Z ⟶ X

B X ⟶ Z

C Y ⟶ X

D X ⟶ Y

moves up $E = \frac{hc}{\lambda}$ $E \propto \frac{1}{\lambda}$

Your answer A ✓ **[1]**

13 Light from a hydrogen source is incident normally at a diffraction grating. The first order maximum of the H-alpha spectral line of wavelength 486 nm is observed at angle of 30.0°.

Light from a distant receding star is observed using the same diffraction grating. The light is incident normally at the grating as before. The speed of this star is 0.16*c*, where *c* is the speed of light in a vacuum.

What is the observed angle of the first order maximum of the H-alpha spectral line from the light of this receding star?

A 24.8°

B 30.0°

C 34.8°

D 35.5°

$z = \frac{v}{c} = 0.16 = \frac{\Delta\lambda}{\lambda}$

$\Delta\lambda = 0.16 \times 486 = 77.76$ nm

$\lambda_2 = 563.76$ nm

Your answer D ✓ **[1]**

$n\lambda = d \sin\theta$

$\frac{n}{d} = \frac{\sin\theta}{\lambda}$ $\frac{\sin 30}{486} = \frac{\sin\theta}{563.76}$

$\theta = 35.45°$

9.5×10^{15}

14 A galaxy, 1.0×10^9 light-years away from the Earth, has a recession speed of 23000 km s^{-1}.

Which expression, based on the information above, is correct for the age of the universe in seconds?

A age = $\dfrac{1.0 \times 10^9}{23000 \times 10^3}$

B age = $\dfrac{1.0 \times 10^9 \times 1.5 \times 10^{11}}{23000}$

C age = $\dfrac{1.0 \times 10^9 \times 9.5 \times 10^{15}}{23000 \times 10^3}$

D age = $\dfrac{1.0 \times 10^9 \times 3.1 \times 10^{16}}{23000 \times 10^3}$

$v = H_0 d$ $\quad t = \dfrac{1}{H_0}$

$t = \dfrac{d}{v} = \dfrac{1.0 \times 10^9 \times 9.5 \times 10^{15}}{23\,000 \times 10^3}$

Your answer C ✓ **[1]**

15 Astronomers observe approximately the same number of distant galaxies per unit volume of space in all directions.

Which idea does this observation support?

A Big bang model of the universe

B Cosmological principle — Universe is homogeneous and isotropic

C Existence of dark matter

D Hubble's law

Your answer B ✓ **[1]**

SECTION B

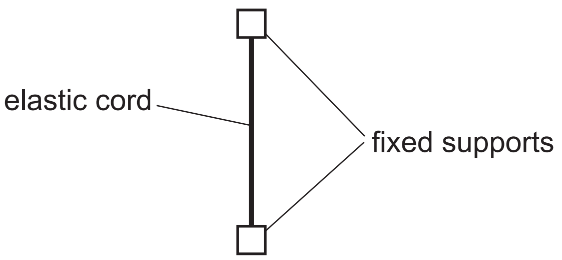
Answer **all** the questions.

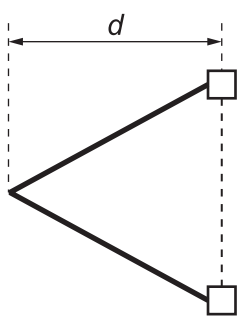
16 (a) Describe how an experiment can be carried out to determine the force constant of an elastic cord in the laboratory by plotting a suitable graph. You may assume that the cord obeys Hooke's law.

• Hang a range of masses on the end of the cord. ✓
• Measure the extension. ✓
• Plot a graph of the extension on the x-axis vs. weight on the y-axis. ✓
• Calculate the gradient of the straight line of best fit. This is equal to the force constant. ✓

[4]

(b) A simple catapult is made by an elastic cord fixed to two supports, as shown below.

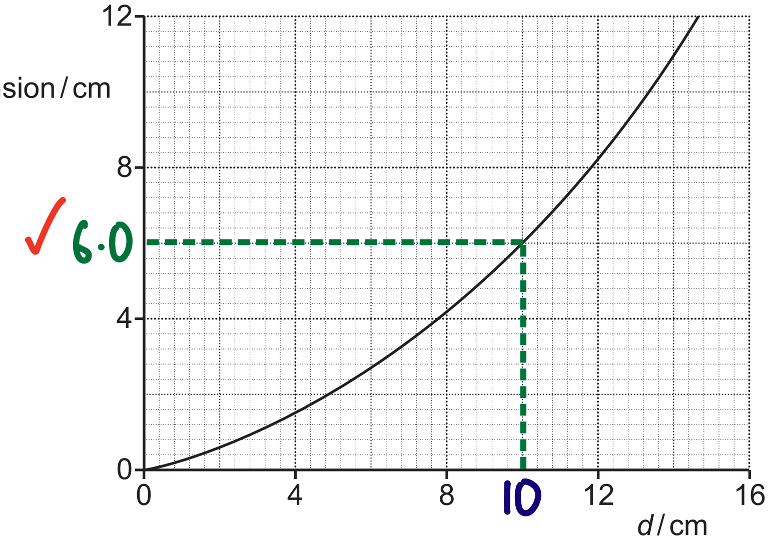




The unstretched length of the cord is the same as the distance between the supports.
The distance that the centre of the cord has been pulled back is *d*.

The cord has a force constant of 500 N m^{-1}.

The variation of the extension of the cord with distance d is shown below.



A small ball of mass 30 g is placed at the centre of the cord and drawn back with d = 10 cm.

The ball is released and launched horizontally from a height of 1.5 m above the horizontal ground.

(i) Use the graph to show that the elastic potential energy E in the cord is about 1 J.

$E_e = \frac{1}{2} kx^2$

$= \frac{1}{2} \times 500 \times 0.060^2$

$= 0.90\ \text{J} \approx 1\ \text{J}$

[3]

(ii) Show that the maximum speed at which the ball leaves the catapult is about 8 m s^{-1}.

$E_e \rightarrow E_k = \frac{1}{2} mv^2$

$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 0.90}{30 \times 10^{-3}}} = 7.746\ \text{ms}^{-1} \approx 8\ \text{ms}^{-1}$

[2]

(iii) Calculate the horizontal distance R travelled by the ball before it strikes the horizontal ground.
Ignore the effects of air resistance in your calculation.

↓ $s = 1.5\text{ m}$
$u = 0\text{ ms}^{-1}$
v
$a = 9.81\text{ ms}^{-2}$
$t = ?$

$s = ut + \frac{1}{2}at^2$ $\quad t = \sqrt{\frac{2s}{a}}$

$t = \sqrt{\frac{2 \times 1.5}{9.81}} = 0.553\text{ s}$ ✓ ✓

→ $s = vt = 7.746 \times 0.553 = 4.28\text{ m}$

R = 4.3 ✓ m **[3]**

(iv) Explain how the value of R calculated in **(iii)** compares with the actual value.

Actual distance would be smaller, as not all the elastic potential energy stored in the cord is transferred to kinetic ✓, so the horizontal velocity is smaller. ✓ **[2]**

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17 An electric engine of mass 17 000 kg has a constant power output of 280 kW and it can reach a maximum speed of $42\,\mathrm{m\,s^{-1}}$ on horizontal rails. The maximum kinetic energy of the engine is 15 MJ.

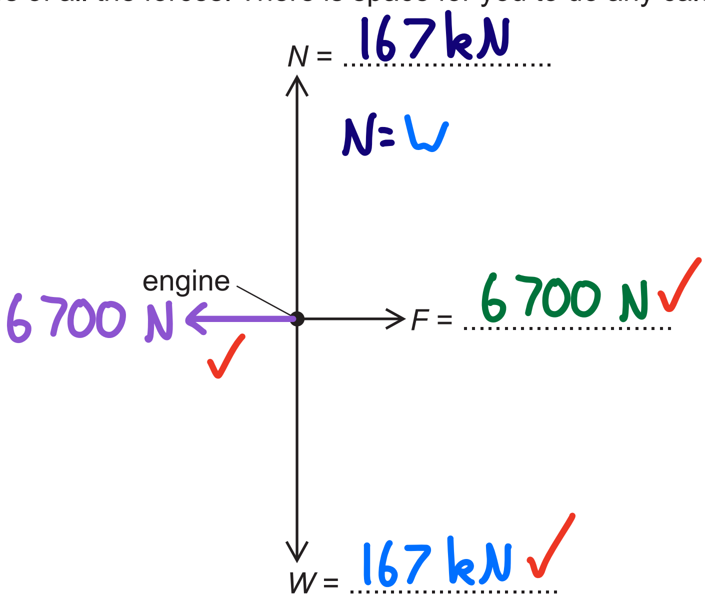
(a) The engine is initially at rest on long horizontal rails.
Show that the minimum time taken for the engine to reach its maximum speed is about 1 minute.

$P = \frac{E}{t}$ $\quad t = \frac{E}{P} = \frac{15\times10^6}{280\times10^3} = 54\,\mathrm{s} \approx 1$ min

[1]

(b) The engine is moving along the horizontal rails at the constant maximum speed of $42\,\mathrm{m\,s^{-1}}$.
The weight of the engine is W, the total normal contact force from the rails is N and the total friction between the wheels and the rails is F.
F is responsible for the motion of the engine to the **right**.

Complete the free body diagram for the engine by showing a missing force, and the magnitudes of all the forces. There is space for you to do any calculations below the diagram.



$P = Fv$

$F = \frac{P}{v} = \frac{280\times10^3}{42}$

$F = 6670$

$W = mg = 17\,000 \times 9.81$
$= 166\,770$
$= 167\,\mathrm{kN}$

[3]

(c) The speed of the engine is 42 m s^{-1}.

The driver sees an obstruction 167 m from the front of the engine. The engine is switched off and the brakes are applied.
The constant force opposing motion is 120 kN. The reaction time of the driver is 0.40 s.

Show with the help of calculations, that the engine will stop before reaching the obstruction.

stopping distance = thinking distance + braking distance

work done by brakes

$s = vt$

$= 42 \times 0.40$

$= 16.8\text{m}$ ✓

$Fs = E_k$

$s = \frac{E_k}{F}$ ✓ $= \frac{15 \times 10^6}{120 \times 10^3}$

$= 125\text{m}$ ✓

stopping distance = 16.8 + 125 = 141.8

[4]

$141.8 < 167$

∴ it will stop in time ✓

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18 A tent is secured by 3 ropes along each of its long sides, as shown in **Fig. 18.1**.

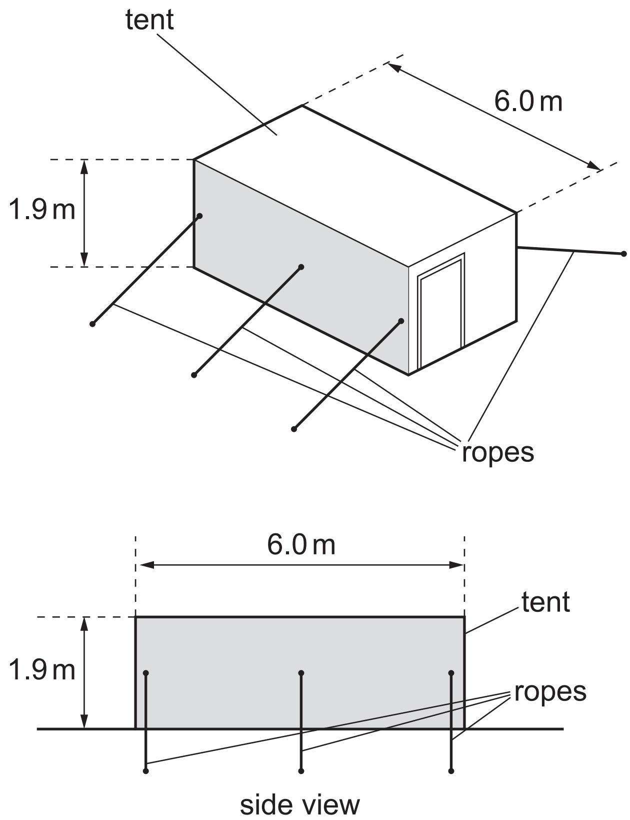


Fig. 18.1

(a) Wind of speed 12 m s^{-1} blows at right angles to the **shaded** side of the tent for 3.0 s. The density of air is 1.2 kg m^{-3}.

(i) Show that the mass of air which hits the tent in this time is about 490 kg.

$(m s^{-1} \times s \times m^2 = m^3)$

$\rho = \frac{m}{V}$ $\quad V = vtA = 12 \times 3.0 \times 6.0 \times 1.9$ ✓

$= 410.4\ m^3$ ✓

$m = \rho V = 1.2 \times 410.4 = 492.48$ N ✓ ≈ 490 kg

[3]

(ii) All of the air incident on the shaded side of the tent is deflected at 90° to the original direction as shown in **Fig. 18.2**.

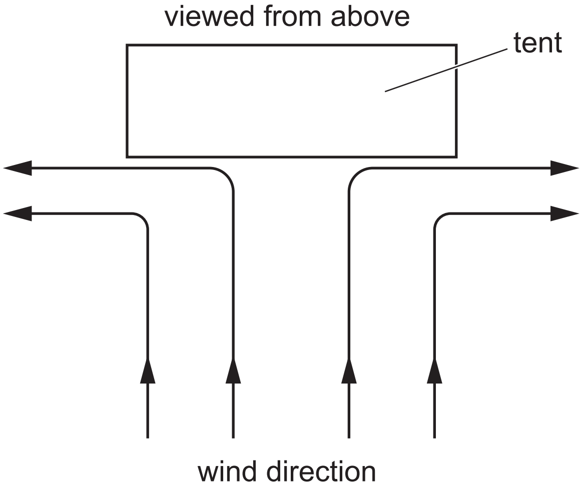


Fig. 18.2

Use the information given in **(a)(i)** to calculate the magnitude of the force F exerted by the wind on the shaded side of the tent.

In direction of tent $\Delta p = m\Delta v = 492.48 \times (12 - 0)$
$= 5909.76 \text{ kg m s}^{-1}$ ✓

$F = \frac{\Delta p}{\Delta t} = \frac{5909.76}{3.0} = 1969.92$

F = 2.0×10^3 ✓ N **[2]**

(b)* When the wind speed exceeds 20 m s^{-1} the ropes securing the tent break.

Describe, and explain in terms of forces, how the ropes and the shape of the tent could be modified to withstand wind speed exceeding 40 m s^{-1}. **[6]**

• By increasing the cross sectional area of the guy ropes. $F = \Delta p/\Delta t = m\Delta v/\Delta t$ ∴ if both mass/time and change in velocity double ✓, then the force on the ropes increases by a factor of 4 ✓ ∴ A of ropes must be 4 ✓ times as great (by doubling the diameter).

• Modify the shape of the tent so it is more streamlined ✓, this allows the wind to pass over it with a smaller change in momentum ∴ a smaller force. ✓

• The angle between the guy ropes and the ground could be reduced ∴ reducing component of tension perpendicular to the ground ∴ tension decreases. ✓

Additional answer space if required

19 (a) A fixed mass of nitrogen changes phase from liquid to gas at a constant temperature.

Explain the change in the total internal energy of nitrogen.

E_K of particles is constant but the E_p increases ✓ ∴ internal energy has increased. ✓

....

.... **[2]**

(b) In a factory, nitrogen gas is added to packets of food to keep it fresh for longer.
In 1.0 hour, the factory uses 15 m^3 of nitrogen at pressure 100 kPa and temperature 23 °C.

(i) Show that the number of moles n, of nitrogen used per hour is about 600.

$pV = nRT$

$$n = \frac{pV}{RT} = \frac{100 \times 10^3 \times 15}{8.31 \times (23 + 273)} = 609.8 \approx 600$$

✓ ✓ ✓

[3]

(ii) Calculate the mass of nitrogen gas used in one hour.

molar mass of nitrogen = 0.028 kg mol^{-1}

$m = M_r \times n = 0.028 \times 609.8 = 17.07$

mass = 17 ✓ .... kg **[1]**

(iii) The volume of nitrogen being used cannot be changed.

State how the rate of mass of nitrogen used can be reduced.

Reduce the pressure. ✓

.... **[1]**

(iv) The nitrogen at the factory is stored as a liquid.
The liquid expands at constant temperature to form gas in a short section of pipe.

When the air temperature is 0 °C, a thick layer of ice forms on the outside of the pipe from water vapour in the air. In 1.0 hour, the mass of ice formed is 1.3 kg at a temperature of 0 °C.

Use the data below and your answer to **(b)(ii)**, to estimate the specific latent heat of vaporisation *L* of nitrogen.

- specific latent heat of fusion of ice = $3.34 \times 10^5\,J\,kg^{-1}$
- specific latent heat of vaporisation of water = $2.26 \times 10^6\,J\,kg^{-1}$

E transferred to liquid nitrogen = E transferred from water vapour ✓

$m_N \cdot L_{vN} = m_w L_{fw} + m_w L_{vw}$

$L_{vN} = \frac{m_w(L_{fw} + L_{vw})}{m_N}$ ✓ $= \frac{1.3 \times (3.34 \times 10^5 + 2.26 \times 10^6)}{17.07}$ ✓

= 197,495

L = 2.0×10^5 ✓ $J\,kg^{-1}$ **[4]**

20 (a) For a simple harmonic oscillator, the acceleration a is given by the equation $a = -\omega^2 x$, where ω is the angular frequency and x is the displacement.

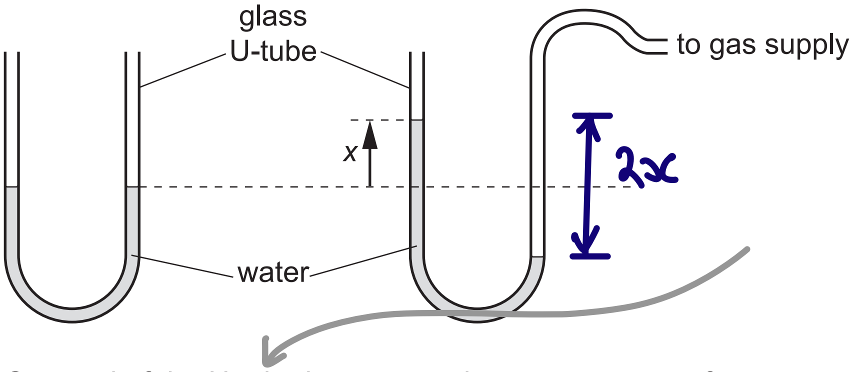
Show that this equation is homogeneous by reducing both sides to S.I. base units.

$\omega = [s^{-1}]$ $\omega^2 = [s^{-2}]$ ✓ $x = [m]$

$\omega^2 x = [s^{-2} m]$ & $a = [ms^{-2}]$ ✓

[2]

(b) The diagram shows a glass U-tube partially filled with a mass of water.



One end of the U-tube is connected to a gas supply of **constant** pressure and the other end is open to the atmosphere. The displacement of the water from its equilibrium position is x. The density ρ of water is 1000 kg m^{-3}.

(i) The pressure from the gas supply raises the water in the U-tube.
The vertical distance between the two levels of water in the two vertical sections of the U-tube is 10.0 cm (x = 5.0 cm).

Δp is the difference between the gas pressure and atmospheric pressure.
Calculate Δp.

$\Delta p = \rho g \Delta h = \rho g 2x = 1000 \times 9.81 \times 2 \times 5.0 \times 10^{-3}$ ✓
$= 981$

Δp = 980 ✓ .... Pa **[2]**

(ii) When the gas supply is disconnected, the water levels in the U-tube oscillates with simple harmonic motion. The acceleration a of the water level in the left-hand side of the U-tube is given by the equation

$$a = -\frac{2\rho g A}{m}x$$

where m is the mass of the water in the U-tube, A is the internal cross-sectional area of the U-tube, ρ is the density of water, g is the acceleration of free fall and x is the displacement of the water level in the left-hand side of the U-tube.

For this U-tube, $A = 1.0 \times 10^{-4}\,\text{m}^2$ and $m = 0.052\,\text{kg}$.

1 Show that the period T of the oscillations is about 1 second.

$a = -\frac{2\rho g A}{m}x$ $a = -\omega^2 x$ $\omega = \frac{2\pi}{T}$

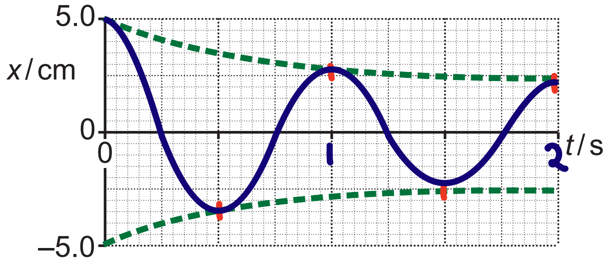
$-\frac{2\rho g A}{m}x = -\omega^2 x$ $T = \frac{2\pi}{\omega} = \frac{2\pi}{6.14} = 1.023\,\text{s}$ ✓ ✓

$\approx 1\,\text{s}$

$\omega = \sqrt{\frac{2\rho g A}{m}} = \sqrt{\frac{2 \times 1000 \times 9.81 \times 1.0 \times 10^{-4}}{0.052}} = 6.14\,\text{s}^{-1}$ ✓ **[3]**

2 The oscillations of the water level are slightly **damped**.
At time $t = 0$, $x = 5.0\,\text{cm}$.

Sketch a suitable graph of displacement x against time t for the oscillating water level. Add suitable values to the time t axis.



✓✓✓

[3]

3 The U-tube is now connected to another gas supply where the pressure oscillates at a frequency of about 1 Hz.

Explain the effect this will have on the water in the U-tube.

The driving frequency is close to the natural frequency ✓ ∴ resonance occurs causing large amplitude vibrations. ✓ **[2]**

21 (a) A nebula is a giant cloud of gas and dust in space. The nebula can produce a star over a long period of time.

State what causes the initial collapse of the nebula.

Gravitational force ✓ **[1]**

(b) A nebula **X** is modelled as a sphere of gas and dust particles of diameter 6.4 pc.

The nebula has 1.0×10^{12} gas and dust particles per m^3 and a temperature of 250 K. The nebula behaves like an ideal gas.

(i) Show that the volume of the nebula is $4.1 \times 10^{51}\,m^3$.

$1\ pc = 3.1 \times 10^{16}\,m$

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times \left(\frac{6.4}{2} \times 3.1\times10^{16}\right)^3 ✓$$

$$= 4.089\times10^{51} ✓ \approx 4.1\times10^{51}\,m^3$$

[2]

(ii) Calculate the **total** kinetic energy E_k of the gas and dust particles in the nebula.

$$E_K = \frac{3}{2}kT = \frac{3}{2}\times 1.38\times10^{-23} \times 250$$

$$= 5.175\times10^{-21}\,J \text{ (per particle) } ✓$$

$$\Delta E = 5.175\times10^{-21} \times 1.0\times10^{12} \times 4.089\times10^{51} ✓$$

$$= 2.116\times10^{43}$$

E_k = 2.1×10^{43} ✓ J **[3]**

(E per particle × no. particles per m^3 × m^3)

(c) The nebula that formed the Sun is estimated to have a diameter of 3.0 pc and had a similar composition to nebula **X** in **(b)**.

The mass of the nebula **X** is **much greater** than the mass of the Sun.

(i) Calculate the ratio $\frac{\text{mass of nebula } \mathbf{X}}{\text{mass of the Sun}}$.

$\rho = \frac{m}{V}$ $m = \rho V$ $\therefore m \propto V \propto d^3$

$\frac{m_X}{m_\odot} = \frac{d_X^3}{d_\odot^3} = \left(\frac{6.4}{3.0}\right)^3 = 9.71$ ✓

ratio = 9.7 ✓ **[2]**

(ii) After a long time, nebula **X** will form a stable star.

Describe the eventual evolution of this star.

Fuel runs out and star evolves into a super red giant ✓. Mass of the core is greater than the Chandrasekhar limit ✓ so it will supenova ✓, leaving either a neutron star or a black hole. ✓

[4]

22 (a) A team of astronomers have measurements to determine the peak surface temperature T and luminosity L of a distant star. They plan to use Stefan's law to estimate the radius r of this star.

Explain whether the astronomers should attempt to measure T or L more precisely to reduce the uncertainty in r.

$L = \sigma A T^4$ where $A \propto r^2$ $\therefore$ percentage uncertainty in T will be 4 times ✓ as significant as the percentage uncertainty in L. $\therefore$ need to attempt to measure T more precisely. ✓ **[2]**

(b)* It is suggested that the luminosity L and the mass M of a star can be compared to the Sun by the equation

$$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^b$$

where $L_\odot$ is the luminosity of the Sun and $M_\odot$ is the mass of the Sun.

The value of b is between 3 and 4.

Table 22 shows some data of five stars.

Main sequence star	$\frac{M}{M_\odot}$	$\frac{L}{L_\odot}$
Pi Andromedae A	6.5	800
Alpha Coronae Borealis A	3.2	80
Gamma Virginis	1.7	6.0
Eta Arietis	1.3	2.5
70 Ophiuchi A	0.78	0.4

Table 22

Fig. 22 shows the $\lg\left(\frac{L}{L_\odot}\right)$ against $\lg\left(\frac{M}{M_\odot}\right)$ plot for these stars.

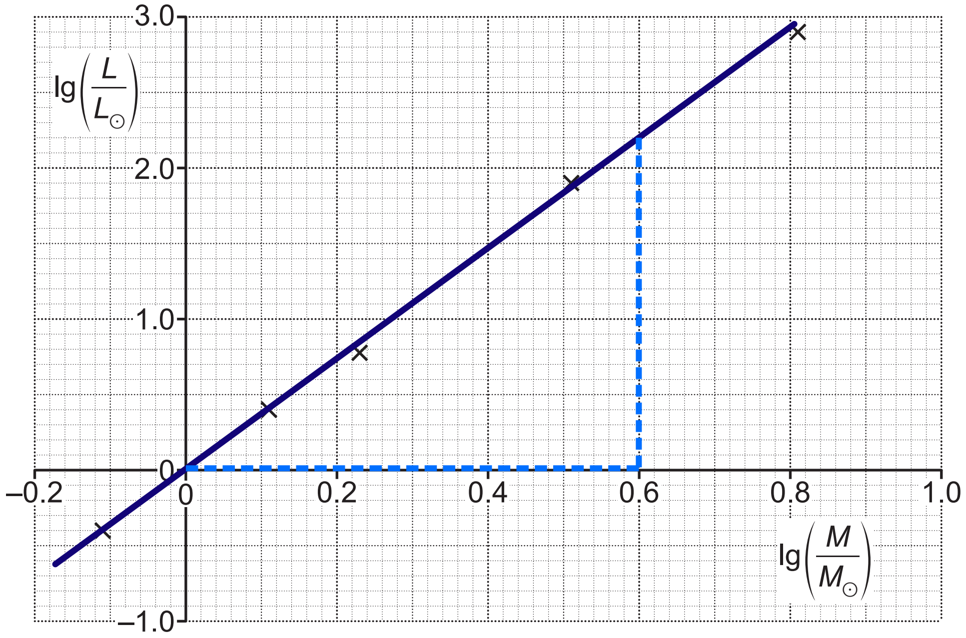


Fig. 22

The luminosity of a star is directly proportional to the rate of fusion of hydrogen nuclei.

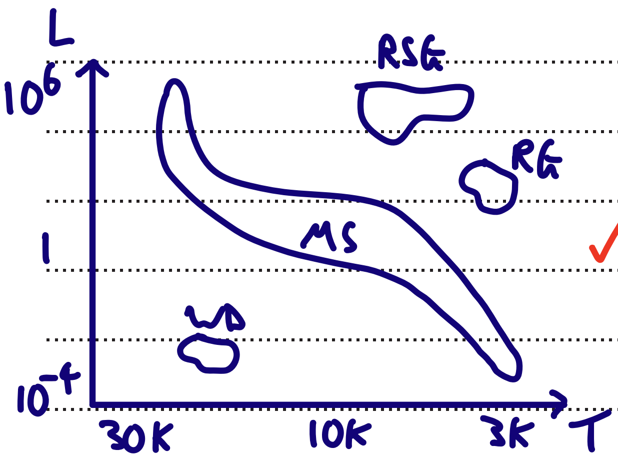
Use **Fig. 22** to determine *b* and use your knowledge of Hertzsprung–Russell (HR) diagrams to deduce how the lifespan of hotter stars compares with lifespans of cooler stars. **[6]**

$\frac{L}{L_\odot} = \left(\frac{M}{M_\odot}\right)^b$ $\log\left(\frac{L}{L_\odot}\right) = b \log\left(\frac{M}{M_\odot}\right)$ ✓

$y = m x + c$

∴ gradient = b & y-intercept goes through origin ✓

$b = \text{gradient} = \frac{\Delta y}{\Delta x} = \frac{2.2 - 0}{0.6 - 0} = 3.67$ ✓



✓

$L = \sigma A T^4$, so hotter stars have a greater luminosity ∴ much smaller mass ratio than luminosity ratio.

Additional answer space if required

A luminosity of 8000 times greater means the mass is about 8.3 times greater, and hotter stars lose mass at a much higher rate relative to their mass ✓ ∴ lifespan must be significantly smaller. ✓

23 (a) A planet of mass m is in a circular orbit around a star of mass M.

Use the equation for Newton's law of gravitation and your knowledge of circular motion to show that the relationship between the orbital period T of the planet and its orbital radius r is $T^2 \propto r^3$.

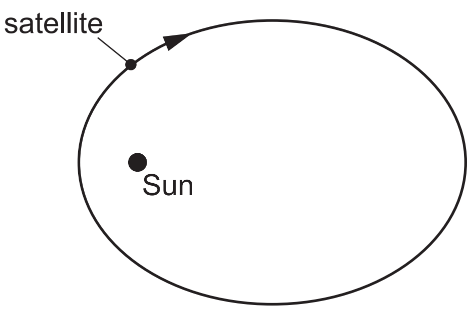
$$F = \frac{GmM}{r^2} = \frac{mv^2}{r} \qquad v = \frac{2\pi r}{T}$$

$$\frac{GM}{r} = v^2 \qquad v^2 = \frac{4\pi r^2}{T^2}$$

$$\frac{GM}{r} = \frac{4\pi r^2}{T^2} \qquad T^2 = \frac{4\pi r^3}{GM} \qquad \therefore T^2 \propto r^3$$

[3]

(b) The Solar Orbiter satellite was launched in February 2020.
This satellite moves around the Sun in an elliptical orbit with a period of 168 days.
The diagram below shows the elliptical orbit of this satellite.



The closest distance of the satellite to the Sun is 4.20×10^{10} m and its furthest distance from the Sun is 1.37×10^{11} m.
The mass of the Sun is 2.0×10^{30} kg and the mass of the satellite is 209 kg.

(i) The Earth has a mean orbital distance of 1.50×10^{11} m around the Sun and an orbital period of 365 days.

Use **Kepler's third law** to calculate the mean orbital distance of the satellite from the Sun.

$T^2 \propto r^3 \quad \therefore \frac{T^2}{r^3} = \text{constant}$

$\frac{T_E^2}{r_E^3} = \frac{T_{sat}^2}{r_{sat}^3}$ ✓ $\therefore r_{sat} = r_E \sqrt[3]{\frac{T_E^2}{T_{sat}^2}} = 1.5\times10^{11} \times \sqrt[3]{\frac{168^2}{365^2}}$

$= 8.942 \times 10^{11}$

distance = 8.9×10^{11} ✓ m **[2]**

(ii) The total kinetic and gravitational potential energy of the satellite in its orbit remains constant.

Calculate the change in the kinetic energy of the satellite as it travels from its furthest point from the Sun to its closest point to the Sun.

$\Delta GPE = \Delta KE$

$= \frac{GmM}{\Delta r} = GmM\left(\frac{1}{r_0} - \frac{1}{r}\right)$ ✓

$= 6.67\times10^{-11} \times 209 \times 2.0\times10^{30} \left(\frac{1}{4.2\times10^{10}} - \frac{1}{1.37\times10^{11}}\right)$ ✓

$= 4.603 \times 10^{10}$

change in kinetic energy = 4.6×10^{10} ✓ J **[3]**

(iii) Suggest why the total energy of the satellite in its orbit around the Sun is not the same as the total energy of the satellite during its launch from the surface of the Earth.

This has not accounted for the work done as the satellite went through the atmosphere. ✓ **[1]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).