OCR
Oxford Cambridge and RSA

Friday 8 October 2021 – Morning

A Level Physics A

H556/01 Modelling physics

Time allowed: 2 hours 15 minutes

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

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

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H556/01

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

Centre number | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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 **28** pages.

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

SECTION A

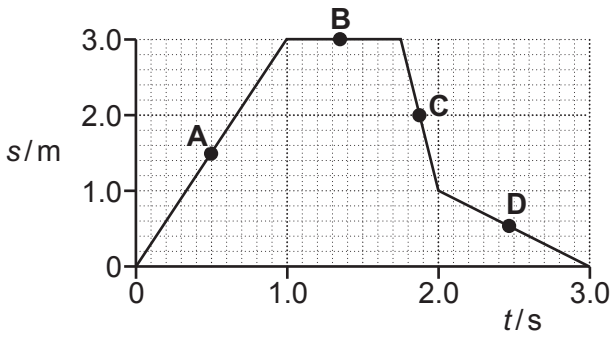
You should spend a maximum of 30 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

1 An object is moving in a straight line.

The displacement *s* against time *t* graph for this object is shown below.



At which point **A**, **B**, **C** or **D**, does the object have the **greatest** speed?

Your answer ☐ **[1]**

2 Which one of the following prefixes represents the **smallest** multiplication factor?

A femto (f)

B micro (μ)

C nano (n)

D pico (p)

Your answer ☐ **[1]**

3 The table shows some data for a car travelling on a straight road with an initial speed of $13\,m\,s^{-1}$.

Thinking distance / m	**9.0**
Braking distance / m	**14**
Stopping distance / m	**23**

The car has a constant deceleration when the brakes are applied.

What is the magnitude of the deceleration of the car during braking?

A $0.46\,m\,s^{-2}$

B $3.7\,m\,s^{-2}$

C $6.0\,m\,s^{-2}$

D $9.4\,m\,s^{-2}$

Your answer ☐ **[1]**

4 The freezing point of ethanol is 159 K.

What is 159 K in °C?

A −432 °C

B −114 °C

C 114 °C

D 432 °C

Your answer ☐ **[1]**

5 A spectral line corresponds to a wavelength λ_1 in the laboratory.
The same spectral line observed in the spectrum of a receding galaxy corresponds to a wavelength λ_2.
The distance of the galaxy from the Earth is d. The speed of light in a vacuum is c.

What is the correct expression for the Hubble constant H_0?

A $H_0 \approx \frac{c(\lambda_2 - \lambda_1)}{d\lambda_1}$

B $H_0 \approx \frac{c\lambda_1}{d(\lambda_2 - \lambda_1)}$

C $H_0 \approx \frac{c\lambda_2}{d\lambda_1}$

D $H_0 \approx \frac{c\lambda_1}{d\lambda_2}$

Your answer ☐ **[1]**

6 For a simple harmonic oscillator, the maximum speed is v_{max} when the amplitude is A. The frequency of the oscillations is f.

Which expression is correct for this oscillator?

A $v_{max} = fA$

B $v_{max} = 2\pi fA$

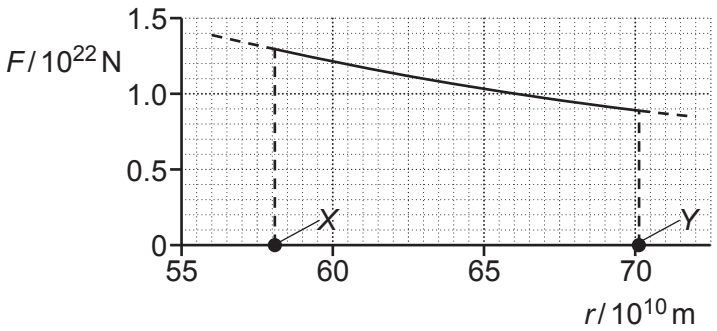
C $v_{max} = f^2A$

D $v_{max} = 4\pi^2f^2A$

Your answer ☐ **[1]**

7 The planet Mercury has a highly elliptical orbit around the Sun.

The gravitational force F acting on Mercury due to the Sun varies with its distance r from the centre of the Sun. The graph of F against r for Mercury in its orbit is shown below.



Mercury is closest to the Sun when $r = X$ and furthest when $r = Y$.

What does the **area** under the graph between the distances X and Y represent?

A The centripetal force acting on Mercury.

B The change in the gravitational potential energy of Mercury.

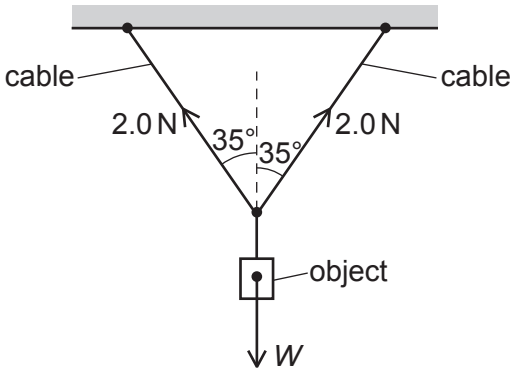
C The impulse of the force acting on Mercury.

D The kinetic energy of Mercury.

Your answer ☐ **[1]**

8 An object of weight W is suspended from two identical cables.

The tension in each cable is 2.0 N. Each cable makes an angle of 35° to the vertical.



What is the weight W of the object?

A 1.6 N

B 2.3 N

C 2.8 N

D 3.3 N

Your answer ☐ **[1]**

9 A piston has a fixed amount of trapped ideal gas.

The gas exerts pressure p and has volume V. The thermodynamic (absolute) temperature of the gas is T. The mass of each atom is m. There are N atoms of the gas. The Boltzmann constant is k.

What quantities are required to determine the root mean square speed $\sqrt{\overline{c^2}}$ of the atoms?

A k and T

B p and V

C p, V and T

D p, V, N and m

Your answer ☐ **[1]**

10 An object of mass 0.12 kg is lifted through a height of 0.60 m at a constant speed 3.0 m s^{-1}.

What is the minimum power needed to lift the object?

A 0.36 W

B 0.54 W

C 3.5 W

D 4.1 W

Your answer ☐ **[1]**

11 Kepler-90 is a star with several planets orbiting it.
The two outermost planets are Kepler-90g and Kepler-90h.
Kepler-90g has an orbital period of 210 days and is 0.71 AU from the centre of Kepler-90.
Kepler-90h is 1.01 AU from the centre of Kepler-90.

Kepler's third law of planetary motion can be applied to the planets of Kepler-90.

What is the orbital period of Kepler-90h?

A 50 days

B 299 days

C 356 days

D 4350 days

Your answer ☐ **[1]**

12 Oscillations of an object can either be **free** or **forced**.

Which of the following is an example of a **forced** oscillation?

A A ball rolling to-and-fro on a curved track.

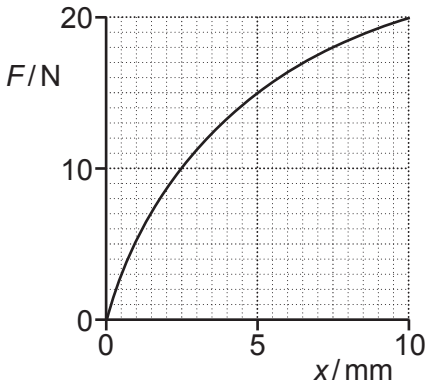
B A loudspeaker oscillating and producing a continuous note.

C A mass oscillating from the end of a suspended spring.

D A pendulum bob oscillating from the end of a fixed length of string.

Your answer ☐ **[1]**

13 The force F against extension x graph for a material being stretched is shown.



What is best estimate for the energy stored in the material when the extension is 10 mm?

A 0.07 J

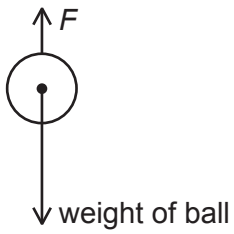
B 0.10 J

C 0.13 J

D 0.20 J

Your answer ☐ **[1]**

14 A ball of mass m is falling vertically through the air.



The total upward force acting on the ball is F. The force F is less than the weight of the object. The acceleration of free fall is g.

Which expression is correct for the acceleration a of the ball?

A $a = 0$

B $a = \frac{mg - F}{m}$

C $a = \frac{mg + F}{m}$

D $a = g$

Your answer ☐ **[1]**

15 The parallax angle for a star is 0.015 seconds of arc.

What is the distance in parsecs (pc) of the star from the Earth?

A 67 pc

B 133 pc

C 220 pc

D 2.1×10^{18} pc

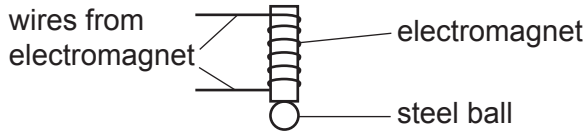
Your answer ☐ **[1]**

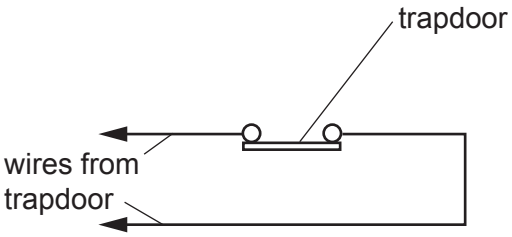
SECTION B

Answer **all** the questions.

16 A student wants to determine the value of the acceleration of freefall g.

(a) The diagram below shows part of the arrangement which the student used.





A steel ball is dropped from an electromagnet. The ball falls vertically. The ball hits a trapdoor and opens the trapdoor.
The ball travels a distance s from the bottom of the electromagnet to the trapdoor in a time t.
The student uses the equation $s = \frac{1}{2} gt^2$ to determine g.

(i) Show that the equation $s = \frac{1}{2} gt^2$ is homogeneous, with both sides of the equation having the same base units.

[2]

(ii) Describe how the student could use standard laboratory equipment to take accurate measurements of the distance s and the time t.

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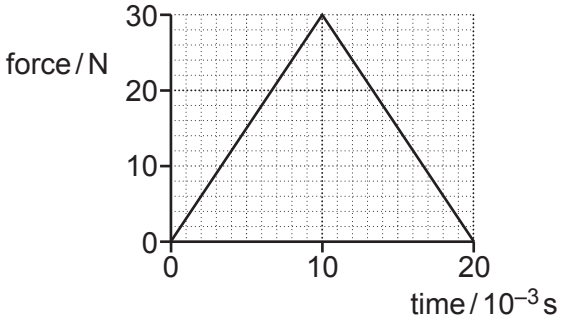
..... **[4]**

(b) The trapdoor falls downwards when the ball hits it.
The ball collides **elastically** with the trapdoor with a speed of $4.4\,m\,s^{-1}$.

The graph of force acting on the ball against time is shown below.



The mass of the ball is 0.050 kg.

(i) Calculate the initial momentum p_1 of the ball just before it hits the trapdoor.

p_1 = ... $kg\,m\,s^{-1}$ **[1]**

(ii) Use the graph to calculate the magnitude of the final momentum p_2 of the ball immediately after the collision.

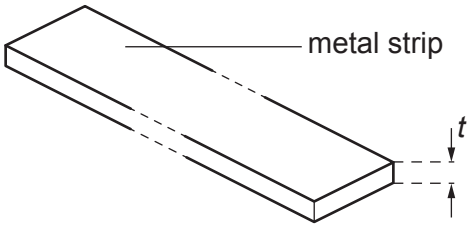
p_2 = ... $kg\,m\,s^{-1}$ **[3]**

(iii) The mass of the trapdoor is 100 g.

Calculate the final speed v of the trapdoor immediately after the collision.

v = ... $m\,s^{-1}$ **[2]**

17 (a) A metal strip has thickness *t*, as shown below.



Five measurements of the thickness *t* at different positions along the length of the strip are shown below.

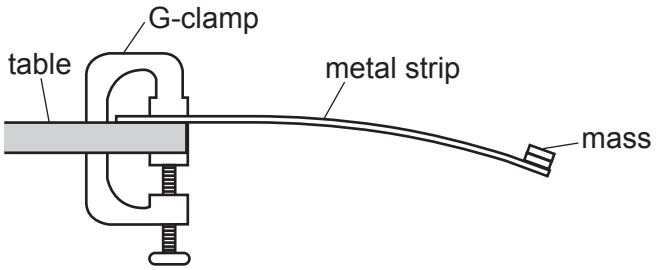
1.86 mm 1.88 mm 1.85 mm 1.89 mm 1.88 mm

Determine the percentage uncertainty in the thickness *t*.

percentage uncertainty = ... % **[3]**

(b)* A student wants to determine the Young modulus *E* of the metal of the strip in **(a)**.

The student clamps the metal strip to the edge of a table using a G-clamp. A mass is **permanently** fixed to the end of the strip as shown.



The mass oscillates freely when it is moved away from its equilibrium position and then released.

The Young modulus *E* of the metal can be determined using the equation $E = \frac{16\pi^2 mL^3}{wt^3T^2}$, where *m* is the mass fixed to the end of the strip, *L* is the length of the strip from the end of the table to the centre of the mass, *w* is the width of the strip, *t* is the thickness of the strip, and *T* is the period of oscillations.

Describe how an experiment may be safely conducted, and how the data can be analysed to determine an accurate value for *E*. **[6]**

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Additional answer space if required.

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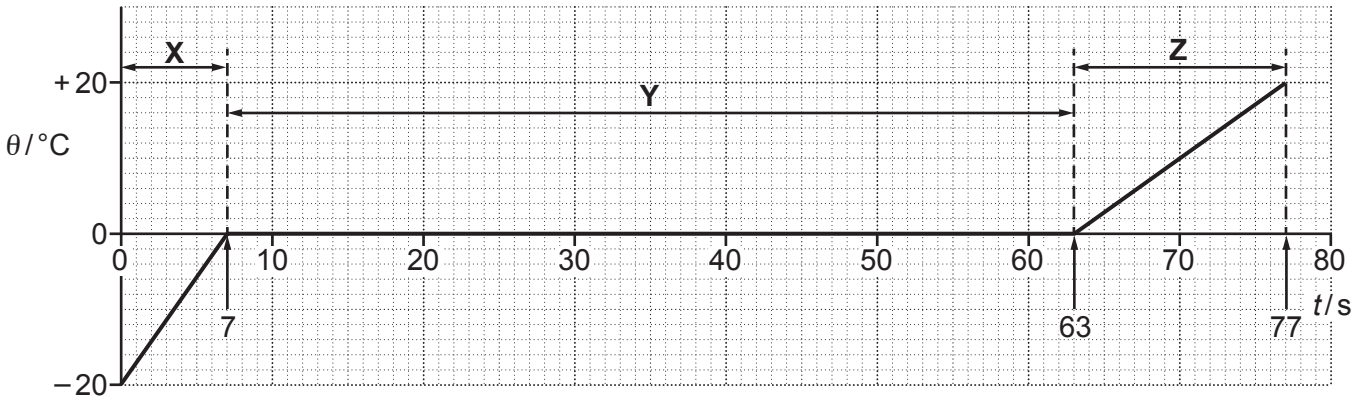
18 A 150 W heater is used to heat 25 g of ice in a sealed and well-insulated container. The initial temperature of the ice is –20 °C.

The graph shows the variation of temperature θ with time t as the ice is heated.



There are three distinct regions of the graph, **X**, **Y** and **Z**.

(a) (i) Use the graph to determine the specific heat capacity c of the ice.

c = ... $\text{J kg}^{-1}\text{K}^{-1}$ **[3]**

(ii) Use the graph to determine the specific latent heat of fusion of ice L_f.

L_f = ... J kg^{-1} **[2]**

(iii) Use the graph to compare the specific heat capacities of ice and water. Explain your answer.

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..... **[2]**

(b) (i) Describe the motions of the molecules in region **X** and in region **Z**.

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..... **[2]**

(ii) The internal energy of the ice increases from $t = 0$ to $t = 77$ s.
Complete the table below using the following key for the physical quantities:

- K = kinetic energy of molecules
- P = potential energy of molecules.

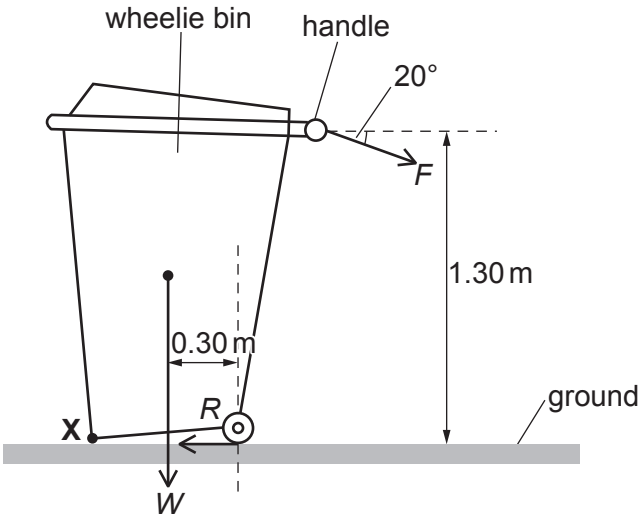
Region	Physical quantity, or quantities, that increases as time increases	Physical quantity, or quantities, that remain constant as time increases
X		
Y		
Z		

[3]

(iii) State the temperature of the ice at which its molecules have zero kinetic energy.

..... **[1]**

19 A wheelie bin is tipped onto its wheels by applying two forces *F* and *R*.



F is applied to the handle. *F* is to the right at an angle 20° below the horizontal.
The height of the handle above the ground is 1.30 m.
R is a horizontal force applied to the left to the wheels.
The total weight of the wheelie bin and its contents is *W*.
The perpendicular distance between the line of action of the weight and the bottom of the wheels is 0.30 m.

The wheelie bin and contents have a total mass of 40 kg.

(a) State the **principle of moments**.

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..... **[1]**

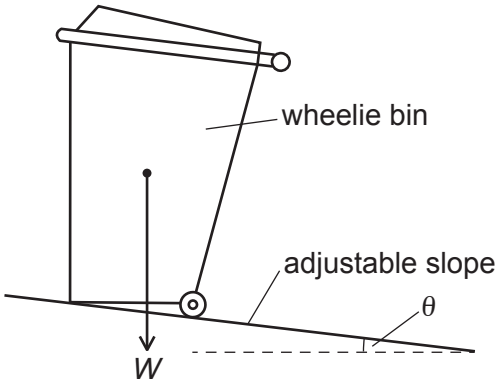
(b) **(i)** Show that the magnitude of the minimum force *F* which lifts the front end of the wheelie bin (point **X**) off the ground is 96 N.

[3]

(ii) Use your answer to **(b)(i)** to calculate the magnitude of the force R required to stop the wheelie bin from moving to the right.

R = ... N **[2]**

(c) The wheelie bin in now placed on an adjustable slope. The wheels are now fixed so they cannot move.



The angle θ made by the slope with the horizontal is steadily increased from zero.

Explain, without calculation, at what angle θ the wheelie bin starts to topple clockwise.

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..... **[1]**

20 (a) The diagram below shows the Earth in space.

(i) On the diagram above, draw a minimum of **four** gravitational field lines to map out the gravitational field pattern around the Earth. **[1]**

(ii) On the same diagram above, show **two** different points where the gravitational potential is the same. Label these points **X** and **Y**. **[1]**

(b)* A satellite is in a circular geostationary orbit around the centre of the Earth. The satellite has both kinetic energy and gravitational potential energy.

The mass of the satellite is 2500 kg and the radius of its circular orbit is 4.22×10^7 m.
The mass of the Earth is 5.97×10^{24} kg.

- Describe some of the features of a geostationary orbit.
- Calculate the **total** energy of the satellite in its geostationary orbit. **[6]**

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Additional answer space if required.

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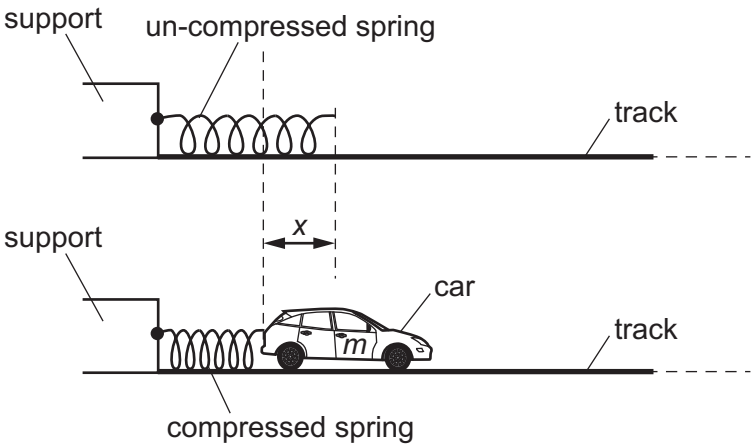
21 **(a)** One end of a spring is fixed to a support.
A toy car, which is on a smooth horizontal track, is pushed against the free end of the spring. The spring compresses. The car is then released. The car accelerates to the right until the spring returns back to its original length.



The car moves with **simple harmonic motion** as the spring returns to its original length.

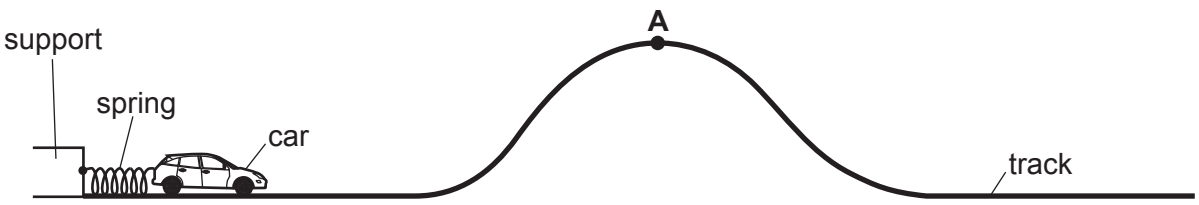
The acceleration of the car is given by the expression $a = -\left(\frac{k}{m}\right) x$, where m is the mass of the car, k is the force constant of the spring and x is the compression of the spring.

Use the data below to calculate the time t it takes for the spring to return to its original length after the car is released.

- mass of car $m = 80\,\text{g}$
- force constant k of the spring $= 60\,\text{N m}^{-1}$.

$t =$ ..... s **[4]**

(b) The arrangement in **(a)** is used to propel the toy car along a smooth track.



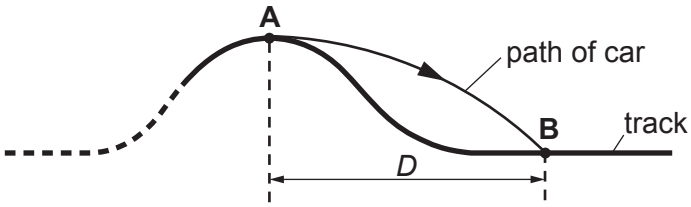
(i) Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

All the elastic potential energy of the spring is transferred to gravitational potential energy of the car.

Calculate the initial compression x of the spring.

x = ... m **[3]**

(ii) At a specific speed, the car leaves point **A** horizontally and lands on the track at point **B**.
The horizontal distance between **A** and **B** is D.



Air resistance has negligible effect on the motion of the car between **A** and **B**.

1 Explain how the time of flight between **A** and **B** depends on the speed of the car at **A**.

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..... **[2]**

2 Explain how the distance D depends on the speed of the car at **A**.

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..... **[2]**

22 **(a)** A particle-accelerator uses a ring of electromagnets to keep protons moving continuously in a **circle**.

The speed v of the protons depends on the frequency f of rotation of the protons in the circular orbit.

Fig. 22 shows data points plotted on a v against f grid.

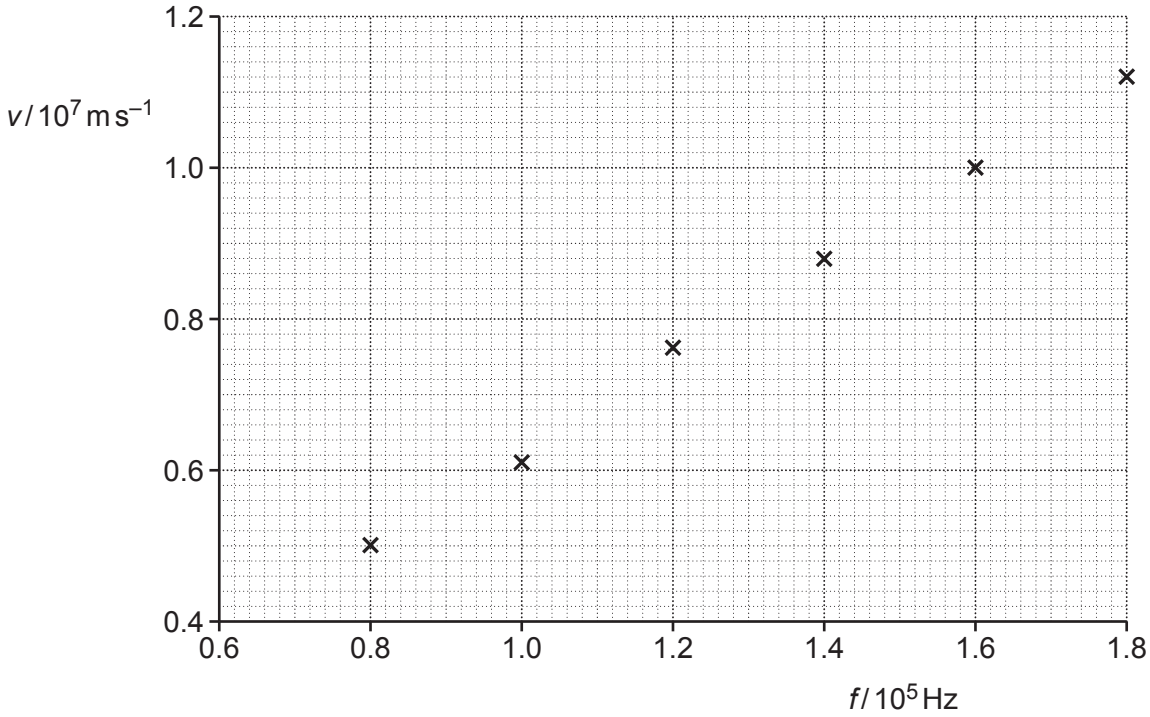

Fig. 22

(i) Show that the gradient of the graph of v against f is equal to $2\pi r$, where r is the radius of the circular path of the protons.

[2]

(ii) Show that r is about 10 m by determining the gradient of the line of best fit through the data points in **Fig. 22**.

[3]

(iii) The maximum speed of the protons from this accelerator is $2.0 \times 10^{7}\,\text{m s}^{-1}$.

Calculate the maximum centripetal force F acting on a proton at this speed.

- mass of proton = 1.7×10^{-27} kg.

F = ... N **[3]**

(b) A new particle-accelerator is now built for moving the protons in a circle of a radius 20 m.

The ring of electromagnets for this new accelerator provides the same **maximum** centripetal force as the accelerator in **(a)**.

Calculate the maximum speed of the protons in this new accelerator.

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

23 Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other.
This triple-star is 90 light-years from the Earth.

(a) Here is some data on the star Aa1.

- radius = $(1.90 \pm 0.14) \times 10^{9}$ m
- mass = $(6.31 \pm 0.42) \times 10^{30}$ kg.

Calculate the gravitational field strength g at the surface of Aa1 to **3** significant figures.
Include the absolute uncertainty in your answer. Assume that the other stars of the system exert negligible gravitational force on Aa1.

g = ... ± ..... $N\,kg^{-1}$ **[4]**

(b) The table shows some data about the three stars of Algol.

Star	Luminosity of star / $L_{\odot}$	Surface temperature of star / K
Aa1	182	13 000
Aa2	6.92	4500
Aa3	10.0	7500

The luminosity of each star is in terms of the solar luminosity $L_{\odot}$.

(i) Define the **luminosity** of a star.

.....

..... **[1]**

(ii) Use Stefan's law to determine the ratio $\frac{\text{radius of star Aa2}}{\text{radius of star Aa3}}$.

ratio = ... **[2]**

(iii) Use Wien's displacement law to explain which star would have the **longest** wavelength at the peak intensity of the emitted electromagnetic radiation.

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..... **[2]**

(iv) Suggest how an astronomer using just an optical telescope can deduce that the three stars of Algol have different surface temperatures.

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..... **[1]**

(v) The light from each star passing through a diffraction grating shows an absorption line spectrum.

Explain how a specific absorption line is produced in this type of spectrum in terms of **photons** and **electrons**.

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..... **[3]**

(c) The Aa1 star could evolve into a black hole.

State **two** ways in which the black hole would differ from the Aa1 star.

1. .....

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2. .....

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[2]

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).

OCR
Oxford Cambridge and RSA

Thursday 26 May 2022 – Afternoon

A Level Physics A

H556/01 Modelling physics

Time allowed: 2 hours 15 minutes

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

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

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H 5 5 6 0 1

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

Centre number | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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ADVICE
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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 ☐ **[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

Your answer ☐ **[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

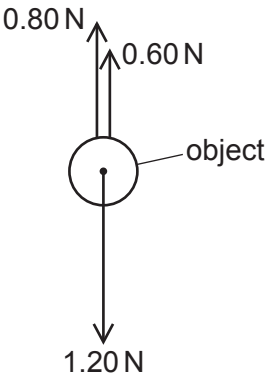
B acceleration, impulse

C displacement, kinetic energy

D force, work done

Your answer ☐ **[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.



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.

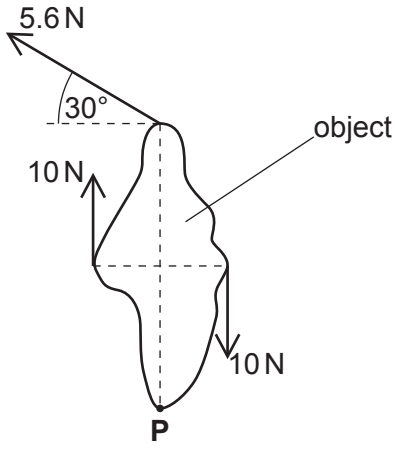
B It is accelerating.

C It is decelerating.

D It is moving upwards.

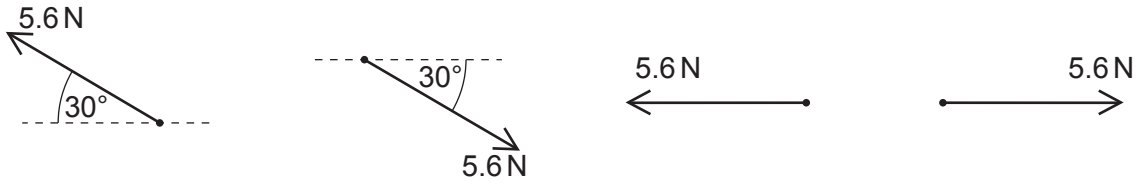
Your answer ☐ **[1]**

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**?



A **B** **C** **D**

Your answer ☐ **[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

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

A 2.3

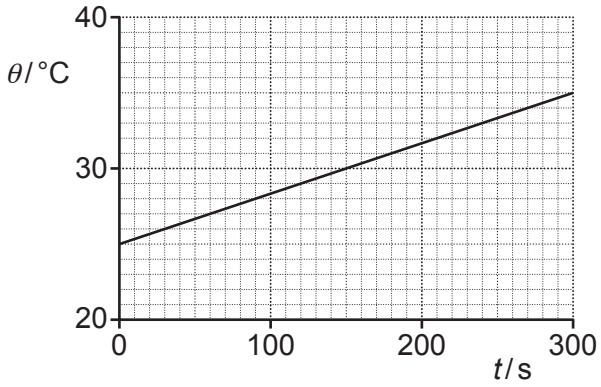
B 3.9

C 4.0

D 6.9

Your answer ☐ **[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 $c = \frac{PG}{m}$

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

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

Your answer ☐ **[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 ☐ **[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 $4.7 \times 10^{-2}\,m^3$

Your answer ☐ **[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

Your answer ☐ **[1]**

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

A acceleration, gravitational field strength

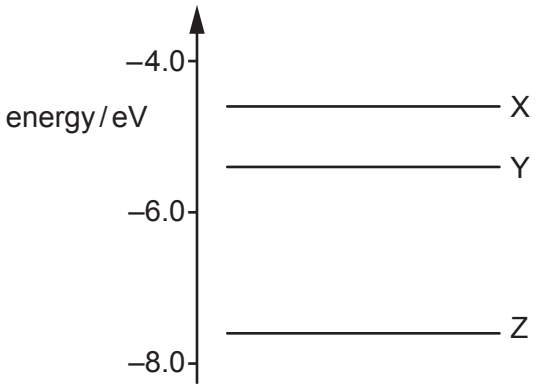
B angular frequency, angular velocity

C gravitational potential, kinetic energy

D impulse, momentum

Your answer ☐ **[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 $Z \longrightarrow X$

B $X \longrightarrow Z$

C $Y \longrightarrow X$

D $X \longrightarrow Y$

Your answer ☐ **[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°

Your answer ☐ **[1]**

14 A galaxy, 1.0×10^9 light-years away from the Earth, has a recession speed of $23\,000\,\text{km}\,\text{s}^{-1}$.

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

A $\text{age} = \dfrac{1.0 \times 10^9}{23\,000 \times 10^3}$

B $\text{age} = \dfrac{1.0 \times 10^9 \times 1.5 \times 10^{11}}{23\,000}$

C $\text{age} = \dfrac{1.0 \times 10^9 \times 9.5 \times 10^{15}}{23\,000 \times 10^3}$

D $\text{age} = \dfrac{1.0 \times 10^9 \times 3.1 \times 10^{16}}{23\,000 \times 10^3}$

Your answer ☐ **[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

C Existence of dark matter

D Hubble's law

Your answer ☐ **[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.

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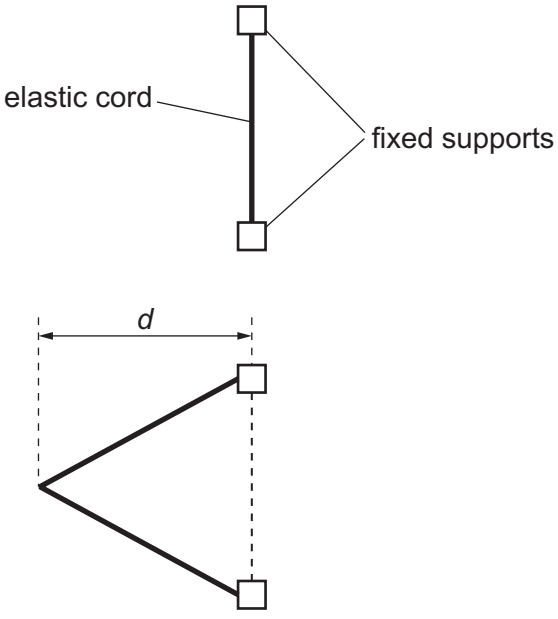
..... **[4]**

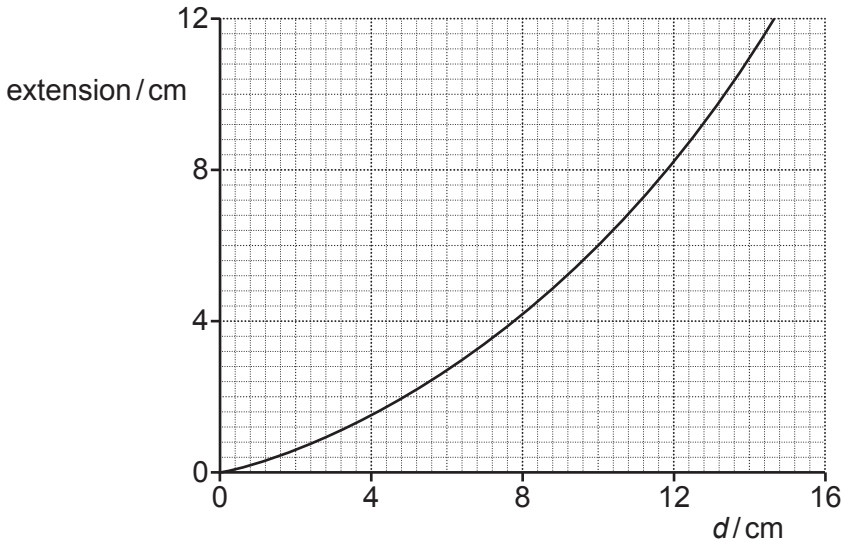
(b) A simple catapult is made by an elastic cord fixed to two supports, as shown below.



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 $500\,\text{N}\,\text{m}^{-1}$.

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.

[3]

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

R = ... m **[3]**

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

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..... **[2]**

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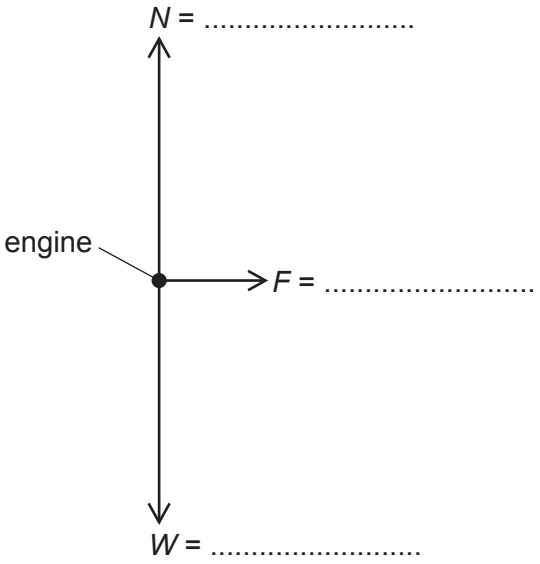
17 An electric engine of mass 17 000 kg has a constant power output of 280 kW and it can reach a maximum speed of 42 m s^{-1} on horizontal rails. The maximum kinetic energy of the engine is 15 MJ.

(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.

[1]

(b) The engine is moving along the horizontal rails at the constant maximum speed of 42 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.



[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.

[4]

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

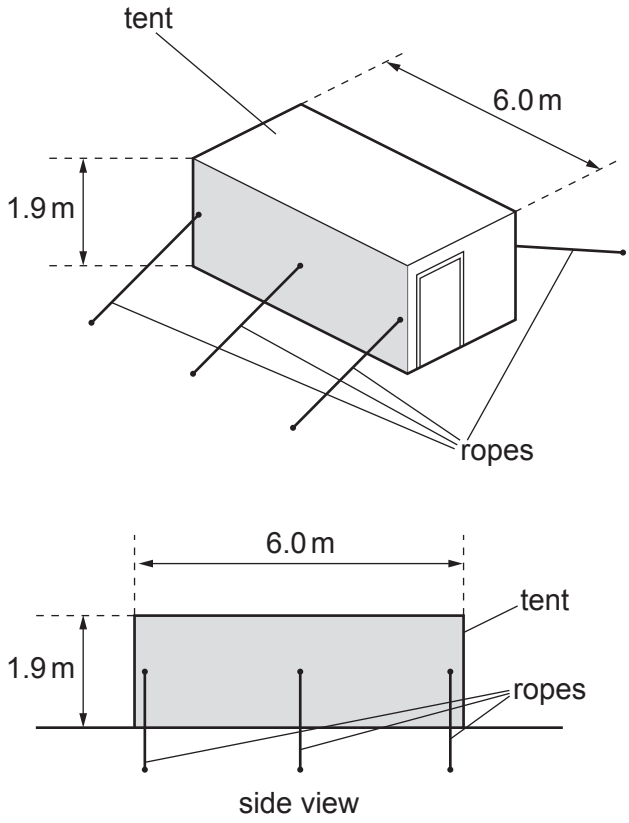

Fig. 18.1

(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.

[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**.

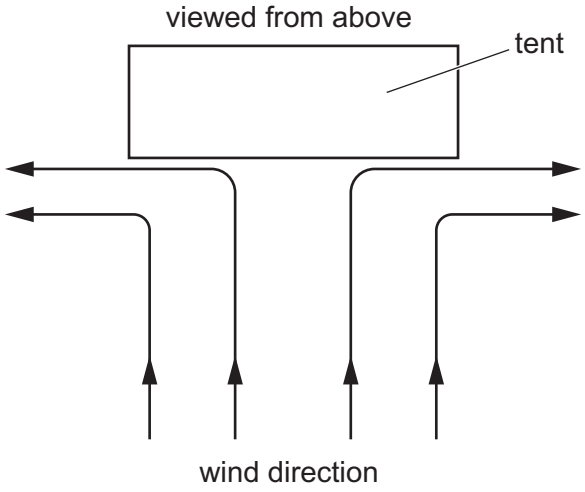

Fig. 18.2

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.

F = ... 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]**

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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.

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..... **[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.

[3]

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

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

mass = ... kg **[1]**

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

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

.....

..... **[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 = $3.34 \times 10^5\,\text{J kg}^{-1}$
- specific latent heat of vaporisation of water = $2.26 \times 10^6\,\text{J kg}^{-1}$

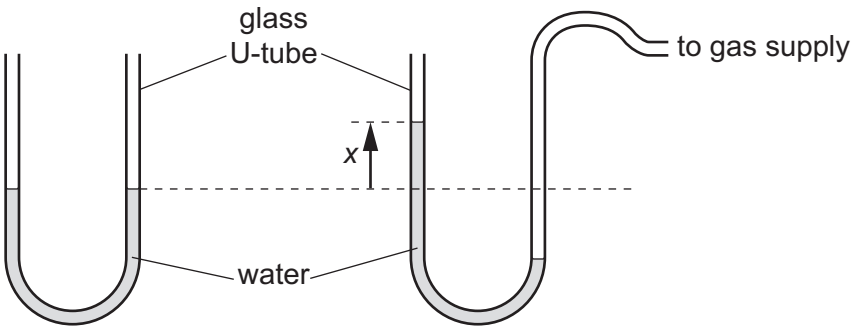
L = ... J kg^{-1} **[4]**

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.

[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 $1000\,\text{kg}\,\text{m}^{-3}$.

(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.

Δp = ... 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.

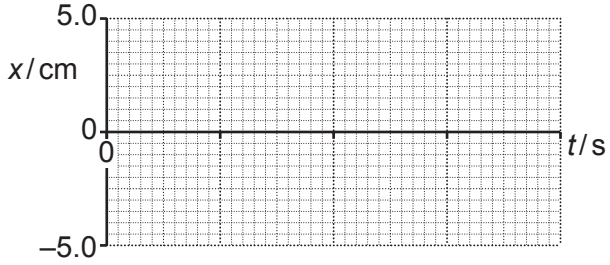
For this U-tube, $A = 1.0 \times 10^{-4}\,\text{m}^2$ and $m = 0.052\,\text{kg}$.

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

[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.

.....

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..... **[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.

..... **[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 = 3.1×10^{16} m

[2]

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

E_k = ... J **[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 $\frac{\text{mass of nebula } \mathbf{X}}{\text{mass of the Sun}}$.

ratio = ... **[2]**

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

Describe the eventual evolution of this star.

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..... **[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.

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..... **[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.

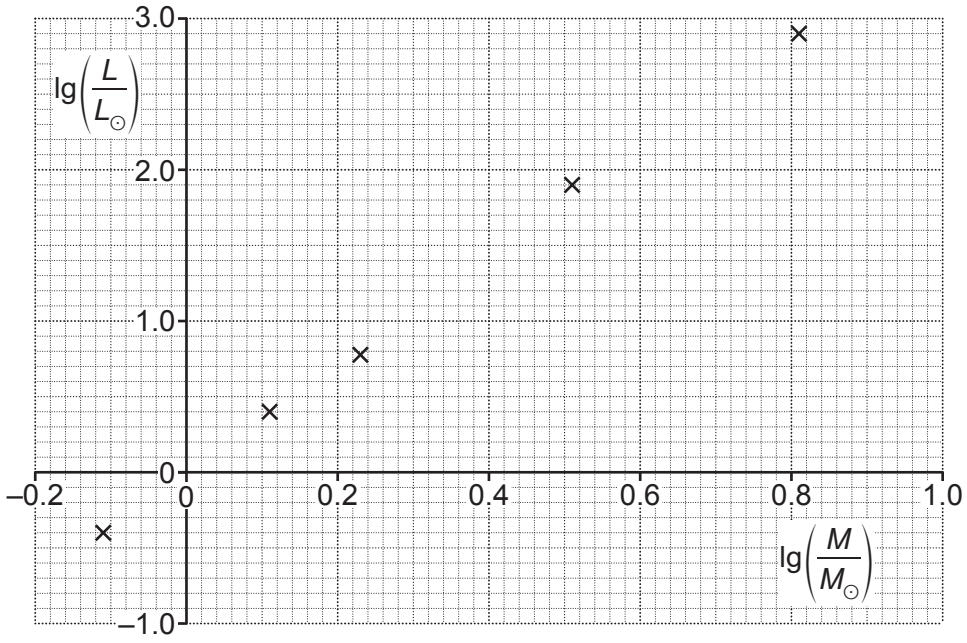

Fig. 22

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]**

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Additional answer space if required

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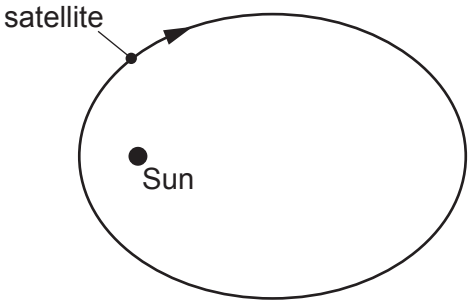
23 **(a)** A planet of mass m is in a circular orbit around a star of mass M.

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 $T^2 \propto r^3$.

[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.

distance = ... 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.

change in kinetic energy = ... 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.

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..... **[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).

OCR
Oxford Cambridge and RSA

Wednesday 24 May 2023 – Afternoon

A Level Physics A

H556/01 Modelling physics

Time allowed: 2 hours 15 minutes

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 | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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 **36** 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.

1 Which row contains **only** scalar quantities?

A Absolute temperature, displacement, moment

B Acceleration, force, momentum

C Gravitational potential, kinetic energy, mass

D Kinetic energy, mass, momentum

Your answer ☐ **[1]**

2 Forces are applied to a circular shaft of diameter d.

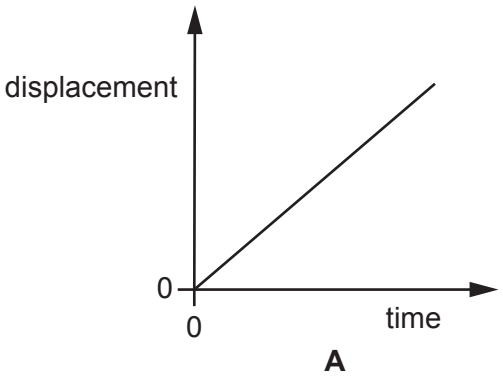
Which diagram shows a torque of a couple with magnitude Fd?

A **B** **C** **D**

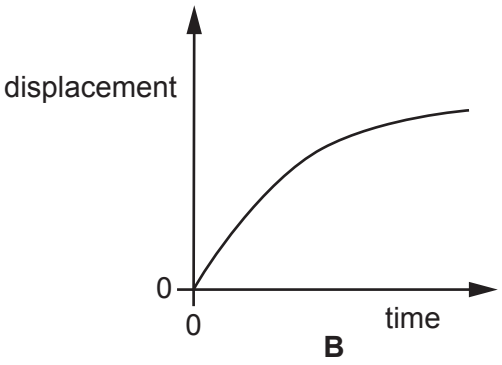
Your answer ☐ **[1]**

3 The resultant force acting on a moving object is zero.

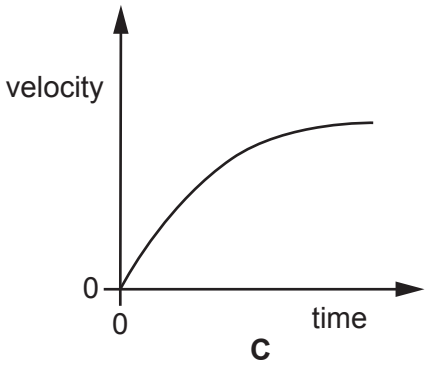
Which graph shows this?



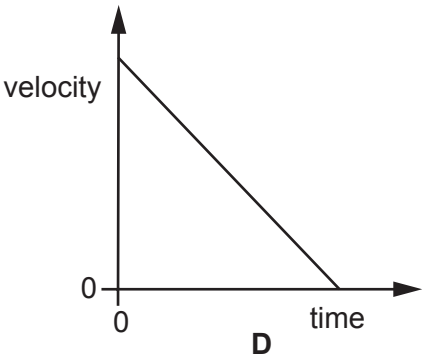
A



B



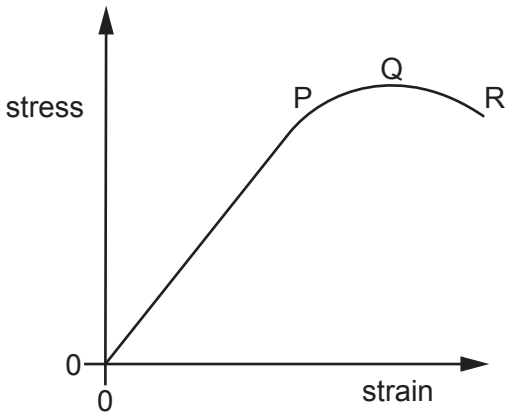
C



D

Your answer ☐ **[1]**

4 Which row in the table correctly identifies the elastic limit, fracture and ultimate tensile strength in the graph below?



	Elastic limit	Fracture	Ultimate tensile strength
A	P	Q	R
B	P	R	Q
C	P	R	R
D	Q	R	P

Your answer ☐ **[1]**

5 A wire of cross-sectional area $3.9 \times 10^{-6}\,m^2$ carries a load of 240 N. The strain in the wire is 0.30%.

Which value of the Young modulus, in Pa, is correct and expressed to an appropriate number of significant figures?

A 2.05×10^{8}

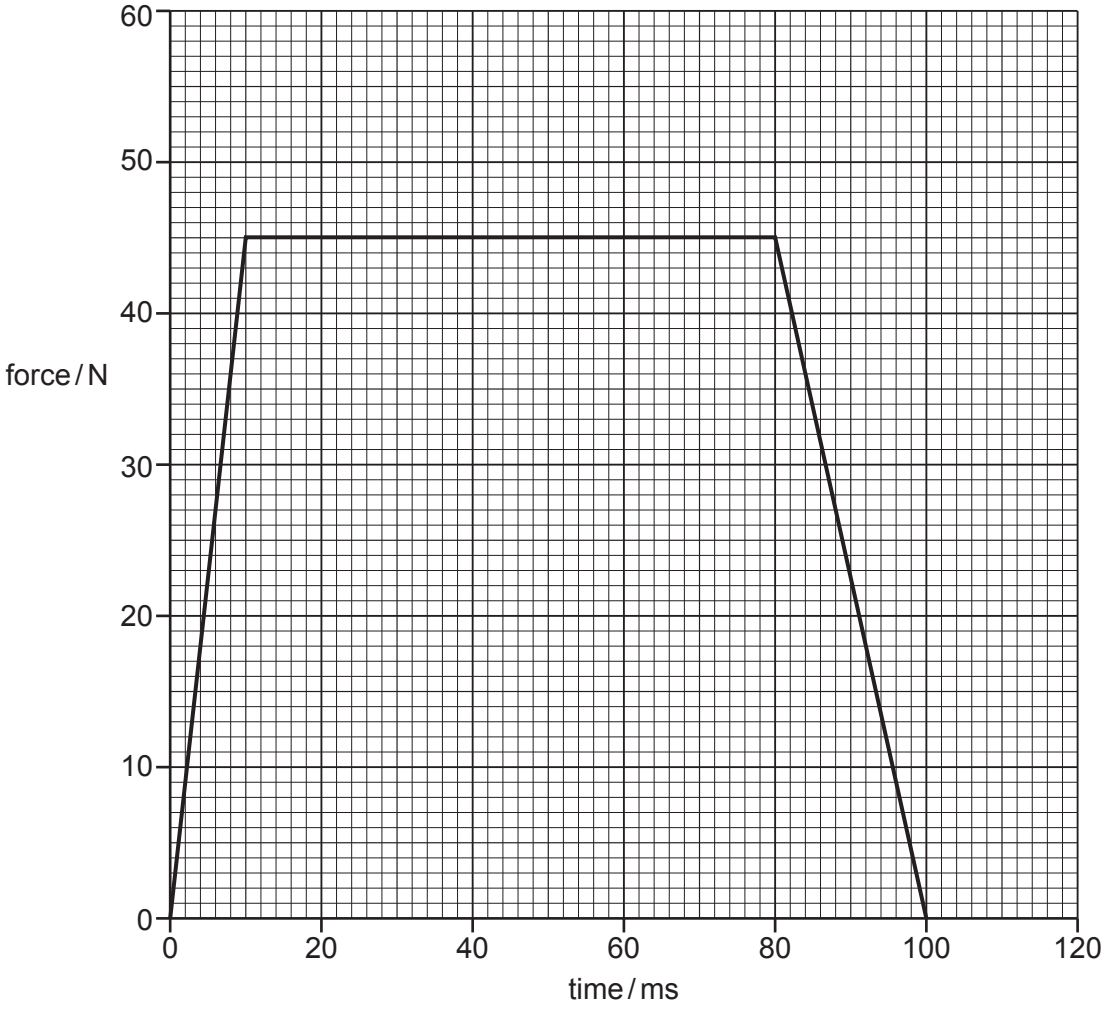
B 2.1×10^{8}

C 2.05×10^{10}

D 2.1×10^{10}

Your answer ☐ **[1]**

6 A tennis ball is hit with a racket. The graph shows the force the ball exerts on the racket.



What is the magnitude of the change in momentum of the ball?

A $2.3\,kg\,m\,s^{-1}$

B $3.8\,kg\,m\,s^{-1}$

C $2300\,kg\,m\,s^{-1}$

D $3800\,kg\,m\,s^{-1}$

Your answer ☐ **[1]**

7 Two identical spheres, each of mass 8700 kg, have a space of 3.6 m between their centres.

What is the magnitude of the gravitational force they exert on each other?

A 2.0×10^{-3} N

B 3.9×10^{-4} N

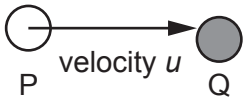
C 7.5×10^{-4} N

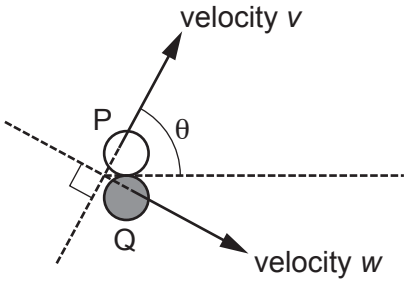
D 4.5×10^{-8} N

Your answer ☐ **[1]**

8 A particle P of mass *m* and moving at velocity *u* collides **elastically** with a stationary particle Q also of mass *m*.

After the collision particle P moves with velocity *v* at an acute angle θ to the direction of the original motion. Particle Q moves in a perpendicular direction to P with velocity *w*.
The velocities *u*, *v* and *w* are constant.





Before collision After collision

Which of the following equations is/are correct?

1. $u = w\cos\theta + v\cos\theta$
2. $w\cos\theta = v\sin\theta$
3. $u^2 = w^2 + v^2$

A 1 only

B 1 and 2

C 2 and 3

D 1, 2 and 3

Your answer ☐ **[1]**

9 During cold weather salt is spread on roads causing ice to melt without changing its temperature.

Which statement correctly describes the energy of the water particles during this process?

A Potential and kinetic energies increase

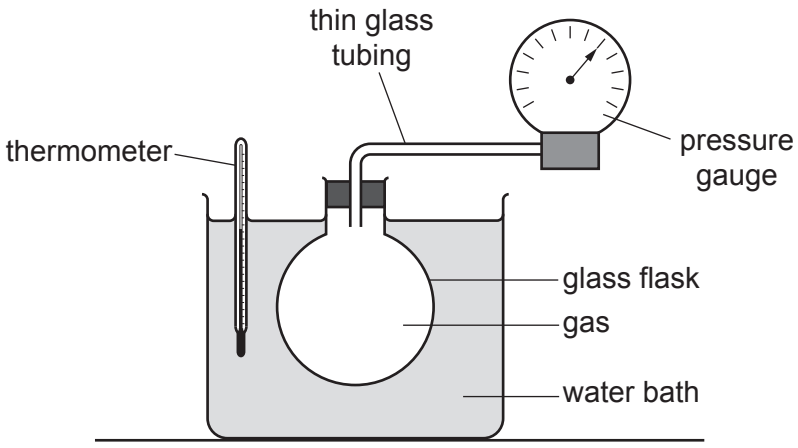
B No energy changes occur

C Only kinetic energy increases

D Only potential energy increases

Your answer ☐ **[1]**

10 An experiment is carried out to estimate the value of absolute zero using the variation of gas pressure with temperature. The apparatus is shown below.



Which variable must be controlled during the experiment?

A Pressure of the gas

B Temperature of the gas

C Volume of the gas

D None of the above

Your answer ☐ **[1]**

11 A satellite is in geostationary orbit 36 000 km above the Earth's surface. The Earth has a radius of 6400 km.

At what speed is the satellite moving relative to the centre of the Earth?

A $0\,m\,s^{-1}$

B $490\,m\,s^{-1}$

C $2.6\,km\,s^{-1}$

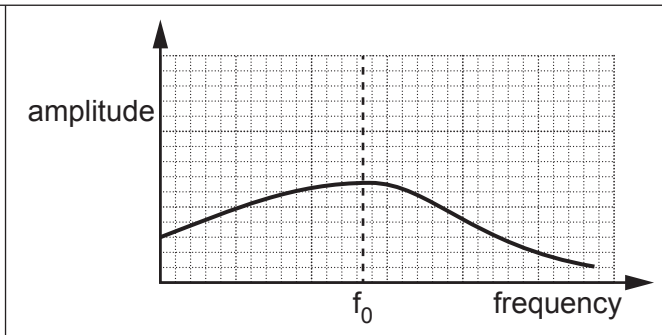
D $3.1\,km\,s^{-1}$

Your answer [ ] **[1]**

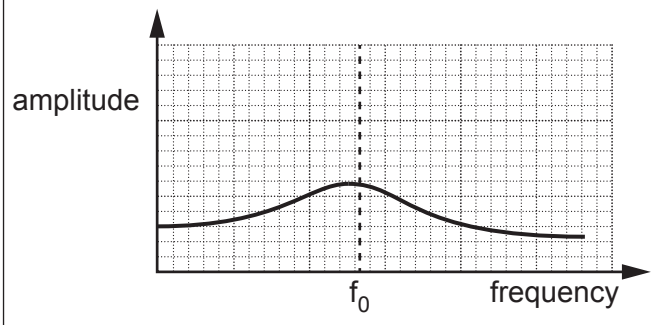
12 Four different oscillator systems are forced to oscillate at various frequencies. The graphs show the amplitude of oscillation for each frequency. f_0 is the undamped resonant frequency for each oscillator. The vertical axes on the graphs are all to the same scale.

Which of the oscillators, **A** to **D**, is the most heavily damped?

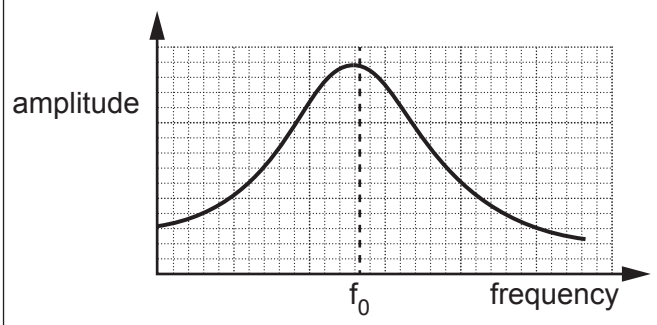
A



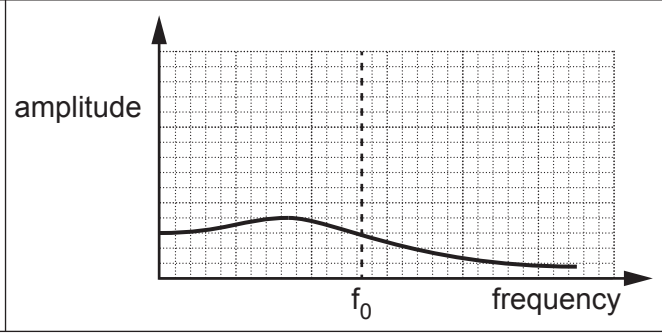
B



C



D



Your answer ☐ **[1]**

13 During the evolution of the universe there was a period of inflation.

Which forms of matter, if any, existed 10^{-10} s after the big bang?

A Atoms

B Leptons

C None

D Quarks

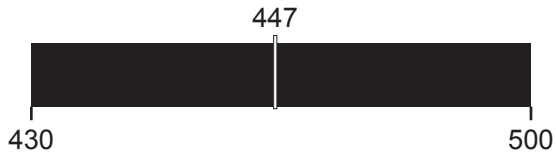
Your answer ☐ **[1]**

14 Part of the emission spectrum for hydrogen in a laboratory is shown. All wavelengths are given in nm.

Which diagram shows the corresponding part of the absorption spectrum observed from Earth emitted from a galaxy moving away with a velocity of 0.031 c?

A

B



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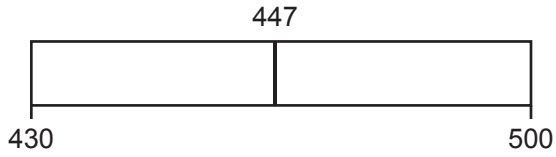
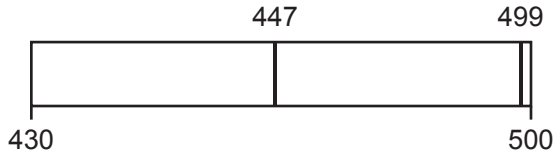


D



Your answer ☐ **[1]**

15 An early estimate for the Hubble constant was 500 km s^{-1} Mpc^{-1}.

What is the value of this estimate in units of s^{-1}?

1 parsec = 3.1×10^{16} m

A 2.3×10^{-18}

B 1.6×10^{-17}

C 1.6×10^{-5}

D 0.5

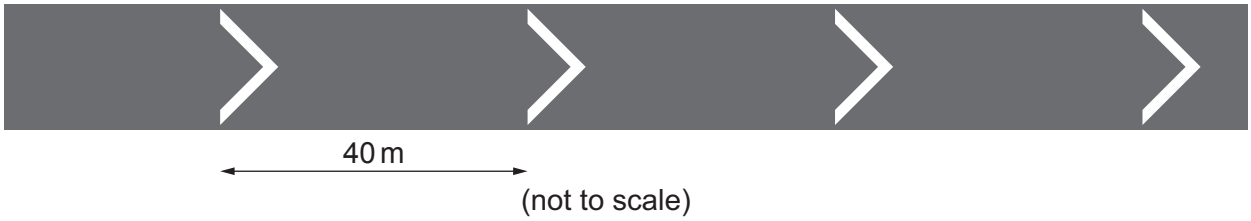
Your answer ☐ **[1]**

Section B

16 The diagram shows a road where vehicles travel at high speeds.

Markings painted on the road surface are spaced 40 m apart.

Drivers are advised to keep at least two markings visible on the road between them and the vehicle in front.



(not to scale)

The maximum speed vehicles travel at on the road is 110 km/hr. The table shows data from a driving manual for a vehicle travelling on a straight, horizontal road.

Speed (km/hr)	Braking distance (m)	Stopping distance (m)
110	75	96

(a) (i) Calculate the maximum speed v of vehicles on the road in S.I. units.

v = ... Unit = ... **[2]**

(ii) A vehicle passes over one of the markings.

Calculate time taken to travel the 40 m distance between the two markings.

t = ... s **[1]**

(iii) Using the table, explain why having markings 40 m apart helps prevent collisions.

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..... **[3]**

(b) A vehicle with mass 1600 kg is travelling at 110 km / hr.
The driver sees an obstruction and applies the brakes to bring the vehicle to rest in 5.6 s.

(i) Estimate the magnitude of the average resultant force *F* required to bring the vehicle to rest.

F = ... N **[2]**

(ii) Explain the effect on the distance required to bring the vehicle to rest if the road has an upwards slope.

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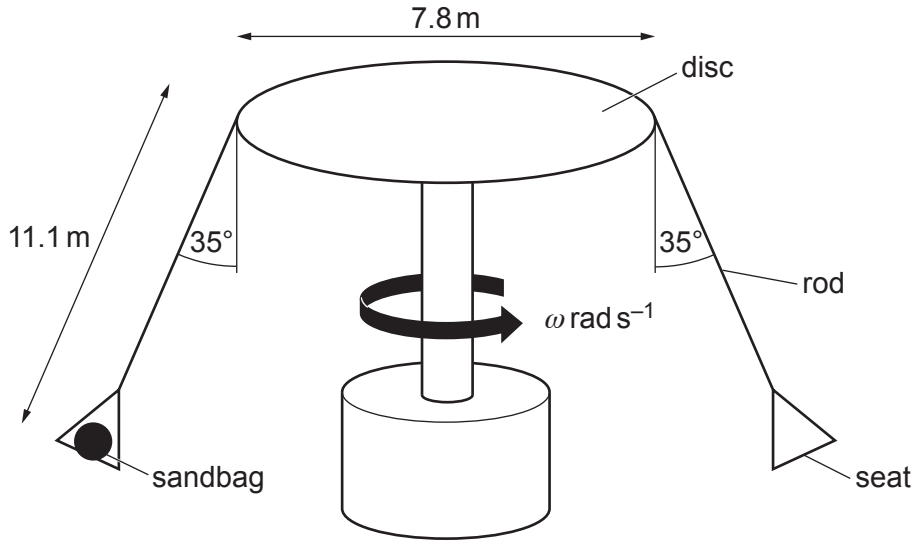
..... **[2]**

17 The diagram below shows a fairground ride. Each rider is secured in a seat suspended by a rod.

The distance from the top of the rod to the base of the seat is 11.1 m.

The rod is attached to the edge of a disc of diameter 7.8 m.



(not to scale)

To test the equipment a sandbag is attached to the seat and the ride is started.

The combined mass of the seat and the sandbag is 12 kg.

The rod makes an angle of 35° with the vertical.

(a) (i) Draw an arrow labelled T on the diagram to represent the tension in the rod. **[1]**

(ii) Show that the radius of the circular path followed by the sandbag is about 10 m.

[2]

(iii) Calculate the tension T in the rod.

$T =$ ..... N **[3]**

(iv) Show that the angular velocity of the ride is about 0.8 radians per second.

[2]

(b) When the seat is at its highest point the sandbag is 17 m above the ground. The sandbag is released from the seat to model an object being dropped by a rider.

(i) Calculate t, the time taken for the sandbag to reach the ground.

$t =$ ..... s **[2]**

(ii) Using your answer to **(a)(iv)**, determine the horizontal displacement s travelled by the sandbag before hitting the ground.

$s =$ ..... m **[3]**

(iii) Determine, with reasons, the effect on the horizontal displacement travelled if the object released from the ride was a shoe from a rider.

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..... **[3]**

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18* A student is attempting to determine the value of *g*, the acceleration due to gravity, by two different methods.

Method 1. Vertical drop method

Measuring the time of fall of a small dense ball being dropped from rest from different heights.

Method 2. Rolling ball method

Measuring the time it takes for the same ball to roll 1.900 m down a ramp, set at different angles.

Single sets of results are shown below. The times were measured using a standard stopwatch operated by the student.

Compare and discuss the uncertainties of the two values of *g* that could be obtained using these single measurements.

Describe how the student would analyse both sets of data when a full range of results has been taken.

Vertical drop method

Drop height / m	Time taken / s
1.20	0.50

Rolling ball method

Length of ramp / m	Angle / °	Time taken / s
1.900	30	0.90

[6]

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Additional space if required

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19 **(a)** Describe how to find the centre of mass of a 2-dimensional shape, including any equipment required.

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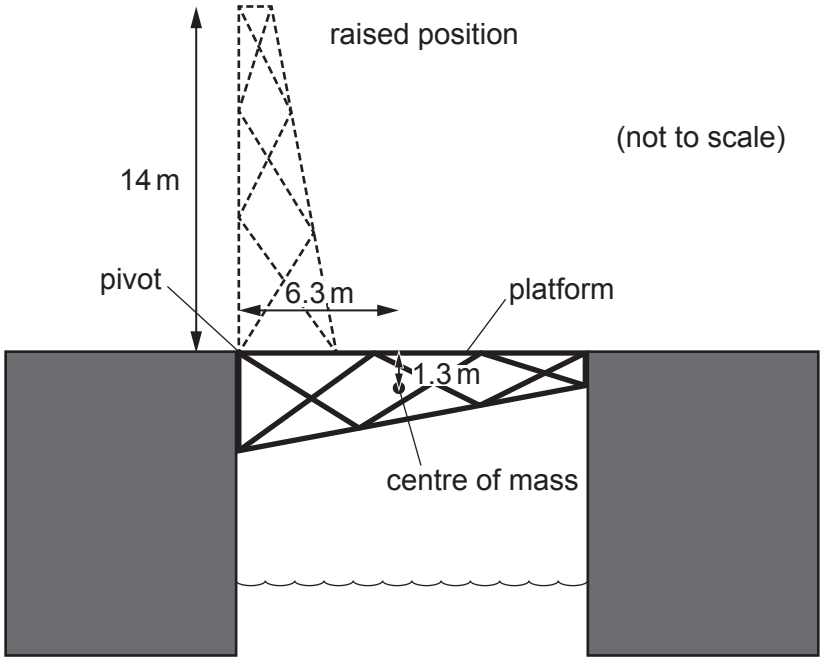
..... **[3]**

(b) **Fig. 19** shows a bridge.

The bridge can be raised by an electric motor to allow tall ships to pass underneath.

Fig. 19



The moving section of the bridge is 14 m long and has a weight of 120 kN.

The centre of mass of the structure is 6.3 m from the pivot.

(i) Calculate the average power required to raise the bridge to a vertical position in 90 s.

power ..... W **[2]**

(ii) Suggest why the actual electric motor used to lift the bridge has a maximum power output several times larger than the value calculated in **(b)(i)**.

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..... **[1]**

20 **(a)** A sealed container contains n moles of an ideal gas. The gas has pressure p, absolute temperature T and occupies volume V.

The mass of one mole of the gas is M.

Use an ideal gas equation to show that the density ρ of the gas is given by the expression $\rho = \frac{pM}{RT}$.

[3]

(b) An airship has a cabin suspended underneath a gasbag inflated with helium.

The airship is floating above the ground and is stationary.

The volume of the gasbag is 12 000 m^3.
The temperature of the helium and the surrounding air is 20 °C.
Atmospheric pressure is 1.0×10^5 Pa.
The molar mass of air is 0.029 kg mol^{-1}.
The volume of the cabin is negligible compared to the volume of the gasbag.

(i) Show that the density of air under the conditions described is about 1.2 kg m^{-3}.

[1]

(ii) Calculate the weight of air displaced by the airship.

weight of air ..... N **[2]**

(iii) Explain why the weight of air displaced by the airship has the same magnitude as the weight of the airship and its contents.

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..... **[2]**

(iv) The pressure of the helium in the gasbag is maintained at a value only slightly greater than atmospheric pressure.
Suggest why a larger pressure is not used.

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..... **[2]**

(c) The airship engine drives a fan which moves 7.8 kg of air per second at a relative speed of $45\,m\,s^{-1}$, so the airship starts to move.

All other conditions given in **(b)** remain the same.

Calculate the thrust that the engine produces.

thrust ..... N **[2]**

(d) The airship has a higher maximum speed at high altitudes, but also produces less thrust from the engine.

Explain these observations.

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..... **[2]**

21 (a) **Fig. 21.1** shows a stationary glider of mass m on an air track.

The glider has identical springs with force constant k attached to each end which are secured to fixed posts.

The air track blower is turned on and the glider is displaced a small distance x_0, as seen in **Fig. 21.2**. It is then released.

The glider moves horizontally in simple harmonic motion.

The springs remain in tension throughout the motion.

The time taken for 20 complete oscillations is measured, and the period T calculated.

Fig. 21.1

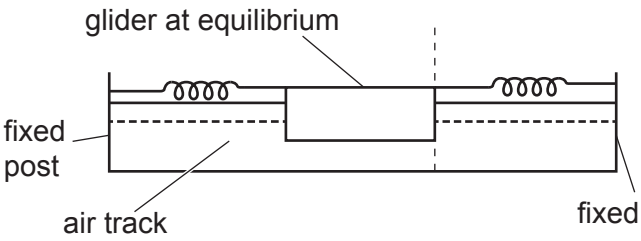
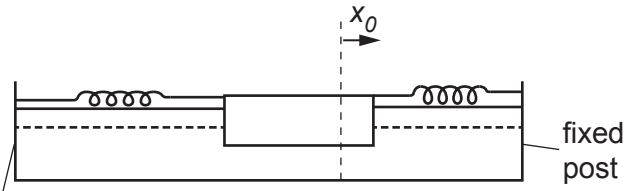


Fig. 21.2



The relationship between the period T, the mass of the glider m and the force constant k is described by the equation

$$T^2 = \frac{2\pi^2 m}{k}.$$

(i) Show that the equation above is homogeneous by reducing the equation to SI base units.

[2]

(ii) Explain why the magnitude of the resultant force F on the glider is given by $F = 2kx$ where x is the displacement at any time.

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..... **[2]**

(iii) State and explain the effect, if any, of increasing the initial displacement on the period of the subsequent motion.

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..... **[2]**

(b) Masses are added to the glider, and the measurement of $20T$ repeated.

The results table is below.

m/kg	$20T$/s	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(i) Describe **two** different errors in the table.

1 .....

.....

2 .....

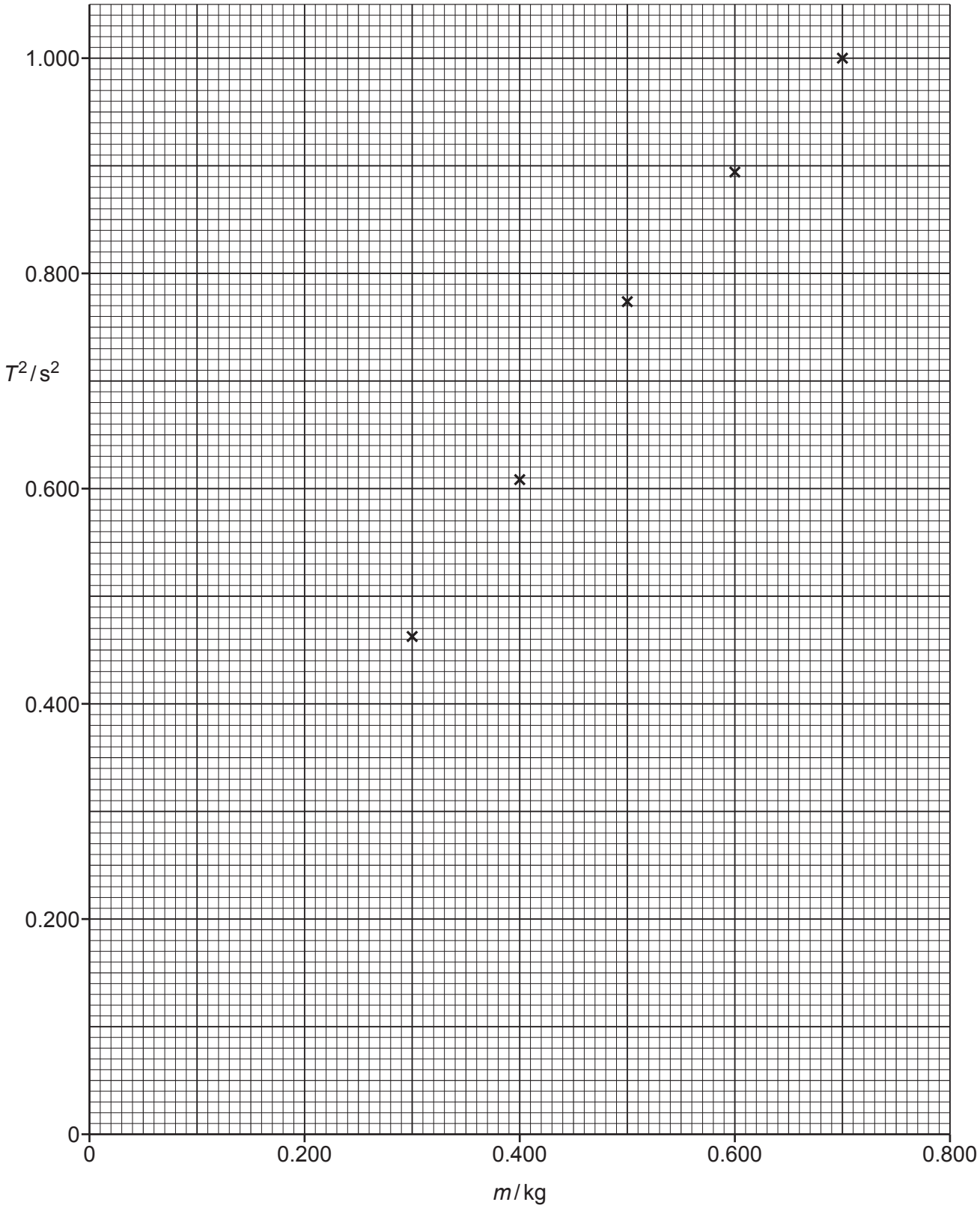
.....

[2]

(ii) Plot the **first** data point from the table on the graph below.

The other points have all been plotted. The table of results is repeated on the opposite page.

Include on your graph a line of best fit. **[2]**



m/kg	$20T$/s	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(iii) Use the graph to determine the value of k.

k = ... N m^{-1} **[3]**

(c) When the initial displacement is increased, one spring increases its extension while the extension of the other spring decreases.

Explain why the **maximum** kinetic energy of the motion increases.

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..... **[4]**

22* A star has a mass similar to that of the Sun.

Describe how the position of this star on a Hertzsprung-Russell (H-R) diagram changes as it evolves.

Fig. 22.1 is a blank H-R diagram.

You may add information to **Fig. 22.1** as part of your response.

Fig. 22.2 shows the relative intensities of different wavelengths of light in the spectrum of a star.

Explain how information from **Fig. 22.2** could be used to suggest the stage of evolution of the star. Describe the limitations of the analysis.

[6]

Fig. 22.1

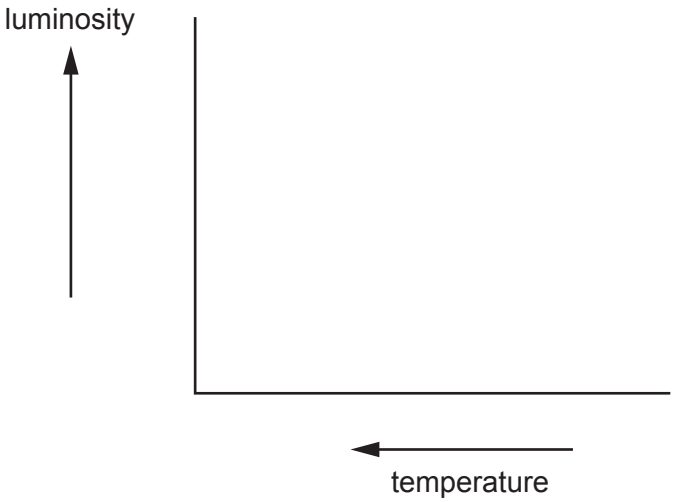
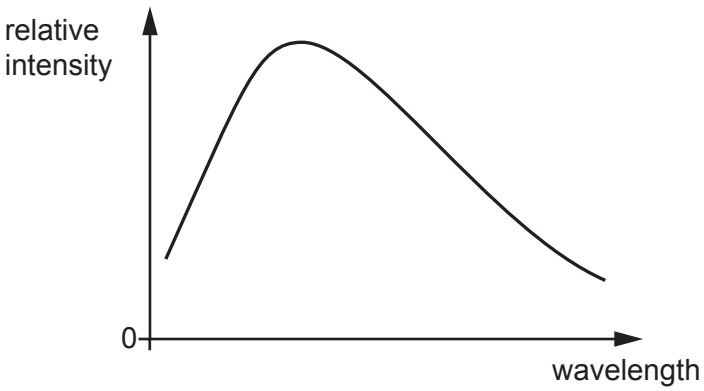


Fig. 22.2



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23 The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^{6} K

(a) (i) Estimate the maximum stellar distance in parsecs that could be measured using Hipparcos.

maximum stellar distance = ...pc **[1]**

(ii) Calculate the percentage uncertainty in the calculated value of the distance to Polaris A.

percentage uncertainty = ... % **[2]**

(b) A continuous stream of particles called a solar wind flows from the surface of the star into the surrounding space.

These particles include helium nuclei of mass 6.6×10^{-27} kg.

Assume that the atmosphere is modelled as an ideal gas.

(i) Show that the typical kinetic energy of a helium nucleus in the atmosphere is about 10^{-16} J.

[2]

(ii) The gravitational potential energy of a helium nucleus in the outer layer of the star is -2.3×10^{-16} J.

Calculate the gravitational potential energy U at the maximum distance from the star that a helium nucleus could reach.

U = ... J **[1]**

(iii) Calculate the distance from the centre of the star reached by this helium nucleus.

distance = ... m **[3]**

(iv) Explain why the star has a solar wind that reaches a much greater distance from the star than found in **(iii)**.

.....

..... **[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).

OCR
Oxford Cambridge and RSA

Friday 24 May 2024 – Morning

A Level Physics A

H556/01 Modelling physics

Time allowed: 2 hours 15 minutes

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 | | | | | | Candidate number | | | | |

First name(s) _____

Last name _____

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.

1 Which row in the table shows two equivalent physical quantities?

A	0 °C	–273.15 K
B	1 kg m s^{-1}	1000 N s
C	10 kW	10 000 N m
D	1.0 mPa	0.0010 N m^{-2}

Your answer ☐ **[1]**

2 What are the SI base units of the Boltzmann constant *k*?

A J K^{-1}

B kg m s^{-2} K^{-1}

C kg m^2 s^{-2} K^{-1}

D N m K^{-1}

Your answer ☐ **[1]**

3 A rubber bung is attached to a string. The bung is whirled around in a horizontal circle of radius r. The rotational period of the bung is T. The tension in the string is kept constant as the bung is whirled around at different speeds.

Which relationship is correct for this whirling bung?

A $T \propto r$

B $T^2 \propto r$

C $T \propto r^2$

D $T \propto \sqrt{r}$

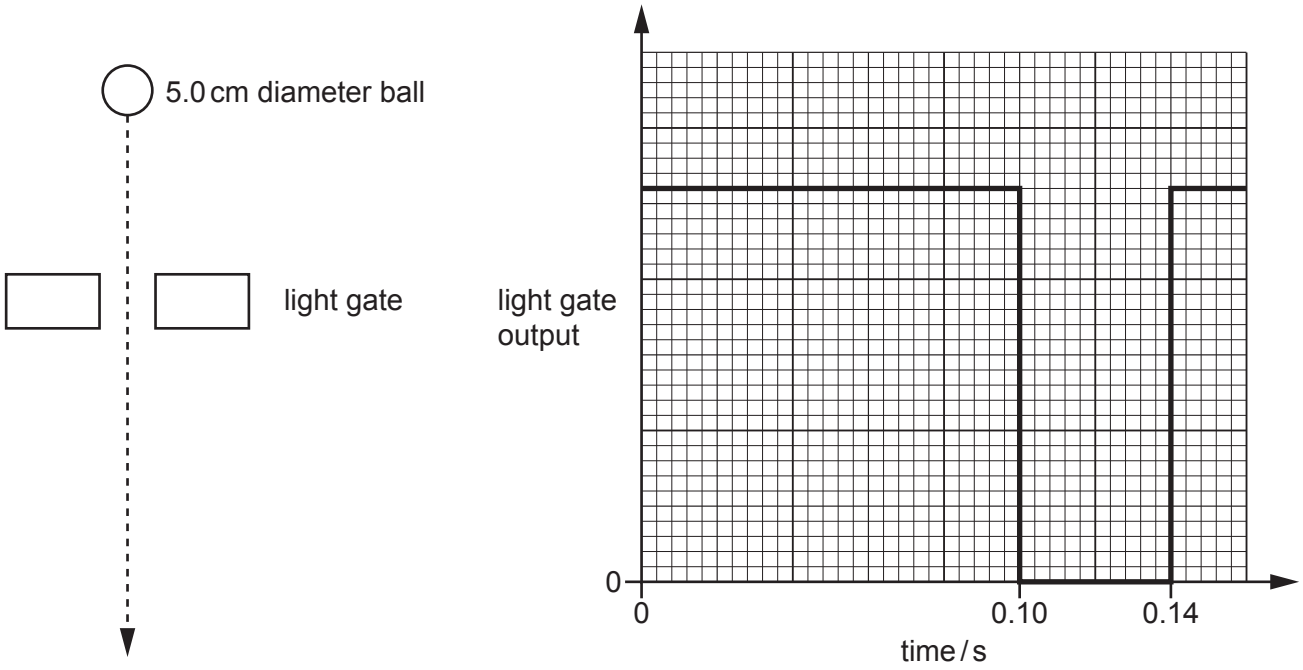
Your answer ☐ **[1]**

4 To determine the acceleration of free fall g, a ball is dropped from rest from a point vertically above a light gate.

The ball has a diameter of 5.0 cm. It is dropped at time $t = 0$.

The light gate output shows that the ball passes through the gate between times $t = 0.10$ s and $t = 0.14$ s.

The graph shows the output from the light gate.



Air resistance has negligible effect on the motion of the ball.

What is the value of g in m s^{-2} from these measurements?

A 8.93

B 9.81

C 10.4

D 12.5

Your answer ☐ **[1]**

5 A block of wood is floating in calm water.

The density of the wood is 700 kg m^{-3}. The density of water is 1000 kg m^{-3}.

What percentage of the volume of the block is **above** the waterline?

A 30

B 50

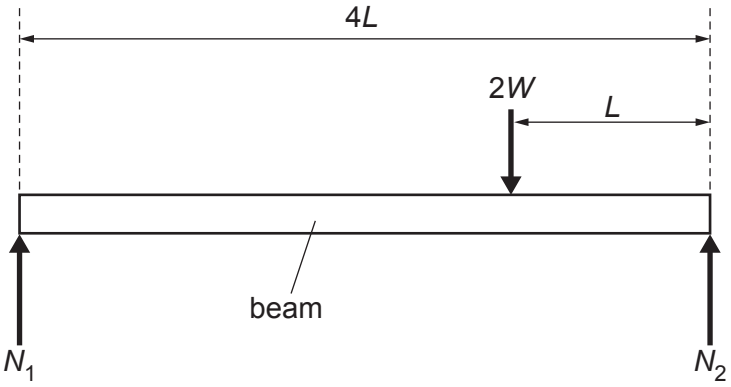
C 70

D 89

Your answer ☐ **[1]**

6 A horizontal uniform beam of length 4*L* and weight *W* is supported at both ends.

An object weighing 2*W* is placed on the beam at a distance *L* from one end.



What are the magnitudes of the normal reactions N_1 and N_2 on the supports at the ends of the beam?

A $N_1 = 0.5W$, $N_2 = 1.5W$

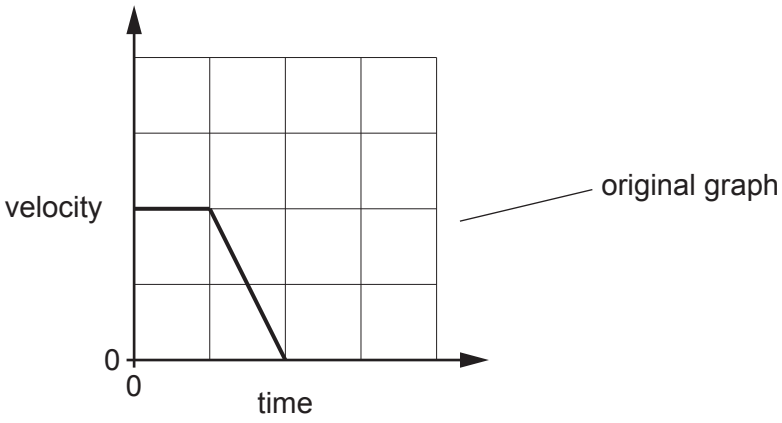
B $N_1 = W$, $N_2 = 2W$

C $N_1 = 1.5W$, $N_2 = 1.5W$

D $N_1 = 2W$, $N_2 = W$

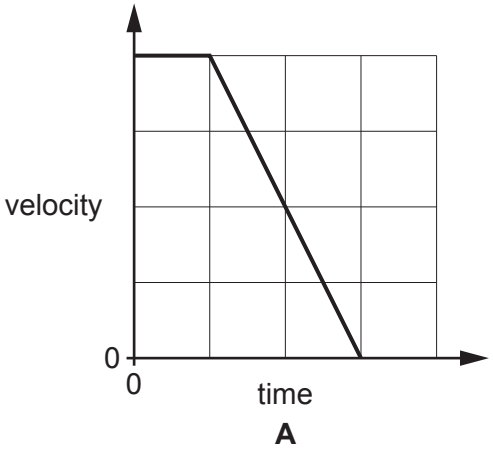
Your answer ☐ **[1]**

7 The graph shows a velocity-time graph for a vehicle. At time $t = 0$ the driver observes an obstruction in the road. A short time later the brakes are applied, and the vehicle stops. The braking force remains constant.

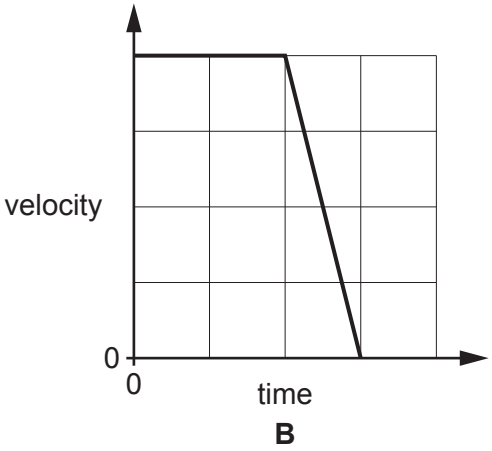


The situation is repeated. This time the vehicle starts with twice the original velocity. All other variables remain the same.

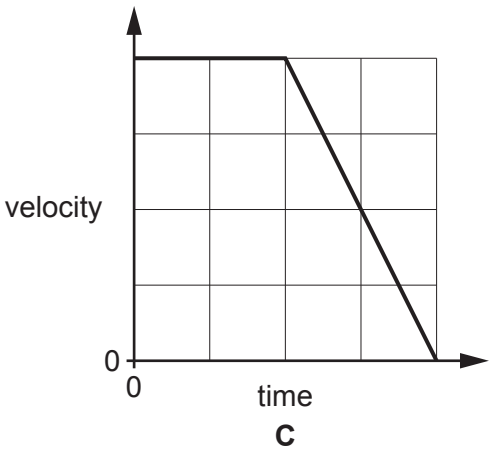
Which diagram shows the correct velocity-time graph for this new situation? The same scales are used on all graphs.



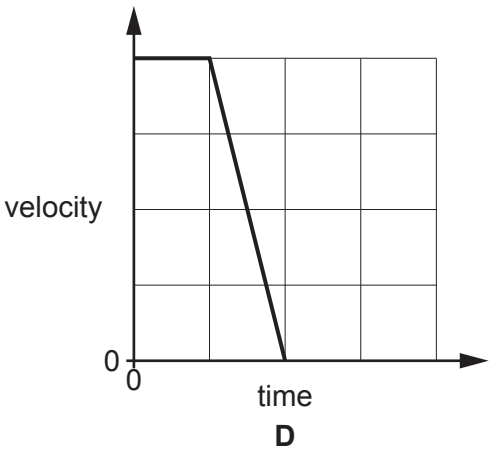
A



B



C

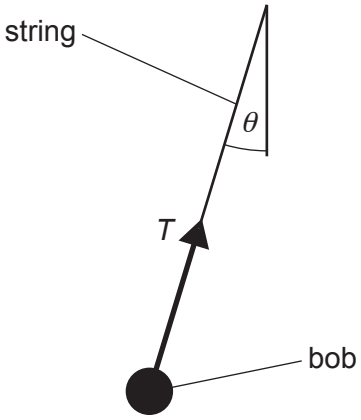


D

Your answer ☐ **[1]**

8 The bob of a pendulum is displaced slightly so that the string forms a small angle $\theta < 10°$ with the vertical.

The tension in the string is T. The small angle approximation applies.



Which of the following pairs of quantities would give approximately, within 2 significant figures, the same value for the horizontal component of T?

1 $T\cos\theta$ and $T\sin\theta$

2 $T\cos\theta$ and $T\tan\theta$

3 $T\sin\theta$ and $T\tan\theta$

A 1 only

B 1 and 3

C 3 only

D 2 and 3

Your answer ☐ **[1]**

9 A mass suspended from a spring is pulled down 0.05 m from the equilibrium point and released.

It oscillates in simple harmonic motion. The frequency of the motion is 2 Hz.

At time $t = 0$ the mass passes through the equilibrium point.

What is the displacement in metres from the equilibrium point at time t?

A $0.05 \cos 2t$

B $0.05 \cos 4\pi t$

C $0.05 \sin 2t$

D $0.05 \sin 4\pi t$

Your answer [ ] **[1]**

10 The natural frequency of an oscillator vibrating in air is 20 Hz.

Which statement is correct about this oscillator?

A The natural period of the vibrating oscillator is 5.0 ms.

B The oscillator can be forced to vibrate at maximum amplitude at a frequency of about 20 Hz.

C The oscillator can be made to resonate at a frequency of about 40 Hz.

D The period of the freely vibrating oscillator gets smaller as its amplitude decreases.

Your answer [ ] **[1]**

11 A car drives over a bridge at speed v. The path of the car is part of a vertical circle of radius r. The mass of the driver is m.

At the top of the bridge the driver of the car experiences apparent weightlessness and no normal contact force from the car seat.

The acceleration of free fall is g.

Which statement is correct?

A $mg = 0$

B $v \geqslant gr$

C $v^2 \geqslant gr$

D $mv^2 \geqslant gr$

Your answer [ ] **[1]**

12 An object is released from rest and oscillates with simple harmonic motion. The maximum kinetic energy is U.

The object is stopped and the process is repeated with the initial displacement doubled.

What is the new maximum kinetic energy?

A U

B $1.4U$

C $2U$

D $4U$

Your answer ☐ **[1]**

13 An object of mass 1.0 kg is moving in a straight line at velocity $10\,m\,s^{-1}$.

It collides with an identical object also travelling at $10\,m\,s^{-1}$ in a straight line. Their initial velocities are perpendicular.

The two objects stick together.

What is the magnitude in $m\,s^{-1}$ of the new combined velocity?

A 7.1

B 10

C 14

D 20

Your answer ☐ **[1]**

14 At the surface of a planet with radius r the magnitude of the gravitational field strength is g.

What is the escape velocity from the surface of the planet?

A $\sqrt{rg}$

B $\sqrt{2g}$

C $\sqrt{2rg}$

D $2rg$

Your answer ☐ **[1]**

15 Stars rotate around the centre of their galaxy.

Observations suggest that the stars at the edges of galaxies are moving at much higher velocities than expected.

What is the name given to the current explanation for these observations?

A Chandrasekhar limit

B Dark matter

C The Cosmological principle

D Wien's displacement law

Your answer ☐ **[1]**

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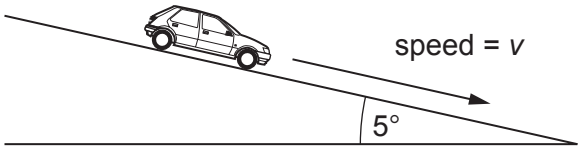
Section B

16 A car of weight 9300 N is moving at speed v. The total resistive force, F, acting against the motion of the car is given by the formula

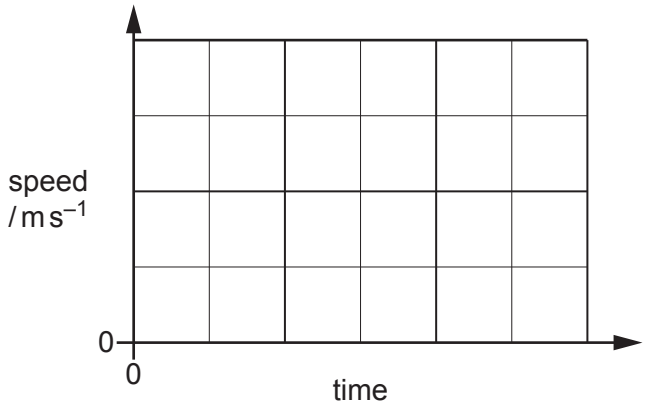
$F = kv^2$

where k is a constant.

(a) The car is allowed to roll from rest down a slope of 5° to the horizontal. The engine of the car is not switched on. The car reaches a maximum speed of 30 m s^{-1}.



(i) Sketch a graph on the axes below to show how the speed of the car changes over time. Add a suitable value to the vertical axis.



[2]

(ii) Explain why the car reaches a maximum speed.

.....

.....

..... **[2]**

(iii) Show that the value of k in the equation $F = kv^2$ is about 1.

[3]

(b) The car is now moving along a straight, level track. The engine of the car delivers a maximum power of 75 kW.

Calculate the maximum speed of the car.

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

(c) Changes are made to the engine of the car so that it can produce double the original maximum power.

Explain why the maximum speed of the modified car is **not** doubled.

.....

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..... **[2]**

17

(a) State Newton's second law of motion.

.....

..... **[1]**

(b) A model of an aircraft is being tested in a wind tunnel. The model is fixed in position by a support, and air is blown horizontally towards it by fans.

In one second, 35 kg of air moving at 50 m s^{-1} hits the model. After flowing around the model, the airflow is diverted downwards at an angle of 30° to the horizontal. The speed of the diverted airflow remains at 50 m s^{-1}.

(i) Calculate the horizontal and vertical components of the velocity of the diverted airflow.

horizontal component of velocity = ... m s^{-1}

vertical component of velocity = ... m s^{-1}

[2]

(ii) Explain how the airflow around the model produces a force on the model.

.....

.....

..... **[2]**

(iii) Calculate the **vertical** lift force *F* acting on the model due to the airflow around it.

F = ... N **[3]**

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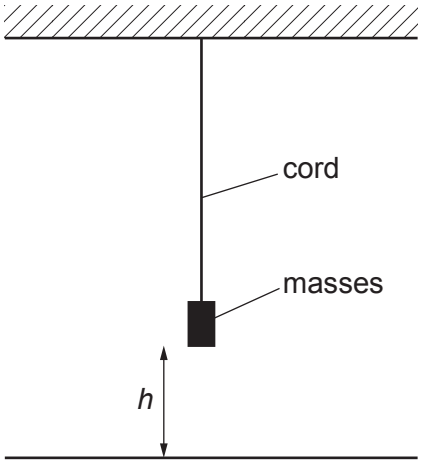
18 Mats made from rubber are often used in laboratories where heavy objects might be dropped.

A rubber cord is tested to determine the material's mechanical characteristics.

(a) The cord is suspended from a ceiling and masses can be attached to the free end.

The apparatus is set up as shown in **Fig. 18.1**.

Fig. 18.1

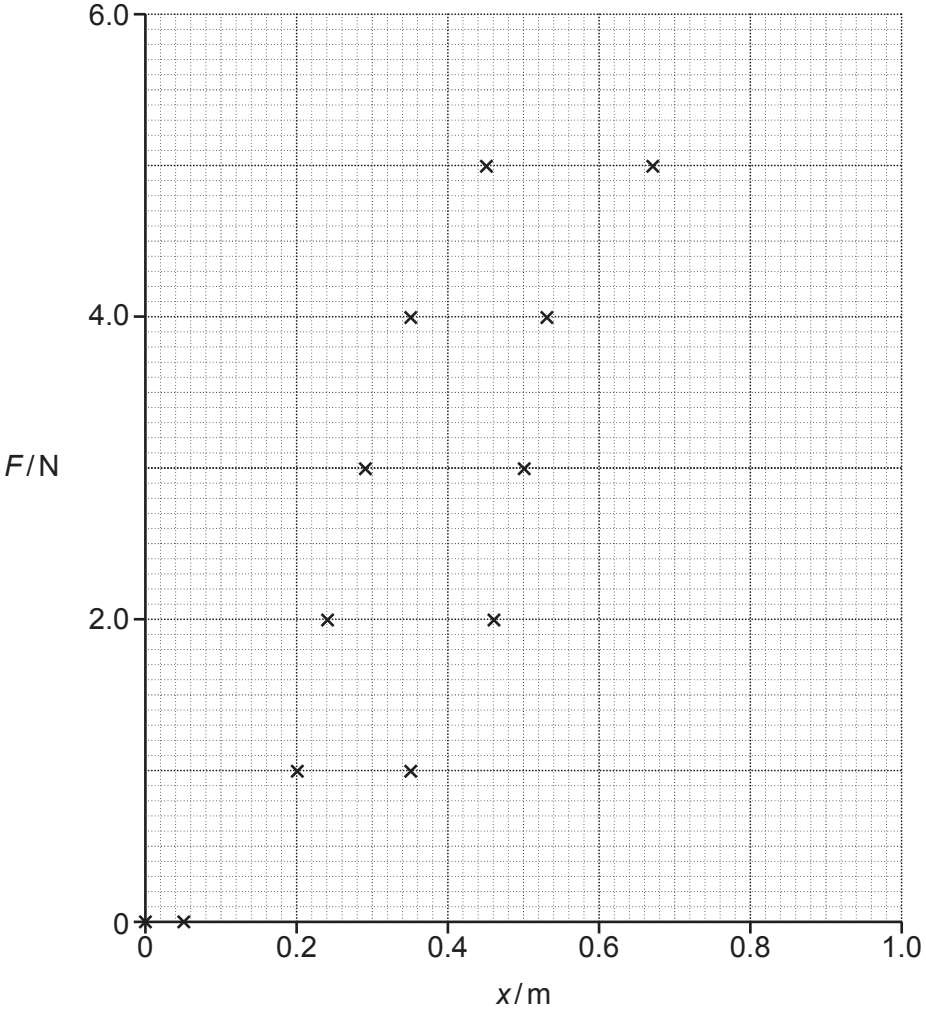


Masses are added and the height, *h*, of the base of the bottom mass from the floor is measured. The extension of the cord is *x* when the tension in the cord is *F*. After six masses have been added, they are removed one at a time and *h* measured each time.

The table shows the data collected.

***F*/N**	***h*/m**	***x*/m**
0.0	1.80	0.00
1.0	1.60	0.20
2.0	1.56	0.24
3.0	1.51	0.29
4.0	1.45	0.35
5.0	1.35	0.45
6.0	0.81	
5.0	1.13	0.67
4.0	1.37	0.53
3.0	1.30	0.50
2.0	1.34	0.46
1.0	1.45	0.35
0.0	1.75	0.05

(i) Complete the final column of the table. **[1]**



(ii) Plot the data point for $F = 6.0\,\text{N}$ on the graph above. The other points have been plotted.

Draw and label **two** curves to show the loading and unloading of the cord. **[3]**

(iii) Discuss whether Hooke's law can be applied to the cord.

.....

..... **[2]**

(iv) There is an area between the two curves that you have drawn on the graph.

1. State the **name** of the derived SI unit of this area.

..... **[1]**

2. Explain the significance of this area to the planned use of the rubber.

.....

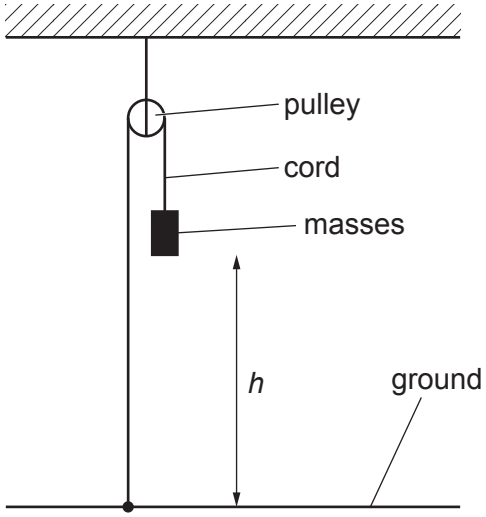
.....

..... **[2]**

(b) An alternative arrangement for the experiment is to use a pulley as shown in **Fig. 18.2**.

The arrangement makes it possible to cover a larger range of extensions.

Fig. 18.2



The cord is fixed to the ground.

Describe **two** factors that would affect the accuracy of the results obtained using this alternative arrangement.

1 .....

.....

2 .....

.....

[2]

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19* Describe how to determine the wavelength λ of a monochromatic laser pointer using a diffraction grating.

As part of your answer, explain how to

- analyse the measurements collected using a graphical method.
- improve the accuracy of the measurements taken.

You are given the number of lines per mm for the diffraction grating.

[6]

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20

(a)

(i) Define the internal energy of an ideal gas.

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..... **[1]**

(ii) Use the formulae below to show that the average kinetic energy of a particle of an ideal gas is directly proportional to the absolute temperature of the gas.

$pV = \frac{1}{3}Nm\overline{c^2}$ $\quad pV = NkT$

[2]

(b) The velocities of four gas particles at 290 K are given below in $m\,s^{-1}$.

310 370 440 550

(i) Show that the root-mean-square (r.m.s.) speed of the sample is about $430\,m\,s^{-1}$.

[2]

(ii) Calculate the molar mass of the gas assuming an absolute temperature of 290 K and r.m.s. speed of $430\,m\,s^{-1}$.

molar mass = ... $kg\,mol^{-1}$ **[3]**

(c) Spherical filament lamps are manufactured by a process where they are filled with a gas at 290 K and low pressure.

When the filament lamp is switched on, the filament reaches a constant temperature of 2400 K. At this temperature, the pressure inside the filament lamp is 120 kPa.

(i) Explain, in terms of energy transfers, why the temperature of the filament does **not** increase beyond 2400 K. You are **not** expected to refer to the electrical characteristics of the filament lamp.

.....

.....

.....

.....

..... **[3]**

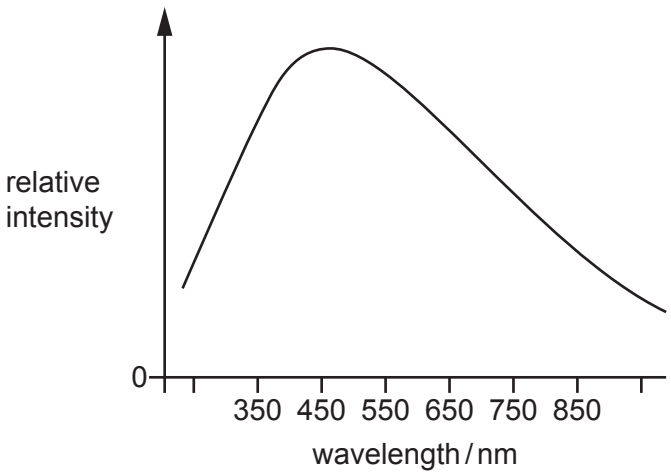
(ii) Calculate the pressure of the gas within the filament lamp during manufacture.

pressure = ... kPa **[2]**

21 This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy.

Fig. 21.1 shows the relative intensities of different wavelengths of electromagnetic radiation from Nu Persei.

Fig. 21.1



The surface temperature of the Sun is 5800 K and its wavelength at which maximum intensity is emitted is 500 nm.

The luminosity of Nu Persei is 2.3×10^{29} W.

(a)

(i) Use **Fig. 21.1** to show that the surface temperature of Nu Persei is about 6300 K.

[2]

(ii) Estimate the radius of Nu Persei.

radius = ... m **[3]**

(b) Electromagnetic radiation is collected from Nu Persei by a sensor with an efficiency of 11% and cross-sectional area $1.0 \times 10^{-4}\,m^2$.

The radiant power collected by the sensor is $7.0 \times 10^{-15}\,W$.

(i) Show that the radiant power per unit area arriving at the sensor is about $6 \times 10^{-10}\,W\,m^{-2}$.

[2]

(ii) By the time the electromagnetic radiation from Nu Persei reaches Earth, the radiation from Nu Persei is evenly distributed over a spherical area with radius equal to the distance between Nu Persei and Earth.

Calculate the distance of Nu Persei from Earth in light years.

distance = ... light years **[4]**

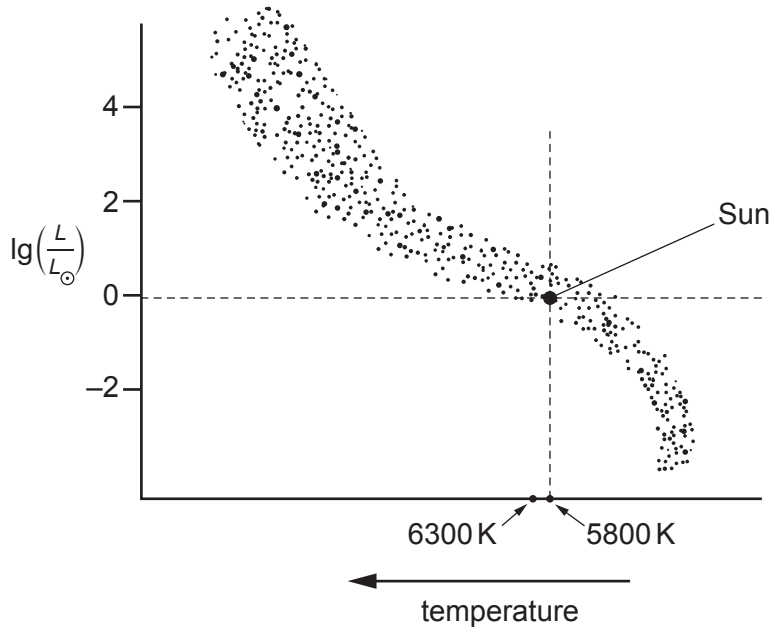
(c) The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. L is the luminosity of a star and $L_\odot$ is the luminosity of the Sun.

The temperature data from earlier in this question is repeated in the table below.

Star	Surface temperature / K
Sun	5800
Nu Persei	6300

Comment on the uncertainty in your value, calculated in **b(ii)**, of the distance of Nu Persei from Earth. You may write on the diagram as part of your answer.

Fig. 21.2



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..... **[3]**

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22

(a) A satellite in a geostationary orbit around the Earth appears to remain at the same point in the sky when viewed from the ground.

(i) State **one** condition required for an orbit to be geostationary.

.....

..... **[1]**

(ii) Calculate the orbital radius of the geostationary satellite. The mass of the Earth is 6.0×10^{24} kg.

orbital radius = ... m **[3]**

(b) A satellite of mass m is in a circular orbit around a planet of mass M. The radius of the orbit from the centre of the planet is r.

The gravitational potential V_g at a point a distance r from the centre of the planet is given by the equation

$$V_g = -\frac{GM}{r}.$$

(i) By considering the cause of the centripetal force on the satellite, show that the kinetic energy of the satellite is equal to half the magnitude of its gravitational potential energy.

[2]

(ii) A tiny satellite of mass 1.0 kg is to be launched from rest from the surface of the Earth into a low Earth orbit. The gravitational potential at any point in this orbit is $-56\,MJ\,kg^{-1}$.

The value of the gravitational potential at the Earth's surface is $-63\,MJ\,kg^{-1}$.

Show that the satellite must gain more than 30 MJ of **total** energy to achieve and remain in orbit.

[2]

(c)* Large satellites are often launched by rockets from sites near the equator. The rotation of the Earth increases the initial kinetic energy of the rocket and satellite.

A new strategy is to launch using a smaller rocket from a high flying aircraft.

Using the information in **(b)(ii)** and the data below, evaluate the advantages and limitations of this strategy. Use calculations to support your evaluation.

Rotational speed at the equator	$460\,m\,s^{-1}$

Typical aircraft operating altitude	10,000 m
Aircraft cruise velocity (relative to the ground)	$230\,m\,s^{-1}$

[6]

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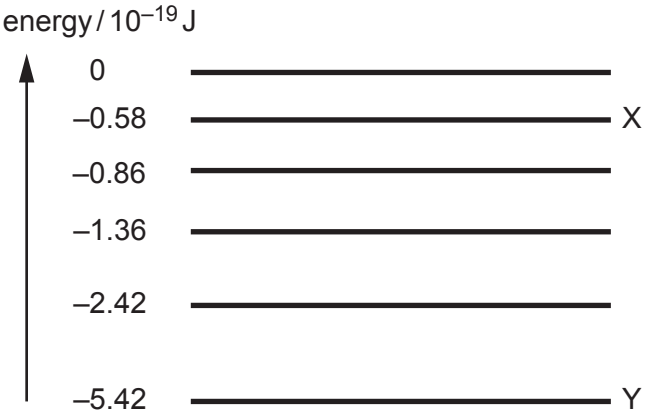
23 The diagram shows some of the energy levels of the electron in a hydrogen atom.



(a) An electron moves from energy level X to energy level Y.

Show that the wavelength of the photon produced is about 410 nm.

[2]

(b) The light from the stars in a distant galaxy is analysed on the Earth using a diffraction grating.

Dark lines are observed in the spectrum.

An astronomer concludes that the dark line at a wavelength 432 nm corresponds to the electron transition between X and Y.

(i) Explain the origin of the dark lines.

.....

.....

.....

..... **[2]**

(ii) Calculate the recession velocity v of the galaxy.

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

(iii) State the name of the theory that is supported by evidence from the measurement of the recession velocities of galaxies in the universe.

..... **[1]**

END OF QUESTION PAPER

EXTRA ANSWER SPACE

If you need extra space use this lined page. You must write the question numbers clearly in the margin.

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 set of prefixes **A**, **B**, **C** or **D** are in order of **increasing** magnitude?

A micro, milli, centi, kilo

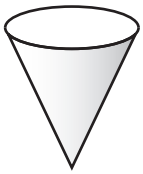
B milli, centi, micro, kilo

C kilo, centi, milli, micro

D centi, micro, milli, kilo

Your answer ☐ **[1]**

2 A paper cone is held above the ground and dropped. It falls vertically and reaches terminal velocity before it hits the ground.



Which statement correctly describes the **resultant** force on the falling cone before it reaches terminal velocity?

A decreasing and upwards

B decreasing and downwards

C increasing and downwards

D increasing and upwards

Your answer ☐ **[1]**

3 A solid cylindrical glass rod has length 20.0 ± 0.1 cm and diameter 5.00 ± 0.01 mm.

What is the percentage uncertainty in the calculated volume of this rod?

A 0.1%

B 0.2%

C 0.7%

D 0.9%

Your answer ☐ **[1]**

4 A simple harmonic oscillator has maximum speed 24 m s^{-1} and amplitude 5.6 cm.

What is its angular frequency?

A 0.23 rad s^{-1}

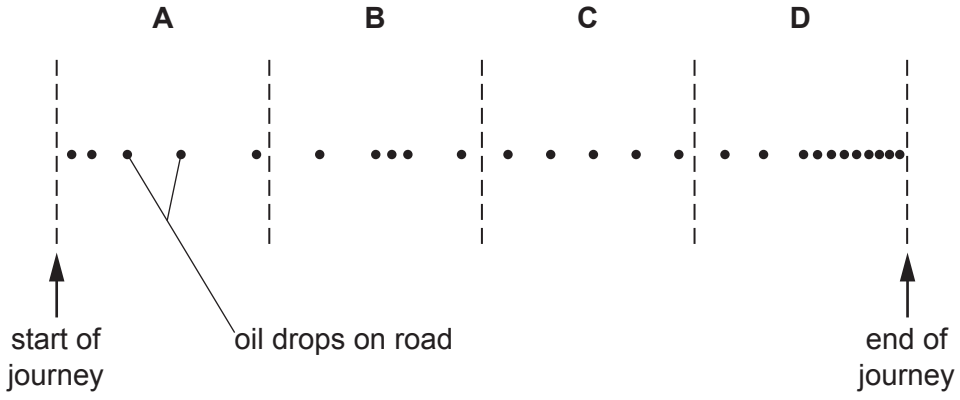
B 21 rad s^{-1}

C 68 rad s^{-1}

D 430 rad s^{-1}

Your answer ☐ **[1]**

5 A car is dripping oil at a steady rate on a straight road.
The road is divided into four sections **A**, **B**, **C**, and **D**.



Which section of the road shows the car travelling at a constant speed?

Your answer ☐ **[1]**

6 The Earth is surrounded by a gravitational field.

Which of the following statements is/are correct about the gravitational field lines near the **surface** of the Earth.

1 They are parallel.
2 They show the direction of the force on a small mass.
3 They are equally spaced.

A Only 1

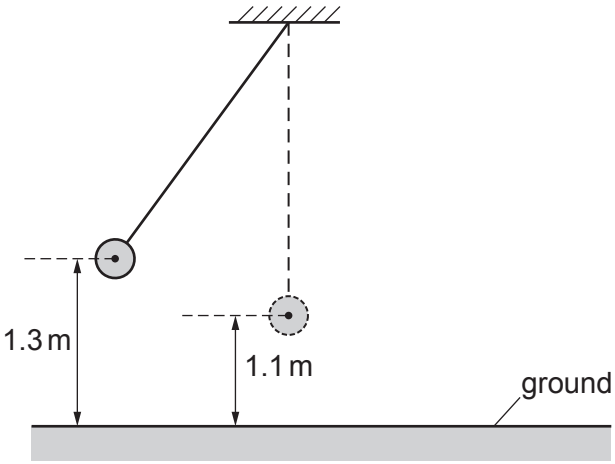
B Only 1 and 2

C Only 2 and 3

D 1, 2 and 3

Your answer ☐ **[1]**

7 A pendulum bob is oscillating in a vacuum.
The maximum height of the bob from the ground is 1.3 m and its minimum height is 1.1 m.



What is the maximum speed of the pendulum bob?

A $2.0\,m\,s^{-1}$

B $3.9\,m\,s^{-1}$

C $5.1\,m\,s^{-1}$

D $26\,m\,s^{-1}$

Your answer ☐ **[1]**

8 An object is falling.
The weight of the object is 4.5 N.
The wind provides a horizontal force of magnitude *F* on the object.
The **resultant** force on the object is 5.8 N.
Air resistance and upthrust on the object are negligible.

What is the value of *F*?

A 1.3 N

B 3.7 N

C 7.3 N

D 13 N

Your answer ☐ **[1]**

9 A solid molecular substance is supplied with energy and it starts to melt.

Which of the following pairs of quantities remains the same as the substance melts?

A Kinetic energy of molecules and internal energy of molecules.

B Potential energy of molecules and internal energy of molecules.

C Kinetic energy of molecules and temperature of substance.

D Potential energy of molecules and temperature of substance.

Your answer ☐ **[1]**

10 Which of the following shows the correct base units for pressure?

A $kg\,m^{-2}$

B $kg\,m^{-2}\,s^{-2}$

C $kg\,m^{-1}\,s^{-2}$

D $kg\,m^{2}\,s^{-3}$

Your answer ☐ **[1]**

11 A student has collected some data on the Solar System.
The student plots a graph, but only two data points are shown below.

The distance from the centre of the Sun is *r*.

Which quantity *y* is represented on the vertical axis?

A Speed of a planet.

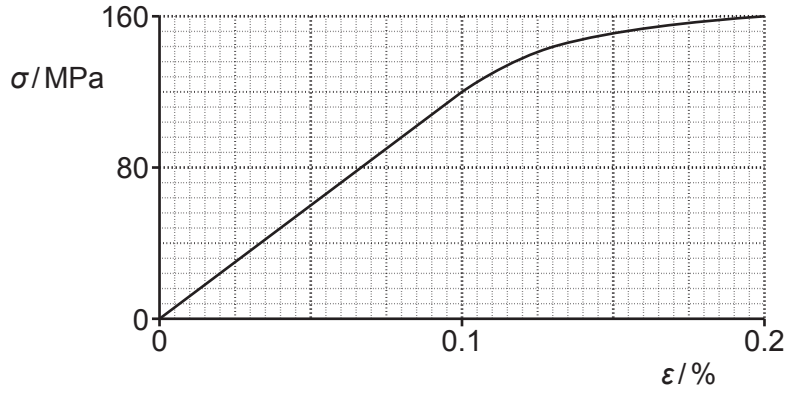
B Period of a planet.

C Gravitational potential of the Sun.

D Gravitational field strength of the Sun.

Your answer ☐ **[1]**

12 A graph showing the variation of the stress σ with strain ε for a material is shown below.



What is the Young modulus of the material?

A 6.0×10^4 Pa

B 1.2×10^9 Pa

C 8.0×10^{10} Pa

D 1.2×10^{11} Pa

Your answer ☐ **[1]**

13 Which column **A**, **B**, **C** or **D**, shows the correct sequence for the evolution of the Universe between the Big Bang and the formation of stars?

A	**B**	**C**	**D**
Universe starts to expand ↓ quarks and leptons form ↓ hadrons form ↓ nuclei form ↓ atoms form	Universe starts to expand ↓ hadrons form ↓ quarks and leptons form ↓ nuclei form ↓ atoms form	quarks and leptons form ↓ nuclei form ↓ Universe starts to expand ↓ atoms form ↓ hadrons form	quarks and leptons form ↓ hadrons form ↓ Universe starts to expand ↓ nuclei form ↓ atoms form

Your answer ☐ **[1]**

14 Some stars will evolve into white dwarfs.
The mass of the Sun is 2.0×10^{30} kg.

Which of the following **cannot** be the mass of a white dwarf?

A 1.2×10^{30} kg

B 2.0×10^{30} kg

C 2.7×10^{30} kg

D 3.2×10^{30} kg

Your answer ☐ **[1]**

15 An astronomer analyses the light from a distant galaxy.
One of the spectral lines in the spectrum observed from the galaxy has wavelength 610 nm.
The same spectral line has a wavelength of 590 nm when measured in the laboratory.

What is the speed of this galaxy?

A $9.8 \times 10^{6}\,\text{m s}^{-1}$

B $1.0 \times 10^{7}\,\text{m s}^{-1}$

C $2.9 \times 10^{8}\,\text{m s}^{-1}$

D $3.0 \times 10^{8}\,\text{m s}^{-1}$

Your answer ☐ **[1]**

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Question 16 begins on page 10

SECTION B

Answer **all** the questions.

16 (a) Explain what is meant by the **ultimate tensile strength** of a material.

.....

..... **[1]**

(b) A footbridge is supported by a number of metal cables of the same length.
Each cable has uniform cross-section and diameter 4.20 mm as shown in Fig. 16.1.

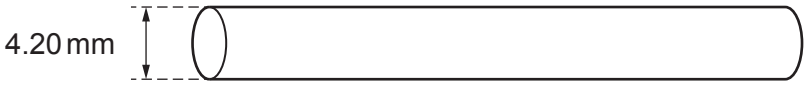

Fig. 16.1 (not to scale)

A group of engineers investigate how the extension x varies with applied force F for one of the cables.

The results of the investigation are shown in Fig. 16.2.

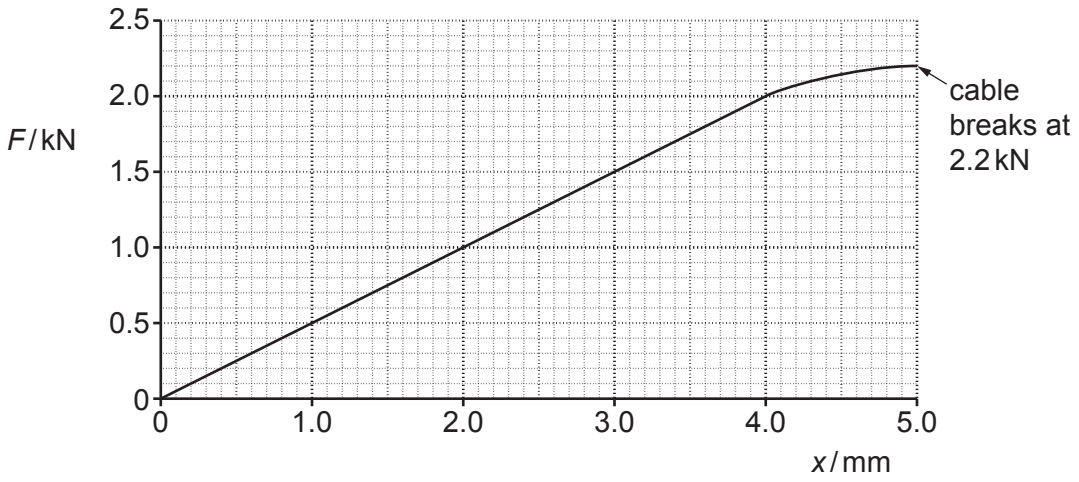

Fig. 16.2

The cable breaks when the force is 2.2 kN.

(i) Describe how a suitable measuring device may have been used by the engineers to demonstrate that the cable had uniform cross-section.

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..... **[2]**

(ii) State any value of F when the cable behaves

1. elastically

F = ... kN

2. plastically.

F = ... kN
[2]

(iii) Use Fig. 16.2 to determine the force constant k in $\mathrm{N\,m^{-1}}$ of the cable.

k = ... $\mathrm{N\,m^{-1}}$ **[2]**

(c) Determine the breaking stress σ of the cable.
Assume that the cross-sectional area of the cable remains constant during the test.

σ = ... Pa **[2]**

(d) Explain why the work done on the cable when its extension changes from 3.0 mm to 4.0 mm is greater than when its extension changes from 1.0 mm to 2.0 mm.

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..... **[2]**

17 A student uses a motion-sensor connected to a laptop to investigate the motion of a hollow ball of mass 1.2×10^{-2} kg falling through air.

The ball is dropped from rest. It reaches terminal velocity before it reaches the ground.

The upthrust on the ball is negligible.

Fig. 17 shows the variation with time t of the velocity v of the ball as it falls towards the ground.

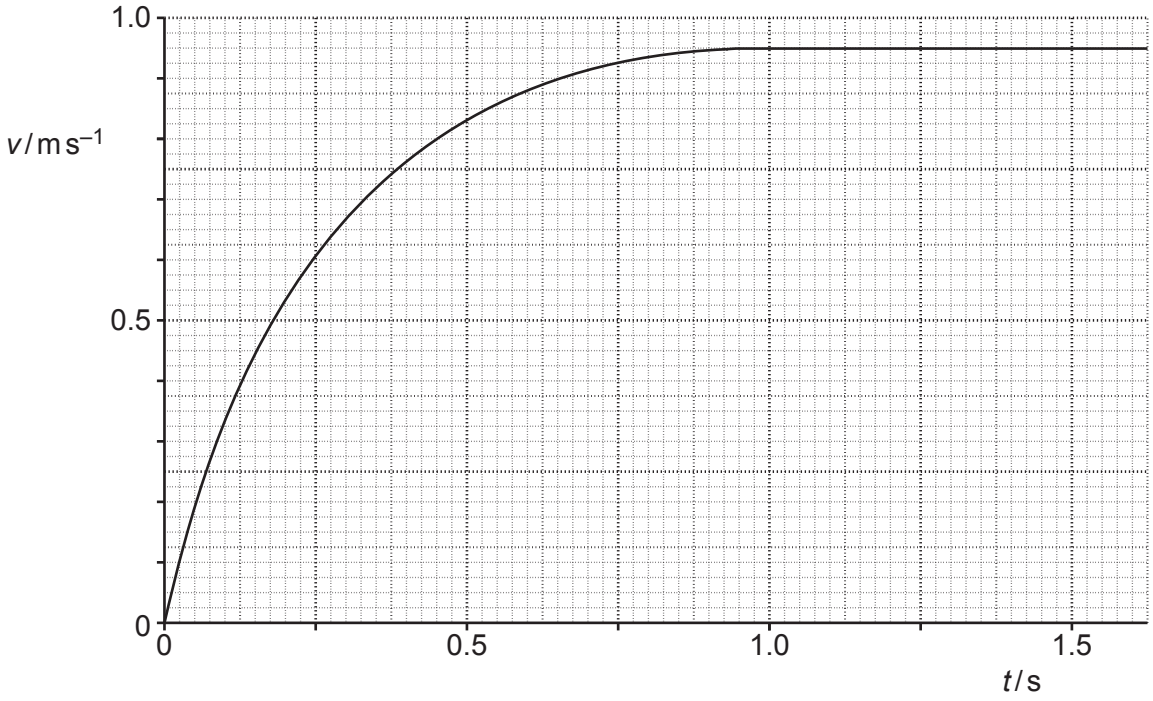

Fig. 17

(a) Draw a tangent to the curve at $t = 0.25$ s and determine the acceleration of the ball.

acceleration = ... $m\,s^{-2}$ **[3]**

(b) Calculate the resultant force F acting on the ball at $t = 0.25\,\text{s}$.

$F =$ ..... N **[1]**

(c) Use your answer in **(b)** to calculate the drag on the ball at time $t = 0.25\,\text{s}$.

drag = ... N **[3]**

(d) The student now adds a small amount of sand inside the hollow ball.
As before, the ball is dropped from rest and it also reaches terminal velocity before it reaches the ground.

(i) Describe how the forces acting on the sand-filled ball at $v = 0.50\,\text{m s}^{-1}$ compare with the forces acting on the hollow ball at this speed.

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..... **[2]**

(ii) Explain why the terminal velocity of the sand-filled ball will be greater than the terminal velocity of the hollow ball.

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..... **[2]**

18 A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

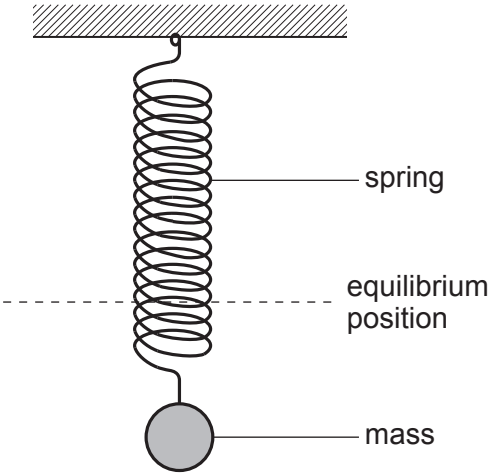

Fig. 18.1

At time $t = 6.5\,\text{s}$ the magnitude of the acceleration a of the mass is $3.6\,\text{m s}^{-2}$ and its displacement x is $4.6 \times 10^{-2}\,\text{m}$.

(a) (i) Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz.

[3]

(ii) Calculate the amplitude *A* of the oscillations.

A = ... m **[2]**

(b) The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

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..... **[4]**

Question 18 continues on page 16

(c) Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

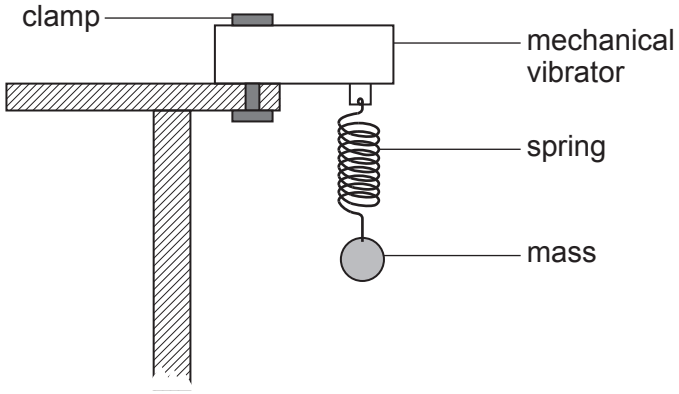

Fig. 18.2

The mass oscillates in air.

(i) The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

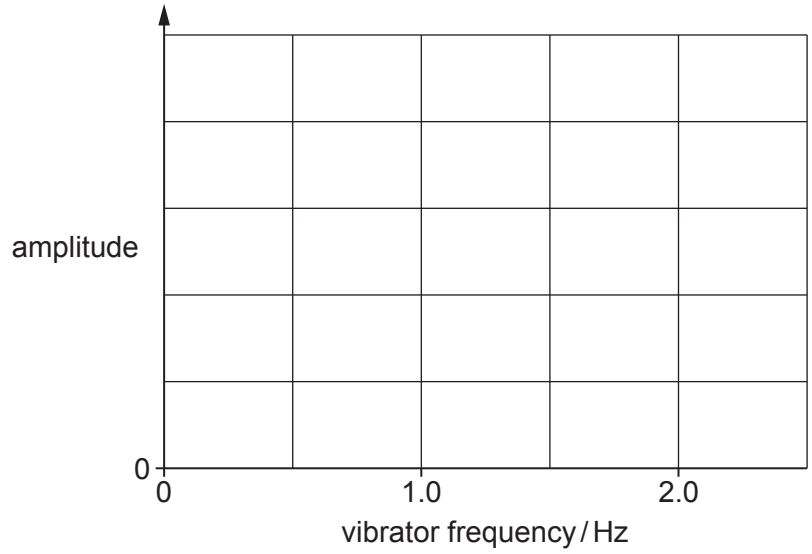

Fig. 18.3

[2]

(ii) A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**. **[1]**

(iii) Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

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..... **[2]**

19 (a) A car is travelling along a straight road at $18\,m\,s^{-1}$.
The driver sees an obstacle and after 0.50 s applies the brakes.
The **stopping** distance of the car is 38 m.

Calculate the magnitude of the deceleration of the car when the brakes are applied.

deceleration = ... $m\,s^{-2}$ **[3]**

(b)* A student rolls a marble at different speeds on a carpet to model the braking of a car.

The student wishes to investigate how the total distance x travelled before the marble stops (braking distance) depends on its initial speed v.

The speed v and distance x are related by the equation $\frac{1}{2}mv^2 = Fx$ where m is the mass of the marble and F is the constant frictional force acting on the marble.

- Describe how an experiment can be conducted in the laboratory to investigate the relationship between v and x.
- Explain how the data can be analysed to determine F. **[6]**

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Additional answer space if required.

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20 A bicycle manufacturer carries out tests on the braking system of their new model.
A cyclist on this new bicycle travels at a constant initial speed U.
The cyclist applies the brakes at time $t = 0$ and the bicycle comes to a stop at time $t = 2.0\,s$.

Fig. 20.1 shows the variation of the braking force F on the bicycle with time t.

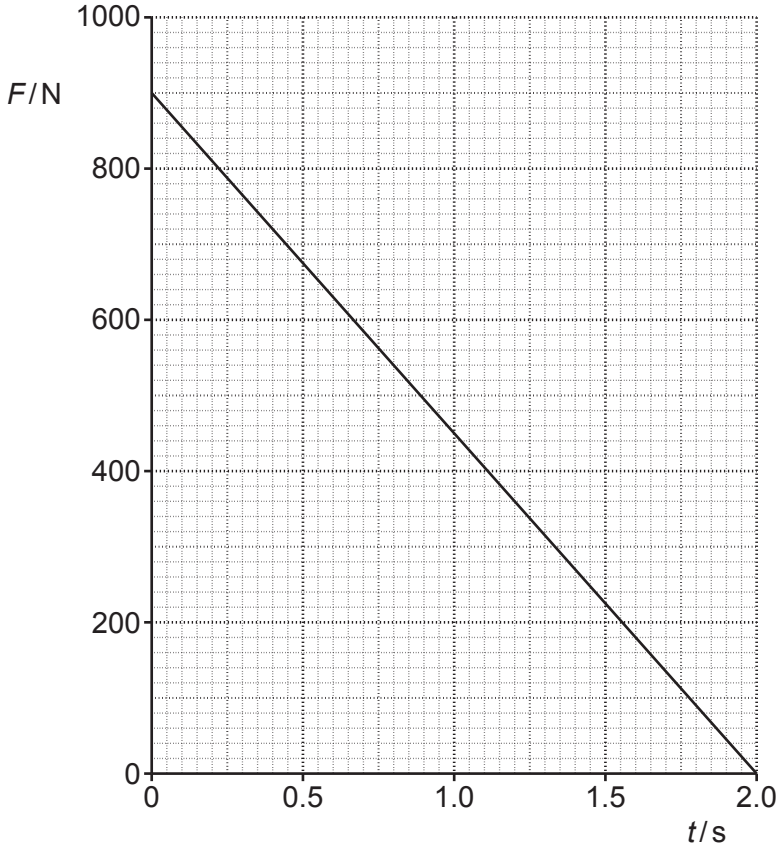

Fig. 20.1

(a) Use Newton's second law of motion to explain the physical quantity represented by the area under the graph shown in Fig. 20.1.

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..... **[2]**

(b) The total mass of cyclist and bicycle is 71 kg.

Use Fig. 20.1 to calculate the initial speed U.

U = ... $m\,s^{-1}$ **[2]**

(c) Complete Fig. 20.2 to show the variation of the speed of the bicycle from $t = 0$ to $t = 2.0$ s.

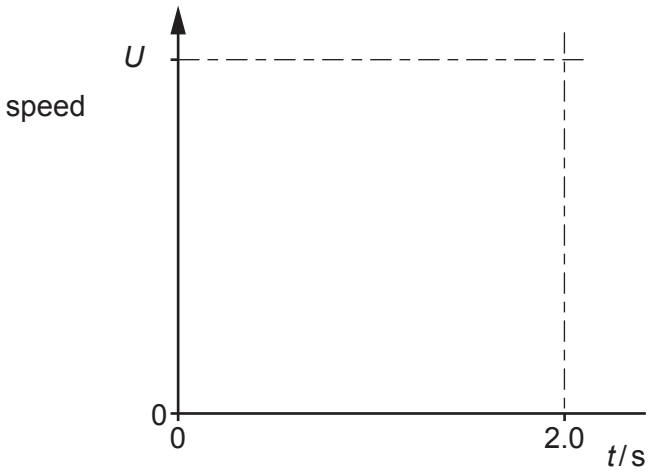

Fig. 20.2

[2]

21 A substance can exist as a crystalline solid, a liquid or a gas.
A solid sample of the substance is placed in a sealed container and heated at a constant rate until it changes into a gas.

Fig. 21 shows the variation with time t of the temperature θ for the substance.

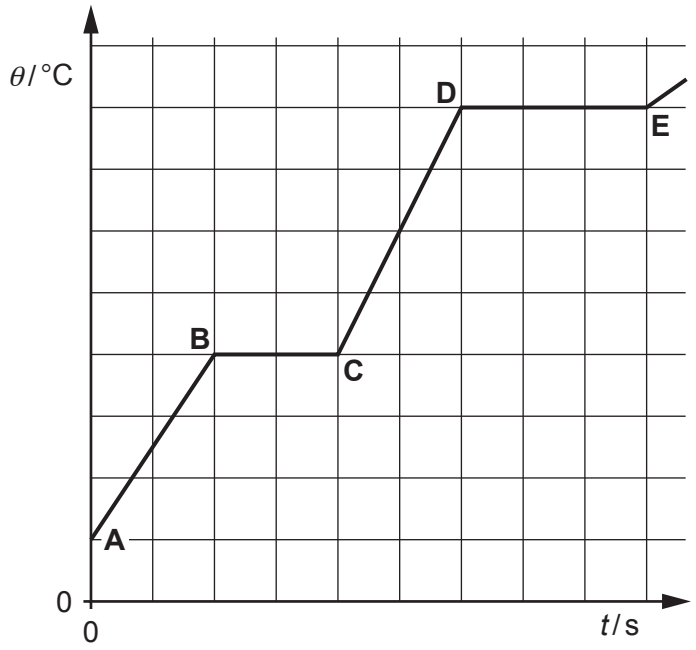

Fig. 21

(a) Use the kinetic theory of matter to describe the solid phase (section **AB**) and the liquid phase (section **CD**) in terms of the motion and arrangement of the molecules of the substance.

Section **AB**: .....

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Section **CD**: .....

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[4]

(b) Use Fig. 21 to explain how the specific heat capacity of the liquid compares with the specific heat capacity of the solid.

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..... **[2]**

(c) State what is meant by the **internal energy** of the substance.

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..... **[1]**

(d) Beyond the point **E** in Fig. 21, the substance behaves as an ideal gas.

(i) The mass of a gas molecule is 4.8×10^{-26} kg.
Calculate the root mean square speed of the gas molecules at a temperature of 250 °C.

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

(ii) Calculate the internal energy of 1.3 moles of the gas at 250 °C.

internal energy = ... J **[3]**

22 A screw is used to hang a wooden sign on a wall. It is screwed into the wall using a screwdriver.

(a) The width of the screwdriver blade is 5.0×10^{-3} m from end to end.
The ends of the blade exert equal and opposite forces on the screw.
The magnitude of each force is 350 N, as shown in Fig. 22.1.

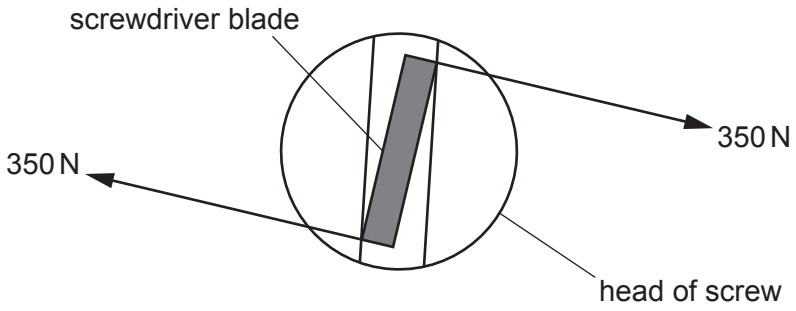

Fig. 22.1

Calculate the magnitude of the torque of the couple produced by the forces at each end of the screwdriver blade.

torque = ... N m **[1]**

(b) The wooden sign is then hung on the screw at point **A**.
The forces acting on the screw are shown in Fig. 22.2.

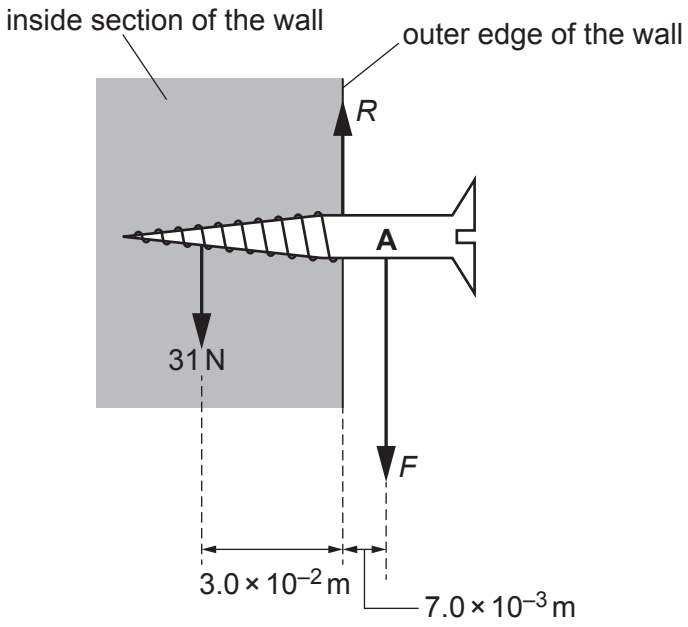

Fig. 22.2

The inside section of the wall exerts a maximum downwards force of 31 N at a distance of 3.0×10^{-2} m from the outer edge of the wall.
The hanging wooden sign exerts a force *F* at a distance 7.0×10^{-3} m from the outer edge of the wall.
There is a force *R* acting on the screw at the outer edge of the wall.
The mass of the screw is negligible.

Use the principle of moments to calculate the maximum mass of the wooden sign.

mass = ... kg **[3]**

23 (a)* In 2017, an ultra-cool star TRAPPIST-1 was discovered with at least five of its own orbiting planets. Astronomers are interested about the possibility of finding life on some of the planets orbiting TRAPPIST-1.

The table below shows some data.

	TRAPPIST-1	**Sun**
Luminosity *L* / W	2.0×10^{23}	3.8×10^{26}
Surface temperature *T* / K	2500	5800
Radius of star / m	*R*	7.0×10^{8}
Distance between Earth and Sun / m		1.5×10^{11}
Distance between planets and TRAPPIST-1 / m	1.6×10^{9} to 9.0×10^{9}	

The temperature *T* in kelvin of a planet, its distance *d* from the star and the luminosity *L* of the star are related by the expression

$\frac{T^4 d^2}{L}$ = constant.

- The average temperature of the Earth is about 290 K. Explain how life may be possible on some of the planets orbiting TRAPPIST-1.
- Use your knowledge of luminosity to show that the radius *R* of TRAPPIST-1 is smaller than the Sun.
- Support your answers by calculations. **[6]**

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Question 23 continues on page 28

(b) Kepler's third law can be applied to a satellite in a geostationary orbit around the Earth.

(i) Complete the equation for Kepler's third law below.
You do not need to define any of the terms.

$$\text{.....} = \frac{4\pi^2}{GM} \text{.....}$$

[1]

(ii) The mass of Earth is 6.0×10^{24} kg.
Calculate the radius of the circular path of a satellite in a geostationary orbit around the Earth.

radius = ... m **[2]**

24 **(a)** Proxima Centauri is the closest star to Earth.
Fig. 24.1 shows the apparent positions of this star against the background of very distant stars as seen from the Earth over a period of exactly 6 months.

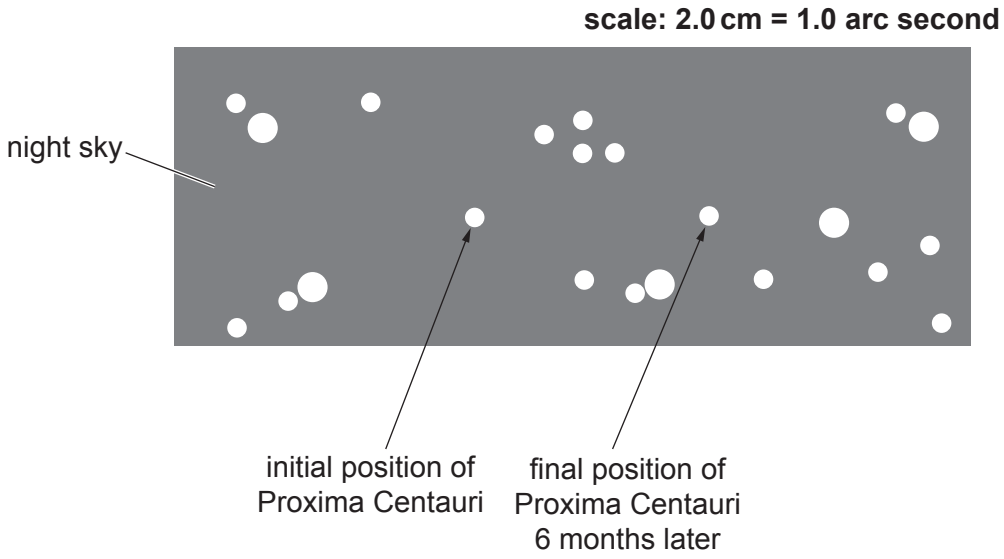

Fig. 24.1

The parallax angle for Proxima Centauri can be determined from Fig. 24.1 using the scale provided.

(i) Show that the parallax angle *p* for Proxima Centauri is about 0.8 arc second.

[2]

Question 24 continues on page 30

(ii) Use your answer in **(i)** to calculate the distance *d* of Proxima Centauri from the Earth in light-years (ly).

1 pc = 3.26 ly

d = ... ly **[2]**

(b) The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is 1.4×10^{23} m and each galaxy occupies a cube of space of volume 2.7×10^{69} m^3 as shown in Fig. 24.2.

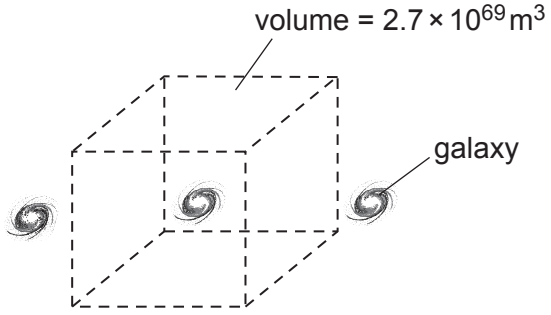

Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about 2.0×10^{30} kg.

(i) Estimate the gravitational force between two neighbouring galaxies.

force = ... N **[2]**

(ii) Show that the mean density of the Universe is about $7 \times 10^{-29}\,\text{kg}\,\text{m}^{-3}$.

[1]

(iii) Suggest why the actual mean density of the Universe is different from the value calculated in **(ii)**.

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..... **[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).