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Examiners' report

PHYSICS A

H556

For first teaching in 2015

H556/01 Summer 2022 series

Version 1

ocr.org.uk/science

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers are also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

Advance Information for Summer 2022 assessments

To support student revision, advance information was published about the focus of exams for Summer 2022 assessments. Advance information was available for most GCSE, AS and A Level subjects, Core Maths, FSMQ, and Cambridge Nationals Information Technologies. You can find more information on our website.

Paper 1 series overview

H556/01 (Modelling Physics) is one of three examination components for the A Level Physics A specification. This component focuses on:

- mechanics
- properties of matter
- thermal physics
- simple harmonic motion
- astrophysics

To do well on this paper, candidates need to be comfortable with performing both simple and multi-step calculations, describing and explaining ideas and phenomena as well as experimental techniques and data analysis.

Where candidates had extensive practical experience, this clearly allowed them to answer both planning investigations and data evaluation questions.

The style, difficulty and content of the paper were in keeping with those of previous series.

Candidates who did well on this paper generally did the following:	Candidates who did less well on this paper generally did the following:
• made their working in calculations clear • showed each step in 'show that' questions carefully • made clear which instruments would be used in investigations • explained what they would do with data taken in investigations clearly. This would often be in the form of a graph, stating what the graph would show and how the gradient and/or the y-intercept of that graph was relevant to the investigation • used the data and relationships book wisely • worked through the multiple choice questions logically having removed unlikely answers first • remembered definitions of important terms and could reproduce them correctly • performed calculator operations accurately.	• showed their thinking in a disorganised way • forgot ideas about how investigative work is performed and reported • muddled trigonometric functions • forgot some aspects of GCSE Physics, such as ideas about resultant force, experimental details regarding Hooke's Law and conservation of momentum • used the data and relationships book sparingly if at all • misread the question.

Section A overview

Candidates answered Section A questions well. In this series, very few multiple choice questions were left blank. Candidates performed very well on Questions 3, 5, 14 and 15. Candidates found Questions 6, 11 and 13 most challenging.

Question 1

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]**

Most candidates got this correct by correctly identifying mass as a scalar and force as a vector. The most likely incorrect answer was C.

Question 2

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

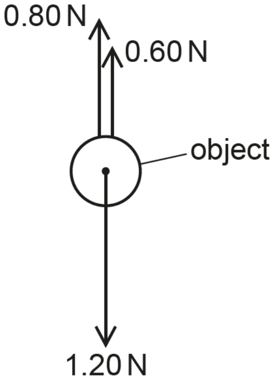
D 0.06 mm

Your answer **[1]**

The candidates who got this correct spotted that the uncertainty should be calculated by finding half of the range.

Question 4

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.

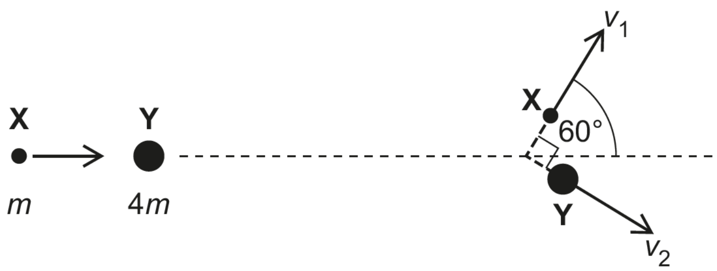
Your answer ☐ **[1]**

The first step with this question is to calculate the resultant force, which is 0.2 N upwards (eliminating option A). As the drag force is upwards, the direction of motion must be downwards (eliminating option D). Since the resultant is opposite to the direction of travel, this object must be decelerating.

Question 6

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

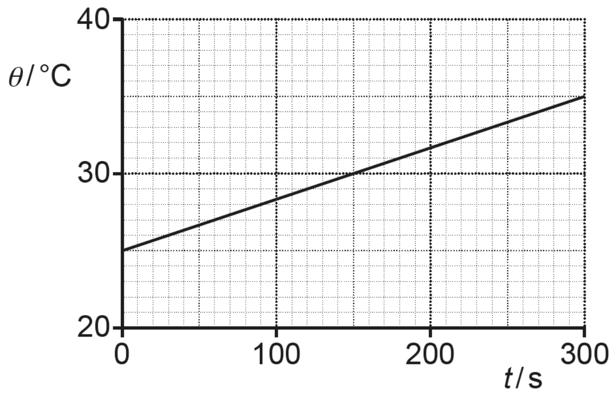
Your answer **[1]**

Candidates found this question challenging. Conservation of momentum applies both horizontally and vertically here. This means that the vertical upwards component of the momentum of X must equal the vertical downwards component of the momentum of Y. So $m\,v_1\sin(60^\circ) = 4m\,v_2\sin(30^\circ)$.

Rearranging this expression will give the correct answer of v_1 / v_2.

Question 7

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



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

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

A $c = G$

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

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

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

Your answer **[1]**

By thinking about the formula for specific heat capacity ($\Delta E = m c \Delta\theta$) and dividing both sides by Δt, the equation becomes $P = m c \Delta\theta / \Delta t$. $\Delta\theta / \Delta t$ is the equivalent to the gradient, G.

Rearranging this will give the correct answer.

Question 8

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]**

Three-quarters of all candidates could recall that statement three is not true, leaving only the first two statements to be implied by the assumption of the kinetic theory of gases.

Question 9

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 3.9×10^{-26} m^3

B 4.7×10^{-5} m^3

C 2.4×10^{-2} m^3

D 4.7×10^{-2} m^3

Your answer **[1]**

A sensible approach here is to use the equation $p = 1/3\, \rho\, \overline{c^2}$ and $\rho = M/V$ where M is the total mass of the gas. Given that there is 1.0 mole of gas, the total mass of gas is Avagadro's number multiplied by the mass of each gas particle.

By suitable rearrangement, the volume can be found.

Question 10

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]**

Most students answered this question correctly. Those that did not tended to refer to the mass at a point other than at the lowest point in its oscillations.

Question 11

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

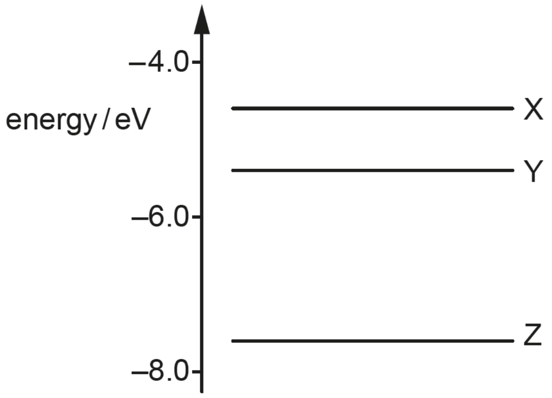
Your answer ☐ **[1]**

Most candidates suggested that angular frequency and angular velocity do not have the same or equivalent units.

The correct answer is C, because gravitational potential is measured in $J\ kg^{-1}$ and kinetic energy is measured in J.

Question 12

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



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

A Z ⟶ X

B X ⟶ Z

C Y ⟶ X

D X ⟶ Y

Your answer ☐ **[1]**

Approximately half of all candidates chose option B, possibly because they missed the idea of photon absorption in the question. The correct answer is A, because the electron is going up the energy scale.

Question 13

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]**

Candidates found this question challenging because it joins two ideas together.

The first idea is that of the Doppler effect on waves from a moving source, which will increase the wavelength received by the observer. This removes options A and B.

Once the new wavelength has been calculated, the corresponding angle should be calculated from the diffraction grating equation.

It is worth mentioning that the correct answer and the most likely incorrect answer are too close together for the candidate to merely guess.

Section B

Question 16 (a) and (b) (i – iv)

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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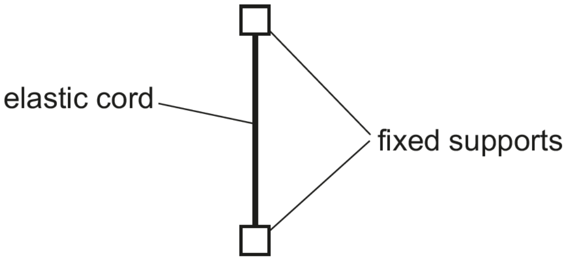
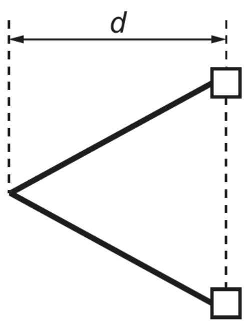
....

....

.... **[4]**

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

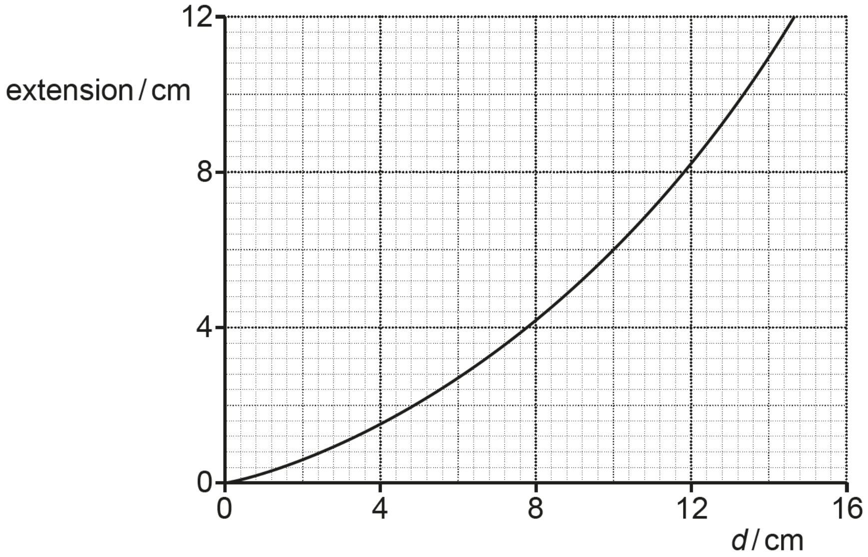




The unstretched length of the cord is the same as the distance between the supports.
The distance that the centre of the cord has been pulled back is d.

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

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



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

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

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

[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.

....

....

....

.... **[2]**

Questions 16 (a), (b) (i) and (ii) were answered very well indeed. Most candidates recalled the experimental procedure for investigating force-extension relationships well.

Question16 (b) (iii) required knowledge of independent motion. Successful candidates used the vertical motion of the object to find the time taken for it to hit the ground. After that, they used that time to find the horizontal range.

Question 16 (b) (iv) was answered well by candidates that realised the distance in real life would be less and could explain why that was the case.

Question 17 (a)

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.

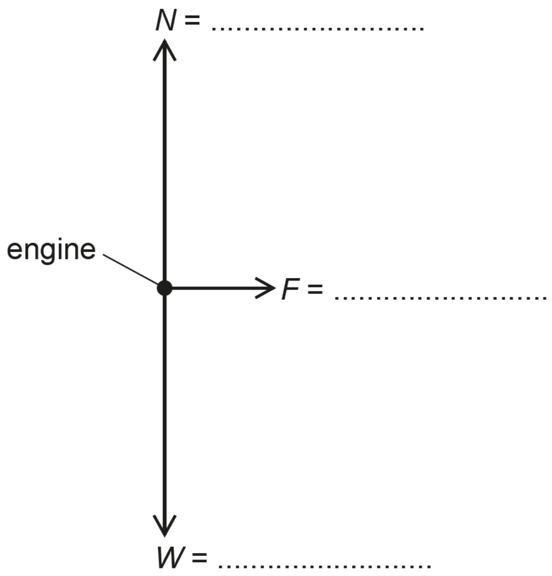
[1]

This was completed well. The mark was lost by those, generally, that did not round their answer correctly.

Question 17 (b)

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

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



[3]

This question was answered well, in part. Candidates found the weight of the engine with ease, broadly. The force *F*, being the value of the power divided by the velocity was less well calculated.

Most candidates realised that this object was in equilibrium and so that there should be a force to the left of equal magnitude to force *F*.

This is an example of a frictional force causing an acceleration. The friction force on the rails is to the left. By Newton's 3rd Law, the friction force on the engine from the rails must therefore be to the right. The force to the left is a drag force, causing equilibrium.

Question 17 (c)

(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]

Candidates employed a range of strategies to demonstrate that the engine will stop before the obstruction.

Very successful candidates often calculated the deceleration of the engine and then employed an equation of motion to work out first the braking distance and then added the thinking distance. Those candidates also added words to signpost their calculations clearly.

Question 18 (a) (i - ii)

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

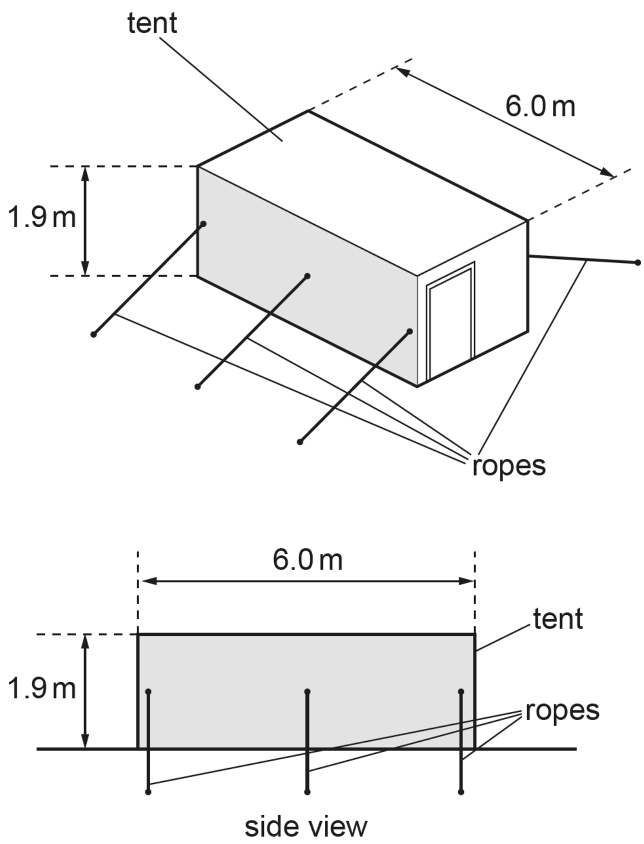


Fig. 18.1

(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**.

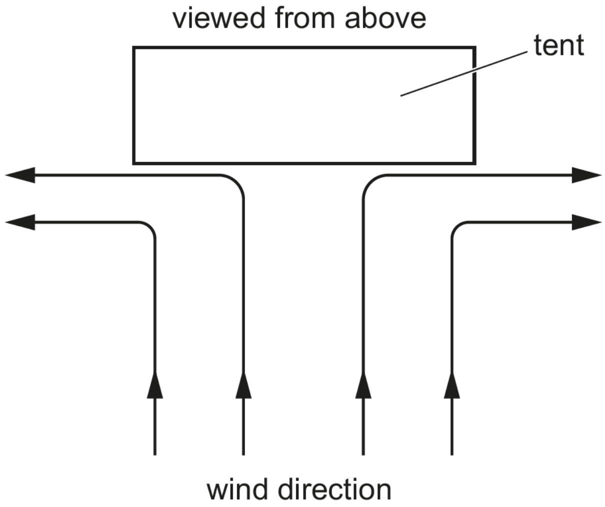


Fig. 18.2

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]**

Candidate's answers to this part were either jumbled or grounded in incorrect physics.

This question is correctly answered by thinking about a cuboid of air that is 36 m long and has a cross-sectional area equal to that of the shaded side of the tent.

That cuboid corresponds to the air that hits the tent in the three second period.

The force applied will be equal to the rate of momentum change. This means multiplying the mass of air that hits the tent by the velocity change (i.e. 12 m/s) and then dividing by the time taken for that momentum change.

Question 18 (b)*

(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]**

This question tested ideas about forces, resolution of forces, behaviour of materials under stress and rate of change of momentum transfer. Level 1 answers were restricted to merely suggestions of what could be done to make the support of the tent stronger. Level 2 answers developed at least one of those suggestions by referring, qualitatively, to the underlying physics. Level 3 answers were rare, as the requirement was for some quantitative physics. Candidates that attempted a quantitative answer often believed that the force would be doubled, when in fact it is quadrupled. This is because both the mass of the air depends on the velocity of air, so doubling the speed will also double the mass, thus quadrupling the momentum transfer.

Exemplar 1

To withstand windspeed of $40ms^{-1}$ more ropes could ~~must~~ be added. This reduces the force acting on each rope increasing the wind speed
force $\propto$ A v^2
so ~~as~~ as the maximum velocity doubles force acting on the tent quadruples.
4 times the number of ropes must be added.
~~or~~ Alternatively reduce the area of the tent that comes in contact with the wind. ~~Eg~~ ~~A~~ Reduce the ~~B~~ width or height or slant the side so the tent has less ~~of the~~ area in contact with the air. ~~The~~ At $40ms^{-1}$ wind the area must quater ~~half~~.
~~Eg~~ Alternatively ~~Addition~~ reduce the length of the rope as ~~F∝1/l~~ $\frac{E a x}{L} = F$ so $F \propto 1/L$ this will increase the force the rope can have across it before breaking.
the lengths of the rope must quater.

Additional answer space if required

~~Howev~~ ~~You~~ One could also increase the thickness of the rope as $F \propto a$. $F \propto r^2$ so the area would need to increase by a factor of 4 or the radius must double.

This candidate clearly states, on lines 3-5, that the force is directly proportional to the square of the speed by thinking about their answers to previous parts of the question.

The statements following this, after the page break, are sensible and grounded in physics in topics typically covered in the first year of study. The candidate mentions about quadrupling the number of ropes and reducing the area presented to the wind by a factor of four.

The candidate goes on, in the additional answer space, to refer to the thickness of the ropes and how the radius would need to double. Level 3 response.

Question 19 (a)

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.

....

....

....

.... **[2]**

Most candidates got at least one of the marking points here. A significant fraction correctly linked the increase in PE and the constant KE to an increase in total internal energy.

Question 19 (b) (i)

(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]

Almost all candidates could show this well, by using the ideal gas equation carefully. Those that scored less than full marks often did so because they forgot to convert the temperature from Celsius to kelvin.

Question 19 (ii)

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

molar mass of nitrogen = $0.028\,\text{kg}\,\text{mol}^{-1}$

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

Candidates consistently used their answer from the previous part of the question to calculate the mass of nitrogen gas.

Question 19 (b) (iii)

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

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

....

.... **[1]**

This question asks the candidate to rearrange the ideal gas equation and think how to reduce the value for n. If V is constant, the only two ways of reducing the expression pV/T is to either reduce the pressure or increase the temperature.

Question 19 (b) (iv)

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

L = ... $\mathrm{J\,kg^{-1}}$ **[4]**

Most candidates calculated the energy loss for either the vapour to liquid change or the liquid to ice change for the water. A minority realised that the correct approach was to add these two energy changes before dividing by the mass of the nitrogen.

Exemplar 2

gas
↓
water
↓
ice

1.3kg

$E = mL$, $E = (1.3)(3.34\times10^5)$
$= 434200\,\mathrm{J}$

$1.3 \times 2.26\times10^6 = 2938000\,\mathrm{J}$

$434200 + 2938000 = 3372200\,\mathrm{J}$

mass used in one hour = 16.8kg

$\frac{3372200}{16.8} = 200726\,\mathrm{Jkg^{-1}}$
≈ 201000

L = 2.01×10^5 $\mathrm{J\,kg^{-1}}$ **[4]**

This candidate has set out the calculation very carefully, with a diagram in the top left to help their thinking. They have calculated the energy loss required to condense the vapour to liquid water and also the energy loss required to freeze the water to ice. These calculations are done on separate lines yet one after the other.

This total energy loss must be equal to the total energy gained by the nitrogen when turning from liquid to gas.

Question 20 (a)

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.

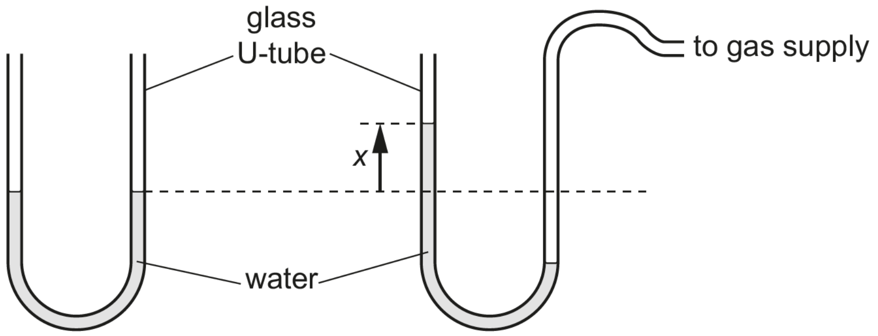
Show that this equation is homogeneous by reducing both sides to S.I. base units.

[2]

A large majority of candidates showed clearly that the units for acceleration were m s^{-2} and that the unit for angular frequency, in base units, was s^{-1}. Showing the resulting unit algebra clearly was often the only barrier to scoring both marks.

Question 20 (b) (i)

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

(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]**

Most candidates thought that the height difference here was 0.05 m, because that is the difference between the final liquid level and the undisturbed level.

The correct approach is to look at the difference between the liquid levels once the liquid has stopped moving.

Question 20 (b) (ii)

(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.

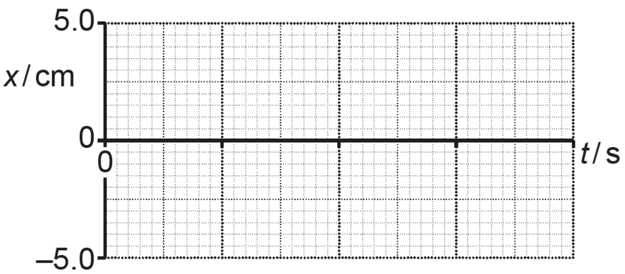
For this U-tube, $A = 1.0 \times 10^{-4}\,\text{m}^2$ and $m = 0.052\,\text{kg}$.

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.

....

....

.... **[2]**

Very few candidates made the link that the gas pressure oscillating would cause a periodic force and so this would become a resonant system. The best way to describe a resonating system in this context is that the amplitude of vibrations becomes significantly larger.

Question 21 (a)

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]**

Most candidates mentioned a word that showed they knew the collapse was to do with gravitational self-attraction.

Question 21 (b) (i)

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

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

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

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

[2]

Candidates successfully converted the radius from parsecs into metres and from there the volume of the nebula.

Question 21 (b) (ii)

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

E_k = ... J **[3]**

This brief yet multi-stage question proved relatively challenging. The correct approach here was to find the average kinetic energy of a single particle (using $E_k = 3/2\ kT$) and then multiplying this by the number of particles in the nebula. The number of particles in the nebula was found by multiplying the number density by the volume of the nebula.

Question 21 (c) (i)

(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]**

Candidates used several different approaches here. By assuming a similar density, the mass is directly proportional to the volume. Some candidates calculated the volume of the Sun's nebula. Others correctly assumed that the volume and hence mass of each nebula was directly proportional to the diameter^3 (or radius^3).

Question 21 (c) (ii)

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

Describe the eventual evolution of this star.

....

....

....

....

....

.... **[4]**

Some candidates used the ratio from the previous part of the question to assume that the star from nebula X would eventually become a white dwarf, as suggested in one of the endorsed textbooks. Others used the information in the question, i.e. that the mass of nebula X was far greater than that of the Sun. This meant they were justified in assuming that this particular star would become a supernova. Both approaches were acceptable, provided the candidate chose one route and described it correctly.

Question 22 (a)

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*.

....

....

....

.... **[2]**

As there is a choice of only two variables here, the first mark was necessarily a 'method' mark. The best answers stated that Stefan's law uses T^4 and so the percentage uncertainty in T would be 4 times more significant (as described in the practical guidance).

OCR support

Teachers and students all have access to the Practical Skills handbook which includes techniques and ideas that prove useful in answering Level of Response and other questions that check practical experience.

Question 22 (b)*

(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.

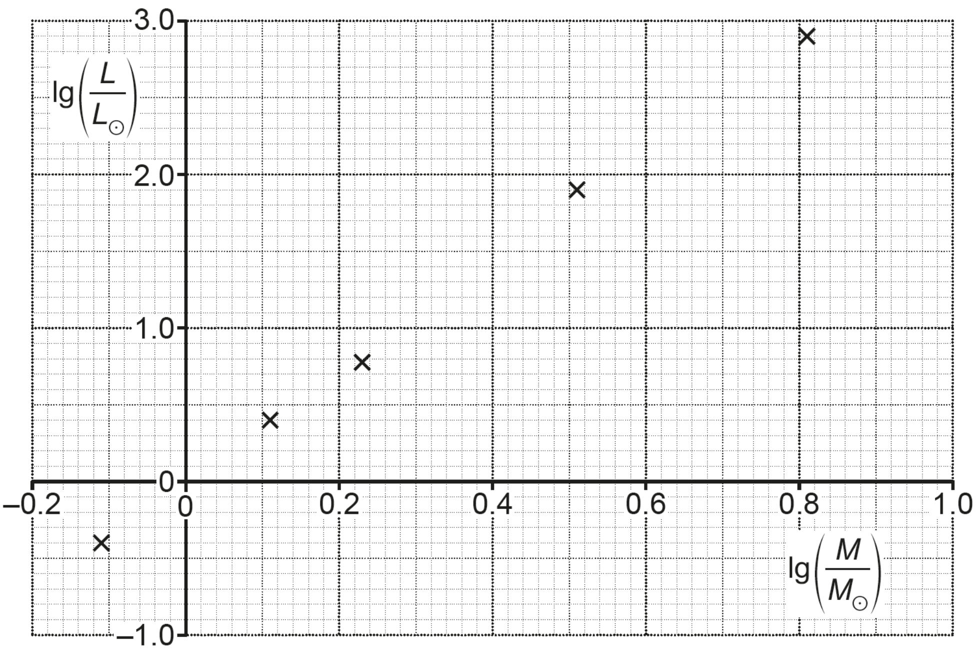


Fig. 22

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]**

This question relied on a small number of different skills. At first the candidate needed to understand how to find the constant '*b*' and be able to communicate that. Comparison with '$y = mx + c$' invariably helps with this task.

Once '*b*' was determined, most candidates didn't refer to it in the rest of their argument, limiting themselves to a Level 2 response. Instead, they talked about features of the HR diagram rather than focusing on the relevance of '*b*'. '*b*' is important because it makes it clear that a small increase in mass gives a much larger increase in luminosity. Luminosity is related to the mass loss per second so a larger luminosity means the mass of hydrogen will 'run out' far quicker in comparison to a larger star.

Question 23 (a)

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

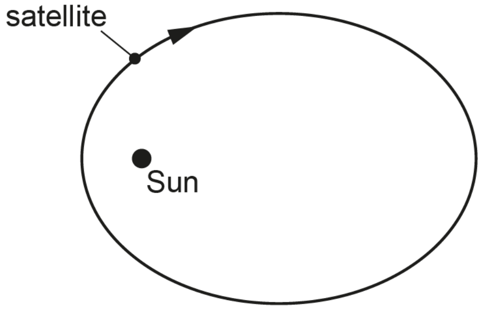
Use the equation for Newton's law of gravitation and your knowledge of circular motion to show that the relationship between the orbital period T of the planet and its orbital radius r is $T^2 \propto r^3$.

[3]

The demonstration of Kepler's 3rd Law was well-remembered by the vast majority of candidates.

Question 23 (b) (i)

(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]**

Fortunately, most candidates saw the reference to Kepler's third law in bold and used it successfully. Only a small fraction found the mean orbital distance by finding the mean of the maximum and minimum distance. While this is mathematically sound, it does not use Kepler's third law and so was not deemed an acceptable answer to the question.

Question 23 (b) (ii)

(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]**

Previous examiner's reports have stated the importance of understanding how gravitational potential energy differences are calculated using the appropriate formula. More candidates got this idea right in this series, which was excellent.

Exemplar 3

$$\text{energy} = -\frac{GMm}{r}, \quad \Delta E_k = \left(-\frac{G(2.0\times10^{30})(209)}{1.77\times10^{11}}\right) - \left(-\frac{G(2.0\times10^{30})(209)}{4.20\times10^{10}}\right)$$

$$\Delta E_k = 4.60\times10^{11}\ \text{J}$$

change in kinetic energy = 4.60×10^{11} J **[3]**

This candidate has understood that the gravitational potential energy at both extremes of the orbit should be calculated and then the difference calculated.

Question 23 (b) (iii)

(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.

....

.... **[1]**

This question provides one of the 'stretch and challenge' marks in this paper. The idea is that the satellite needs first to climb out of the Earth's gravitational well before it can be a satellite of the Sun.

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