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}

$0°C = +273.15\,K$
$1\,kg\,m\,s^{-1} = 1\,Ns$
$10\,kJ = 10000\,Nm$
$1.0\times10^{-3}\,Pa = 1.0\times10^{-3}\,Nm^{-2}$

Your answer D ✓ **[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}

$pV = NkT$

$k = \frac{pV}{NT}$

$p = \frac{F}{A}$ $\quad$ $F = ma$

$[kg\,m\,s^{-2}]$

$\frac{[kg\,m\,s^{-2}]}{[m^2]}$

$k = \frac{[kg\,m^{-1}s^{-2}]\,[m^3]}{[-]\,[K]} = [kg\,m^2 s^{-2} K^{-1}]$

Your answer C ✓ **[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 $T \propto \sqrt{r}$

F_c = tension = constant = $m\omega^2 r$

$\omega = \frac{2\pi}{T}$ $\therefore \frac{4\pi^2 m r}{T^2}$ = constant

Your answer B or D ✓ **[1]**

$\frac{r}{T^2}$ = constant

$r = T^2 \times$ constant

$r \propto T^2$

and

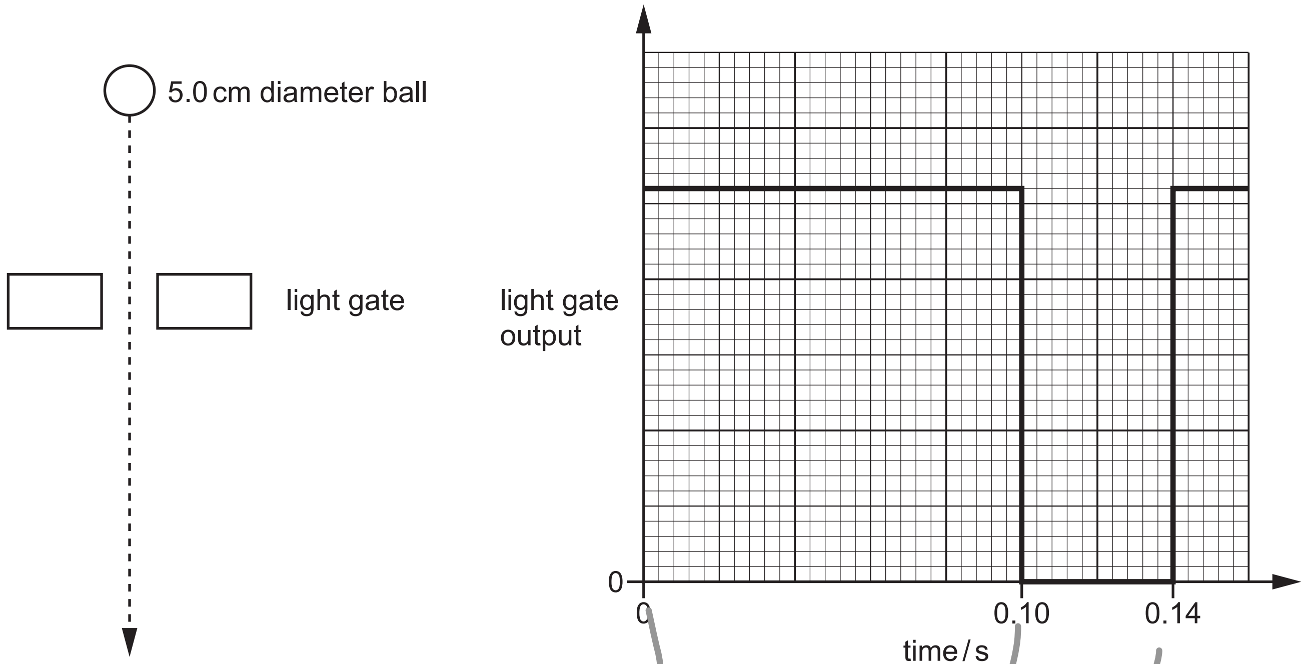
$\sqrt{r} \propto T$

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?

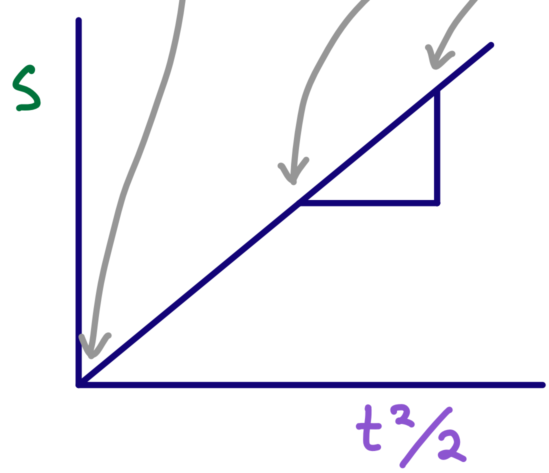
A 8.93

B 9.81

C 10.4

D 12.5

Your answer C ✓ **[1]**



$s = ut + \frac{1}{2}at^2$

gradient = a = g

$s = a \cdot \frac{t^2}{2} + ut$

$y = m x + c$

$\frac{\Delta s}{\Delta \frac{t^2}{2}} = \frac{0.050}{\frac{0.14^2}{2} - \frac{0.10^2}{2}} = 10.42 \text{ m s}^{-2}$

5 A block of wood is floating in calm water.

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

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

A 30

B 50

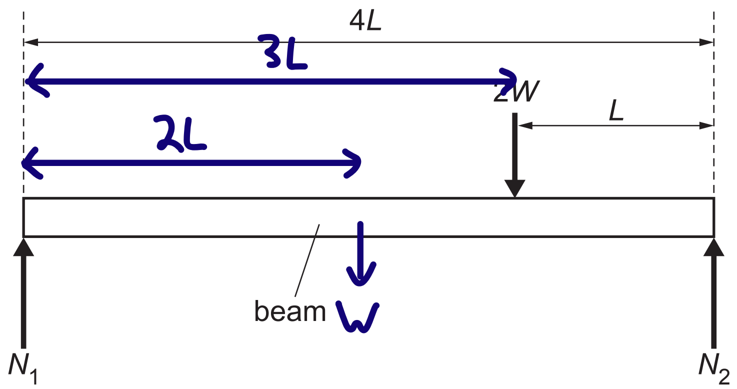
C 70

D 89

Your answer A **[1]**

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

An object weighing $2W$ 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 $N_1 = 0.5W$, $N_2 = 1.5W$

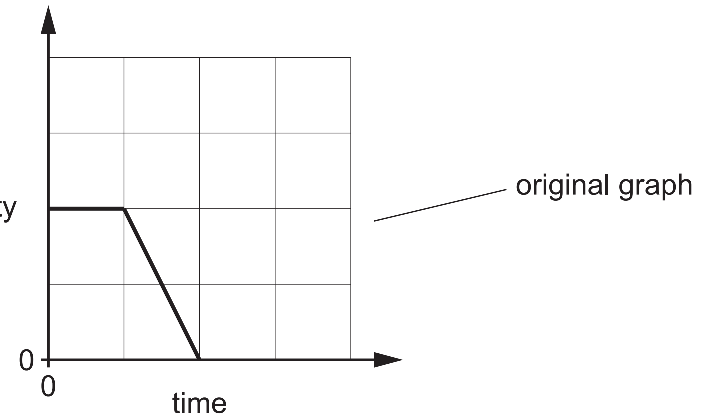
B $N_1 = W$, $N_2 = 2W$

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

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

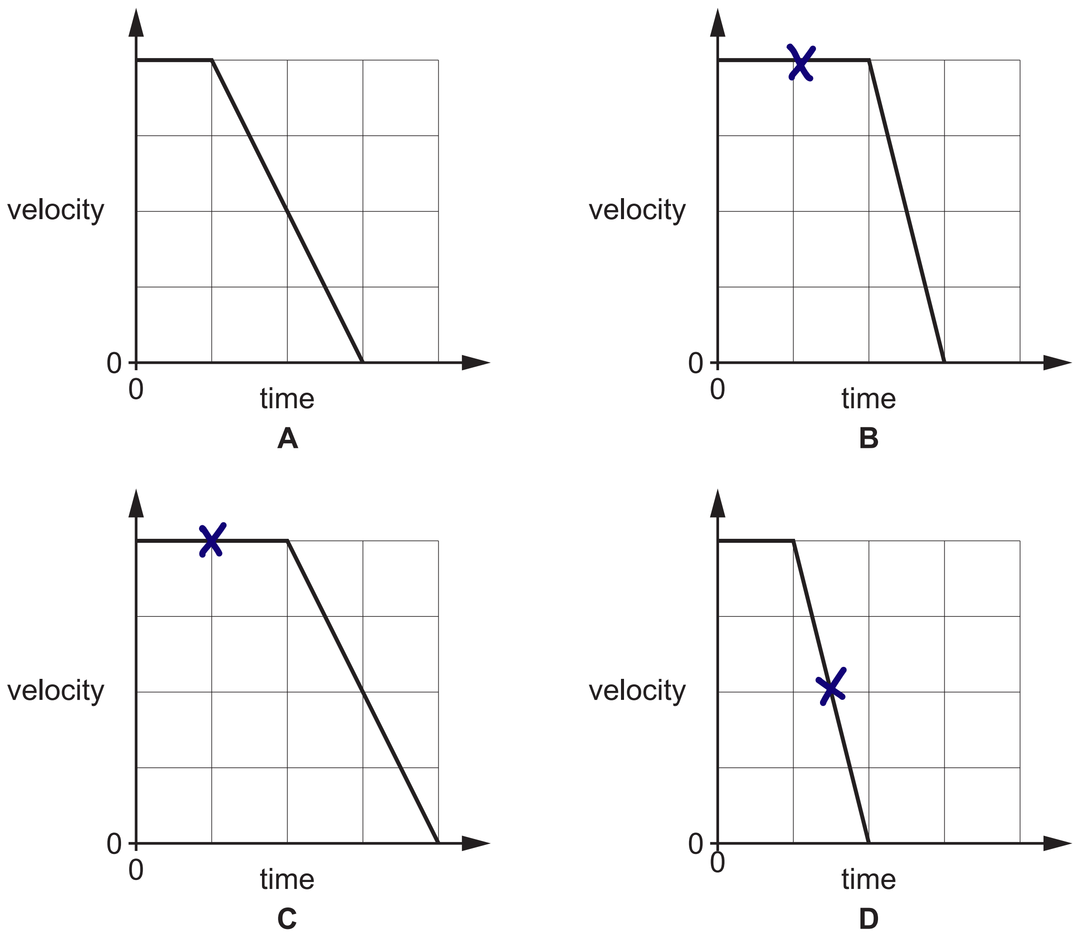
Your answer B **[1]**

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.

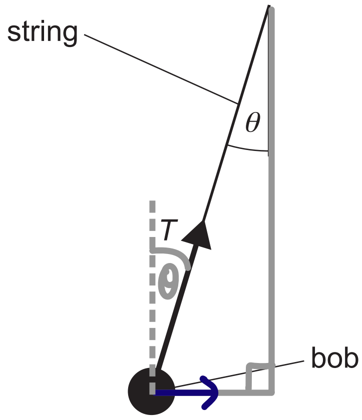
Which diagram shows the correct velocity-time graph for this new situation? The same scales are used on all graphs.



Your answer A ✓ Reaction time remains constant Gradient (deceleration) the same as before. **[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 $T\tan\theta$

sin θ ≈ θ
tan θ ≈ θ
cos θ ≈ 1 − cos² θ
∴ sin and tan

A 1 only

B 1 and 3

C 3 only

D 2 and 3

Your answer C ✓ **[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. → $t = 0$, $x = 0$

What is the displacement in metres from the equilibrium point at time t? ∴ $\sin(\omega t)$

A $0.05 \cos 2t$

B $0.05 \cos 4\pi t$

C $0.05 \sin 2t$

D $0.05 \sin 4\pi t$

$x = A \sin(\omega t)$

$\omega = 2\pi f = 2\pi \times 2 = 4\pi$

$x = 0.05 \times \sin(4\pi t)$

Your answer D ✓ **[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. ✗ $T = \frac{1}{20} = 50\,ms$

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. ✗ resonates at 20 Hz

D The period of the freely vibrating oscillator gets smaller as its amplitude decreases. ✗ T independent of A

Your answer B ✓ **[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. NCF=0

Which statement is correct? mg

A $mg = 0$

B $v \geqslant gr$

C $v^2 \geqslant gr$

D $mv^2 \geqslant gr$

$F_c = \frac{mv^2}{r}$ $F_g = mg$

$F_c \geqslant F_g$

$\frac{mv^2}{r} \geqslant mg$

$v^2 \geqslant gr$

Your answer C ✓ **[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 $4U$

$a \propto -x$

$x \rightarrow 2x \quad \therefore a \rightarrow 2a$

and $v \rightarrow 2v$

$E_K \propto v^2 \quad \therefore \rightarrow 4 E_K$

Your answer: D ✓ **[1]**

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

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

The two objects stick together.

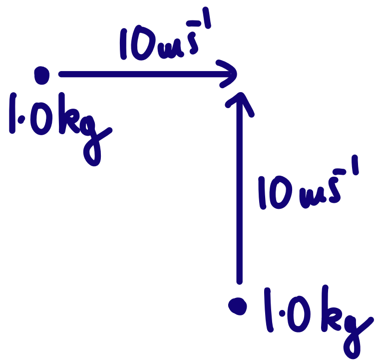
What is the magnitude in $\text{m}\,\text{s}^{-1}$ of the new combined velocity?

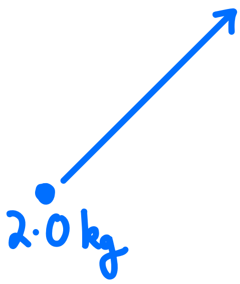
A 7.1

B 10

C 14

D 20





Your answer: A ✓ **[1]**

Before

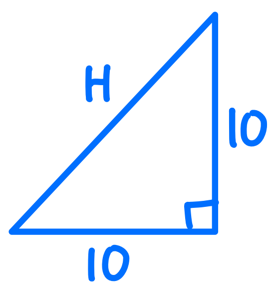
$P_{\rightarrow} = 1.0 \times 10 = 10\ \text{kg ms}^{-1}$

$P_{\uparrow} = 1.0 \times 10 = 10\ \text{kg ms}^{-1}$

After

$P_{\rightarrow} = mV_h = 10\ \text{kg ms}^{-1}$

$P_{\uparrow} = mV_v = 10\ \text{kg ms}^{-1}$



$P_{total} = H = \sqrt{10^2 + 10^2} = 14.14\ \text{kg ms}^{-1}$

$P_{total} = m.V \qquad V = \frac{14.14}{2.0} = 7.07\ \text{ms}^{-1}$

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 $2rg$

$E_k = E_p$

$\frac{1}{2}mv^2 = \frac{GmM}{r} = mgr$

$v^2 = 2gr$

$v = \sqrt{2gr}$

Your answer C **[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 B **[1]**

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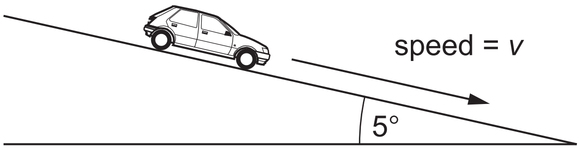
Section B

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

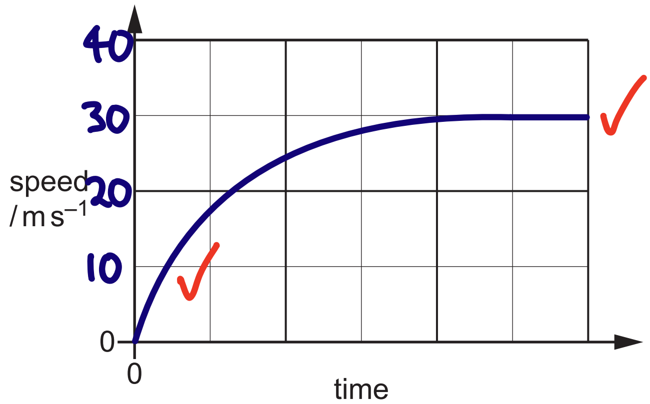
$F = kv^2$

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.

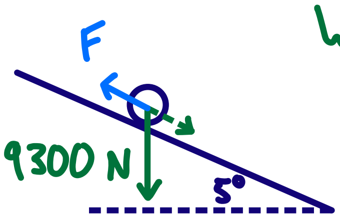


[2]

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

As the car accelerates, the resistive forces increase until forces are balanced. At this point, due to no resultant force, the acceleration = 0. **[2]**

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



Weight parallel to slope = $W \sin \theta$ ✓

$F = W \sin \theta$

$k = \frac{F}{v^2}$ ✓ $= \frac{W \sin \theta}{v^2} = \frac{9300 \sin 5}{30^2} = 0.901$ ✓ ≈ 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.

$P = Fv = kv^2 \times v = kv^3$ ✓

$v = \sqrt[3]{\frac{P}{k}}$ ✓ $= \sqrt[3]{\frac{75 \times 10^3}{0.901}} = 43.67$

maximum speed of car = 44 ✓ $m\,s^{-1}$ **[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.

$P = kv^3 \quad \therefore \quad P \propto v^3 \quad \therefore \quad v \propto \sqrt[3]{P}$ ✓

If the power is doubled, the speed increases by a factor of $\sqrt[3]{2} \approx 1.3$. ✓ **[2]**

17

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

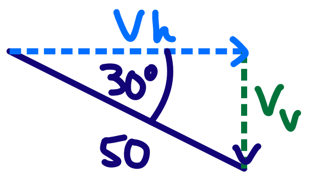
Resultant force is proportional to the rate of change of momentum. ✓

.... **[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.



$V_h = 50\cos 30 = 43.3\ \text{m s}^{-1}$

$V_v = 50\sin 30 = 25.0\ \text{m s}^{-1}$

horizontal component of velocity = 43 ✓ m s^{-1}

vertical component of velocity = 25 ✓ m s^{-1}

[2]

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

The force of the air on the model is equal in size and opposite to the direction of the force of the model on the air. ✓ The model produces a force* **[2]**

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

$$F_v = \frac{\Delta p}{\Delta t} = \frac{\Delta(mv)}{\Delta t} = \frac{m\,\Delta v_v}{\Delta t} = \frac{35 \times 25.0}{1} = 875$$ ✓ ✓

F = 8.8×10^2 ✓ N **[3]**

* on the air as the air's momentum has changed. ✓

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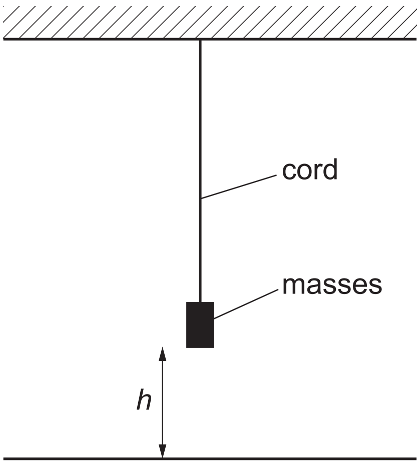
18 Mats made from rubber are often used in laboratories where heavy objects might be dropped.

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



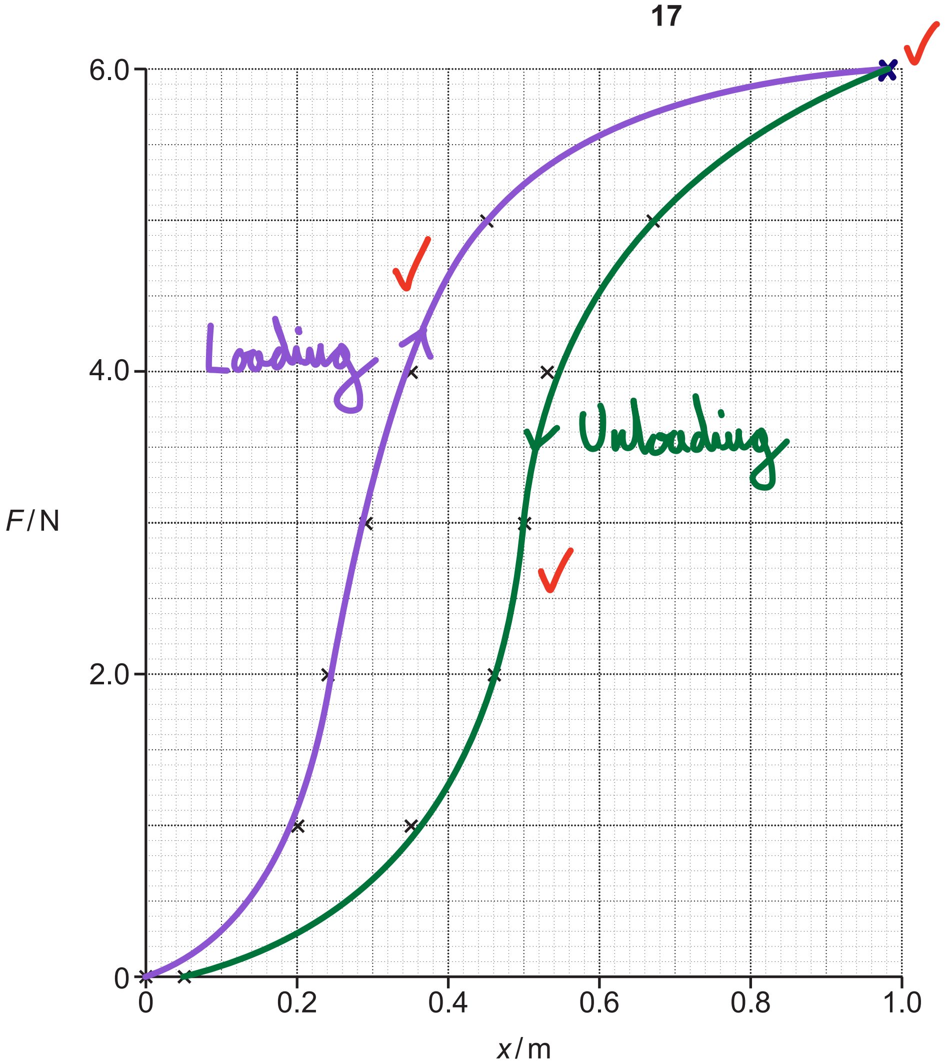
Masses are added and the height, h, of the base of the bottom mass from the floor is measured. The extension of the cord is x when the tension in the cord is F. After six masses have been added, they are removed one at a time and h measured each time.

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	0.99 ✓ (1.80 − 0.81)
5.0	1.13	0.67
4.0	~~1.37~~ 1.27*	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]**

* Mistake made by OCR



(ii) Plot the data point for F = 6.0 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.

No, as the graph is not a straight line, therefore F not directly proportional to x. **[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.

Joule **[1]**

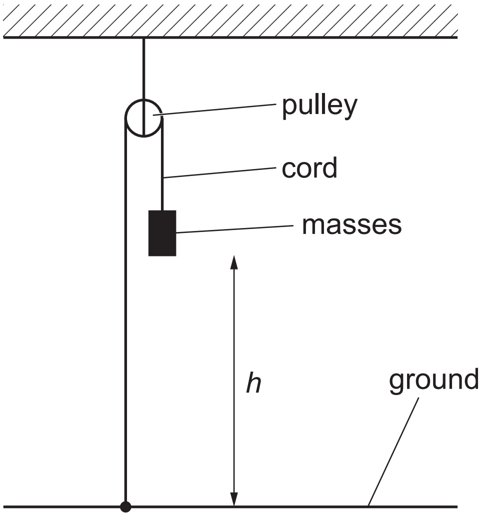
2. Explain the significance of this area to the planned use of the rubber.

This is the increase in thermal energy of the rubber, as it absorbs energy instead of transferring it back to the fallen object. **[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 The pulley adds a friction force to the rope. ✓

2 A greater value of 'h' will reduce the percentage uncertainty in this value. ✓

[2]

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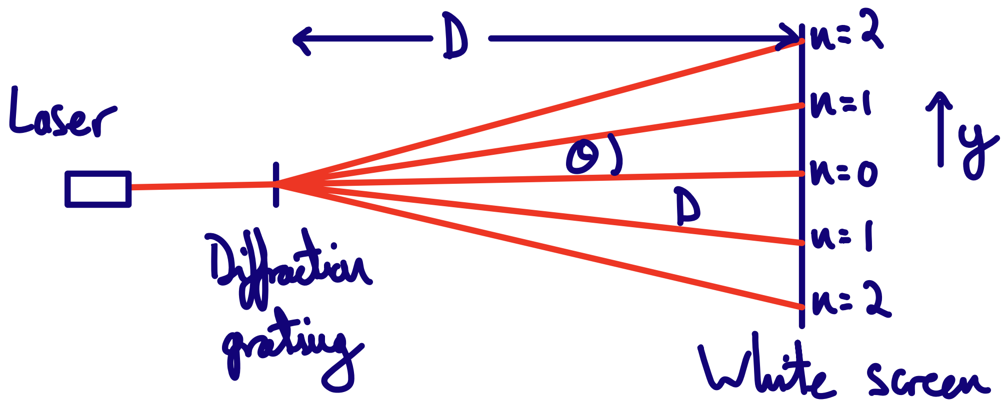
19* Describe how to determine the wavelength λ of a monochromatic laser pointer using a diffraction grating.

As part of your answer, explain how to

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

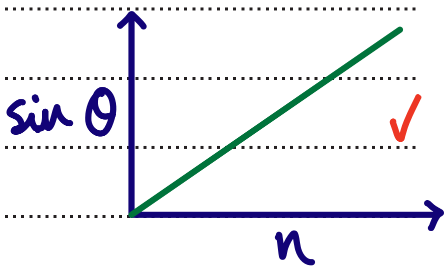
You are given the number of lines per mm for the diffraction grating.

[6]



• Shine a laser through the diffraction grating at the white screen.
• Measure the distance to the screen with a metre ruler.
• Measure the distance from the central maxima to the bright n fringe, with a micrometer or a ruler. ✓
• Calculate θ using θ = $\tan^{-1}(y/D)$
• Repeat for different values of n. ✓

As $d\sin\theta = n\lambda$, plot a graph of $\sin\theta$ against n. Calculate the gradient and multiply by d, the slit spacing, to calculate λ. ✓



Additional space if required

Improve the accuracy by

• Making D as large as possible, to reduce the percentage uncertainty in θ. ✓

• Carrying out the experiment in a darkened room, so its easier to see where the centre of the maxima is. ✓

20
(a)
(i) Define the internal energy of an ideal gas.

The sum of the kinetic energy of all the particles. ✓

.... [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.

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

$\frac{1}{3}Nm\overline{c}^2 = NkT$ ✓

$\times \frac{3}{2}$ $\frac{1}{2}m\overline{c}^2 = \frac{3}{2}kT$

$E_{K_{Av}} = \frac{3}{2}kT$ $\therefore E_k \propto T$ ✓

[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 $430\,m\,s^{-1}$.

$c_{rms} = \sqrt{\frac{310^2 + 370^2 + 440^2 + 550^2}{4}}$ ✓ $= 426.9$ ✓ $\approx 430\,ms^{-1}$

[2]

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

$\frac{1}{2}m\overline{c}^2 = \frac{3}{2}kT$ ✓ $m = \frac{3kT}{\overline{c}^2} = \frac{3 \times 1.38 \times 10^{-23} \times 290}{430^2}$ ✓

$m = 6.49 \times 10^{-26}$ kg

$n = \frac{m}{M_M}$ and $n = \frac{N}{N_A}$

molar mass = 3.91×10^{-2} ✓ $kg\,mol^{-1}$ [3]

Where $N = 1$ $M_M = m.N_A = 6.49 \times 10^{-26} \times 6.02 \times 10^{23} = 0.0391$

(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.

The power supply does electrical work on the filament, increasing its thermal energy store ✓. This is transferred to the internal energy store of the gas, ✓ the rate of transfer of energies is the same so it doesn't increase in temperature. ✓ **[3]**

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

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad P_1 = P_2 \frac{T_1}{T_2} = 120 \times \frac{290}{2400} = 14.5$$ ✓

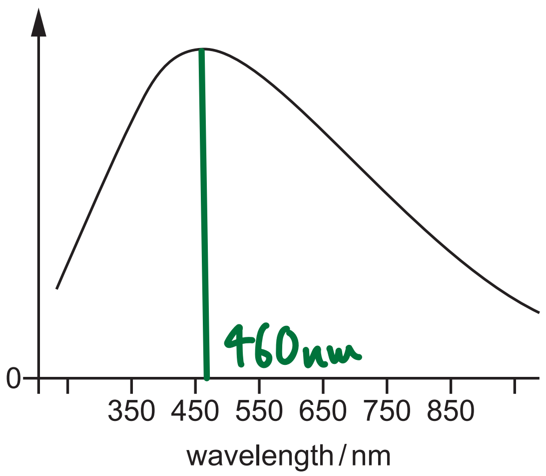
kPa

pressure = 14.5 ✓ 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.

$\lambda_{max} \propto \frac{1}{T}$ $\lambda_{max} T = k$ $\lambda_{max_1} T_1 = \lambda_{max_2} T_2$

$T_2 = T_1 \frac{\lambda_{max_1}}{\lambda_{max_2}} = 5800 \times \frac{500}{460} = 6304 \approx 6300\,K$

[2]

(ii) Estimate the radius of Nu Persei.

$L = 4\pi r^2 \sigma T^4$

$r = \sqrt{\frac{L}{4\pi \sigma T^4}} = \sqrt{\frac{2.3 \times 10^{29}}{4\pi \times 5.67 \times 10^{-8} \times 6304^4}}$

$r = 1.430 \times 10^{10}$ m

radius = 1.4×10^{10} 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 $6 \times 10^{-10}\,W\,m^{-2}$.

$$I = \frac{P}{A} = \frac{7.0 \times 10^{-15}}{1.0 \times 10^{-4}} = 7.0 \times 10^{-11}\ Wm^{-2}$$

$$7.0 \times 10^{-11} \times 0.11 = 6.36 \times 10^{-10} \approx 6 \times 10^{-10}\ Wm^{-2}$$

[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.

$$L = 4\pi r^2 \sigma T^4$$

$$\frac{L}{4\pi r^2} = \sigma T^4 = 6.36 \times 10^{-10}$$

$$r = \sqrt{\frac{2.3 \times 10^{29}}{4\pi \times 6.36 \times 10^{-10}}} = 5.36 \times 10^{18}\ m$$

m → ly

$$\frac{5.36 \times 10^{18}}{9.5 \times 10^{15}} = 564.7$$

distance = 560 light years **[4]**

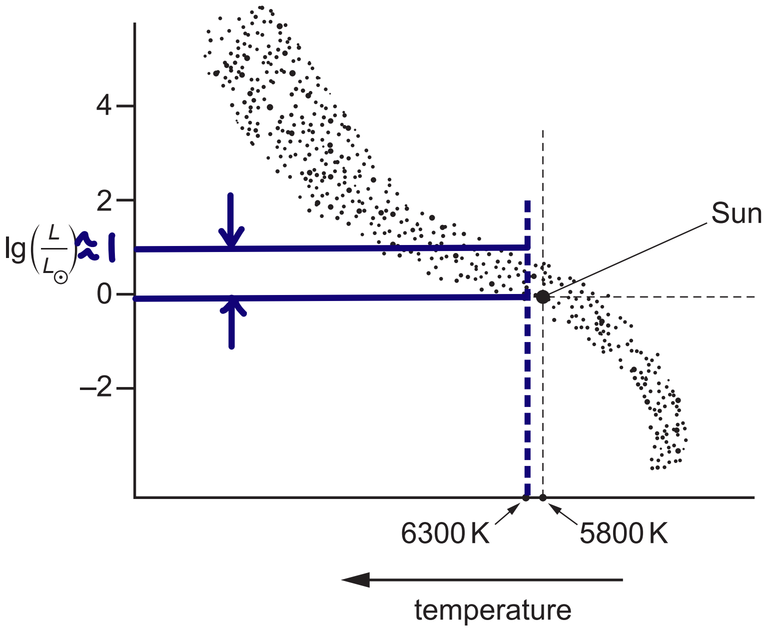
(c) The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. L is the luminosity of a star and $L_{\odot}$ is the luminosity of the Sun.

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



At 6300 K, the range of luminosity values is between $L_{\odot}$ and $10 L_{\odot}$.
Percentage uncertainty in r is half the uncertainty in L, as $r \propto \sqrt{L}$. **[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.

$T = 24$ hours

.... **[1]**

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

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

$$r = \sqrt[3]{\frac{T^2 GM}{4\pi^2}}$$

$$r = \sqrt[3]{\frac{(24\times60\times60)^2 \times 6.67\times10^{-11} \times 6.0\times10^{24}}{4\pi^2}}$$

$$r = 4.229\times10^7$$

orbital radius = 4.2×10^7 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

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

$$\therefore E_p = -\frac{GMm}{r}$$

(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.

$$F = \frac{GMm}{r^2} \qquad F = \frac{mv^2}{r}$$

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$\frac{GMm}{r} = mv^2$$

$$E_K = \frac{1}{2} mv^2$$

$$E_K = \frac{1}{2}\frac{GMm}{r}$$

$$|E_p| = \frac{GMm}{r}$$

$$\therefore E_K = \frac{1}{2}|E_p|$$

[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 $-56\,\text{MJ}\,\text{kg}^{-1}$.

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

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

$\Delta E_p = m\Delta V_p = 1.0 \times (-56 - (-)63) = 7\text{ MJ}$

From part i) $E_K = \frac{1}{2}|E_p| = \frac{1}{2} \times 56 = 28\text{ MJ}$

$\Delta E_T = E_p + E_K = 7 + 28 = 35\text{ MJ}$ $\therefore > 30\text{ MJ}$

[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.

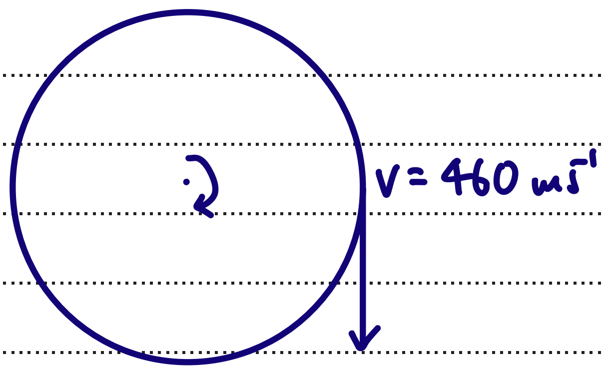
Rotational speed at the equator	$460\,\text{m}\,\text{s}^{-1}$

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

(Assuming $m = 1.0$ kg)

[6]

At equator:



Additional $E_p = 0$, $E_K = \frac{1}{2}mv^2 = 0.5 \times 1.0 \times 460^2$
$= 0.1058\text{ MJ}$

From an airplane. $E_K = \frac{1}{2}mv^2 = 0.5 \times 1.0 \times 230^2$
$= 0.026$ MJ

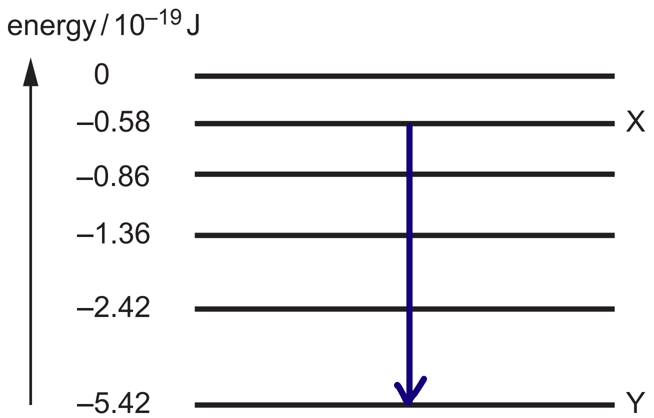
$E_p \approx mgh = 1.0 \times 9.81 \times 10{,}000 = 98{,}100$ J $= 0.098$ MJ

Additional space if required

Aircraft: ✓ Adds additional E_K and E_p, and there will be a component of the Earth's rotational velocity in addition to the velocity of the aircraft.
✓ More energy added ((0.026 + 0.098) > 0.106) than an equitorial launch.
✓ Can be launched from anywhere in the world.
✗ Only suitable for small satellites.

Both methods only allow add a small fraction of the total energy needed.

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.

$E = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{\Delta E} = \frac{6.63\times10^{-34} \times 3.00\times10^{8}}{(5.42-0.58)\times10^{-19}} = 4.11\times10^{-7}$ ✓ ✓

$\approx 410\times10^{-9}$ m **[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.

Absorption lines ✓ caused by light from the star passing through the cooler gas in the stellar atmosphere. ✓

[2]

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

$\frac{v}{c} = \frac{\Delta\lambda}{\lambda}$ $v = c\frac{\Delta\lambda}{\lambda} = 3.00\times10^{8} \times \frac{432-410}{410}$ ✓

v = 1.61×10^{7} ✓ 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.

The Big Bang theory. ✓ **[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.