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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Work, energy and power (3.3)

A Level Physics A (H556) · Module 3: Forces and motion

52 questions · 304 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

52 questions · 304 marks · 3 sub-topics



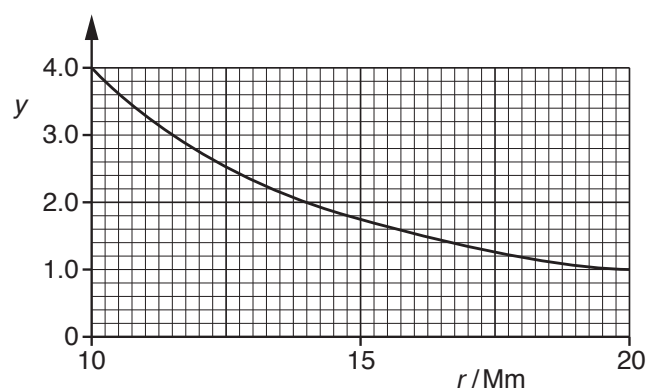
SUB-TOPIC 3.3.1

WORK AND CONSERVATION OF ENERGY

Sub-topic 3.3.1 · 12 questions · 28 marks · lowest tariff first



- 9 A graph of y against distance r from the centre of a planet is shown below.



The graph shows that y is inversely proportional to r^2 .

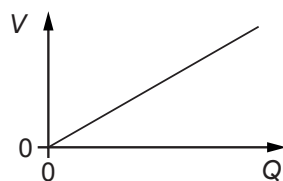
Which quantity is best represented on the y -axis of the graph?

- A Period of a satellite orbiting the planet.
- B Gravitational potential of the planet.
- C Gravitational field strength of the planet.
- D Kinetic energy of a satellite orbiting the planet.

Your answer

[1]

- 7 The graph below shows the variation of potential difference V with charge Q for a capacitor.



Which row is correct for the gradient of the graph and the area under the graph?

	Gradient of graph	Area under the graph
A	capacitance ⁻¹	work done
B	capacitance ⁻¹	permittivity
C	capacitance	power
D	capacitance	energy

Your answer

[1]

- 2 Which set of quantities are all scalar?
- A acceleration, displacement, velocity
 - B energy, mass, power
 - C extension, force, gravitational potential energy
 - D weight, kinetic energy, work done

Your answer

[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.

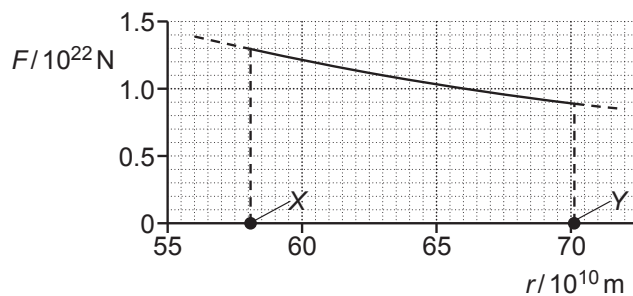
Your answer

[1]



- 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]

- 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]



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]

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Turn over



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]



- 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]



- 5** A material is heated so that it changes state from solid to liquid and after further heating changes to gas.

Which of the following properties of the particles have increased?

- 1 Mean kinetic energy
- 2 Order
- 3 Spacing

A 1 and 3 only

B 1, 2 and 3

C 2 and 3 only

D 3 only

Your answer

☐

[1]

- 16 Fig. 16 shows a hydraulic jack used to lift a car which has a mass of 1200 kg. A mechanic exerts a downwards force of 400 N on the handle of the jack, moving it 80.0 cm downwards. As he moves the handle, the car rises 2.0 cm.

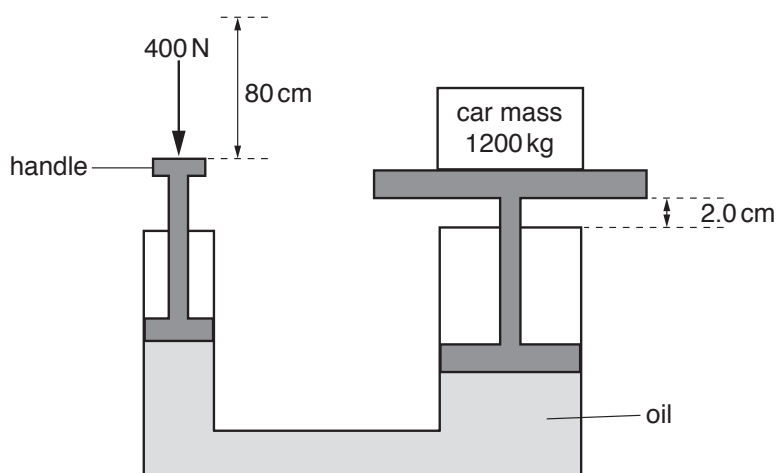


Fig. 16

- (a) Calculate the work done by the 400 N force exerted by the mechanic.

work done = ... J [2]

(b) Calculate the ratio

$$\frac{\text{speed of handle moving down}}{\text{speed of car moving up}}.$$

ratio = ... [2]

(c) Calculate the useful work done on the car and hence the percentage efficiency of the jack.

efficiency = ... % [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 $4.1 \times 10^{51} \text{ m}^3$.

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

[2]

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

$$E_k = \dots\dots\dots \text{ J [3]}$$

- (c) The nebula that formed the Sun is estimated to have a diameter of 3.0pc 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 $\frac{\text{mass of nebula X}}{\text{mass of the Sun}}$.

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]



SUB-TOPIC 3.3.2

KINETIC AND POTENTIAL ENERGIES

Sub-topic 3.3.2 · 32 questions · 224 marks · lowest tariff first



- 3 The braking distance of a car is directly proportional to its initial kinetic energy.

The braking distance of a car is 18 m when its initial speed is 10 m s^{-1} .

What is the braking distance of the car, under the same conditions, when its initial speed is 25 m s^{-1} ?

A 7.2 m

B 45 m

C 113 m

D 222 m

Your answer

[1]



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

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

A 9.1×10^2 J

B 9.9×10^6 J

C 3.2×10^9 J

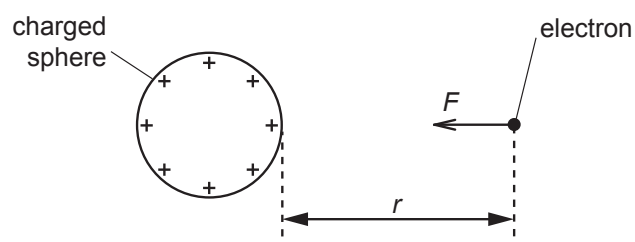
D 3.8×10^9 J

Your answer

[1]



- 13 An electron is released at a distance r from the surface of a positively charged sphere. It is attracted towards the centre of the sphere and moves until it touches the surface.



Which of the following statements is/are correct?

- 1 The area under the F against r graph is equal to work done on the electron.
- 2 The electric field strength E at distance r is equal to $\frac{F}{1.6 \times 10^{-19}}$.
- 3 The work done on the electron is equal to $F \times r$.

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

Your answer

[1]

- 1 An athlete is running at a speed of about 5 m s^{-1} .

What is a reasonable estimate for the kinetic energy of this athlete?

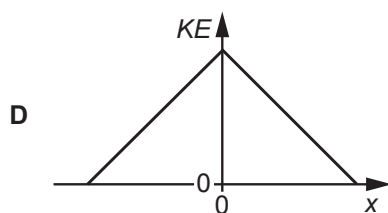
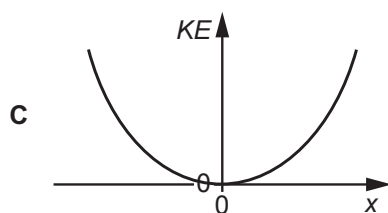
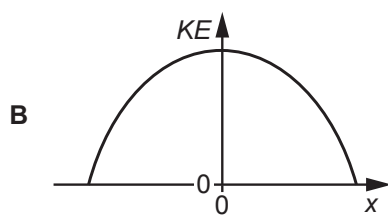
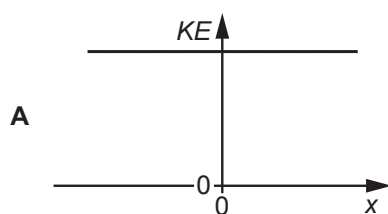
- A 12 J
- B 100 J
- C 900 J
- D 800 000 J

Your answer

[1]

12 An oscillator is executing simple harmonic motion.

Which graph of kinetic energy KE against displacement x is correct for this oscillator?



Your answer

[1]

- 3 Electromagnetic radiation is incident on a metal of work function 2.3 eV .
The maximum kinetic energy (KE) of the photoelectrons is 1.7 eV .

The frequency of this incident electromagnetic radiation is kept the same but its intensity is doubled.

What is the maximum KE of the photoelectrons now?

- A 1.7 eV
- B 2.9 eV
- C 3.4 eV
- D 4.0 eV

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]

- 5 A gamma-ray photon of frequency 6.76×10^{22} Hz creates a particle-antiparticle pair. The particle-antiparticle pair have zero kinetic energy.

What is the mass of the particle?

A 2.49×10^{-28} kg

B 4.98×10^{-28} kg

C 7.47×10^{-20} kg

D 4.48×10^{-11} kg

Your answer

[1]

13 In the Rutherford scattering experiment alpha particles are directed at a gold foil.

Gold nuclei have 79 protons. The distance of closest approach is 47.0 fm.

Which is the best estimate of the work done on an alpha particle as it moves from 53.0 fm to the point of closest approach?

A 10^{-18} J

B 10^{-16} J

C 10^{-15} J

D 10^{-13} J

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]

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]

15 Which sequence shows the energies below in **increasing** order of magnitude?

- 1 The change in kinetic energy of an electron accelerated through a potential difference of 1 V.
- 2 The kinetic energy of a proton with a velocity of 1000 m s^{-1} .
- 3 The energy of an X-ray photon with a frequency of $3 \times 10^{17} \text{ Hz}$.

A 1 2 3

B 3 1 2

C 2 1 3

D 1 3 2

Your answer

[1]

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- 3 Which row of the table describes the conditions which apply to an **inelastic** collision?

	Kinetic energy	Total energy	Momentum
A	Conserved	Not conserved	Conserved
B	Not conserved	Conserved	Conserved
C	Not conserved	Conserved	Not conserved
D	Not conserved	Not conserved	Not conserved

Your answer

[1]



- 11 A proton with kinetic energy $1.6 \times 10^{-17} \text{ J}$ is travelling at right angles to a magnetic field. The magnetic flux density is 0.050 T .

What is the magnitude of the force on the proton?

A $8.0 \times 10^{-19} \text{ N}$

B $1.1 \times 10^{-15} \text{ N}$

C $2.8 \times 10^{-6} \text{ N}$

D 6900 N

Your answer

[1]

12 The diagram shows a circuit with a variable resistor and a voltmeter.



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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- 22** An asteroid of mass 10 kg is in a circular orbit around the Sun at a distance of 3.5AU from the centre of the Sun.

$$1\text{AU} = 1.5 \times 10^{11}\text{m}$$

(a)

- (i)** Use Kepler's third law to calculate the period of the orbit of the asteroid in years.

An object orbiting the Sun at a distance of 1AU has a period of 1 year.

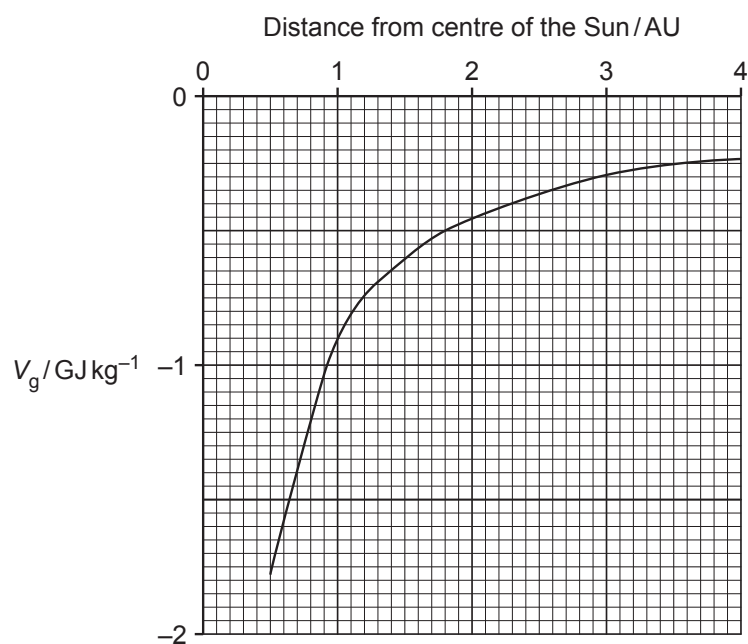
period = ... years **[2]**

- (ii)** Calculate the kinetic energy of the asteroid.

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

- (b) After a collision the asteroid falls towards the Sun.

The graph below shows the variation of gravitational potential, V_g , due to the Sun with the distance from the centre of the Sun.



- (i) Use the graph to calculate the change in gravitational potential energy of the satellite from the moment of collision until it crosses the Earth's orbit.

change in gravitational potential energy = ... GJ [2]

- (ii) Eventually, the asteroid falls into a new orbit around the Sun. This orbit is elliptical.

State the other feature of this orbit predicted by Kepler's first law.

.....
 [1]

- 1 A stationary uranium-238 nucleus (${}^{238}_{92}\text{U}$) decays into a nucleus of thorium-234 by emitting an alpha-particle.

(a) The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

- (b) The mass of the uranium nucleus is $4.0 \times 10^{-25} \text{ kg}$. After the decay the thorium nucleus has a speed of $2.4 \times 10^5 \text{ ms}^{-1}$.

Calculate the kinetic energy, in MeV, of the alpha-particle.

kinetic energy = ... MeV [4]

- (c) The uranium-238 (${}^{238}_{92}\text{U}$) nucleus starts the decay chain which ends with a nucleus of lead-206 (${}^{206}_{82}\text{Pb}$).

Show that 14 particles are emitted during this decay chain. Explain your reasoning.

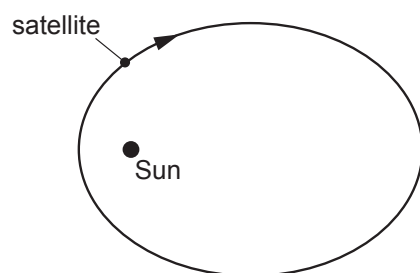
[3]

- 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.

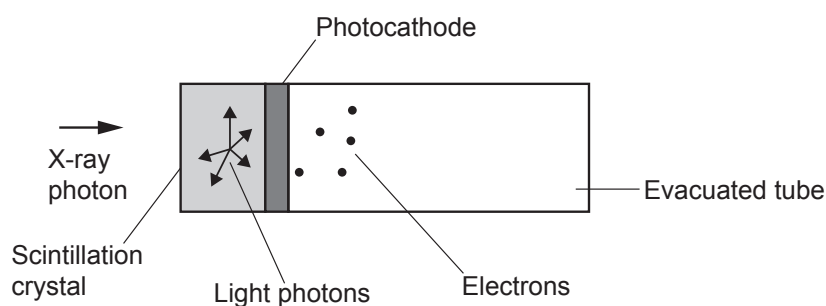
.....

..... [1]



- 19 The diagram shows part of an X-ray telescope which uses a crystal scintillation device to detect low energy X-rays from the stars.

X-rays hit the crystal and cause it to emit visible light photons. These travel to the photocathode in an evacuated tube. The photocathode uses the light photons to produce electrons.



Each X-ray photon detected by the telescope has an energy of 32 keV.

The light photons have a wavelength of 510 nm.

The efficiency of the crystal is 15%.

- (a) Show that each X-ray photon produces about 2000 light photons.

[3]

- (b) The photocathode has a work function of 2.3 eV.

- (i) Explain what is meant by the *work function*.

.....
 [1]

- (ii) Calculate the maximum kinetic energy of the electrons leaving the photocathode.

maximum kinetic energy = ...J [2]

- (iii) 12 X-ray photons are detected every minute.

Use your answer to (a) to calculate the current I leaving the photocathode. Assume that all the photons of light produce photoelectrons.

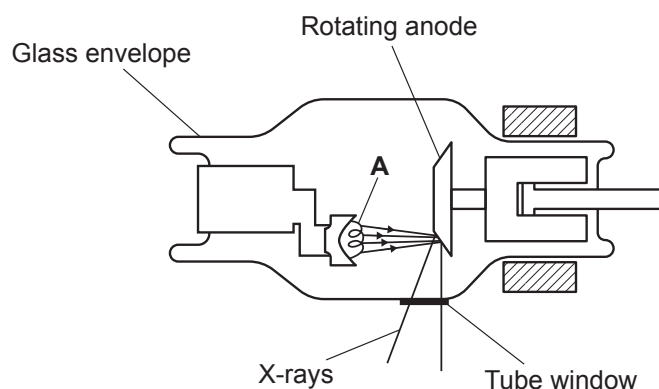
I = ... A [2]

- (iv) State one other assumption you have made to enable you to calculate the current I in (b)(iii).

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

18 X-rays are used for diagnostic imaging in a hospital.

The diagram shows the structure of an X-ray tube.



(a) Name the component labelled **A** on the diagram.

..... [1]

(b) Suggest why the anode is made to rotate.

..... [1]

(c) X-rays are produced at characteristic wavelengths which depend on the material of the anode.

Describe how the electrons from component **A** are responsible for producing X-rays.

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

- (d) An electron strikes the anode. The kinetic energy of the electron changes from 150 keV to 60 keV.

Calculate the minimum wavelength, λ , of the X-ray photon emitted by the interaction of the electron with the anode.

$$\lambda = \dots\dots\dots \text{ m [3]}$$

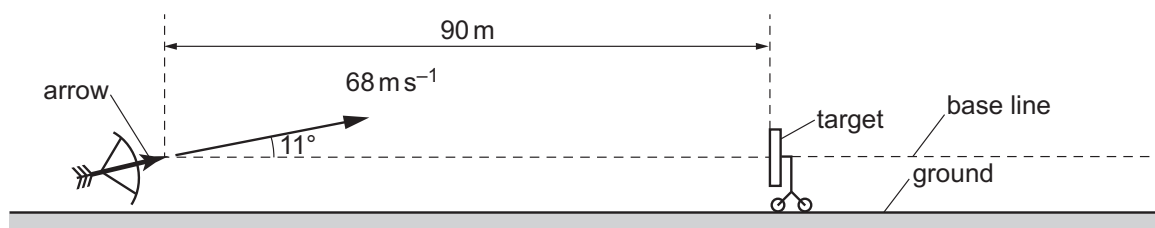
- (e) A radiologist targets a uniform beam of X-rays at a tumour 4.6 cm below the skin of a patient. The beam is at right angles to the surface of the skin.

The intensity of the X-ray beam at the tumour is 30% of the incident intensity.

Calculate the attenuation coefficient, μ , of the tumour tissue in cm^{-1} .

$$\mu = \dots\dots\dots \text{ cm}^{-1} [2]$$

- 18 An archer fires an arrow towards a target as shown below.



The diagram is **not** drawn to scale.

The centre of the target is at the same height as the initial position of the arrow.

The target is a distance of 90 m from the arrow.

The arrow has an initial velocity of 68 m s^{-1} and is fired at an angle of 11° to the horizontal.

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

- (a) Describe how the kinetic energy of the arrow changes during its journey from when it is fired until it reaches its maximum height.

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

- (b) Show that the time taken for the arrow to reach its maximum height is about 1.3 s .

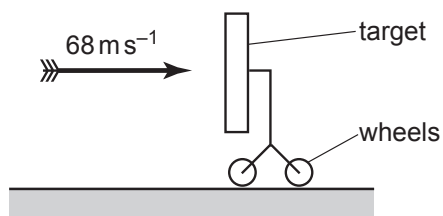
[2]

- (c) The arrow misses the target.

Calculate the horizontal distance, measured along the base line, by which the arrow misses the target.

horizontal distance = ... m [3]

- (d) The arrow is now fired horizontally at 68 m s^{-1} into the target at very close range.



The arrow sticks into the target. The collision between the arrow and the target is inelastic.

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

.....
 [1]

- (ii) The target is mounted on wheels. The target has a much larger mass than the mass of the arrow.

Using ideas of momentum, explain the velocity of the target immediately after the arrow sticks into the target.

.....

 [2]

- 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 $-2.3 \times 10^{-16} \text{ J}$.

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

$U = \dots\dots\dots \text{ J [1]}$

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

distance = $\dots\dots\dots \text{ m [3]}$

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

$\dots\dots\dots$
 $\dots\dots\dots \text{ [1]}$

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

[2]

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

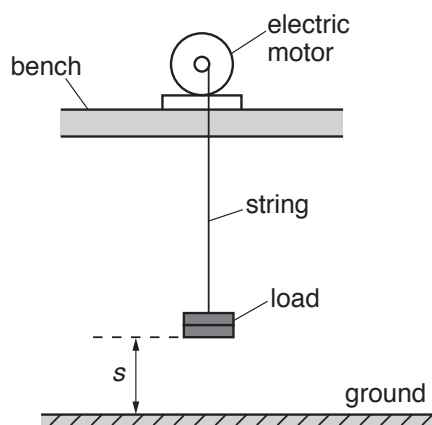


Fig. 20.1

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

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

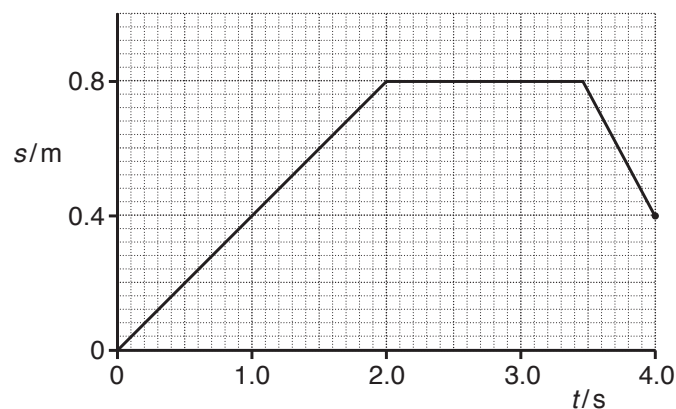


Fig. 20.2

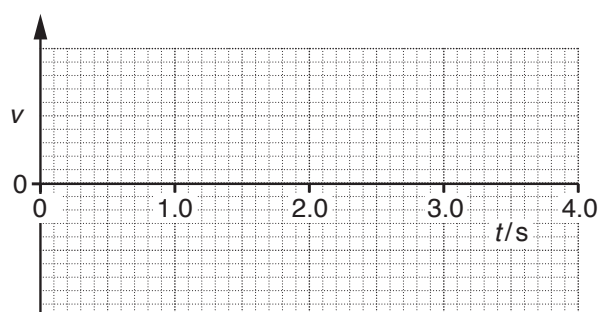


Fig. 20.3

- (i) On Fig. 20.3, sketch a graph to show the variation of the velocity v of the load with time t . You do not need to insert a scale on the v axis. [3]
- (ii) Describe how the kinetic energy and the gravitational potential energy of the load varies from $t = 0$ to $t = 2.0$ s. [2]

.....

.....

.....

..... [2]

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

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

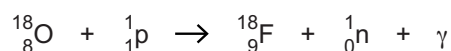
$$V = \dots\dots\dots \text{ ms}^{-1} \text{ [2]}$$

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

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

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

- 25 (a) The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_9\text{F}$) is made from the isotope of oxygen-18 ($^{18}_8\text{O}$).



The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of $0.25 \times 10^{-11} \text{ J}$. The binding energy of the $^{18}_8\text{O}$ nucleus is $2.24 \times 10^{-11} \text{ J}$ and the binding energy of the $^{18}_9\text{F}$ nucleus is $2.20 \times 10^{-11} \text{ J}$. The proton and the neutron have zero binding energy.

- (i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

.....

 [2]

- (ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

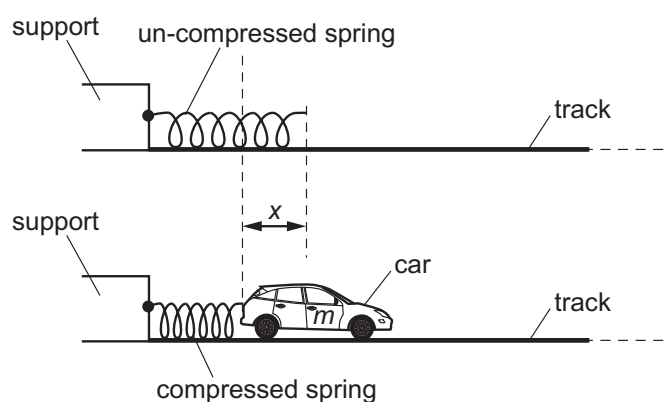
$\lambda = \dots\dots\dots \text{ m}$ [3]

- (iii) Fluorine-18 is a positron emitter.
 Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

.....

 [2]

- 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.

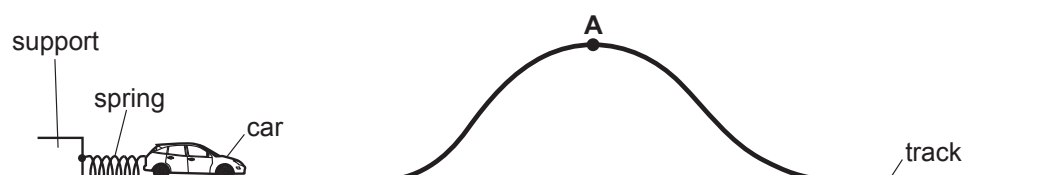
The acceleration of the car is given by the expression $a = -\left(\frac{k}{m}\right)x$, where m is the mass of the car, k is the force constant of the spring and x is the compression of the spring.

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 $= 60 \text{ N m}^{-1}$.

$t = \dots\dots\dots \text{ s}$ [4]

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



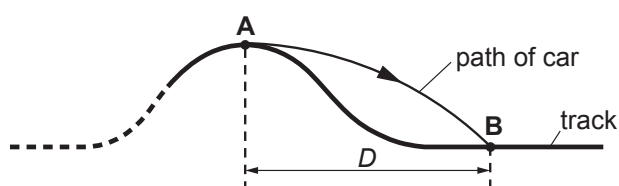
- (i) Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

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.

$x = \dots\dots\dots$ 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**.

.....

 [2]

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

.....

 [2]

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

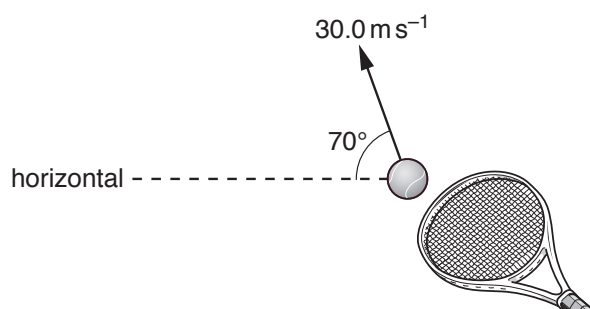


Fig. 16

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

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

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

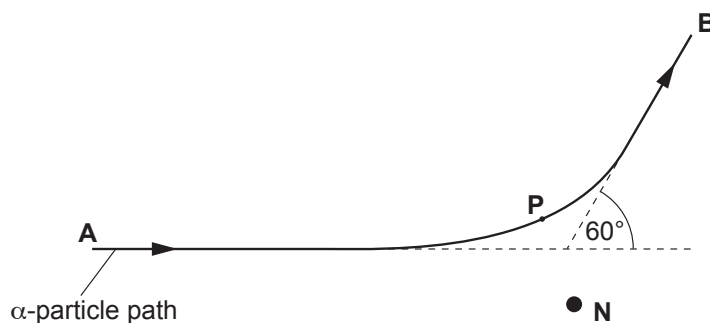
$h = \dots\dots\dots \text{m}$ [2]

Turn over

- 6 A beam of α -particles is incident on a thin gold foil. Most α -particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α -particle which passes close to a gold nucleus **N** in the foil. The α -particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



- (a) Another α -particle in the beam is deflected by the same gold nucleus **N** through an angle of 30° .

Sketch its path onto the diagram above.

[2]

- (b) The distance between **P** and **N** is $6.8 \times 10^{-14} \text{ m}$.

Calculate the magnitude of the electrostatic force F between the α -particle (${}^4_2\text{He}$) and the gold nucleus (${}^{197}_{79}\text{Au}$) when the α -particle is at **P**.

$F = \dots\dots\dots \text{ N}$ [4]

Question 6 continues on page 18

- (c) The initial kinetic energy of each α -particle is 5.0 MeV.

Show that the magnitude of the initial momentum of each α -particle is about $10^{-19} \text{ kg ms}^{-1}$.
Take the mass of the α -particle to be $6.6 \times 10^{-27} \text{ kg}$.

[3]

- (d) The **magnitude** of the final momentum of the α -particle at **B** is equal to its initial value at **A**.

The gold nucleus **N** is initially at rest. During the passage of the α -particle from **A** to **B**, no other forces act on the two particles.

In the following questions label any relevant angles.

- (i) Draw two vectors in the spaces below to represent the initial momentum and the final momentum of the α -particle.

initial momentum at **A**

final momentum at **B**

[2]

- (ii) Draw a vector in the space below to represent the momentum of the nucleus **N** when the α -particle reaches **B**.

Explain how you determined this momentum.

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



3 This question is about a space probe which is in orbit around the Sun.

(a) Define **gravitational potential energy** of an object at a point in a gravitational field.

.....
 [1]

(b) The space probe has mass 810 kg. The orbital radius of the space probe is 1.5×10^{11} m. The orbital period of the space probe around the Sun is 3.16×10^7 s. The mass of the Sun is 2.0×10^{30} kg.

(i) Show that the magnitude of the gravitational potential energy of the space probe is about 7×10^{11} J.

[2]

(ii) Show that the kinetic energy of the space probe is half the value of your answer to (b)(i).

[3]

(iii) Calculate the total energy of the space probe.

total energy = ... J [1]

- (c) The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α -particle emission with a half-life of 88 years.
The kinetic energy of each α -particle is 8.8×10^{-13} J.

- (i) Calculate the number N of plutonium-238 nuclei needed to provide the power of 470 W.

$N = \dots\dots\dots$ [3]

- (ii) Calculate the power P still available from the plutonium-238 source 100 years later.

$P = \dots\dots\dots$ W [3]

20

(a)

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

.....

.....

..... [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
- ms^{-1}
- .

310 370 440 550

- (i) Show that the root-mean-square (r.m.s.) speed of the sample is about
- 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 ms^{-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]



- 1 The Earth's aurora is an atmospheric effect visible in the polar regions.

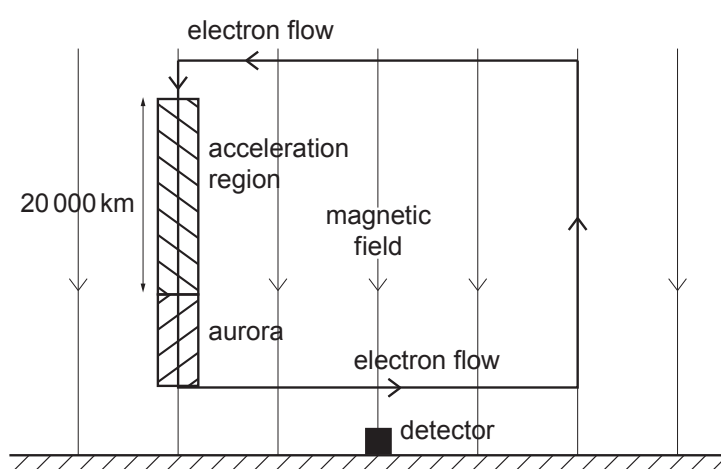
Electrons in the upper atmosphere initially move vertically downwards along one of the Earth's **magnetic** field lines. They are accelerated by an **electric** field.

These electrons collide with oxygen atoms causing atomic electrons to be excited to higher energy levels. The atomic electrons then return to lower energy levels, releasing photons of green light, red light and ultraviolet.

The accelerated electrons then travel horizontally through the atmosphere, before travelling vertically along a different magnetic field line, and then completing the circuit by travelling horizontally back to their starting point.

The situation is shown in **Fig. 1.1**.

Fig. 1.1



not to scale

- (a) The accelerated electrons are accelerated by electric fields parallel to the magnetic field lines.

The length of the acceleration region is 20 000 km and the electric field value is 0.2 mV/m. The electric field can be assumed to be uniform.

- (i) Calculate the kinetic energy gained by the electrons as they pass through the electric field, in joules.

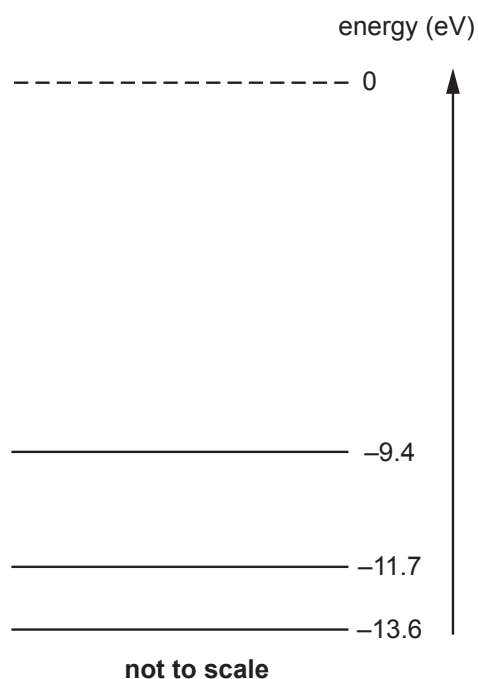
kinetic energy = ...J [3]

- (ii) State and explain the direction of the electric field required to accelerate the electrons **downwards**.

.....

 [2]

- (b) A simplified energy level diagram for atomic oxygen is shown below.



Determine the wavelength of the green light emitted.

Fully justify your answer.

wavelength = ... m [4]

- (c) The horizontal current closest to the Earth produces a magnetic field which can be detected at ground level.

With reference to **Fig. 1.1**, state and explain the direction of this magnetic field.

.....

.....

.....

..... [2]

- (d) Suggest **two** ways that the horizontal current may affect the atmosphere.

1

.....

2

..... [2]

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19 The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

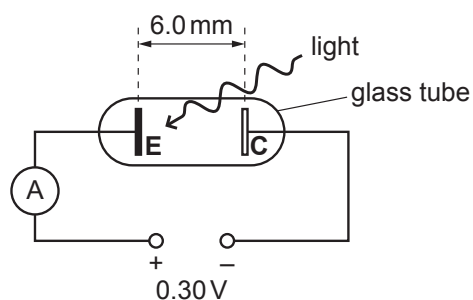


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.

Light of frequency 6.3×10^{14} Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8×10^{-20} J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.

(a) Calculate the work function of potassium in eV.

work function = ... eV [3]

(b) This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8×10^{-20} J.

(i) Show that the magnitude of deceleration of this photoelectron is $8.8 \times 10^{12} \text{ ms}^{-2}$.

[3]

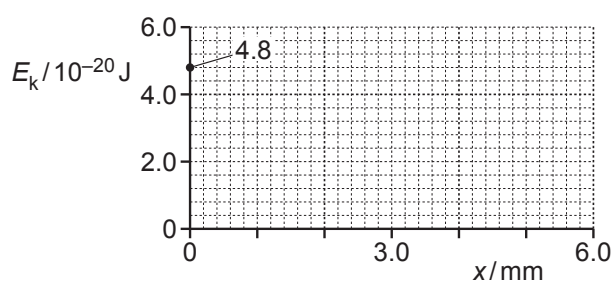
- (ii) Show that the initial speed of the photoelectron is about $3 \times 10^5 \text{ ms}^{-1}$.

[2]

- (iii) Calculate the time t taken by the photoelectron to travel from plate E to plate C.

$t = \dots\dots\dots \text{ s}$ [2]

- (iv) Using the axes shown below, sketch a graph of kinetic energy E_k against distance x from plate E.



[2]

- (c) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than $6.3 \times 10^{14} \text{ Hz}$ is now incident on plate E.

.....

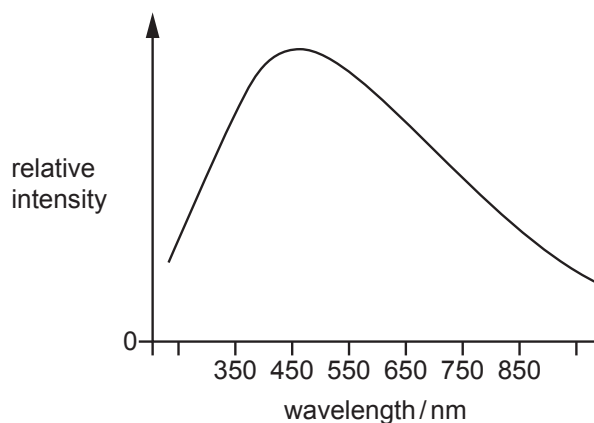
 [2]



- 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 $1.0 \times 10^{-4} \text{ m}^2$.

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

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

[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]



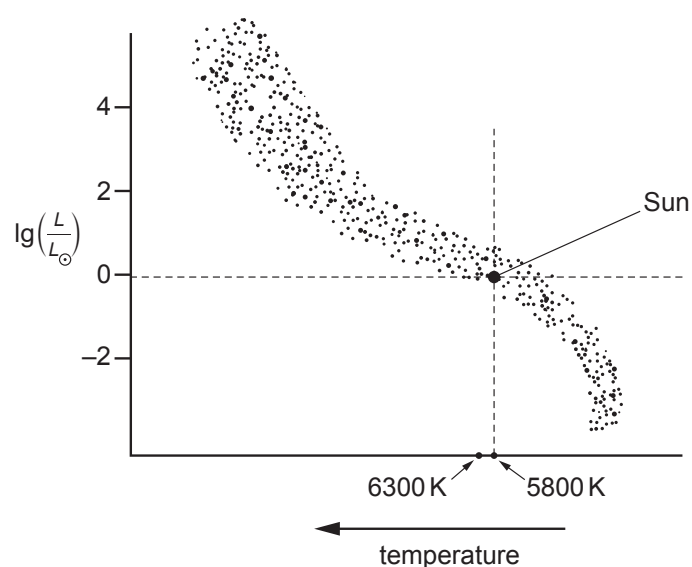
- (c) The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. L is the luminosity of a star and $L_{\odot}$ is the luminosity of the Sun.

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



.....

.....

.....

..... [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]

.....

.....

.....

.....

Additional space if required

.....

.....

.....

.....

.....



SUB-TOPIC 3.3.3

POWER AND EFFICIENCY

Sub-topic 3.3.3 · 8 questions · 52 marks · lowest tariff first



10 An object of mass 0.12 kg is lifted through a height of 0.60 m at a constant speed 3.0 ms^{-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]



- 3 The activity of an alpha-emitting source is 120 kBq. The kinetic energy of each alpha-particle is 4.0 MeV.

What is the rate of energy released by the source?

A $6.4 \times 10^{-13} \text{ W}$

B $4.8 \times 10^{-8} \text{ W}$

C $7.7 \times 10^{-8} \text{ W}$

D $1.2 \times 10^5 \text{ W}$

Your answer

[1]



- 2 A metal block of mass m is at temperature T_0 . An electrical heater of constant power P heats the block for time t and it reaches a temperature T_1 . The overall efficiency of the process is x .

Which expression gives the correct value of c , specific heat capacity of the block?

A $\frac{Pt}{m(T_1 - T_0)}$

B $\frac{Pt}{mx(T_1 - T_0)}$

C $\frac{Ptx}{m(T_1 - T_0)}$

D $\frac{Px}{mt(T_1 - T_0)}$

Your answer

[1]

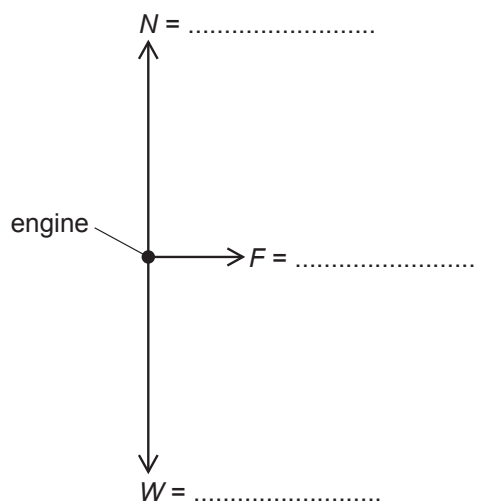
- 17 An electric engine of mass 17000 kg has a constant power output of 280 kW and it can reach a maximum speed of 42 ms^{-1} on horizontal rails. The maximum kinetic energy of the engine is 15 MJ .

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

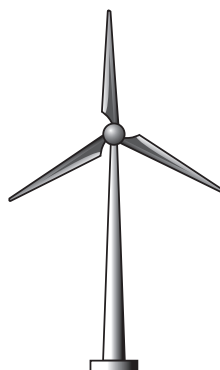


Fig. 18

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

mass per second = ... kg s^{-1} [2]

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

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

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

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

[3]

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

Calculate the length L of the turbine blades.

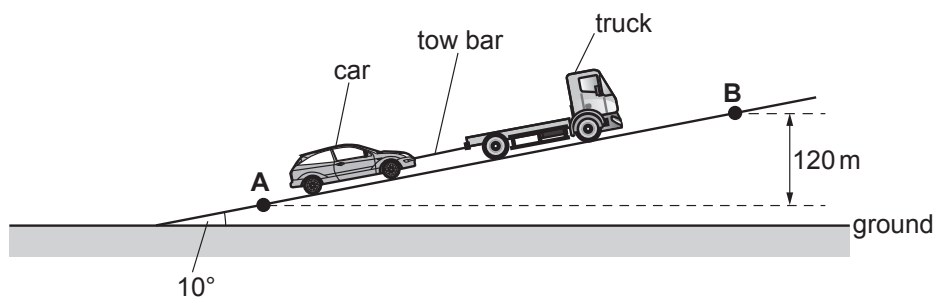
$L = \dots\dots\dots \text{ m}$ [2]

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

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

$N = \dots\dots\dots$ [2]
Turn over

- 16 A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.



The diagram is **not** drawn to scale.

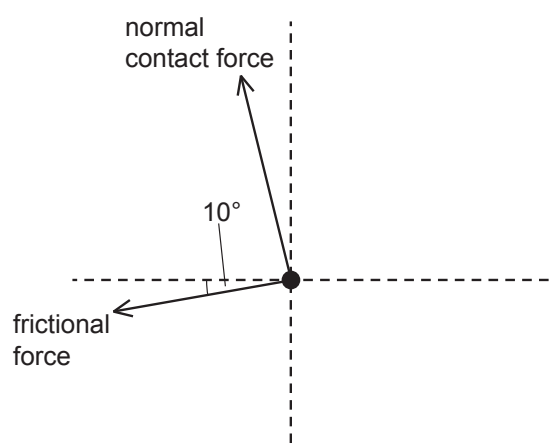
The slope is 10° to the horizontal ground.

The mass of the car is 1100 kg.

The car travels from **A** to **B**. The vertical distance between **A** and **B** is 120 m.

- (a) There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

(b) Show that the component of the weight of the car W_s acting down the slope is about 1900 N.

[1]

(c) The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

force = ... N [1]

(d) Calculate the work done by the force provided by the tow bar as the car travels from **A** to **B**.

work done = ... J [3]



- (e) The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m. The Young modulus of steel is 2.0×10^{11} Pa.

Calculate the extension x of the tow bar as the car travels up the slope.

$x = \dots\dots\dots$ m [3]

3 This question is about the Sun and its radiation.

- (a) (i) Use the data below to show that the luminosity of the Sun is about $4 \times 10^{26} \text{ W}$.
- radius of Sun = $7.0 \times 10^8 \text{ m}$
 - surface temperature of Sun = 5800 K

[1]

- (ii) Sirius, the brightest star in the night sky, has a luminosity 25 times greater than that of the Sun. It has diameter 1.7 times greater than that of the Sun.

Calculate the surface temperature T of Sirius.

$T = \dots\dots\dots \text{ K}$ [3]

***(b)** A student attends a lecture about the Sun and makes the following notes.

1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

[6]

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Additional answer space if required.

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3 This question is about comparing two methods for storing energy.

(a) A proposed method for storing energy uses trucks powered by electric motors.

The trucks carry sand up a mountain, storing surplus energy as gravitational potential energy.

When the energy needs to be released, they carry the sand back down the mountain, converting the gravitational potential energy into chemical energy stored in a battery.

Explain how an electrical generator in the truck could use **electromagnetic induction** to convert gravitational potential energy into chemical energy stored in a battery.

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..... [3]

(b) A second proposed method for storing energy uses a tank of wax.

The wax is heated using an electrical heater, storing surplus energy as internal energy of the wax. The wax increases in temperature and melts as it is heated.

When the energy needs to be released, the wax is allowed to cool, converting the internal energy of the wax into thermal energy.

Explain, in terms of the particles in the wax, how energy is stored when it is heated.

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..... [3]

(c)* A gravitational potential energy storage system, as described in (a), is proposed as follows:

- height of mountain = 1 km
- overall efficiency = 70 %

A thermal energy storage system, as described in (b), is proposed as follows:

- lower operating temperature = 18 °C
- melting point of wax = 51 °C
- upper operating temperature = 70 °C
- specific heat capacity of solid wax = 2.6 kJ kg⁻¹ K⁻¹

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- specific heat capacity of liquid wax = $3.0 \text{ kJ kg}^{-1} \text{ K}^{-1}$
- specific latent heat of fusion of wax = 160 kJ kg^{-1}
- overall efficiency = 95 %

Estimate the energy that can be stored by each system using 1 kg of sand or wax.

Discuss which system would be more appropriate for storing surplus electrical energy. Your answer should include an estimate of the energy that can be stored in each system using 1 kg of sand or wax.

Ignore any financial factors.

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Additional answer space if required

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MARK SCHEMES

official mark schemes



9	C	1	
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7	A		1	
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2	B		1	
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9	C	1	
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7	B	1	
---	---	---	--



3	A		1	
---	---	--	---	--



11	C	1	
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1	C	1	
---	---	---	--



9	D	1	
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5	A	1	
-	-	-	



16	(a)	work done = 400×0.80 work done = 320 (J)	C1 A1	
	(b)	ratio of speeds = ratio of distances (since same time) or ratio = $80 / 2$ ratio = 40	C1 A1	Allow 40:1 Allow 2 marks for ratio 29.4 (assuming p same) Not 1:40 for A1
	(c)	work done = $1200 \times 9.81 \times 0.02$ (= 235.4) efficiency = $235.4 / 320 \times 100$ efficiency = 74 %	C1 A1	Note: Using $g = 10 \text{ N kg}^{-1}$ gives 75%: allow 1 mark max Possible ECF from (a) Note: 0.74 scores 1 mark Allow 2 marks for using $235/320 \times 100 = 73\%$ Allow use of 9.8 N kg^{-1} gives 73.5% for 2 marks Allow 1 mark for 71%, force = $(1200g - 400) \text{ N}$ used Allow 1 mark for 76%, force = $(1200g + 400) \text{ N}$ used
		Total	6	

7

Question	Answer	Marks	Guidance
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21	a		Gravitational force	B1	Allow 'gravity'
	b	i	(diameter =) $6.4 \times 3.1 \times 10^{16}$ or 2.0×10^{17} (m) (volume =) $\frac{4}{3} \pi \times (9.9 \times 10^{16})^3$ (volume =) 4.1×10^{51} (m ³)	C1 C1 A0	Allow (radius =) $3.2 \times 3.1 \times 10^{16}$ or 9.9×10^{16} (m)
		ii	($E = \frac{3}{2} kT$) $\frac{3}{2} \times 1.38 \times 10^{-23} \times 250$ or 5.2×10^{-21} (J) ($N =$) $1.0 \times 10^{12} \times 4.1 \times 10^{51}$ or 4.1×10^{63} ($E_k = 4.1 \times 10^{63} \times 5.2 \times 10^{-21}$) $E_k = 2.1 \times 10^{43}$ (J)	C1 C1 A1	
	c	i	Mass is proportional to volume or diameter ³ or radius ³ or $(\frac{6.4}{3})^3$ or $(\frac{3.2}{1.5})^3$ ratio = 9.7	C1 A1	Allow attempt at calculating volume of second nebula and comparing volumes directly Allow 9.76 (if volume divided by volume of Sun's nebula)
		ii	Fuel (hydrogen) runs out Super red giant star (Mass of core > Chandrasekhar limit /1.4 therefore) supernova neutron star or black hole (formed)	B1 B1 × 3	Note: incorrect order is CON Allow alternative route: Red giant formed (mass of star < 10 solar masses, therefore) planetary nebula (and) white dwarf formed
			Total	12	



3	C		1	
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13	C		1	
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13	B		1	
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1	C	1	
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12	B	1	
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3	A	1	
---	---	---	--



10	B	1	
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5	A		1	
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13	D	1	
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12	D	1	
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15	C	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
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3	B	1	
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11	B	1	
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20	(a)	(i)	Straight symmetrical radial field lines and correct direction of field	B1	Ignore field lines inside the Earth
		(ii)	X and Y labelled which should be an equal distance away from the centre of the Earth	B1	Note Judge by eye Allow X and Y both on the surface of the Earth

	(b)*	Level 3 (5–6 marks) Clear description and correct calculations leading to value of total energy (must include the negative sign) <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some correct calculations or Correct calculations (including the negative sign) <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or Limited calculations <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1×6	Indicative scientific points may include: Description - Orbit above the equator / equatorial orbit - Orbit from west to east/same direction of orbit as Earth's rotation - Orbital period is 24 hours / 1 (sidereal) day / 23hrs 56mins (4 s) - Orbit is circular / above the same point on the Earth Calculation $E = (-) \frac{GMm}{r}$ $E = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 2500}{4.22 \times 10^7} = (-) 2.4 \times 10^{10} \text{ J}$ $v = \frac{2\pi r}{T} = \omega r$ $v = \frac{2\pi \times 4.22 \times 10^7}{24 \times 3600} = 3.07 \times 10^3 \text{ m s}^{-1}$ $E = \frac{1}{2}mv^2$ $E = \frac{1}{2} \times 2500 \times [3.07 \times 10^3]^2 = 1.2 \times 10^{10} \text{ J}$ - Total energy = $-2.4 \times 10^{10} + 1.2 \times 10^{10} = -1.2 \times 10^{10} \text{ J}$ - Allow full credit for algebraic proof using $\frac{GMm}{r^2} = \frac{mv^2}{r}$, $E = (-) \frac{GMm}{r}$, $E = \frac{1}{2}mv^2$ and total energy = KE + PE Allow higher order answers in terms of Lagrange's Identity
		Total	8	

22	(a)	(i)	$T_{\text{asteroid}}^2 = 3.5^3$ $T = 6.5 \text{ (yr)}$	C1 A1	Accept substitution of given formula with AU in metres (giving time in seconds) Answer to 3sf is 6.55 (yr)
		(ii)	$R = 3.5 \text{ AU} = 3.5 \times 1.5 \times 10^{11} = 5.3 \times 10^{11} \text{ (m)}$ $v = 2\pi R/T = 16 \text{ (kms}^{-1}\text{)}$ $KE = \frac{1}{2}mv^2 = 1.3 \times 10^9 \text{ J}$	C1 C1 A1	ECF from (a)(i) for T Note: $v = R/T$ is XP Allow ECF from v Allow $1.2 \times 10^9 \text{ (J)}$ if no premature rounding in calculation Answer is $1.26 \times 10^9 \text{ (J)}$ to 3sf Alternative method $mv^2/r = GMm/r^2 \text{ (C1)}$ $\frac{1}{2}mv^2 = m \times \frac{1}{2}GM/r = \frac{1}{2} \text{ of GPE (C1)}$ $= 1.3 \times 10^9 \text{ J from graph (A1)}$
	(b)	(i)	Potential difference from graph = $0.9 - 0.25 = 0.65 \text{ GJ kg}^{-1}$ GPE = mass $\times$ potential difference = 6.5 GJ	C1 A1	If calculated value is 0.89-0.25 Ignore sign Allow ECF from the graph
		(ii)	The Sun is at one focus	B1	
			TOTAL	8	

Question	Answer	Marks	Guidance
1	(a)		
	${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \dots$ ${}^4_2\text{He}$ or ${}^4_2\alpha$	B1 B1	allow proton and/or nucleon number to the right of symbol allow γ -photon; zero for any other extra particle
	(b)		
	$mv = (4.00 - 0.0665) \times 10^{-25} \times 2.40 \times 10^5 = 9.44 \times 10^{-20}$ $v = 9.44 \times 10^{-20} / 6.65 \times 10^{-27} = 1.42 \times 10^7$ $\text{k.e.} = \frac{1}{2} \times 6.65 \times 10^{-27} \times (1.42 \times 10^7)^2 = 6.70 \times 10^{-13} \text{ (J)}$ $6.70 \times 10^{-13} / 1.60 \times 10^{-13} = 4.19 \text{ (MeV)}$	C1 C1 A1 B1	allow 0.07×10^{-25} for α -particle mass max 3 if use 4.00 instead of 3.93 in momentum eq'n allow ratio of masses 234 and 4 or calculations using 234u and 4u allow $p^2/2m$ calculation for k.e. accept 4.0 to 4.2; ecf (calculated value of k.e. in J)/e N.B. the correct answer automatically gains all 4 marks
	(c)		
	$\Delta A = 32 = 4n_\alpha$ so $n_\alpha = 8$ $\Delta Z = 10 = 2n_\alpha - n_\beta$ so $n_\beta = 6$ argument/reasoning given for both n_α and n_β	B1 B1 B1	allow 8 (decays), i.e no mention of α particles allow $10 - 16 = -6$; NOT $14 - 8 = 6$; must state $\beta(-)$ particles e.g. change in mass number caused by α decay, change in proton number combination of α and β
	Total	9	

Question	Answer	Marks	Guidance
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Question	Answer	Mark	Comments
23 a	$G \frac{Mm}{r^2} = \frac{mv^2}{r}$ or $G \frac{Mm}{r^2} = mr\omega^2$ $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ Substitution and manipulation to give $T^2 = \frac{4\pi^2}{GM} r^3$ (with $\frac{4\pi^2}{GM}$ is constant)	M1 M1 A1	Allow any subject
b i	$\left(\frac{168}{365}\right)^2 = \left(\frac{r}{1.50 \times 10^{11}}\right)^3$ distance = 8.9×10^{10} (m)	C1 A1	Ignore calculation of arithmetic mean of data in question Allow substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ Ignore units for subs into Kepler's law NOT 8.95 or $9(.0) \times 10^{10}$ (m) (mean calculated)
ii	$(\Delta GPE = \Delta KE)$ $GMm \left(\frac{1}{4.20 \times 10^{10}}\right)$ or $GMm \left(\frac{1}{1.37 \times 10^{11}}\right)$ (change in KE =) $6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times m \left(\frac{1}{4.20 \times 10^{10}} - \frac{1}{1.37 \times 10^{11}}\right)$ change in kinetic energy = 4.6×10^{11} (J)	C1 C1 A1	Allow this mark without the m Allow this mark without the m Allow 2 marks for 2.2×10^9 ; ΔV calculated Ignore sign
iii	Description of reasonable effect of Earth has been ignored / work done by fuel (during lift off) / idea that atmosphere has been ignored previously	B1	
	Total	9	

19	(a)		Calculation in eV: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ $E_{\text{light photon}} = 3.9 \times 10^{-19} / 1.6 \times 10^{-19}$ $= 2.44 \text{ (eV)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (32\,000 / 2.44) \times 0.15$ $= 1969$	C1 Calculation in J: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ C1 $E_{\text{x-ray photon}} = 32 \times 10^3 \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15} \text{ (J)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (5.12 \times 10^{-15} / 3.90 \times 10^{-19}) \times 0.15$ C1 $= 1969$ A0 Answer to at least 3sf Allow use of 2.4eV for energy of light photon to give 2000 in either method
	(b)	(i)	(The work function is) the minimum energy required to release an electron (from the surface of a metal)	B1 Allow minimum work done for minimum energy Do not allow idea of energy needed to release multiple electrons Do not allow release of electron from atom Do not allow idea of ionisation energy
		(ii)	$\phi = 2.3 \times 1.6 \times 10^{-19} \text{ (= } 3.68 \times 10^{-19} \text{ J)}$ $KE_{\text{max}} = (3.90 - 3.68) \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$	C1 Or $\phi = 2.44 - 2.3 \text{ (= } 0.14 \text{ eV)}$ A1 $KE_{\text{max}} = 0.14 \times 1.6 \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$ Answer to at least 2sf Allow use of 2.4 eV to give $1.6 \times 10^{-20} \text{ (J)}$ ecf light photon energy from (a)

Question			Answer	Mark	Guidance
		(iii)	$I \left(= \frac{Q}{t} \right) = \frac{12 \times 1969 \times 1.6 \times 10^{-19}}{60}$ $= 6.3 \times 10^{-17} \text{ (A)}$	C1 A1	Allow full credit for use of 2000 Answer to at least 2sf (6.30) Allow use of $N = 2000$ to give $I = 6.4 \times 10^{-17} \text{ (A)}$ Allow ecf on N from (a)
		(iv)	One from: One to one interaction between (light) photon and electron That there are no secondary electrons That the current is continuous / X-rays arrive at a constant rate within the minute (or 1 every 5s) All the electrons leave the photocathode	B1	

18	(a)	Heater / cathode / filament	B1	ALLOW filament lamp IGNORE Thermionic
18	(b)	Cooling / preventing melting (of anode)	B1	NOT just 'so the same spot isn't hit all the time'
18	(c)	Electrons (in anode) are removed from (inner) energy level (by collision) (Outer) electron (in anode) falls to lower energy level (emitting characteristic X-ray photon)	B1 B1	Alternative answer: Electrons decelerate on collision with anode (X-rays / photons are produced) because of change in <u>kinetic</u> energy (of electrons)
18	(d)	Photon energy, $(E) = 90 \times 10^3 \times 1.6 \times 10^{-19}$ (= 1.44×10^{-14} J) $\lambda = hc/E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 10^{-14}}$ = 1.4×10^{-11} (m)	C1 C1 A1	ALLOW calculation of conversion of 150 keV (2.4×10^{-14}) or 60 keV (9.6×10^{-15}) for this mark only No conversion to J or conversion using wrong physics (e.g. division by 1.6×10^{-19}) to J is XP Use of $\lambda = h/p$ and $E = mc^2$ is XP Correct to at least 2 significant figures

Question		Answer	Mark	Guidance
18	(e)	$(I = I_0 e^{-\mu x} \text{ to give}) 0.3 = e^{-(\mu \times 4.6)}$	C1	ALLOW $3.3 = e^{(\mu \times 4.6)}$ Expect to see both 0.3 and 4.6 correctly substituted into equation
		$\mu (= -\ln(0.3) / 4.6) = 0.26 \text{ (cm}^{-1}\text{)}$	A1	Correct to at least 2 significant figures (0.262 cm ⁻¹) Negative final answer (- 0.26) loses second mark



18	(a)		(Kinetic energy) reduces (with height) At maximum height, KE is minimum / non-zero	B1 B1	Allow idea that KE is transferred to GPE/KE store reduces and GPE store increases Not references to KE being a vector/having components for second mark
	(b)		$(u =) 68 \sin 11^\circ$ or $13.0 \text{ (m s}^{-1}\text{)}$ $t = 13.0 / 9.81$ and t correctly evaluated $t = 1.3(2) \text{ (s)}$	C1 C1 A0	Not $t = 90 / (68 \cos(11)) = 1.35$ for zero marks. Allow any subject
	(c)		$(t =) 2 \times 1.3$ or 2.6 (s) $(x =) 68 \cos 11^\circ \times 2.6$ or 174 (m) horizontal distance = $174 - 90$ horizontal distance = 84 (m)	C1 C1 A1	 Note answer is 86 (m) if 1.32 s is used Note answer is 87 (m) if $1.3226 \dots \text{ s}$ is used Allow $1.3 \times 68 \cos 11^\circ$ for 1 mark Allow 3 or -3 m for 2 marks
	(d)	(i)	A collision in which kinetic energy is lost	B1	Allow KE is not conserved
		(ii)	Conservation of momentum Idea that velocity is to the right and velocity is very small / much smaller than $68 \text{ (m s}^{-1}\text{)}$	B1 B1	Not 'goes backwards'
			Total	10	

23	(a)	(i)	$= 1 \div 0.00097$ $= 1000$ parsecs	A1	1030 to 3sf
		(ii)	$= 0.00097 \div 7.5 \times 10^{-3} (\times 100\%)$ $= 13\%$	C1 A1	NOT half of the precision here (reference specification) Accept 1 sig fig value 10% Unrounded answer is 12.93... %
	(b)	(i)	Use of $KE_{\text{mean}} = \frac{3}{2} kT = \frac{3}{2} \times k \times 4.0 \times 10^6$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \times 4 \times 10^6$ $= 8.3 \times 10^{-17} \text{ J.}$	C1 A1	Allow k Unrounded answer is $8.28 \dots \times 10^{-17}$
		(ii)	$= -2.3 \times 10^{-16} + 8.3 \times 10^{-17}$ $= -1.5 \times 10^{-16} \text{ J.}$	B1	Allow use of 10^{-16} J from stem to give $-1.3 \times 10^{-16} \text{ J}$ Reject response without negative sign

Question			Answer	Mark	Guidance
		(iii)	selection of GMm/r Substitution of values for M,m and energy and rearrangement $3.2 \times 10^{10} \text{ m}$ e.g. $(-) \frac{GMm}{r} = (-) 1.5 \times 10^{-16}$ $r = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{31} \times 6.6 \times 10^{-27}}{1.5 \times 10^{-16}}$ $= 3.2 \times 10^{10} \text{ m}$	C1 C1 A1	Allow ECF from (b)(ii) NB Use of values in stem gives 3.7×10^{10}
		(iv)	Reference to Boltzmann distribution / AW OR Some particles will have greater kinetic energies /lower masses	B1	
			TOTAL	10	



20	(a)		$E_k = \frac{1}{2} mv^2$ <u>and</u> $p = mv$ (Correct manipulation leading to) $E_k = \frac{1}{2} p^2/m$	M1	Allow: any subject
				A1	Allow: $E_k = p^2/(2m)$
	(b)	(i)	From $t = 0$ to $t = 2.0$ s: a non-zero horizontal line From $t = 2.0$ to $t = 3.5$ s: line showing $v = 0$ From $t = 3.5$ to $t = 4.0$ s: non-zero horizontal line showing v is <u>opposite</u> in direction <u>and</u> magnitude larger than that of line drawn at $t = 0$ to $t = 2.0$.	B1 B1 B1	Judgement by eye
		(ii)	KE is constant. GPE increases linearly / proportional to t	B1 B1	Allow: 'at constant rate' for 'linear' Not: unqualified 'constantly'
		(iii)1	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ $V = 2.9 \text{ (m s}^{-1}\text{)}$	C1 A1	Allow 1 mark for $(2 \times 9.81 \times 0.40)^{1/2} = 2.8 \text{ (m s}^{-1}\text{)}$
		(iii)2	$F = 0.12 \times 2.9/0.025$ $F = 14 \text{ (N)}$	C1 A1	Possible ECF from (iii)1 Note: use of 2.8 m s^{-1} gives $F = 13(.44 \text{ N})$ Note: $1.4 \times 10^n \text{ (N)}$ scores 1 mark
			Total	11	



25	(a)	(i)	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	B1 B1	Allow 'proton can experience the strong (nuclear) force' Not 'collide / hit nucleus'
		(ii)	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11} \text{ (J)}$ or $0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}}$ (Any subject) $\lambda = 9.5 \times 10^{-14} \text{ (m)}$	C1 C1 A1	Allow 2 marks for 6.9×10^{-14} ; $E = 0.29 \times 10^{-11}$ used Allow 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. $8(.0) \times 10^{-14}$ for $E = 0.25 \times 10^{-11}$ and $5(.0) \times 10^{-13}$ for $E = 0.04 \times 10^{-11}$)
		(iii)	Used in PET (scans) Any one from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	
	(b)		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any one from: - A three-dimensional image is produced (Soft) tissues can be identified	B1 B1 B1 B1	Allow 'X-rays passed through different angles.' Allow 'slice(s)' Allow 'good contrast image'
			Total	11	



21	(a)		$\omega^2 = k/m$ or 60/0.080 or $\omega^2 = 750$ $T = 2\pi/27.39$ or $T = 0.2295$ (s) $t = \frac{1}{4} \times 0.2295$ $t = 0.057$ (s)	C1 C1 C1 A1	Allow correct algebraic expression for T Allow incorrect value for omega Allow incorrect value of T
	(b)	(i)	$E = \frac{1}{2}kx^2$ or $E = mgh$ or $0.080 \times 9.81 \times 0.20$ or $\frac{1}{2} \times 60 \times x^2$ $0.080 \times 9.81 \times 0.20 = \frac{1}{2} \times 60 \times x^2$ $x = 0.072$ (m)	C1 C1 A1	
		(ii)1	Time of flight is independent of speed/AW Because distance of fall is the same and initial velocity vertically is zero / velocity is horizontal at X	B1 B1	Allow algebraic answers that assume initial vertical velocity is zero/velocity is horizontal at X.
		(ii)2	D increases as speed at X increases because the time of flight is constant/AW D is directly proportional to speed at X	M1 A1	Allow d = vt idea “D is directly proportional to speed at X because the time of flight is constant” scores 2.
			Total	11	

Question	Answer	Marks	Guidance
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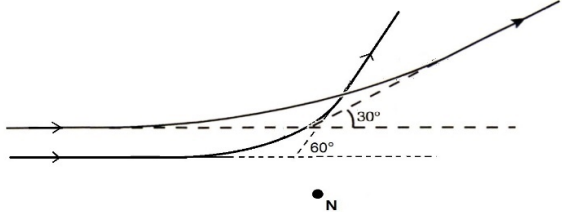


16	(a)	(i)	vertical component = $30.0 \sin(70^\circ)$ or $30.0 \cos(20^\circ)$ vertical component = $28.2 \text{ (m s}^{-1}\text{)}$	A1	Allow 2 SF answer of 28
		(ii)	Evidence of $v^2 = u^2 + 2as$ and $v = 0$ or $gh = \frac{1}{2} u^2$ $h = \frac{28.2^2}{2 \times 9.81}$ (Any subject) $h = 40.5 \text{ (m)}$	C1 M1 A0	Allow v and u interchanged; a and g interchanged Allow use of candidate's answer for (a)(i) at this point Ignore sign Allow $h = \frac{28^2}{2 \times 9.81}$ or $(30 \sin(70))^\circ / (2 \times 9.81)$ No ECF from (a)(i) for the second mark
		(iii)	The ball has horizontal motion / velocity (AW)	B1	Allow idea of horizontal e.g. sideways, forwards Not: 'moving' unqualified
		(iv)	(horizontal velocity =) $30.0 \cos 70^\circ$ or $10.2 \text{ (m s}^{-1}\text{)}$ or $30.0 \sin 20^\circ$. $E_k = \frac{1}{2} \times 0.057 \times 10.26^2$ $E_k = 3.0 \text{ (J)}$	C1 A1	Allow 1 SF answer Not 22 (J), $v = 28$ used Not 23 (J), $v = 28.2$ used Not 140 (J), $v = 70$ used



Question	Answer	Marks	Guidance
(b)*	Level 3 (5–6 marks) Clear description and analysis. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description and limited analysis or limited description or limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response (NR) or no response worthy of credit (0).	B1× 6	Indicative scientific points may include: Description • Ruler used to determine x • Average readings to determine x • x recorded for various v • Suitable method for consistent v or varying v e.g. • Released from same point on a track • Ejected from a spring device with different compressions • Suitable method of determining point of impact e.g. • trial run to get eye in approximate correct position • carbon paper so that ball makes a mark on paper • scale in frame of video recording • tray of sand to catch ball • Suitable instrument used to determine v (light-gate / motion sensor / video techniques) or suitable description of inference of v from other measurements such as energy released from spring of known k and x • Ensuring the initial velocity of ball is horizontal Analysis • Horizontal velocity is constant • Time of fall is independent of v/horizontal velocity • Suggested relationship: e.g. $x \propto v$, x d.p. to v^2, etc • Plot a graph of x against v or graph consistent with candidate's suggested relationship • If relationship is correct, then a straight line through the origin. • Suggested relationship supported by correct physics or algebra. • Correct relationship supported by physics. Note: L1 is used to show 2 marks awarded and L1^ is used to show 1 mark awarded.
	Total	12	

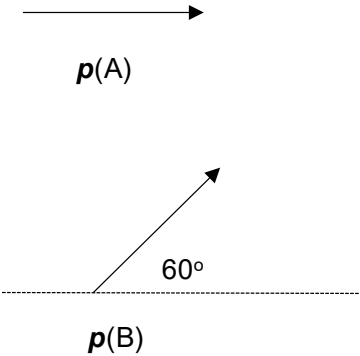
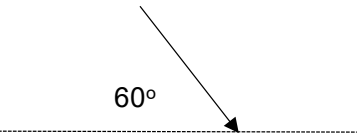


6	(a)		B1	Path is initially horizontal and further up the page than original
		$Q = 79e$ and $q = 2e$ $F = (1/4\pi\epsilon_0)Qq/r^2$ $= 79 \times 2 \times (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (6.8 \times 10^{-14})^2]$ $= 7.9 \text{ (N)}$	B1	Path <u>ends</u> at 30° to horizontal (angle must be labelled) in the direction shown
6	(b)	$Q = 79e$ and $q = 2e$ $F = (1/4\pi\epsilon_0)Qq/r^2$ $= 79 \times 2 \times (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (6.8 \times 10^{-14})^2]$ $= 7.9 \text{ (N)}$	C1	Apply ECF for wrong charge(s), e.g. Q and/or $q = e$, or $Q = 79$ and/or $q = 2$, etc
6	(c)	(k.e. =) $E = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ $v = \sqrt{(2E/m)}$ or $= \sqrt{(2 \times 8.0 \times 10^{-13} / 6.6 \times 10^{-27})} = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ $p (= mv) = 6.6 \times 10^{-27} \times 1.6 \times 10^7$ giving $p = 1.1 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$	C1	$E = 8(.0) \times 10^{-13} \text{ J}$ or ($E = p^2/2m$ so) $p = \sqrt{(2mE)}$ Note: A value of $v = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ automatically scores both C1 marks even if the calculation for E is not shown or $p (= \sqrt{(2mE)}) = \sqrt{(2 \times 6.6 \times 10^{-27} \times 8.0 \times 10^{-13})}$ giving $p = 1.0 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$ Full substitution of values must be shown and answer (if calculated) must be correct
6	(c)		A1	

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6	(d)	(i)	Example (not to scale):  $p(A)$ 60° $p(B)$	B1	horizontal arrow (judge by eye), in the direction shown
				B1	arrow drawn at an angle of 60° to the horizontal (angle must be shown), in the direction shown
		(ii)	Example (not to scale):  60° (Can apply principle of) conservation of momentum (since no external forces are acting)	B1	arrow drawn at an angle of 60° to the horizontal (angle must be shown), in the direction shown
				B1	
			Total	13	



3	(a)		GPE is the work done in bringing an object from infinity (to that point)	B1	Ignore any equations
	(b)	(i)	GPE = (-) GMm/r GPE = (-) $6.67 \times 10^{-11} \times 2 \times 10^{30} \times 810 / 1.5 \times 10^{11}$ GPE = (-) 7.2×10^{11} (J)	C1 C1 A0	Mark is for full substitution, including 6.67×10^{-11} for G
		(ii)	$v = 2\pi r/T = 2\pi \times 1.5 \times 10^{11} / 3.16 \times 10^7$ (= 29.8 km s ⁻¹) KE = $\frac{1}{2}mv^2 = 0.5 \times 810 \times (29.8 \times 10^3)^2$ KE = 3.6×10^{11} (J)	C1 M1 A1	Allow proof by algebraic method for full marks e.g. $mv^2/r = GMm/r^2$ so $mv^2 = GMm/r$ Therefore KE/GPE = $\frac{1}{2}mv^2 / (GMm/r) = \frac{1}{2}$
		(iii)	total energy = (-) ($7.2 \times 10^{11} - 3.6 \times 10^{11}$) total energy = (-) 3.6×10^{11} (J)	M1 A0	working must be shown; ECF (i) and (ii)
	(c)	(i)	$A = 470 / 8.8 \times 10^{-13} = 5.3 \times 10^{14}$ (Bq) $\lambda = \ln 2 / (88 \times 3.16 \times 10^7)$ (= 2.5×10^{-10} s ⁻¹) ($A = \lambda N$); N (= $5.3 \times 10^{14} / 2.5 \times 10^{-10}$) = 2.1×10^{24}	C1 C1 A1	Mark is for correct calculation of A (in Bq or decays per s) Mark is for correct working to give λ in s ⁻¹
		(ii)	$P = P_0 \exp(-\lambda t)$ $P = 470 \exp(-\ln 2 \times 100 / 88)$ $P = 210$ (W)	C1 C1 A1	Allow formula in terms of N or A Allow calculation in terms of N or A ; allow ECF for N or A
			Total	13	

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Question	Answer	Marks	Guidance
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20	a	i	Internal energy (of an ideal gas) is the sum of the (randomly distributed) kinetic energies of the particles	B1	Allow use of KE or E_k and atoms/molecules for particles. Ignore reference to PE (of particles)
		ii	evidence of $NkT = \frac{1}{3}Nm\overline{c^2}$ Manipulation to insert $\frac{1}{2}$ to give $\frac{1}{2}mc^2 = \frac{3}{2}kT$	M1 A1	
	b	i	(r.m.s. speed =) $\sqrt{\frac{310^2+370^2+440^2+550^2}{4}}$ r.m.s. speed evaluated as 427 (m s ⁻¹)	M1 A1	Not arithmetic mean 418. Treat as XP. Allow 729100 as evidence of summation of squares Allow mean squared speed = 182275 (m ² s ⁻²) Allow any candidate evaluation that rounds to or is 427 i.e. 426.93...
		ii	$\frac{1}{2}mc^2 = \frac{3}{2}kT$ $\frac{1}{2}m \times 430^2 = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ (molar mass = $6.02 \times 10^{23} \times 6.49 \times 10^{-26}$) molar mass = 0.039 (kg mol ⁻¹)	C1 C1 A1	allow $\frac{1}{2}Mc^2 = \frac{3}{2}RT$ allow any valid rearrangement allow $\frac{1}{2}M \times 430^2 = \frac{3}{2} \times 8.31 \times 290$ allow $m = 6.5 \times 10^{-26}$ (kg) or $m = 6.7 \times 10^{-26}$ (kg) Using 427 m s ⁻¹ gives 0.0396 i.e. 0.040
	c	i	Energy transferred from electrical (energy) to internal (energy) or thermal (energy) of filament	B1	Allow power supply doing electrical work on filament

Question			Answer	Mark	Guidance
			Energy transferred from filament to internal energy of gas	B1	Allow heating of gas by conduction Allow description of Newton's Law of Cooling Allow heating of gas by radiation
			(because) the (rate of) energy lost to the surroundings = the (rate of) energy transfer gained (by filament)	B1	Allow reference to thermal equilibrium of any part or whole of lamp structure
		ii	$(P/T = \text{constant}) \frac{120}{2400} = \frac{p}{290}$	C1	
			pressure = 14.5 (kPa)	A1	Allow 15 Allow 14
			TOTAL	13	

1	(a)	(i)	$V (= Ed) = 0.2 \times 10^{-3} \times 20,000 \times 10^3$ or $V = 4000 \text{ (V)}$ $W (= QV) = 1.6 \times 10^{-19} \times 4000$ $6.4 \times 10^{-16} \text{ (J)}$	C1 C1 A1	Allow $F (= QE) = 1.6 \times 10^{-19} \times 0.2 \times 10^{-3}$ or $F = 3.2 \times 10^{-23} \text{ (N)}$ Allow $W (= Fd) = 3.2 \times 10^{-23} \times 20,000 \times 10^3$
1	(a)	(ii)	electrons move in opposite direction to (electric) field/conventional current (so electric field is) upwards	M1 A1	Allow electrons are negatively charged
1	(b)		$11.7 - 9.4 (= 2.3 \text{ eV})$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.3 \times 1.6 \times 10^{-19}}$ $5.4 \times 10^{-7} \text{ (m)}$ Correct reasoning to select 540 nm - the middle wavelength (from red, green, UV) - the middle frequency - the middle photon energy - the middle-sized electron transition	C1 C1 A1 B1	Allow $13.6 - 11.7 (= 1.9 \text{ eV})$ or $13.6 - 9.4 (= 4.2 \text{ eV})$ Allow a <u>full</u> substitution with an energy level change of 9.4, 11.7 or 13.6 eV for this C1 mark only Allow an answer consistent with 1.9 eV or 4.2 eV (i.e. 296 nm or 654 nm gains 3 marks) Allow up to 4 marks for working backwards from stating wavelength of green light is ~550 nm i.e. $E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{550 \times 10^{-9} \times 1.6 \times 10^{-19}}$ $E = 2.3 \text{ eV}$ $11.7 - 9.4 (= 2.3 \text{ eV})$

Question			Answer	Mark	Guidance
1	(c)		(conventional) current opposite to electron flow or (right) to left (magnetic field) out of the page	B1 B1	Allow annotation of figure to show circular magnetic field lines around current or arrow labelled current towards left on Fig 1.1
1	(d)		heating effect ionisation of atoms / lightning strikes	B1 B1	 Allow (ionisation causes) horizontal force / acceleration of gas (due to $F = BIL$ / motor effect)
			Total	13	

19	(a)	$(hf = \phi + KE_{\max}) = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} = \phi + 4.8 \times 10^{-20}$ $\phi = 3.6969 \times 10^{-19} \text{ (J)}$ $\phi = 2.3 \text{ (eV)}$	C1 C1 A1	OR (in eV) $hf = 6.63 \times 10^{-34} \times 6.3 \times 10^{14} / 1.6 \times 10^{-19}$ $\phi = 2.6 - 0.30 \text{ (eV)}$ $\phi = 2.3 \text{ (eV)}$
	(b)	(i) $a = \frac{VQ}{dm}$ OR $a = \frac{EQ}{m}$ OR $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ OR $KE = F \times d$ and $F = m \times a$ $a = \frac{0.30 \times 1.6 \times 10^{-19}}{6.0 \times 10^{-3} \times 9.11 \times 10^{-31}}$ / $a = \frac{50 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ / (Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$ and (use of $v^2 = u^2 + 2as$) $\Rightarrow v^2 = (1.05 \times 10^{11}) = 2 \times a \times 6 \times 10^{-3} (\pm 0^2)$ / (Use of $KE = F \times d$) $= 4.8 \times 10^{-20} = F \times 6 \times 10^{-3}$ and (use of $F = m \times a$) $F = (8.0 \times 10^{-18}) = 9.11 \times 10^{-31} \times a$ $a = 8.78 \times 10^{12} \text{ (m s}^{-2}\text{)}$	C1 M1 A1	Allow u and v interchangeably throughout Allow calculation of $E = (0.30 / 6 \times 10^{-3}) = 50 \text{ (V m}^{-1}\text{)}$ or $v = 3.2 \times 10^5 \text{ (m s}^{-1}\text{)}$ or $v^2 = 1.05 \times 10^{11} \text{ (m s}^{-1}\text{)}^2$ or $F = 8.0 \times 10^{-18} \text{ (N)}$ for C1 mark Substitution mark – in any arrangement. Expect full substitutions including numerical value of m_e if appropriate Method 1: direct calculation of a Method 2: using $KE = \frac{1}{2}mv^2$ and $v^2 = u^2 + 2as$ Method 3: using $KE = F \times d$ and $F = m \times a$ Note must be more than 2 SF (not paper SF penalty) Ignore negative sign
		(ii) (Use of $KE = \frac{1}{2}mv^2$) $= 4.8 \times 10^{-20} = \frac{1}{2} \times m \times v^2$ OR $(u^2 = v^2 - 2as) = 0^2 - [2 \times (-) 8.8 \times 10^{12} \times s]$ Full substitution leading to $v = 3.2 \times 10^5 \text{ (m s}^{-1}\text{)}$	C1 A1	Allow u and v interchangeably Numerical value of m_e must be used if using KE method Note must be more than 1 SF (not paper SF penalty) Note 3.25 is acceptable for A1, but not 3.3

Question			Answer	Marks	Guidance
		(iii)	$t = \frac{3.2 \times 10^5}{8.8 \times 10^{12}}$ $t = 3.6 \times 10^{-8} \text{ (s)}$	C1 A1	Allow correct full substitution into any suvat equation Allow 3×10^5 for v Ignore signs of substituted values Expect values between 3.4×10^{-8} and 3.8×10^{-8} (s) No ecf from (b)(i) or (b)(ii)
		(iv)	Any line with negative slope starting from 0, 4.8×10^{-20} A straight line finishing at 6.0,0	M1 A1	$\frac{1}{2}$ square tolerance. ALLOW a curve with negative gradient. ALLOW a region of zero gradient, but not whole line $\frac{1}{2}$ square tolerance on axis intercepted
	(c)		Energy of photon increases (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach C and there is a current or reading (on ammeter)	B1 B1	Do not allow increased <u>kinetic</u> energy of photons Do not allow explanation in terms of increased number of emitted electrons (per second) Allow photoelectrons for electrons
			Total	14	

21	a	i	Estimate of $\lambda_{\max}$ between 440 and 470 nm (T =) $5800 \times 500/460 = 6300$ K i.e. candidate's value	M1 A1	Allow 2.9 million for 5800×500 Allow assumption of 6300 K, calculation of lambda (M1) and then confirmation on graph (A1) for 2 marks
		ii	$L = 4\pi r^2 \sigma T^4$ Correct substitution of values i.e. $2.3 \times 10^{29} = 4 \pi r^2 \sigma 6300^4$ radius = $1.4(3) \times 10^{10}$ (m)	C1 C1 A1	
	b	i	$P = 7.0 \times 10^{-15} \div 0.11$ $I = 6.36 \times 10^{-14} / 1.0 \times 10^{-4} = 6.4 \times 10^{-10} \text{ (Wm}^{-2}\text{)}$	M1 A1	
		ii	$L/4\pi r^2 = 6.4 \times 10^{-10}$ $r = (L \div (6.4 \times 10^{-10} \times 4\pi))^{0.5}$ $= 5.4 \times 10^{18}$ (m) ($\div 9.5 \times 10^{15} =$) 560 light years	C1 C1 C1 A1	Allow use of 6×10^{-10} Allow alternative method: Finding intensity at star surface C1 Using ratio of intensities = square of ratio of (star radius / distance to earth) C1 Use of 6×10^{-10} for I gives 580 ly

Question		Answer	Mark	Guidance
	c	Any three from: There is a range/ 'band' in the luminosity values at 6300 K range of luminosity is between $L_{\odot}$ and about $10 L_{\odot}$ The uncertainty in the distance calculated = $\frac{1}{2}$ the uncertainty in the luminosity AW Reference to Nu Persei not necessarily being on the main sequence	B1 B1 B1 B1	Check diagram for rewardable content
		TOTAL	14	

22	a	i	Period equal to one day/24 hours/rotational period of Earth Or Rotation in same direction as the rotation of the Earth (on its axis) Or Equatorial orbit Or radius of orbit is approx 42 000 km Or height of orbit above Earth's surface is approx 36 000 km Or zero velocity relative to Earth's surface	B1	
		ii	Use of $T=3600 \times 24$ (or 86,400 from data book) Substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ i.e. $(86400)^2 = (4\pi^2 / (G \times 6.0 \times 10^{24})) r^3$ $r = 4.2 \times 10^7$ (m)	C1 C1 A1	NOT 'is in the same place in the sky'
	b	i	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ $\frac{1}{2}mv^2 = \frac{1}{2} \frac{GMm}{r}$	M1 A1	Allow omission of 'm' on both sides of equation (gravitational field strength = centripetal acceleration) Cancelling/rearrangement/identification of GMm/r as GPE
	b	ii	(Increase in) GPE = $(-56 - -63 \text{ MJ}) = 7 \text{ (MJ)}$ or (Increase in) KE = $0.5 \times 56 = 28 \text{ (MJ)}$ Sensible reasoning, e.g. $7+28 > 30$	M1 A1	Allow evaluation of total energy of 35 (MJ)

Question		Answer	Mark	Guidance
22	c	Level 3 (5–6 marks) Correct calculations, and advantages and limitations discussed. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Correct calculations and an advantages discussed or Correct calculations and a limitation discussed. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Attempted calculations or a single correct calculation or incomplete explanations of advantages and/or limitations. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor Ignore general knowledge answers e.g. accidents, cost, politics Allow references to energy, energy per unit mass or potential as interchangeable Allow ecf from candidate's value for total energy per unit mass in orbit from (i.e. 35 MJ) 22bii or use of 30 (MJ) Indicative scientific points may include: Calculations • (Minimum) additional KE from aircraft=26 kJ • Additional GPE from aircraft = 100 kJ • Additional KE from equatorial launch=110 kJ • GPE calculated by mgh as an acceptable approximation • (Without taking Earth's rotation into account,) KE at equator is about 4x aircraft KE • GPE calculated from $v_g = (-)GM/r$ • Total energy = $0.5GM/r$

Question			Answer	Mark	Guidance
					Advantages • Aircraft launch provides KE and GPE • Aircraft velocity will be higher than 230 depending on where the aircraft takes off. • Less (rocket) fuel required • Aircraft launch has similar/slightly larger energy to equatorial • Equatorial launches can only happen in limited locations/aircraft launches can take place almost anywhere Limitations • Aircraft launches only suitable for small satellites. • Effects (for either) only significant for near earth orbits/low altitudes • Either launch provides very small fraction (less than 1%) of the energy required
			TOTAL	14	

10	C	1	
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3	C		1	
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2	C	1	
-	-	-	



Question	Answer	Mark	Comments
17 a	Working that leads to $t = \frac{15 \times 10^6}{280 \times 10^3} = 54$ (s)	B1	Allow KE = t × P approach
b	Horizontal arrow to the left same size as F At least one horizontal magnitude given as 6700 (N) At least one vertical magnitude given as 170 000 (N)	B1 B1 B1	by eye Allow $280 \times 10^3 \div 42$ or 6670 (N) Allow 17000×9.81 or 167000 (N)
c	(thinking distance =) 0.40×42 or 17 m Acceleration = $7 \text{ (m s}^{-2}\text{)}$ or $\frac{1}{2} m v^2 = F d$ (braking distance =) 125 m Total stopping distance is 142 m (which is less than 167m)	B1 C1 A1 B1	Allow ECF in subsequent marks if thinking distance incorrect or omitted Alternative approach using braking distance (work done =) $120 \times 10^3 \times (167 - \text{thinking distance})$ (work done =) 18×10^6 (J) Work done calculated and this is less than the initial KE Allow braking distance calculated and 125 m is less than the available braking distance of (167 – thinking distance)
	Total	8	

18	(a)		$1.2 \times 10^6 = \frac{1}{2} \times (\text{mass per second}) \times 8.0^2$ $\text{mass per s} = 3.8 \times 10^4 \text{ (kg s}^{-1}\text{)}$	C1 A1	Answer is $3.75 \times 10^4 \text{ (kg s}^{-1}\text{)}$ to 3sf Note: $3.8 \times 10^n \text{ (kg s}^{-1}\text{)}$ scores 1 for PoT error.
	(b)	(i)	$A \rightarrow \text{m}^2$ <u>and</u> $\rho \rightarrow \text{kg m}^{-3}$ $P \rightarrow \text{kg m}^2 \text{ s}^{-3}$ Clear working to show units are equivalent on either side of equation	M1 M1 A1	Note: No mark for $v \rightarrow \text{m s}^{-1}$ since units are in (a) Allow $P \rightarrow \text{kg m s}^{-2} \text{ m s}^{-1}$ (from $P = Fv$ or $P = \text{Work done/t}$) Note: clear working includes $\text{m}^3 \text{ s}^{-3}$ seen.
		(ii)	$1.2 \times 10^6 = \frac{1}{2} \times 1.3 \times A \times 8.0^3$ or $A = 3600 \text{ (m}^2\text{)}$ seen $L = 34 \text{ (m)}$	C1 A1	Allow volume $\text{s}^{-1} = 28846 \text{ (m}^3\text{)}$ using $3.75 \times 10^4 \text{ (kg s}^{-1}\text{)}$ or $29231 \text{ (m}^3\text{)}$ using $3.8 \times 10^4 \text{ (kg s}^{-1}\text{)}$ Allow ECF from (a) Note: $3.4 \times 10^n \text{ (m)}$ scores 1 for PoT error.
		(iii)	(output power =) 0.42×1.2 / 0.504 (MW) $(N = 50/0.504 = 99.2)$ $N = 100$	C1 A1	Allow: $50 \times 10^6 / 0.42 = 119 \text{ MW}$ and then $119 / 1.2$ Not 99 Note: answer of 99.2 scores 1 mark max
			Total	9	



16	(a)	Arrow vertical down <u>and</u> an arrow opposite to the frictional force. Both arrows labelled correctly.	M1 A1	Allow weight / mg / W for the downward arrow <u>and</u> tension / T / 'force in rod' / 'force in tow bar' / 'driving force' for the 'upward' arrow
	(b)	$(W_s =) 1100 \times 9.81 \times \sin 10^\circ$ or $1100 \times 9.81 \times \cos 80^\circ$ $(W_s = 1874 \text{ N or } 1900 \text{ N})$	C1 A0	Allow g instead of value
	(c)	force = $1900 + 300$ force = 2200 (N)	A1	Allow $1870 + 300 = 2170 \text{ (N)}$
	(d)	(distance =) $120 / \sin 10^\circ$ or 691 (m) (work done =) 2200×691 work done = $1.5 \times 10^6 \text{ (J)}$	C1 C1 A1	Allow ECF from (c) Allow ECF from an incorrect attempt at first mark.
	(e)	$(A =) \pi \times 0.006^2$ or $1.1 \times 10^{-4} \text{ (m}^2\text{)}$ (stress =) $\frac{2200}{\pi \times 0.006^2}$ <u>and</u> $2.0 \times 10^{11} = \frac{\text{stress}}{\text{strain}}$ $x = 4.8 \times 10^{-5} \text{ (m)}$	C1 C1 A1	Allow ECF from (c) Allow $x (=FL/EA) = \frac{2174 \times 0.5}{2.0 \times 10^{11} \times 1.1 \times 10^{-4}}$ Allow 2 marks for 1.2×10^{-5} ; $1.2 \times 10^{-2} \text{ m}$ used as radius Allow answer between 4.7 and $5.1 \times 10^{-5} \text{ (m)}$
Total			10	

3	(a)	(i)	$L (= 4\pi r^2 \sigma T^4) = 4 \times \pi \times (7.0 \times 10^8)^2 \times 5.67 \times 10^{-8} \times 5800^4$ $L = 3.95 \times 10^{26} \text{ (W)}$	M1 A0	Mark is for substitution of values Allow σ for 5.67×10^{-8}
		(ii)	By ratios: $25 = 1.7^2 \times (T/5800)^4$ $T^4 = 9.8 \times 10^{15}$ $T = 9950 \text{ (K)}$	C1 C1 A1	or $T^4 = \frac{25L}{4\pi\sigma(1.7r)^2}$ $= \frac{25 \times 3.95 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times (1.7 \times 7 \times 10^8)^2}$ ECF for L in a(i) but only if $L = 4 \times 10^{26}$ to 1s.f. ECF for incorrect σ in a(i) Allow 9.9×10^{15} (using $L = 4 \times 10^{26}$) Allow 10,000 K
	(b)		see next page	B1 x 6	
			Total	10	

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November 2020

Question			Answer	Marks	Guidance
3	(b)	*	Level 3 (5 - 6 marks) Clear expansion of three statements <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.</i> Level 2 (3 – 4 marks) Clear expansion of two statements or Limited attempt at all three <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Limited attempt at one or two statements <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. Indicative scientific points may include: statement 1 - fusion reactions are occurring - which change H into He - and mass is lost which releases energy - energy released = $c^2\Delta m$ Δm per second = luminosity / c^2 statement 2 - average k.e. of each proton is $\frac{3}{2}kT$ - high T means protons are travelling at high speed - so fast enough to overcome repulsive forces - and get close enough to fuse - p.e. = $e^2/4\pi\epsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\epsilon_0 r$ r is approximately 3fm statement 3 - k.e. $\propto T$ so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse - but M-B distribution applies so at the high energy end there will be a few p with enough energy - quantum tunnelling across potential barrier is possible - small probability of many favourable collisions to boost energy of p 4 p must fuse to produce He; it is complicated process making probability of fusion much less - number of p in Sun is so huge that, even with such a small probability, 4×10^9 kg of p still interact s^{-1} - a larger probability means lifetime of the Sun would be shorter



H556/03**Mark Scheme****November 2020**

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3	(a)	(motion of truck) moves/spins coil/wire in magnetic field (rate of) change in flux linkage (causes induced e.m.f. driving a current through the battery) Any one from: • <u>work done</u> by gravity / weight (reduces GPE) • <u>work done</u> on charge by magnetic field (transfer to electric energy) • <u>work done</u> by charge passing through battery (transfer to chemical energy)	B1 B1 B1	Allow (motion of truck) moves/spins magnet in coil of wire or description of relative motion between coil and magnet/magnetic field Allow lines of flux are cut (inducing an emf)
3	(b)	Any 3 from: • (internal energy is) sum of kinetic and potential energy of particles (in the wax) • increase in temperature in solid wax corresponds to particles increasing their kinetic energy (but potential energy remains constant) • change of state corresponds to particles increasing their potential energy • increase in temperature in liquid wax corresponds to particles increasing their kinetic energy (but potential energy remains constant)	B1x3	Accept KE for kinetic energy and PE for potential energy throughout Allow $KE \propto \text{temperature}$ Allow during change of state work is being done against intermolecular attractive forces Note only award KE mark once unless one comment is clearly for solid wax and the other for liquid wax i.e. before and after melting

3	(c)	Level 3 (5–6 marks) Clear correct calculations, including efficiency, for both sand and wax and clear quantitative discussion comparing the two methods or limited quantitative discussion and discussion of pros/cons of both methods <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some correct calculations for both sand and wax including a specific heat capacity calculation OR Limited calculation(s) for sand and/or wax and some discussion of pros/cons <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited calculation(s) OR Limited discussion <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	6 × B1	Use level of response annotations in RM Assessor No ticks Indicative scientific points may include: Calculations • $\Delta GPE = mg\Delta h \approx 1 \times 9.81 \times 1000 = 9.8 \text{ kJ}$ • $\text{useful} = 0.7 \times 10 \text{ kJ} = 6.9 \text{ kJ}$ • $\Delta E = mc\Delta\theta = 1 \times 2.6 \times (51-18) = 86 \text{ kJ}$ • $\Delta E = mL = 1 \times 160 = 160 \text{ kJ}$ • $\Delta E = mc\Delta\theta = 1 \times 3.0 \times (70-51) = 57 \text{ kJ}$ • Total E for wax = 300 kJ • useful for wax = $0.95 \times 300 \approx 290 \text{ kJ}$ Discussion • Thermal system stores ~40 times as much energy per kg of material • GPE pros: readily available material; no new infrastructure required; energy stored in batteries can be directly released to the grid; energy can be stored indefinitely • GPE cons: requires mountainous terrain; slow response time • Thermal pros: high energy density; easily scaled up or automated; can be built in any location • Thermal cons: energy stored cannot readily be converted to electrical energy for the grid; limited storage time as wax cools
		Total	12	

