Please check the examination details below before entering your candidate information

| Candidate surname | Other names |
|---|---|
| | |

Centre Number | Candidate Number

# Pearson Edexcel International Advanced Level

## Friday 9 June 2023

Morning (Time: 1 hour 45 minutes)

Paper reference **WPH15/01**

# Physics

## International Advanced Level
## UNIT 5: Thermodynamics, Radiation, Oscillations and Cosmology

**You must have:**
Scientific calculator, ruler

Total Marks

## Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*
- **Show all your working out** in calculations and **include units** where appropriate.

## Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- In the question marked with an **asterisk (*)**, marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- The list of data, formulae and relationships is printed at the end of this booklet.

## Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

*Turn over*

## SECTION A

**Answer ALL the questions in this section.**

**For questions 1–10, in Section A, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.**

**1** The ultimate fate of the universe is uncertain.

Which of the following would result in an open universe?

☐ **A** The average density of the universe is equal to the critical density of the universe.

☐ **B** The average density of the universe is less than the critical density of the universe.

☐ **C** The mass of the universe is equal to the critical mass of the universe.

☐ **D** The mass of the universe is greater than the critical mass of the universe.

**(Total for Question 1 = 1 mark)**

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**2** A hydrogen source on Earth emits a spectral line with a wavelength of 410 nm.

An observer determines the wavelength of the same line in the spectrum of a star. The star is moving away from the Earth at 2.5% of the speed of light.

What is the wavelength of the line as determined by the observer?

☐ **A** 400 nm

☐ **B** 410 nm

☐ **C** 420 nm

☐ **D** 430 nm

**(Total for Question 2 = 1 mark)**

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**3** The distances to stars can be determined using trigonometric parallax.

Star X has twice the parallax angle of Star Y.

Which of the following statements is correct?

☐ **A** The distance of Star X from Earth is twice the distance of Star Y from Earth.

☐ **B** The distance of Star X from Earth is four times the distance of Star Y from Earth.

☐ **C** The distance of Star Y from Earth is twice the distance of Star X from Earth.

☐ **D** The distance of Star Y from Earth is four times the distance of Star X from Earth.

**(Total for Question 3 = 1 mark)**

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DO NOT WRITE IN THIS AREA

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**4** A satellite of mass $m$ is on the Earth's surface.

The satellite is moved into a circular orbit of height $h$ above the Earth.

The mass of the Earth is $M$ and the radius of the Earth is $R$.

Which of the following gives the change in gravitational potential energy of the satellite?

- ☒ **A** $\frac{GM}{(R+h)} - \frac{GM}{R}$
- ☒ **B** $\frac{GMm}{R} - \frac{GMm}{(R+h)}$
- ☒ **C** $\frac{GM}{(R+h)^2} - \frac{GM}{R^2}$
- ☒ **D** $\frac{GMm}{R^2} - \frac{GMm}{(R+h)^2}$

**(Total for Question 4 = 1 mark)**

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**5** Measurements related to a distant galaxy may be used to determine the value of the Hubble constant.

Which two measurements related to a distant galaxy must be used?

- ☒ **A** distance from the Earth and mass
- ☒ **B** distance from the Earth and recession velocity
- ☒ **C** luminosity and mass
- ☒ **D** luminosity and recession velocity

**(Total for Question 5 = 1 mark)**

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**6** Buildings in earthquake zones often have a structure that includes ductile materials. These materials help to damp oscillations of the building during an earthquake.

Which of the following describes a ductile material?

- ☒ **A** A material that behaves elastically under tension.
- ☒ **B** A material that has a large plastic deformation before it breaks.
- ☒ **C** A material that has a large value of breaking stress.
- ☒ **D** A material that has a large value of the Young modulus.

**(Total for Question 6 = 1 mark)**

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**7** A student is investigating the absorption of gamma radiation by lead. Before starting the investigation, she determines the background count.

Which of the following does **not** affect the background count?

☒ **A** the count time

☒ **B** the location

☒ **C** the temperature

☒ **D** the type of detector

**(Total for Question 7 = 1 mark)**

**8** Mars has approximately 8 times the mass of the Moon.

Mars has twice the diameter of the Moon.

The value of $g$ on the surface of the Moon is $1.6\,\text{N kg}^{-1}$.

What is the value of $g$ on the surface of Mars?

☒ **A** $0.8\,\text{N kg}^{-1}$

☒ **B** $1.6\,\text{N kg}^{-1}$

☒ **C** $3.2\,\text{N kg}^{-1}$

☒ **D** $6.4\,\text{N kg}^{-1}$

**(Total for Question 8 = 1 mark)**

**9** Two gas cylinders have the same volume. One cylinder contains nitrogen gas. The other cylinder contains oxygen gas.

Both gases are at the same temperature and pressure.

Which of the following statements is **not** correct?

☒ **A** Each cylinder contains the same number of molecules.

☒ **B** The average molecular kinetic energy is the same for each gas.

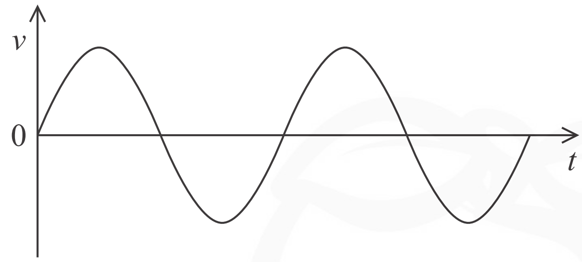
☒ **C** The density of gas is the same in each cylinder.

☒ **D** The internal energy is the same for each gas.

**(Total for Question 9 = 1 mark)**

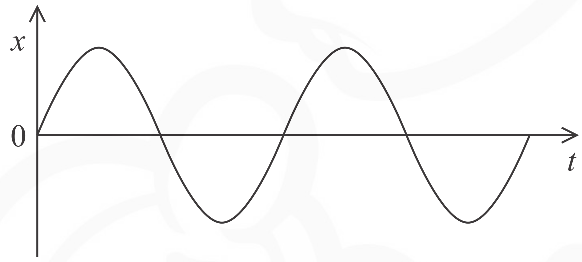
**10** A particle is undergoing simple harmonic motion.

The graph shows how the velocity $v$ varies with time $t$ for the particle.

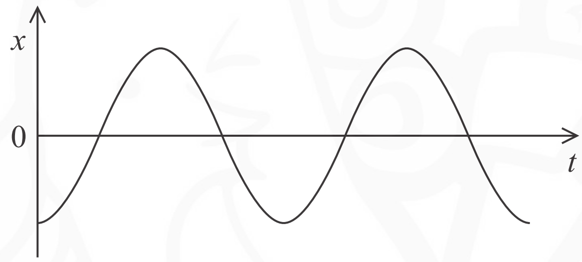



Which of the following graphs shows how the displacement $x$ varies with $t$ during the same time interval?

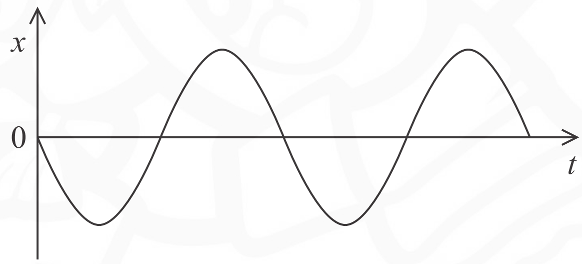
☒ **A**



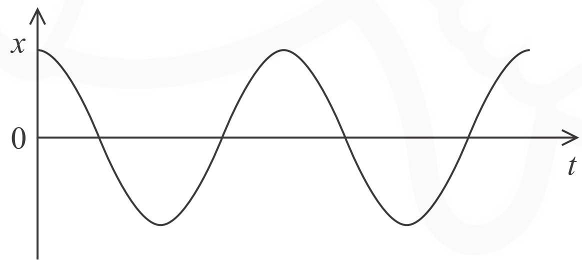

☒ **B**




☒ **C**




☒ **D**




**(Total for Question 10 = 1 mark)**

**TOTAL FOR SECTION A = 10 MARKS**

## SECTION B

**Answer ALL questions in the spaces provided.**

**11** A nucleus of rhenium-187 decays to a nucleus of osmium by emitting a $\beta^-$ particle.

(a) Complete the nuclear equation for the decay of rhenium-187.

**(2)**

$$^{187}_{75}\text{Re} \rightarrow {}^{\dots}_{\dots}\text{Os} + {}^{\dots}_{\dots}\beta^- + {}^{0}_{0}\overline{\nu}$$

(b) The energy released in the decay is 2.6 keV. You may assume that, in this case, the beta particle receives all the emitted energy.

Calculate the speed of a $\beta^-$ particle emitted in this decay.

**(3)**

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Speed of $\beta^-$ particle = ..........................................

**(Total for Question 11 = 5 marks)**

**12** An airbag is a safety feature used in cars.

Nitrogen gas is released into an airbag. The airbag inflates to a volume of $7.08 \times 10^{-2}\,m^3$.
The pressure of gas in the inflated airbag is $1.24 \times 10^5$ Pa.

(a) Show that the number of molecules of nitrogen gas released into the airbag is about $2 \times 10^{24}$.

temperature of gas in airbag = 25 °C

**(3)**

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(b) Nitrogen gas escapes from small holes in the inflated airbag. The pressure decreases to $3.45 \times 10^4$ Pa.

Calculate the number of nitrogen molecules that escape from the airbag.

The volume and temperature remain constant.

**(2)**

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Number of nitrogen molecules that escape = ..............................................

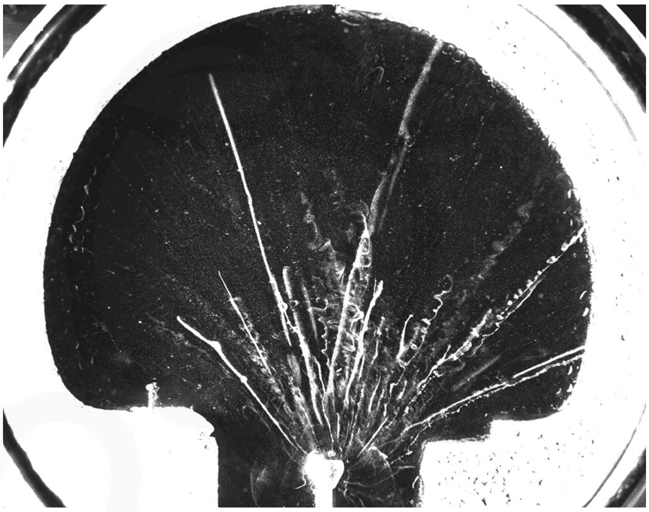
**(Total for Question 12 = 5 marks)**

**13** A cloud chamber is used to show the tracks of alpha particles and beta particles.

These particles ionise the air as they pass through the chamber.

Liquid droplets form around the ions. The droplets form visible tracks, as shown.

View from above



(Source: © sciencephotos/Alamy Stock Photo)

A student makes the following observations:

- the alpha particle tracks are thick and straight
- the beta particle tracks are thin and twisted.

Explain these observations.

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**(Total for Question 13 = 4 marks)**

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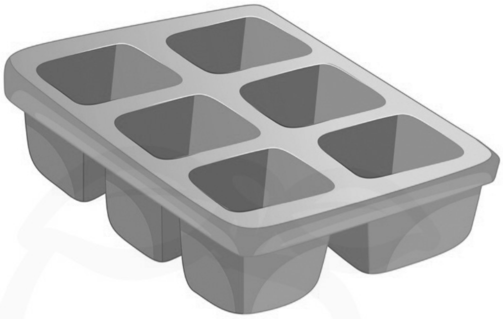
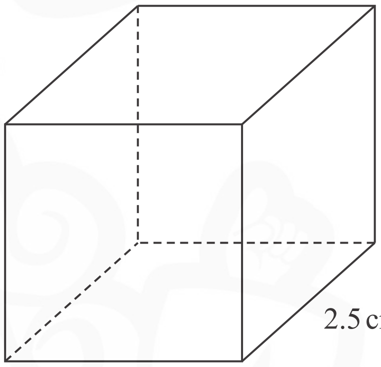
**14** Ice cubes can be made in an ice cube tray. One type of ice cube tray is shown.



(Source: © GraphicsRF.com/Shutterstock)

Each compartment in the ice cube tray has dimensions 2.5 cm by 2.5 cm by 3.5 cm, as shown.




(a) Show that the mass of water needed to fill one compartment is about 0.02 kg.

density of water = $1.00 \times 10^3\,\text{kg}\,\text{m}^{-3}$

**(3)**

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(b) All 6 compartments in the ice cube tray are filled with water to a depth of 3.5 cm. The ice cube tray is placed in a freezer.

The initial temperature of the water is 22.5 °C.

It takes 12 minutes for all the water to become ice at 0 °C.

The manufacturer of the freezer states that the freezer can transfer energy at a rate of 110 W.

Evaluate whether energy is transferred from the water in the tray at a rate of 110 W.

specific heat capacity of water = $4180\,J\,kg^{-1}\,K^{-1}$
specific latent heat of fusion of water = $3.34 \times 10^{5}\,J\,kg^{-1}$

**(4)**

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**(Total for Question 14 = 7 marks)**

**15** Doctors can use ultrasound to monitor the heartbeat of a baby when it is developing inside the mother.

(a) A baby's heart was beating at 142 beats $minute^{-1}$. The wall of the baby's heart was moving with a maximum velocity of $22.0\,mm\,s^{-1}$.

Calculate the maximum displacement, in mm, of the wall of the baby's heart. Assume that the motion of the wall of the baby's heart is simple harmonic.

**(4)**

Maximum displacement of wall of heart = .................................... mm

(b) The motion of the wall of the baby's heart only approximates to simple harmonic.

State what is meant by simple harmonic motion.

**(2)**

**(Total for Question 15 = 6 marks)**

**16** A nucleus of thorium-230 is unstable and decays to a nucleus of radium-226 by emitting an alpha particle.

The table shows the masses of the particles involved.

| | **Mass / u** |
|---|---|
| Thorium-230 nucleus | 230.0331 |
| Radium-226 nucleus | 226.0254 |
| Alpha particle | 4.0026 |

(a) Determine the energy, in J, released when a nucleus of thorium-230 emits an alpha particle.

**(4)**

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Energy released = .................................................. J

(b) Determine the time taken, in years, for 90% of the thorium-230 in a sample to decay to radium-226.

half-life of thorium-230 = 75 400 years

**(4)**

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Time taken = .................................................. years

**(Total for Question 16 = 8 marks)**

**17** In France, scientists from many countries are working together to build the International Thermonuclear Experimental Reactor (ITER).

(a) On the ITER website it states:

"Fusion is the energy source of the Sun and stars. In the core of these stellar bodies, hydrogen nuclei fuse into helium nuclei and release tremendous amounts of energy."

Explain why energy is released when hydrogen nuclei fuse to form helium nuclei.

**(2)**

(b) It is hoped that the ITER will be the first fusion device on Earth to maintain nuclear fusion for long periods of time.

To achieve fusion in the ITER, a hot plasma is used.

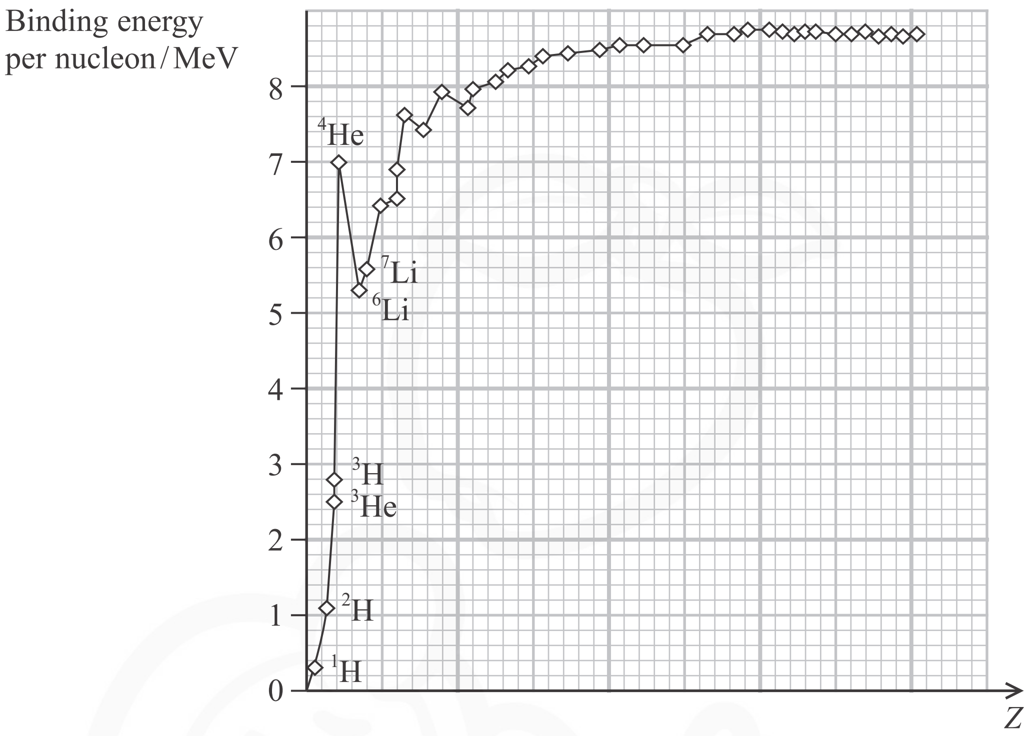
The plasma must

- be at an extremely high temperature
- have sufficient density for fusion.

Explain why each of these two conditions must be met.

**(4)**

(c) The graph shows the variation of binding energy per nucleon with proton number $Z$.




In one possible fusion reaction, a nucleus of $^{2}H$ fuses with a nucleus of $^{3}H$.

A nucleus of $^{4}He$ and a free neutron are produced as shown in the following nuclear equation.

$$^{2}H + {}^{3}H \rightarrow {}^{4}He + {}^{1}n$$

Determine the energy, in MeV, released when a nucleus of $^{2}H$ fuses with a nucleus of $^{3}H$.

**(3)**

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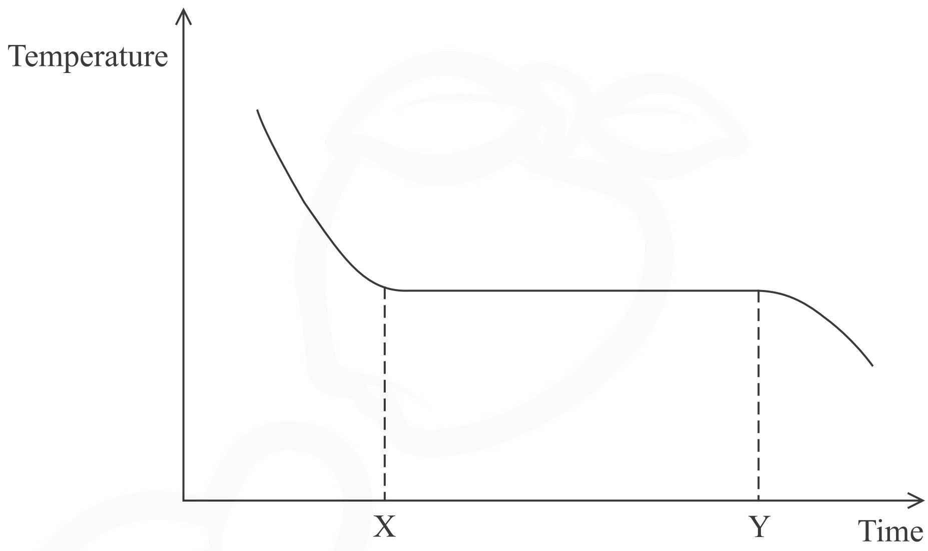
Energy released = .............................................. MeV

**(Total for Question 17 = 9 marks)**

***18** Wax is heated until the temperature is above the melting point of the wax. The hot wax is poured into a bowl and allowed to cool.

The graph shows how the temperature of the wax varies with time as it cools.




Describe how the internal energy of the wax changes as the wax cools.

You should refer to the energy of the wax molecules as the liquid wax cools and becomes solid, and the solid wax cools.

Times X and Y have been included to help you refer to the graph.

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**(Total for Question 18 = 6 marks)**

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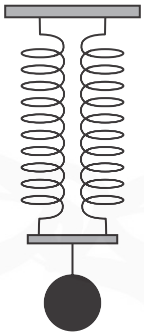
**19** A student hangs a mass of 0.22 kg from two identical springs as shown.



She displaces the mass vertically and the mass oscillates with simple harmonic motion.

(a) The student measures the time $t$ for the mass to complete 30 oscillations. She repeats this measurement.

Her measurements are given in the table.

| $t_1$ / s | $t_2$ / s |
|---|---|
| 13.65 | 13.70 |

The springs are taken from a box labelled $k = 21\,\text{N}\,\text{m}^{-1}$.

Deduce whether the value of $k$ stated on the label is correct.

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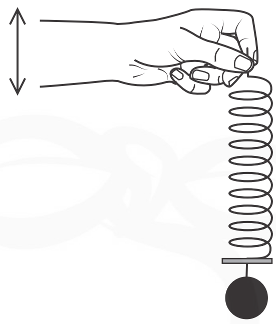
(b) The student attaches the mass to one spring and holds the other end. She sets the mass into oscillation by oscillating her hand vertically, as shown.



The student increases the frequency at which she oscillates her hand. She keeps the amplitude of oscillation of her hand constant.

She observes that the amplitude of oscillation of the mass increases to a maximum and then decreases.

(i) Explain this observation.

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(ii) The student makes the following conclusion:

"As the frequency is increased, the amplitude of the mass increases to a maximum, so energy conservation does not apply to this situation."

Explain whether her conclusion is correct.

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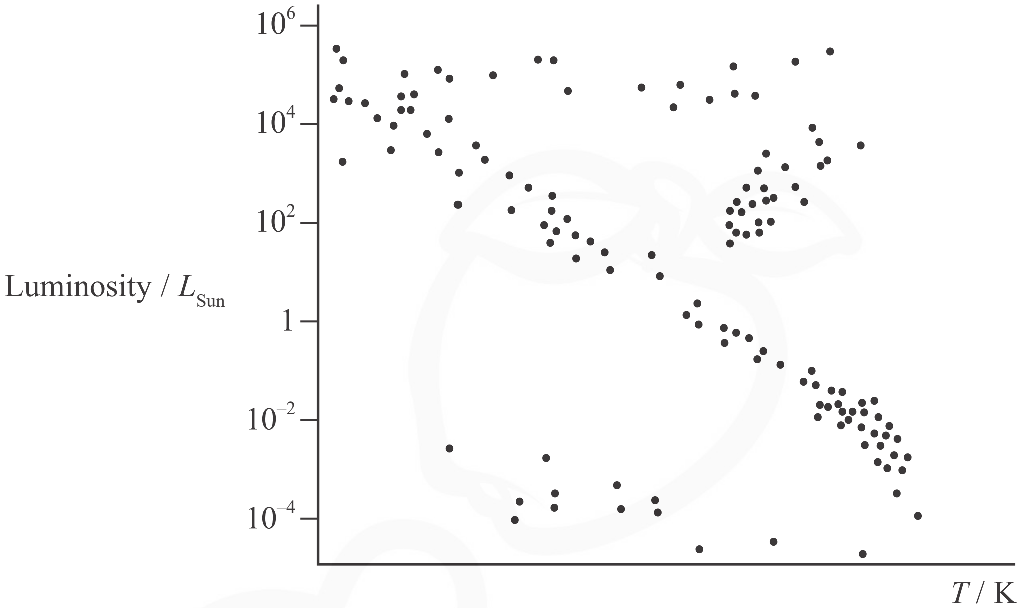
**(Total for Question 19 = 10 marks)**

**20** The Hertzsprung-Russell diagram for a star cluster is shown.




(a) Add a scale to the horizontal axis.

**(2)**

(b) Explain how this Hertzsprung-Russell diagram shows that the star cluster is not a young star cluster.

You should refer to groups of stars and their positions on this diagram.

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(c) In the early 20th century, Edwin Hubble observed the Andromeda Nebula. He saw stars similar to the stars in our galaxy.

One star he saw was a standard candle known as V1.

Describe how measurements of this standard candle could demonstrate that the Andromeda Nebula is **not** a nearby star cluster.

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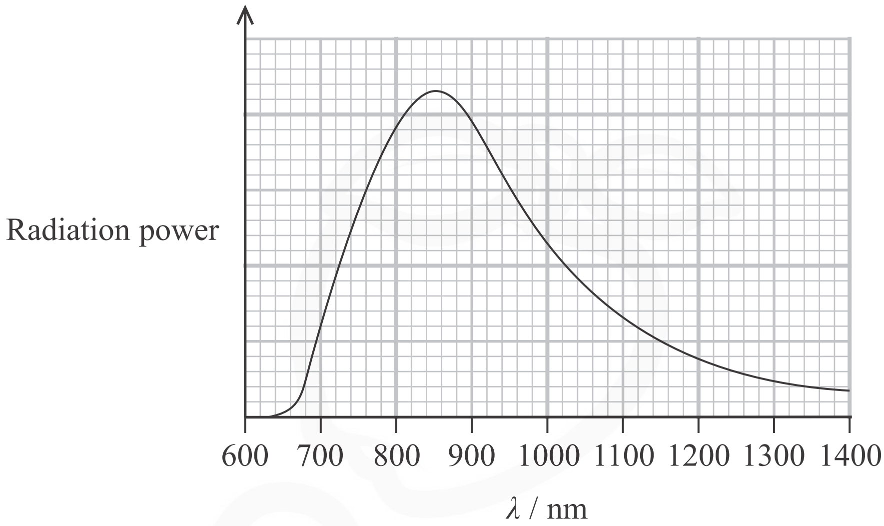
**(Total for Question 20 = 9 marks)**

**21** Ross-154 is one of the closest stars to the Sun. The graph shows how the power radiated from Ross-154 depends upon wavelength $\lambda$.




(a) (i) Show that the surface temperature of Ross-154 is about 3000 K.

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(ii) A website states that the luminosity of Ross-154 is less than 0.5% of the luminosity of the Sun, $L_{Sun}$.

Evaluate whether this statement is correct.

radius of Ross-154 = $1.18 \times 10^{8}$ m
$L_{Sun} = 3.83 \times 10^{26}$ W

**(5)**

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(b) Scientists have observed an Earth-type planet in orbit around Ross-154. The radius of the orbit is 0.096 AU.

Calculate the time for this planet to make one orbit of Ross-154.

1 AU = $1.50 \times 10^{11}$ m
mass of Ross-154 = $3.38 \times 10^{29}$ kg

**(3)**

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Time for one orbit = ........................................................

**(Total for Question 21 = 11 marks)**

**TOTAL FOR SECTION B = 80 MARKS**
**TOTAL FOR PAPER = 90 MARKS**

## List of data, formulae and relationships

| | | |
|---|---|---|
| Acceleration of free fall | $g = 9.81 \text{ m s}^{-2}$ | (close to Earth's surface) |
| Boltzmann constant | $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$ | |
| Coulomb's law constant | $k = 1/4\pi\varepsilon_0$ | |
| | $= 8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$ | |
| Electron charge | $e = -1.60 \times 10^{-19} \text{ C}$ | |
| Electron mass | $m_e = 9.11 \times 10^{-31} \text{ kg}$ | |
| Electronvolt | $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$ | |
| Gravitational constant | $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ | |
| Gravitational field strength | $g = 9.81 \text{ N kg}^{-1}$ | (close to Earth's surface) |
| Permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ | |
| Planck constant | $h = 6.63 \times 10^{-34} \text{ J s}$ | |
| Proton mass | $m_p = 1.67 \times 10^{-27} \text{ kg}$ | |
| Speed of light in a vacuum | $c = 3.00 \times 10^{8} \text{ m s}^{-1}$ | |
| Stefan-Boltzmann constant | $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$ | |
| Unified atomic mass unit | $u = 1.66 \times 10^{-27} \text{ kg}$ | |

***Unit 1***

*Mechanics*

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

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

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

Momentum

$$p = mv$$

Moment of force

$$\text{moment} = Fx$$

Work and energy

$$\Delta W = F\Delta s$$

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

$$\Delta E_{grav} = mg\Delta h$$

Power

$$P = \frac{E}{t}$$

$$P = \frac{W}{t}$$

Efficiency

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

*Materials*

Density $$\rho = \frac{m}{V}$$

Stokes' law $$F = 6\pi\eta rv$$

Hooke's law $$\Delta F = k\Delta x$$

Elastic strain energy $$\Delta E_{el} = \frac{1}{2}F\Delta x$$

Young modulus $$E = \frac{\sigma}{\varepsilon} \text{ where}$$

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$



P 7 3 4 6 0 R A 0 2 5 3 2

***Unit 2***

*Waves*

| | |
|---|---|
| Wave speed | $v = f\lambda$ |
| Speed of a transverse wave on a string | $v = \sqrt{\frac{T}{\mu}}$ |
| Intensity of radiation | $I = \frac{P}{A}$ |
| Refractive index | $n_1 \sin\theta_1 = n_2 \sin\theta_2$ |
| | $n = \frac{c}{v}$ |
| Critical angle | $\sin C = \frac{1}{n}$ |
| Diffraction grating | $n\lambda = d\sin\theta$ |

*Electricity*

| | |
|---|---|
| Potential difference | $V = \frac{W}{Q}$ |
| Resistance | $R = \frac{V}{I}$ |
| Electrical power, energy | $P = VI$ |
| | $P = I^2R$ |
| | $P = \frac{V^2}{R}$ |
| | $W = VIt$ |
| Resistivity | $R = \frac{\rho l}{A}$ |
| Current | $I = \frac{\Delta Q}{\Delta t}$ |
| | $I = nqvA$ |
| Resistors in series | $R = R_1 + R_2 + R_3$ |
| Resistors in parallel | $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ |

*Particle nature of light*

| | |
|---|---|
| Photon model | $E = hf$ |
| Einstein's photoelectric equation | $hf = \phi + \frac{1}{2}mv^2_{max}$ |
| de Broglie wavelength | $\lambda = \frac{h}{p}$ |

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***Unit 4***

*Further mechanics*

| | |
|---|---|
| Impulse | $F\Delta t = \Delta p$ |
| Kinetic energy of a non-relativistic particle | $E_k = \dfrac{p^2}{2m}$ |
| Motion in a circle | $v = \omega r$ |
| | $T = \dfrac{2\pi}{\omega}$ |
| | $a = \dfrac{v^2}{r}$ |
| | $a = r\omega^2$ |
| Centripetal force | $F = ma = \dfrac{mv^2}{r}$ |
| | $F = mr\omega^2$ |

*Electric and magnetic fields*

| | |
|---|---|
| Electric field | $E = \dfrac{F}{Q}$ |
| Coulomb's law | $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ |
| | $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ |
| | $E = \dfrac{V}{d}$ |
| Electrical potential | $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ |
| Capacitance | $C = \dfrac{Q}{V}$ |
| Energy stored in capacitor | $W = \frac{1}{2}QV$ |
| | $W = \frac{1}{2}CV^2$ |
| | $W = \frac{1}{2}\dfrac{Q^2}{C}$ |
| Capacitor discharge | $Q = Q_0 e^{-t/RC}$ |

Resistor-capacitor discharge

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = Bqv \sin \theta$$

$$F = BIl \sin \theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$$

*Nuclear and particle physics*

In a magnetic field

$$r = \frac{p}{BQ}$$

Mass-energy

$$\Delta E = c^2 \Delta m$$

***Unit 5***

*Thermodynamics*

| | |
|---|---|
| Heating | $\Delta E = mc\Delta\theta$ |
| | $\Delta E = L\Delta m$ |
| Ideal gas equation | $pV = NkT$ |
| Molecular kinetic theory | $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ |

*Nuclear decay*

| | |
|---|---|
| Mass-energy | $\Delta E = c^2\Delta m$ |
| Radioactive decay | $A = \lambda N$ |
| | $\frac{dN}{dt} = -\lambda N$ |
| | $\lambda = \frac{\ln 2}{t_{1/2}}$ |
| | $N = N_0 e^{-\lambda t}$ |
| | $A = A_0 e^{-\lambda t}$ |

*Oscillations*

| | |
|---|---|
| Simple harmonic motion | $F = -kx$ |
| | $a = -\omega^2 x$ |
| | $x = A\cos\omega t$ |
| | $v = -A\omega\sin\omega t$ |
| | $a = -A\omega^2\cos\omega t$ |
| | $T = \frac{1}{f} = \frac{2\pi}{\omega}$ |
| | $\omega = 2\pi f$ |
| Simple harmonic oscillator | $T = 2\pi\sqrt{\frac{m}{k}}$ |
| | $T = 2\pi\sqrt{\frac{l}{g}}$ |

*Astrophysics and cosmology*

| | |
|---|---|
| Gravitational field strength | $g = \dfrac{F}{m}$ |
| Gravitational force | $F = \dfrac{Gm_1m_2}{r^2}$ |
| Gravitational field | $g = \dfrac{Gm}{r^2}$ |
| Gravitational potential | $V_{grav} = \dfrac{-Gm}{r}$ |
| Stefan-Boltzmann law | $L = \sigma AT^4$ |
| Wien's law | $\lambda_{max}T = 2.898 \times 10^{-3}\,\mathrm{m\,K}$ |
| Intensity of radiation | $I = \dfrac{L}{4\pi d^2}$ |
| Redshift of electromagnetic radiation | $z = \dfrac{\Delta\lambda}{\lambda} \approx \dfrac{\Delta f}{f} \approx \dfrac{v}{c}$ |
| Cosmological expansion | $v = H_0 d$ |

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