Please check the examination details below before entering your candidate information

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

Centre Number | Candidate Number

# Pearson Edexcel International Advanced Level

## Monday 15 January 2024

Afternoon (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*

P75599A

S:1/1/1/

P 7 5 5 9 9 A 0 1 3 2

## SECTION A

**Answer ALL questions.**

**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** Ice at 0 °C melts into water at 0 °C.

Which row of the table gives the changes in mean molecular kinetic energy and mean molecular potential energy as the ice melts?

| | | **Mean molecular kinetic energy** | **Mean molecular potential energy** |
|---|---|---|---|
| ☒ | **A** | no change | no change |
| ☒ | **B** | no change | increases |
| ☒ | **C** | increases | no change |
| ☒ | **D** | increases | increases |

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

**2** Astronomers can use stellar parallax to determine the distances to stars.

Which of the following statements is correct?

☒ **A** Measurements are made against more distant stars.

☒ **B** Stellar parallax can only be used for distant stars.

☒ **C** The luminosity of the star must be constant.

☒ **D** The parallax effect is greatest for the most distant stars.

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

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

**3** The mass of a muon is 0.113 u.

Which of the following is equal to the equivalent mass-energy, in joules, of the muon?

☒ **A** $0.113 \times (3.0 \times 10^8)^2$

☒ **B** $\dfrac{0.113}{(3.0 \times 10^8)^2}$

☒ **C** $0.113 \times (3.0 \times 10^8)^2 \times 1.66 \times 10^{-27}$

☒ **D** $0.113 \times (3.0 \times 10^8)^2 \times 1.67 \times 10^{-27}$

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

---

**4** A mass is oscillating with simple harmonic motion.

Which of the following statements about the acceleration of the mass is correct?

☒ **A** The acceleration is always in the opposite direction to the velocity.

☒ **B** The acceleration is always in the same direction as the velocity.

☒ **C** The acceleration is always away from the equilibrium position.

☒ **D** The acceleration is always towards the equilibrium position.

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

---

**5** Which of the following correctly describes the spontaneous nature of radioactive decay?

☒ **A** Radioactive decay is a natural process.

☒ **B** Radioactive decay is a random process.

☒ **C** We cannot influence when the decay will occur.

☒ **D** We cannot predict when the next decay will occur.

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

---

**6** The planet Mercury orbits the Sun in an elliptical orbit. As a result, the speed of Mercury varies as it orbits the Sun.

Which row of the table shows how the speed and gravitational potential energy of Mercury change as Mercury approaches the Sun?

| | Gravitational potential energy | Speed |
|---|---|---|
| ☒ **A** | decreases | decreases |
| ☒ **B** | decreases | increases |
| ☒ **C** | increases | decreases |
| ☒ **D** | increases | increases |

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

**7** A mass oscillates with simple harmonic motion. The mass has an angular velocity of $2\,\text{rad}\,\text{s}^{-1}$ and a maximum velocity of $10\,\text{cm}\,\text{s}^{-1}$.

Which of the following gives the magnitude of the amplitude $A$ of the oscillation in cm?

☒ **A** $A = \frac{2}{10}$

☒ **B** $A = \frac{10}{2}$

☒ **C** $A = \frac{2\sin 2t}{10}$

☒ **D** $A = \frac{10}{2\sin 2t}$

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

**8** A mixture of helium gas and hydrogen gas is kept at room temperature.

Which of the following is correct?

☒ **A** The mean kinetic energy of the helium molecules is greater than the mean kinetic energy of the hydrogen molecules.

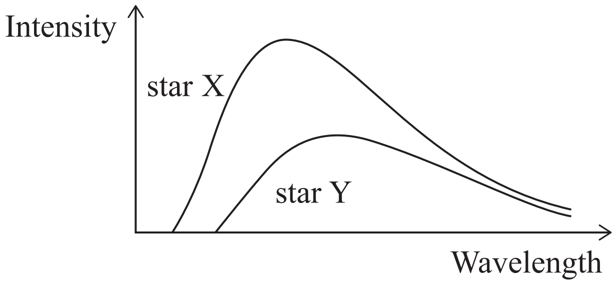
☒ **B** The mean kinetic energy of the helium molecules is less than the mean kinetic energy of the hydrogen molecules.

☒ **C** The mean square velocity of the helium molecules is greater than the mean square velocity of the hydrogen molecules.

☒ **D** The mean square velocity of the helium molecules is less than the mean square velocity of the hydrogen molecules.

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

9 The graphs show how the radiation intensity varies with wavelength for star X and star Y.
The surface temperature of star X is $T_X$ and the surface temperature of star Y is $T_Y$.




Which of the following statements is correct?

- ☒ **A** $T_Y > T_X$ because the peak intensity for star Y is at the lower frequency.
- ☒ **B** $T_Y > T_X$ because the peak intensity for star Y is at the higher frequency.
- ☒ **C** $T_X > T_Y$ because the peak intensity for star X is at the lower frequency.
- ☒ **D** $T_X > T_Y$ because the peak intensity for star X is at the higher frequency.

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

10 The Earth has 10 times the mass of Mars and twice the radius of Mars.

The gravitational field strength at the surface of the Earth is $g_E$.
The gravitational field strength at the surface of Mars is $g_M$.

Which of the following gives the relationship between $g_E$ and $g_M$?

- ☒ **A** $g_E = 2.5\,g_M$
- ☒ **B** $g_E = 5\,g_M$
- ☒ **C** $g_M = 2.5\,g_E$
- ☒ **D** $g_M = 5\,g_E$

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

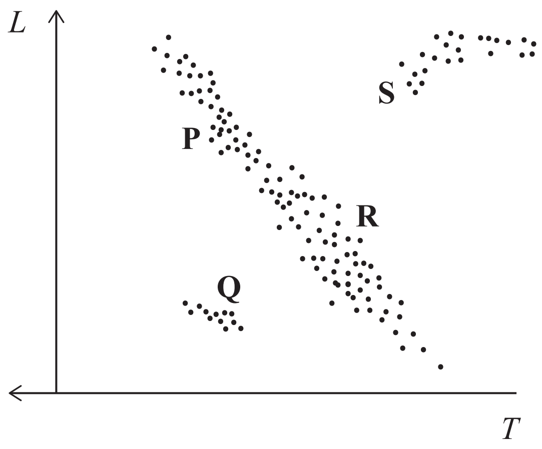
**TOTAL FOR SECTION A = 10 MARKS**

## SECTION B

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

**11** The Hertzsprung–Russell diagram below shows some groups of stars.

**P**, **Q**, **R** and **S** refer to different areas on the diagram.




Describe a possible evolutionary path for stars originally in area **P**.

For each stage in the path, you should refer to the type of star.

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

**(Total for Question 11 = 3 marks)**

**12** A simple pendulum has a period of 2.00 s on Earth.

Calculate what the period would be if the pendulum was on the planet Venus.

mass of Venus = $4.87 \times 10^{24}$ kg
radius of Venus = $6.05 \times 10^{6}$ m

Period on Venus = ........................................

**(Total for Question 12 = 4 marks)**

**13** A particular line in the spectrum of light from a source in the laboratory has a frequency of $6.173 \times 10^{14}$ Hz. The same line in the spectrum of light from a distant galaxy has a frequency of $6.142 \times 10^{14}$ Hz.

Deduce what can be concluded about the distant galaxy.

You should include a calculation.

.......................................................................................................................................................................................................

.......................................................................................................................................................................................................

.......................................................................................................................................................................................................

.......................................................................................................................................................................................................

.......................................................................................................................................................................................................

.......................................................................................................................................................................................................

**(Total for Question 13 = 3 marks)**

**14** A tyre on a racing bicycle contains nitrogen at a temperature of 22 °C. The nitrogen in the tyre has a volume of $2.85 \times 10^{-4}\,m^3$. The pressure of the nitrogen in the tyre is $5.75 \times 10^5\,Pa$.

Nitrogen is pumped into the tyre. The volume of the tyre remains constant. The total mass of nitrogen in the tyre, including the added nitrogen, is 2.00 g.

Calculate the increase in pressure of the nitrogen in the tyre. Assume that the temperature remains constant.

mass of a nitrogen molecule = $4.67 \times 10^{-26}\,kg$

Increase in pressure of nitrogen = ....................

**(Total for Question 14 = 5 marks)**

**15** A teacher used liquid nitrogen to demonstrate low temperature physics.

The teacher dropped a peeled banana at room temperature into a flask of liquid nitrogen.

(a) Explain why the liquid nitrogen boiled when the banana was submerged in the liquid nitrogen.

**(2)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

(b) During the demonstration, the liquid nitrogen remained at its boiling point in a large flask. The teacher estimated that at least 0.5 kg of liquid nitrogen was needed to cool the banana from room temperature to the temperature of the liquid nitrogen.

Assess the accuracy of the teacher's estimate.

latent heat of vaporisation of nitrogen = $1.98 \times 10^{5}\,\mathrm{J\,kg^{-1}}$
boiling point of liquid nitrogen = 77.4 K
specific heat capacity of banana = $1.76 \times 10^{3}\,\mathrm{J\,kg^{-1}\,K^{-1}}$
mass of banana = 0.118 kg
room temperature = 292 K

**(3)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

**(Total for Question 15 = 5 marks)**

**16** Pluto is a dwarf planet in the outer regions of our solar system. Pluto moves in an approximately circular path around the Sun. The mean radius of the orbit is $5.91 \times 10^{12}$ m.

(a) Calculate the intensity of radiation from the Sun incident on Pluto.

radius of Sun = $6.96 \times 10^{8}$ m
surface temperature of Sun = 5800 K

**(4)**

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

Intensity of radiation from Sun incident on Pluto = ..............................................

(b) Calculate the time, in years, that Pluto takes to make one complete orbit of the Sun.

1 year = $3.15 \times 10^{7}$ s
mass of Sun = $1.99 \times 10^{30}$ kg

**(4)**

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

........................................................................................................................................

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

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

DO NOT WRITE IN THIS AREA

**17** Skylab was an early space station that orbited the Earth. Skylab contained a Body Mass Measurement Device. This device was a chair connected to a stiff spring.

(a) Astronauts in orbit about the Earth are sometimes described as 'weightless', although they do experience a weight force.

Explain why astronauts may be described as 'weightless'.

**(2)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

(b) The spring was tested without oscillating. A force of 175 N was applied to the spring and the spring deformed by 28.9 cm.

When no one was sitting in the chair, the chair oscillated with a period of 0.858 s. When one of the astronauts sat in the chair, the chair oscillated with a period of 2.26 s.

Calculate the mass of the astronaut.

**(5)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

Mass of astronaut = ..............................................

**(Total for Question 17 = 7 marks)**

BLANK PAGE

**18** Kruger 60 is a binary star system quite close to the Sun.

(a) The wavelength, $\lambda_{max}$ , at which the intensity of radiation is a maximum is 850 nm for Kruger A and 1500 nm for Kruger B.

A website states that the surface temperature of Kruger A is double the surface temperature of Kruger B.

Assess whether the website statement is accurate.

**(3)**

(b) Kruger B can be used as a standard candle.

Describe how standard candles can be used to determine the distance to galaxies.

**(4)**

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

(c) NGC 1357 is a spiral galaxy moving away from the Milky Way at a speed of $2.02 \times 10^6\,\mathrm{m\,s^{-1}}$. The spiral galaxy is $8.70 \times 10^{23}\,\mathrm{m}$ from the Earth.

Calculate a value for the age of the universe in years.

1 year = $3.15 \times 10^7\,\mathrm{s}$

**(4)**

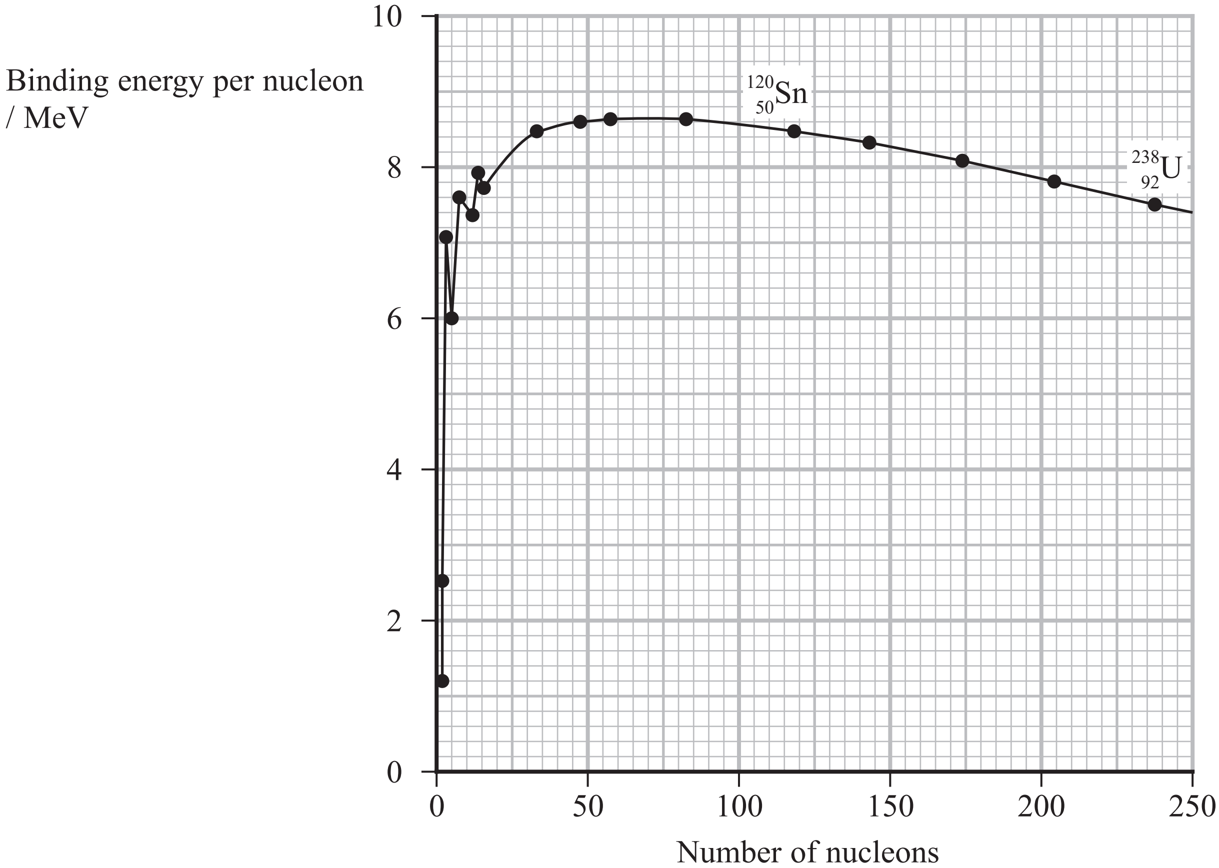
Age of universe = .................................... years

**(Total for Question 18 = 11 marks)**



P 7 5 5 9 9 A 0 1 5 3 2

**19** The graph shows how the binding energy per nucleon varies with number of nucleons.








P 7 5 5 9 9 A 0 1 6 3 2

(a) Explain why energy is released when a nucleus undergoes fission.

**(2)**

(b) A nucleus of $^{238}U$ undergoes fission. One of the fission products is Sn.

Estimate the energy, in MeV, released in the fission.

You should use values from the graph.

**(3)**

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

(c) One fission product is strontium–90.

(i) Complete the nuclear equation for the decay of strontium–90.

**(2)**

$$^{90}_{38}\mathrm{Sr} \rightarrow \;^{\cdots}_{\cdots}\mathrm{Y} + \;^{\cdots}_{\cdots}\beta^{-} + \;^{0}_{0}\overline{\nu}_{e}$$

(ii) In Georgia, in December 2001, some men discovered two small canisters in a forest. The canisters were hot and had melted surrounding snow. The canisters were later identified as containing $^{90}$Sr.

The activity due to the $^{90}$Sr in one canister was measured as $1.295 \times 10^{15}$ Bq.

Calculate the rate of energy release, in watts, due to the $^{90}$Sr in this canister.

energy released in each decay = 0.546 MeV

**(3)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

Rate of energy release in this canister = .............................................. W

(iii) The authorities claimed that the canisters were 50 years old. The activity of each canister when new was $3.700 \times 10^{15}$ Bq.

Assess the accuracy of the claim.

half-life of $^{90}$Sr = 28.8 years

**(3)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

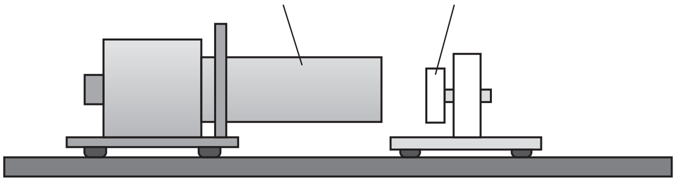
..............................................................................................................................................

..............................................................................................................................................

**(Total for Question 19 = 13 marks)**

**20** The penetration of nuclear radiation through materials depends upon the ionising power of the radiation.

(a) A teacher tested an unknown radioactive source. He set up the source and a GM tube, as shown.




The initial count rate is determined without an absorber between the GM tube and the source.

When an aluminium sheet of thickness 0.5 cm was placed between the source and the GM tube, the count rate decreased to background level.

The teacher then removed the aluminium sheet and replaced it with a sheet of paper. There was no change in the initial count rate.

Explain which type of radiation is emitted from the source.

You should refer to the penetration of each type of radiation through each sheet of absorber.

**(4)**

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

..........................................................................................................................................

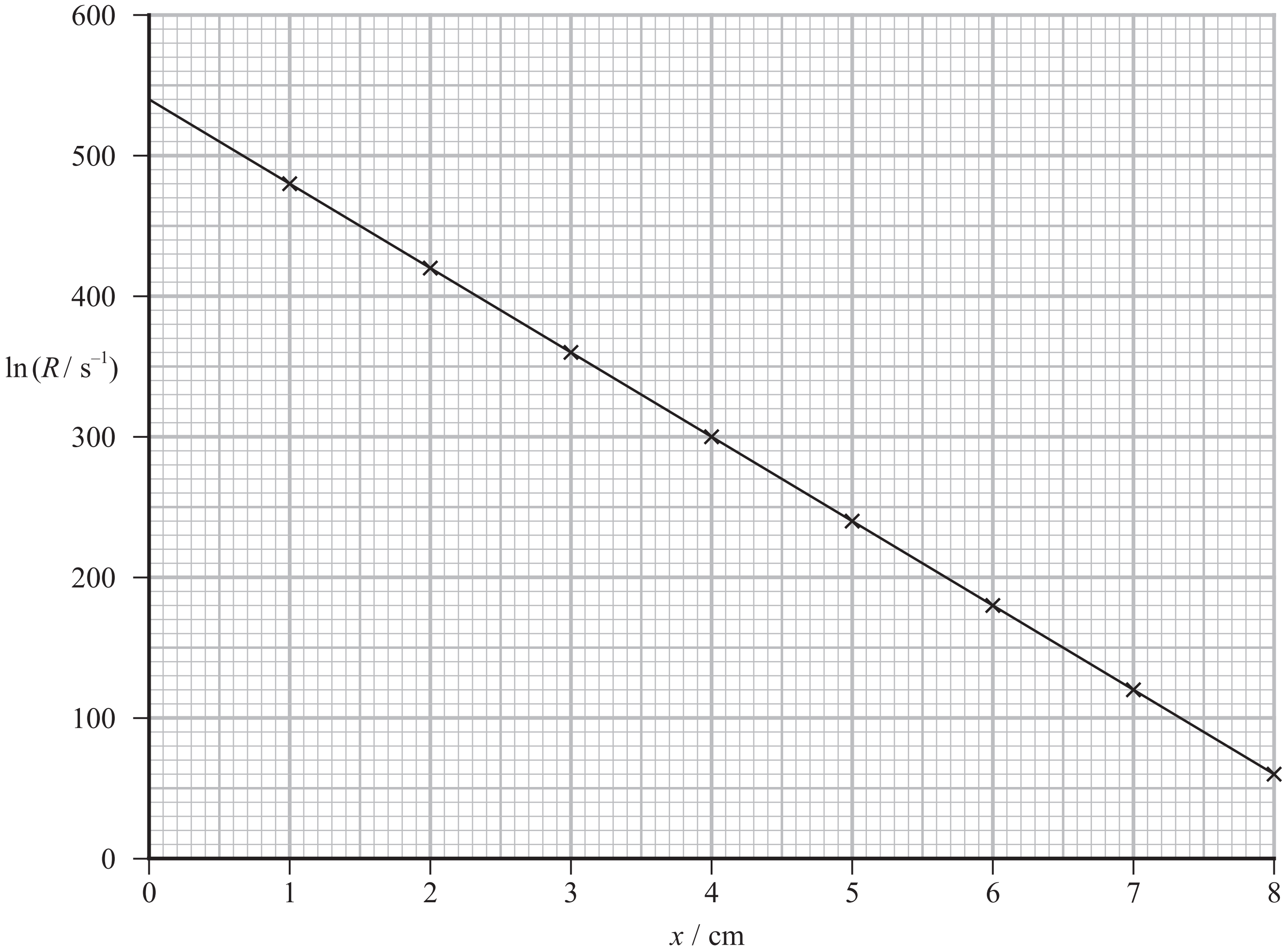
..........................................................................................................................................

(b) The count rate $R$ recorded after gamma radiation has passed through a thickness $x$ of lead is given by

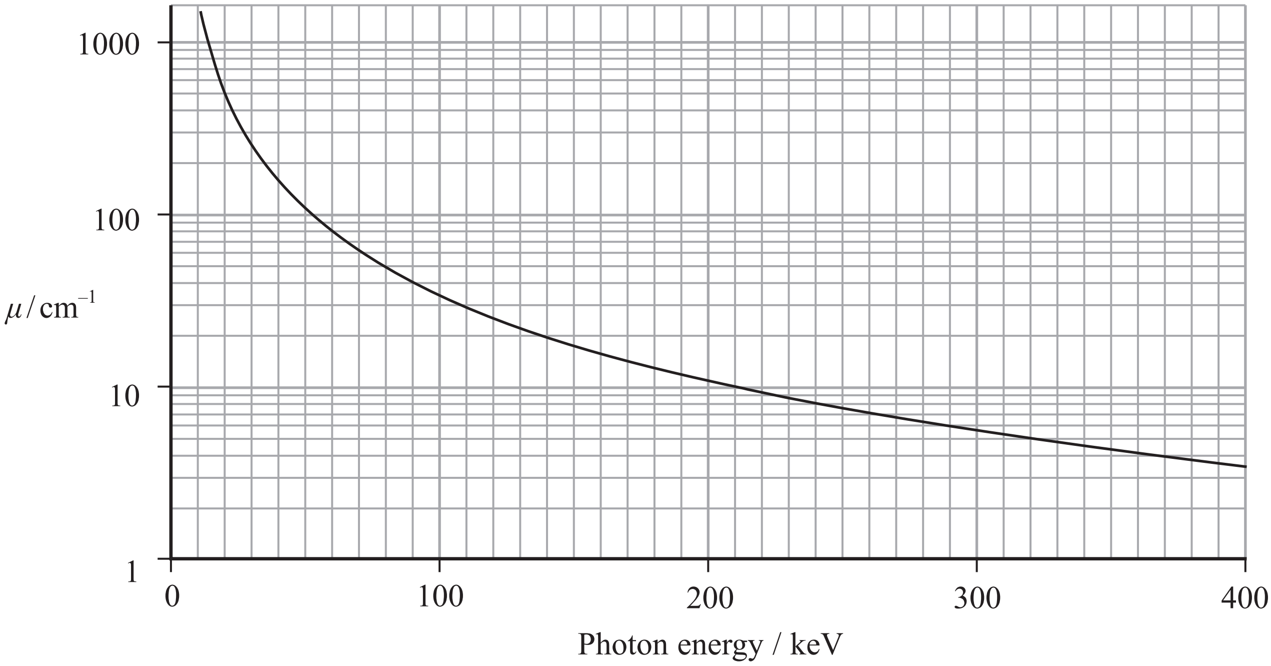
$$R = R_0 e^{-\mu x}$$

where $R_0$ is the count rate with no absorber present, and $\mu$ depends upon the energy of the gamma ray photons.

The graph below shows how $\ln R$ varies with $x$ for a particular source of gamma radiation.



The graph below shows how the value of $\mu$ depends upon the gamma photon energy.




The table shows some sources and their associated photon energy.

| Source | Photon energy / keV |
|---|---|
| $^{133}Xe$ | 80 |
| $^{57}Co$ | 122 |
| $^{133}Ba$ | 360 |

Deduce which source was used for the investigation.

**(5)**

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

..............................................................................................................................................

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

**21** In the core of a main sequence star, nuclear fusion is converting hydrogen into helium.

*(a) Explain the conditions required to bring about and maintain fusion in a main sequence star.

**(6)**

(b) A helium nucleus is a particularly stable nucleus, consisting of 2 protons and 2 neutrons.

(i) Calculate the binding energy per nucleon, in J, of a helium nucleus.

mass of proton = 938.28 MeV / $c^2$
mass of neutron = 939.57 MeV / $c^2$
mass of helium nucleus = 3727.6 MeV / $c^2$

**(4)**

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

Binding energy per nucleon of a helium nucleus = .............................................................. J

(ii) The binding energy per nucleon of helium is relatively large.

Explain why this makes the helium nucleus particularly stable.

**(2)**

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

........................................................................................................................................................................................................

**(Total for Question 21 = 12 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 $E = \frac{\sigma}{\varepsilon}$ where

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

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

***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 | $\lambda = \frac{h}{p}$ |

**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 | $W = \dfrac{1}{2}QV$ |
| | $W = \dfrac{1}{2}CV^2$ |
| | $W = \dfrac{1}{2}\dfrac{Q^2}{C}$ |
| 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 $\Delta E = c^2 \Delta m$

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

***Unit 5***

*Thermodynamics*

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

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

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA DO NOT WRITE IN THIS AREA

**BLANK PAGE**



P 7 5 5 9 9 A 0 3 1 3 2

**BLANK PAGE**