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Examiners' Report
June 2023

International Advanced Level Physics WPH15 01

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June 2023

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Introduction

The assessment structure of WPH15 mirrors that of WPH14. It consists of 10 multiple choice questions, a number of short answer questions and some longer, less structured questions.

As it is an A2 assessment unit, synoptic elements are incorporated into this paper. There is overlap with circular motion and exponential variation in Unit 4, but also overlap with some of the AS content from Units 1 and 2.

The paper includes the use of specific command words as detailed in the specification, Appendix 9: Taxonomy. It is recommended that centres ensure that their students understand what is required when responding to such questions. In this paper where the command word was deduced, evaluated, or assessed, the final mark could sometimes not be awarded on otherwise good responses because a final appropriate comment was missing.

Candidates should be encouraged to read questions carefully to ensure that their responses take into account all the relevant information. Section B questions are set in context. Candidates should be aware that the context of the physics in which the question is set and all supplementary information provided are essential for a complete response that could gain full marks.

Candidates should be encouraged to work with mark schemes in preparation for their exam. However, it is important that they understand that mark schemes do not provide model answers to questions. Mark schemes are written for examiners, and so sometimes refer to what examiners expect to see rather than giving a complete answer.

Question 11 (a)

Nearly all candidates knew that the nucleon number (A) of a β^- particle is zero, and so gained the mark for a correct top line. Most candidates knew that the proton number of a β^- particle is −1, but some struggled to balance the proton numbers (Z), with a common wrong value of 76 being given for the proton number of Re.

Question 11 (b)

This was a straightforward question for candidates to answer, and most scored full marks. For those not scoring full marks a common error was to use $\Delta E = c^2 \Delta m$ to calculate the mass and then to use that value in the expression for kinetic energy. A few candidates used the proton mass. This was acceptable for the initial “use of” mark.

Question 12 (a-b)

12(a) was generally well answered, although a few candidates did not convert the temperature to kelvin.

In 12(b) most candidates knew how to calculate the new number of molecules, but some candidates omitted to calculate the difference and so left the calculation incomplete.

A small number of candidates used the equation $pV = nRT$, but this is not an equation included on our specification. A correct answer using this equation would score full marks, but this requires candidates to remember a value for the Avogadro constant, which some candidates attempting this method did not.

This response scores full marks for both parts of the question.

12 An airbag is a safety feature used in cars.

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

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

temperature of gas in airbag = 25 °C

(3)

$1.24 \times 10^5\,\text{Pa} \times 7.08 \times 10^{-2}\,\text{m}^3 = N \times 1.38 \times 10^{-23}\,\text{J K}^{-1}$

$\times (25 + 273.15)\,\text{K}$

$N = 2.13 \times 10^{24}$

$\simeq 2 \times 10^{24}$

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

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

The volume and temperature remain constant.

(2)

$3.45 \times 10^4\,\text{Pa} \times 7.08 \times 10^{-2}\,\text{m}^3 = N \times 1.38 \times 10^{-23}\,\text{J K}^{-1}$

$\times (25 + 273.15)\,\text{K}$ $\quad N = 5.94 \times 10^{23}$

$2.13 \times 10^{24} - 5.94 \times 10^{23} = 1.536 \times 10^{24}$

Number of nitrogen molecules that escape = 1.534×10^{24}

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Examiner Comments

In (a) a correct substitution into *pV* = *nKT* is made and the correct answer is obtained.

In (b) the correct answer is obtained by using the equation a second time to calculate the final number of molecules in the air bag.

This response scores full marks for both parts of the question.

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 1.24×10^5 Pa.

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

temperature of gas in airbag = 25 °C

(3)

$pV = NkT$

$N = \frac{pV}{kT}$

$N = \frac{1.24 \times 10^5 Pa \times 7.08 \times 10^{-2} m^3}{1.38 \times 10^{-23} \times (25 + 273)}$

$N = 2.13 \times 10^{24}$ molecules.

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

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

The volume and temperature remain constant.

(2)

$1.24 \times 10^5 Pa \longrightarrow 2.13 \times 10^{24}$ molecules.

$3.45 \times 10^4 Pa \longrightarrow \frac{2.13 \times 10^{24}}{1.24 \times 10^5} \times 3.45 \times 10^4$

$3.45 \times 10^4 Pa \longrightarrow 5.93 \times 10^{23}$ molecules.

no. of molecules that escaped = $2.13 \times 10^{24} - 5.93 \times 10^{23} = 1.54 \times 10^{24}$

Number of nitrogen molecules that escape = 1.54×10^{24}

ResultsPlus
Examiner Comments

In (a) a correct substitution into $pV = nKT$ is made and the correct answer is obtained.

In (b) the correct answer is obtained, although it is not immediately clear that the ratio of the numbers of molecules has been equated to the ratio of the pressures.

ResultsPlus
Examiner Tip

Always make it clear which equations you are using.

Question 13

Full marks were rare for this question and the mean mark was close to 2, which is surprising. Differentiating correctly between the effects of the two properties was rarely seen, even when candidates had learnt the physics. In many responses there was a tendency to write everything down at once and the importance of separating causes and effect was not appreciated.

Some attributed both effects to one cause, e.g. “alpha particles are more ionising so their tracks are thick and straight”, whereas others combined causes as well as effects e.g. “alpha particles are more ionising and heavier so their tracks are thick and straight”.

In weaker responses the comparison between ionising power and mass was given, and this could score 2 marks.

Inaccurate reference to ‘ionisation energy’ or ‘ionisability’ were seen, and some candidates seemed to think that the alpha particles are highly ionised.

Stronger responses might give some detail on conservation of momentum, which pointed toward MP3/4, but these marks scored less well than MP1/2 because a reference to momentum required more detail to be included.

The zigzaggedness of the track was often related to velocity or kinetic energy and not mass.

Many thought an E or B field was present and tried to answer in terms of $r = p/Bq$. Others thought the particles would attract each other.

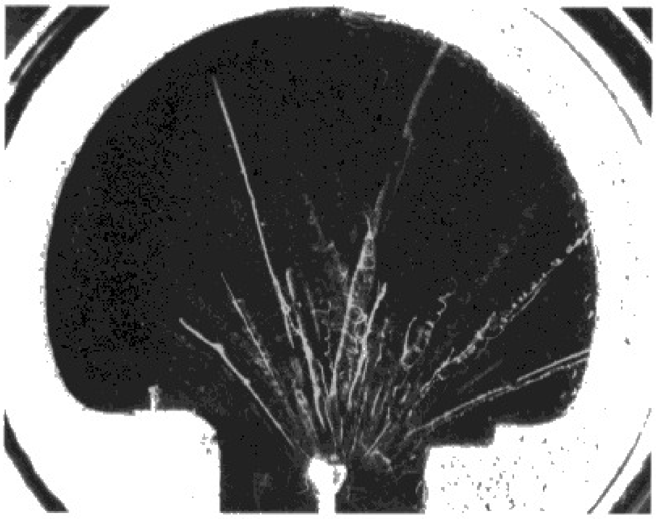
This response is typical of responses gaining 2 marks.

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.

Alpha particles are highly ionising and so are weakly penetrating - have a short range. Therefore, they ionised by greater amounts and the tracks got thicker. Having a short range means they could not travel further and this made the track straight (uniform).

Beta particles are weakly ionising (than alpha) and so have a greater range. They travelled further, allowing them to change path/direction so the tracks are twisted. Being weakly ionising, they could only ionise a few particles and the tracks are thin.

ResultsPlus
Examiner Comments

There is a reference to the thickness of the tracks being related to the ionizing ability of the particles, so MP1 is awarded.

The responses states that alpha particles are highly ionizing, whereas beta particles are weakly ionizing, so MP2 is awarded.

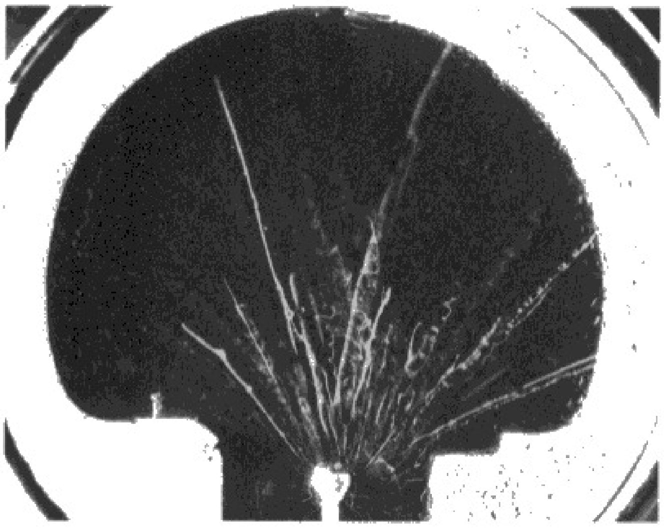
Nothing creditable relating to the shape of the tracks is stated, and so neither MP3 nor MP4 is awarded.

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.

The alpha particles ionise ~~as~~ air particles as they move through the chamber, ~~as they~~ they have more ionisation energy than beta ~~par~~ particle tracks as ~~apl~~ alpha particles are a helium ~~ne~~ nucleus they also have more mass so ~~as~~ as they ionise more they have thick tracks and ~~as~~ as they are heavier they have a straight track whereas Beta particles ~~are~~ are less ionising so thinner tracks and less ~~ka~~ mass so they become twisted bumping into air molecules

(Total for Question 13 = 4 marks)

ResultsPlus
Examiner Comments

There is enough in this response for all 4 marks to be awarded.

ResultsPlus
Examiner Tip

Always use the correct technical terms as identified in the specification.

Question 14 (a-b)

(a) Is a ‘show that’ question and some working is expected for the calculation even if full substitutions are not given. However, quite a few candidates did not show their full working for the volume calculation. There were too many instances of candidates giving their final answer as 0.02kg, i.e to the same significant figures as the ‘show that’ value.

In (b) most candidates used all three equations correctly, and so got the first three marking points. Some hadn’t factored in the six when calculating the mass. In a few responses the mass wasn’t linked to (a), and so there was an attempt to calculate the mass again.

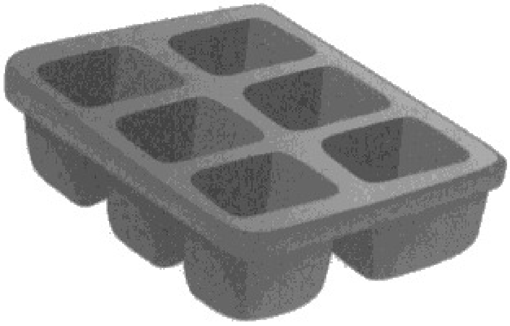
A small number of candidates did not include both contributions to ΔE, with the latent heat value being the more likely to be forgotten. A smaller number of candidates subtracted one energy value from the other.

Full marks for (b) were much less common than full marks for (a). MP4 was the problem for many, insufficient comment was given for an ‘evaluate’ question. “Evaluate whether…” was frequently understood to require the calculation of the actual (effective) power; but in many minds, the result of the calculation made reference to the incorrect 110 W value superfluous.

It was more common for them to try to calculate the power than do a comparison of the energy values.

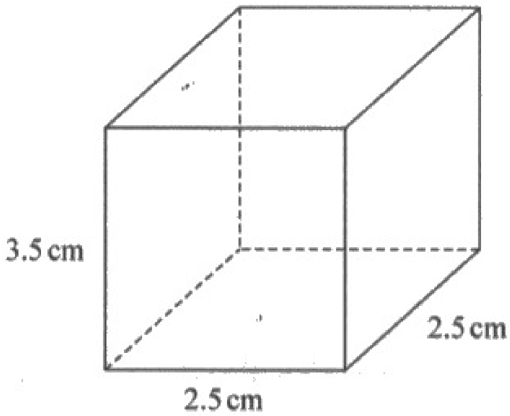
This response gains full marks for both parts of the question.

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 = 1.00×10^3 kg m^{-3}

(3)

$d = \frac{m}{V}$ $V = 0.025 \cdot 0.035 \cdot 0.025$

$dV = m$

$1.00 \times 10^3 \cdot 0.025 \cdot 0.035 \cdot 0.025 = m$

$m = 0.022$ kg

(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 = 3.34×10^5 J kg^{-1}

(4)

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

$E_1 = 6 \cdot 0.021875 \cdot 4180 \cdot (22.5 - 0)$

$P = \frac{mc\Delta T + mL}{t}$

$E_1 = 12344.0625$

$E_2 = 6 \cdot 0.021875 \cdot 3.34 \times 10^5$

$E_2 = 43837.5$

$P = \frac{12344.0625 + 43837.5}{12 \cdot 60}$

$P = 78.0\ \text{W}$

78 ~~6~~ < 110 W hence it does not transfer at a rate of 110 W

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Examiner Comments

In (a) full working is shown, and the answer is given to 2 significant figures. This is the minimum required here, as the 'show that' value is given to 1 significant figure.

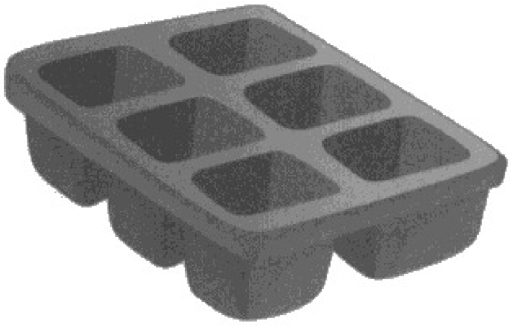
In (b) the rate of energy transfer is compared with 110 W, and a correct conclusion made.

ResultsPlus
Examiner Tip

In a 'show that' question you must give your final answer to at least one more significant figure than the value quoted in the question.

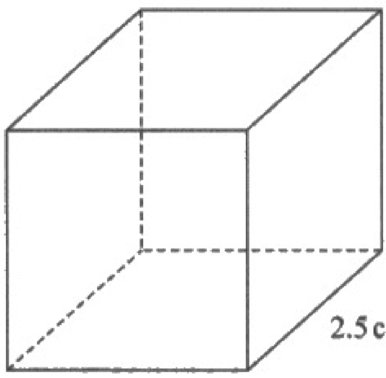
This response gains full marks for both parts of the question.

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 = $1.00 \times 10^3 \text{ kg m}^{-3}$

(3)

Volume = $2.5 \times 10^{-2} \times 3.5 \times 10^{-2} \times 2.5 \times 10^{-2}$

= 2.1875×10^{-5}

density = $\frac{\text{mass}}{\text{volume}}$

mass = $1 \times 10^3 \times 2.1875 \times 10^{-5}$

= 0.021875 kg

(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. • full mass

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 = $3.34 \times 10^5\,J\,kg^{-1}$ → melt

(4)

Total E = Power × time
Acc. to Freezer Power

= 12 × 60 × 110

= 79 200 J

E = mc ΔT

= 6(0.021875) × 4180 × (0 − 22.5)

= ~~2057.34 J~~ −12344.0625

~~DLat~~. E = ΔmL

= −6 × 0.021875 × 3.34 × 10^5

= −43837.5 J

(Total for Question 14 = 7 marks)

Total energy = 43837.5 + ~~2057.34~~ 12344.0625

= ~~56181.5~~ 56181.5625 J

As the total energy ~~requir~~ actually ~~required~~ transferred is less than the total energy that should be transfered acc. to a power of 110W for 12 minutes, the actual rate is less than 110 W

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Examiner Comments

Full marks were obtained for (a).

In (b) the total energy transferred is compared with the total energy transferred at a rate of 110 W, and a correct conclusion made.

Question 15 (a)

Candidates performed well on this question with about half the entry scoring full marks. However, for those responses that did not score full marks, this was often due to not knowing the difference between frequency and period. Other common errors were not realising that sin $\omega t = 1$ at maximum amplitude, and giving the final answer in metres not mm.

So many fractions were seen in candidate's responses. This is despite it being clear that many candidates have only a weak grasp of fractions. Candidates who tried putting vulgar fractions as denominators rarely obtained a correct answer. It is recommended that in future examinations candidates use decimals rather than fractions.

Too many very large values for the amplitude were seen. Candidates should have stopped to think about their value of displacement to consider whether it was a reasonable value for a baby's heart.

As there was some potential debate as to whether the displacement referred to in the question was the displacement from the equilibrium position or the displacement from one extreme position to the other, numerical answers in mm matching the value of A or $2A$ were accepted.

This response gained full 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)

$f = \frac{142}{60} = 2.37\ Hz$

$f = \frac{\omega}{2\pi} \Rightarrow \omega = 2.37 \times 2\pi = 14.89$

$V = -A\omega$

$A = \frac{0.022}{14.89} = 1.48 \times 10^{-3}\ m$

$x = A\cos\omega t = 1.48 \times 10^{-3} \times$ ~~cos(14.89~~ $1 = 1.48 \times 10^{-3}\ m$

Maximum displacement of wall of heart = 1.48 mm

ResultsPlus
Examiner Comments

A correct value for the amplitude has been calculated, and this is given as the maximum displacement (from the equilibrium position).

This response gained full 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)

142 ÷ 60 = 2.366 Hz

V = Aω   ω = 2πf

22 x 10^{-3} ~~22~~ = A(14.866)   ω = 2π (2.366)

~~A = 1.479~~   ω = 14.866

$\frac{22 \times 10^{-3}}{14.866}$ = A

= 1.47 x 10^{-3} x 2 = 2.959 x 10^{-3}

Maximum displacement of wall of heart = 2.959 ~~x 10^{-3}~~ mm

ResultsPlus
Examiner Comments

A correct value for the amplitude has been calculated, and this has been doubled to give the maximum displacement (from extreme position to extreme position). Note that the displacement was initially given in SI units, but then converted into mm as required by the question.

Question 15 (b)

This question has been asked many times in various contexts, but it still elicits a mixed response. Candidates sometimes referred to displacement but not where the displacement is measured from, and acceleration (or resultant force) toward equilibrium, and not toward the equilibrium position. For this reason it was common for responses to score just 1 mark. Candidates need to remember that the displacement must be from the equilibrium position, and that the acceleration (or resultant force) is always towards the equilibrium position.

(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)

The acceleration is directly proportional to the displacement ~~an~~ From the equilibrium position and always acts toward the equilibrium position.

ResultsPlus
Examiner Comments

This question scores both marks succinctly.

Question 16 (a)

Many good responses were seen to this question. Calculation of mass difference was generally well done as was use of $\Delta E = c^2 \Delta m$. A few candidates multiplied by the mass of the proton rather than using the correct conversion for *u*.

This response scores all 4 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

230.0280 → $0.0051u$

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

(4)

$\Delta m = 230.0331 - (226.0254 + 4.0026)$

$\Delta m = 0.0051u$

$\Delta m = 0.0051 \times 1.66 \times 10^{-27}$

$\Delta m = 8.466 \times 10^{-30}$ kg.

$E = \Delta m c^2$.

$E = 8.466 \times 10^{-30} \times (3 \times 10^8)^2$

$E = 7.62 \times 10^{-13}$ J.

Energy released = 7.62×10^{-13} J

ResultsPlus
Examiner Comments

The working is clearly set out, so that each stage of the calculation can be clearly seen.

This response scores all 4 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)

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

$= (230.0331 - 226.0254 - 4.0026) \times 1.66 \times 10^{-27} \times (3 \times 10^8)^2$

$= 7.62 \times 10^{-13}$ J

Energy released = 7.62×10^{-13} J

ResultsPlus
Examiner Comments

The calculation is carried out all in one go. Although this is not a problem when the final answer is correct, it could make it difficult for 'use of' marks to be awarded if an incorrect final answer were to be obtained.

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Examiner Tip

Always show each step in a calculation clearly.

Question 16 (b)

Some candidates only calculated the decay constant and didn't know what to do next. Some candidates wasted time by converting years to seconds and then converted back again at the end. This caused more than one candidate to make a slip and so get the final answer incorrect. Candidates should be aware that when using the exponential equation, as long as *t* and *l* are in complementary units, there is no need to convert to SI units of time.

Some candidates attempted to work out how many half-lives had elapsed by using powers of 2. Unfortunately 10% is not an integer multiple of half-lives and so the answer obtained was inaccurate unless candidates were aware of how to use logs to determine a non-integer value for the number of half-lives.

There were problems for some candidates caused by using 90% as the ratio in the exponential equation, where 10% should have used. Many candidates thought that after 250,553 years the extra 0.3 years was also important to state. Unless it is a 'show that' question, significant figures is not considered. However, candidates should be encourage not to write down all the figures from their calculator display.

This response was awarded all 4 marks.

(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)

$0.1 = e^{-\frac{\ln(2)}{75400} \times t}$ $\quad \frac{\ln 2}{75400} = 9.19293 \times 10^{-6}$

$\ln(0.1) = -9.19293 \times 10^{-6} t$ $\quad t = \frac{\ln(0.1)}{-9.19 \times 10^{-6}}$ $\quad t = 250473.4$ years.

$t \approx 250500$ years.

Time taken = 250473.4 years

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The value of half life used to calculate a value for the decay constant is in years, so the decay constant has units year $^{-1}$. This is fine, as the time taken for the decay is required in years.

This response was awarded all 4 marks.

(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)

$N = N_0 \cdot e^{-\lambda t}$, ~~$\lambda = \frac{\ln 2}{75400 \cdot 12 \cdot 30 \cdot 60 \cdot 60} =$~~

$\lambda = \frac{\ln 2}{75400 \cdot 365 \cdot 24 \cdot 60 \cdot 60}$, $\lambda = 2.92 \cdot 10^{-13}$

$N \div N_0 = 0.1$ $\quad 0.1 = e^{-\lambda t}$, $0.1 = e^{-2.92 \cdot 10^{-13} \cdot t}$

$\ln(0.1) = -2.92 \cdot 10^{-13} \cdot t$, $t = 7.89 \cdot 10^{12}$ s

$t = 250050$ years

Time taken = 250050 years

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Examiner Comments

The value of half life used to calculate a value for the decay constant has been converted into seconds. This means that the time for the decay is obtained in seconds, and so this has to be converted back into years for the final answer. This is done correctly in this response, but a number of responses were seen in which the time conversion was carried out incorrectly.

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Examiner Tip

If the equation $A = \lambda N$ is used, λ must be in s^{-1}. Otherwise, λ and t just need to be in complementary units.

Question 17 (a)

This was not particularly well answered. MP1 could be gained in various ways; for example by mentioning 'mass defect' or 'mass deficit'. However, many candidates didn't describe the mass difference the correct way round for MP1 e.g. by stating mass difference but not saying that the mass decreases. Few went on to use mass decrease as the basis for an explanation and gain MP2.

This response scores both 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)

when hydrogen nuclei fuses to form helium, ~~binding e~~ there is a mass defect, and this change in mass is converted to energy, according to mass-energy equivalence, $\Delta E = \Delta mc^2$.

ResultsPlus
Examiner Comments

The response refers to mass defect and the 'equivalence' of mass and energy.

This response scores both 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)

It is because the when Hydrogen nuclei fuses to form Helium nuclei so binding energy per nucleon increases. So mass decreases and this mass is converted ~~intt~~ into the energ released as $\Delta E = \Delta mc^2$

ResultsPlus
Examiner Comments

The response refers to the increase in binding energy *per nucleon* when fusion of low mass nuclei takes place.

ResultsPlus
Examiner Tip

Always use the correct technical terms as identified in the specification.

Question 17 (b)

Many candidates struggled to reach the level of detail required by the mark scheme, even though similar questions in different contexts have been set a number of times previously. Only a very few gave enough relevant detail to score full marks.

Examples of essential detail that was often not seen in candidates responses include:

- Kinetic energy, not just energy.
- Electrostatic repulsion, not just repulsion.
- Close enough to fuse, not just close enough.
- Rate of collision, not just number of collisions.
- Missing rate, not high but sufficient

The question is expressed in terms of the release of energy when hydrogen nuclei fuse to form helium nuclei. It was expected that candidates would pick up on the use of the word nuclei and use this in their explanation. However, there were many references to particles, atoms, and even molecules. A reference to protons rather than hydrogen nuclei was fine.

This response gained full marks.

(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)

High temperature is required so the nuclei can have enough kinetic energy to overcome the electrostatic repulsion force, so nuclei can be close enough to fuse.

Sufficient density is required to maintain high collision rate between nuclei.

ResultsPlus
Examiner Comments

The response is succinct, and says enough for the first 4 marking points to be awarded.

This response gained full marks.

(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)

Sufficient kinectic energy is needed to overcome the repulsion caused by electrostatic force between protons.
High temperature can increase the kinetic energy of protons.
High density is required to provide sufficient collision rate to make fusion occurs.
High temperature provide kinetic energy and allow protons be closed to each other and close enough to fuses.

ResultsPlus
Examiner Comments

The response refers to protons rather than nuclei, but this is fine in the context of the question. There is enough here for the first 4 marking points to be awarded.

Question 17 (c)

Most candidates were able to read two correct values from the graph, but not all of these could calculate binding energies for two (or more) nuclides. Most candidates did not understand the relation between the superscript numbers in the nuclear equation and the values on the y axis, even though an understanding of the binding energy per nucleon graph is a specification item.

Question 18

The six mark linkage question is a challenging form of assessment. Candidates should be encouraged to plan out their response before they begin to write. The best responses seen had evidence of this.

The question asks candidates to describe how the internal energy of the wax changes as the wax cools. However, there is an important hint given that many candidates missed. Candidates are asked to refer to the energy of the wax molecules as the liquid wax cools and becomes solid, and as the solid wax cools.

A minority associated internal (as well as kinetic) energy with temperature, which led some to say that PE increases when KE decreases to keep total energy (internal energy) constant. Others said that internal energy did fall, but only before X and after Y, i.e. when the temperature was decreasing.

Many candidates referred to wax particles. Given that the question refers to wax molecules it was expected that this would be the term that candidates would use.

A summary of the key points in terms of the indicative content points is outlined below:

IC1 Most did not survive their whole explanation with this intact. It was not uncommon to see internal energy rising between X and Y, staying constant or no mention of internal energy beyond the initial cooling at all. Some confused internal energy with potential energy, and some related this to temperature.

IC2 Often no mention of molecules anywhere but common to see a internal energy = kinetic energy + potential energy

IC3 Probably the most likely mark, as there were two places on the curve to score it. Many candidates referred to losing kinetic energy.

IC4 Many thought that potential energies increased (“*as energy is used to form bonds”)* and this often cancelled any credit for IC1 as well, as this often led to the statement that internal energy would rise between X and Y.

IC5 Scored well

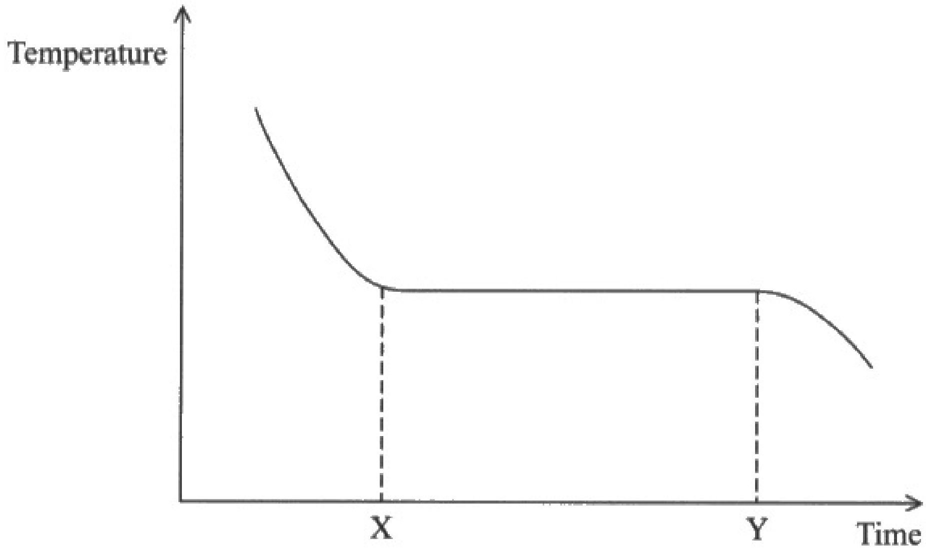
IC6 was often not stated.

Some candidates didn’t refer to the graph at all, others just described the graph in very basic terms.

In the six mark linkage question there are 4 marks for indicative content and 2 marks for logical sequencing of ideas. This response scores all 6 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.

· Before X, the temperature falls and the molecular kinetic energy is gradually decreasing. The internal energy is decreasing.
~~· Between X and Y~~ · After reaching the melting point at t = X, the wax begin to solidify. ~~However~~

· However, temperature remains unchanged between T = X and T = Y. so the molecular kinetic energy is constant. But as it ~~releases~~ solidifies, the molecular potential energy falls and wax molecules are closer together. so the internal energy falls as well

· After t = Y, the wax is all solid and temperature drops again, leading to fall in molecular kinetic energy. The structure of wax is unchanged, so the molecular potential energy remains the same. The internal energy decreases

· In general, Internal energy = molecular kinetic energy + molecular potential energy

ResultsPlus
Examiner Comments

All six indicative content points are included. IC1 is not stated exactly as in the mark scheme, but can be inferred from the reference to internal energy decreasing seen in the response at each stage of the cooling process.

ResultsPlus
Examiner Tip

Plan your response to an extended open response question so that you are clear which points you are going to make before you start writing your response.

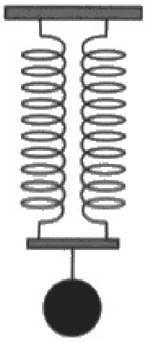
Question 19 (a)

There were problems with fractions for some candidates who got t_{mean} upside down. A significant number that did end up with 41.8 Nm^{-1}, thought that was the end and their comment was that the label was incorrect. Those candidates that did manage to get to 20.9 Nm^{-1} sometimes failed to give a comment about the label.

There were some attempts at reverse reasoning from k = 21 Nm^{-1} which almost invariably did not include the factor of 2 and they could not make good sense of their time period.

This response scored full marks.

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.

30 : 13 s
1 : x
30x = 13

t_1 / s	t_2 / s
13.65	13.70

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

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

(4)

mean $t = \frac{13.65 + 13.7}{2} = 13.675 = 13.68$ s

$T = \frac{13.68 \text{ s}}{30} = 0.456$ s

$T = 2\pi\sqrt{\frac{m}{k}}$

$0.456 = 2\pi\sqrt{\frac{0.22}{k}}$

$0.072.. = \sqrt{\frac{0.22}{k}}$

$5.26.. \times 10^{-3} = \frac{0.22}{k}$

K of one spring = 20.9 N/m

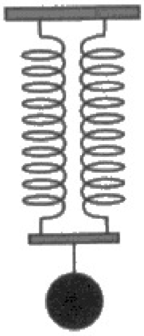
so value is correct as 20.9 N/m

k = 41.79 N/m for the two springs together. is ≈ 21 N/m

ResultsPlus
Examiner Comments

Each step in the calculation is shown, and there is a correct value linked to a valid conclusion.

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

5.26×10^{-3}

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

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

(4)

~~$T = 2\pi\sqrt{\frac{m}{k}}$~~ $T = \left(\frac{13.65 + 13.7}{2}\right) \div 30$

$T = \frac{547}{1200}$ s

Thus each spring has a k value of $20.9\,\mathrm{N\,m^{-1}}$ so the label is correct

$T = 2\pi\sqrt{\frac{m}{k}}$

$\frac{547}{1200} = 2\pi \times \sqrt{\frac{0.22}{k}}$ $\frac{547}{1200 \times 2\pi}$

$k = \frac{0.22 \times (2400\pi)^2}{(547)^2}$

$= 41.8\,\mathrm{N\,m^{-1}}$ (3 s.f.) but it has 2 springs

ResultsPlus Examiner Comments

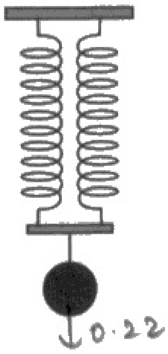
Each step in the calculation is shown, but the order is a little random.

ResultsPlus Examiner Tip

Always set your work out in a logical sequence.

This response scored 3 marks, as it was incomplete.

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.

$T = 2\pi\sqrt{\frac{m}{k}}$

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.

(4)

average Time → $\frac{13.65 + 13.70}{2} = 13.675$ s

Time taken fore 1 occillation = $547/1200$ s

$T = 2\pi\sqrt{\frac{m}{k}}$ → $\frac{547}{1200} = 2\pi\sqrt{\frac{0.22}{k}}$

$\frac{547}{1200} = 2\pi\sqrt{\frac{0.11}{k}}$

$k = 20.8997$

$k \approx 21\ \text{Nm}^{-1}$ //

ResultsPlus
Examiner Comments

Each step in the calculation is shown, and there is a correct value calculated, but no conclusion is given.

ResultsPlus
Examiner Tip

Be sure to write a full conclusion for assess/deduce/evaluate questions.

Question 19 (b)(i)

The majority of responses referred to resonance, and the majority of these candidates were familiar with the concept of maximum energy transfer. A few candidates discussed maximum amplitude rather than maximum energy transfer.

Very few candidates mentioned both a driving frequency and the natural frequency of the mass-spring system for MP1. Amongst those who recognised that this was an example of resonance, the main problem was in not moving from recall of a general principle (“driver frequency matches natural frequency [of driven system]”) to a principle fully applied to the physical context (“driving frequency of hand matches natural frequency of the mass-spring system”).

Question 19 (b)(ii)

This question was not well understood by candidates, and responses were often low scoring. A statement along the lines of: " *Energy is always conserved"* or " *total energy is conserved"* was the most frequent way in which a mark was awarded. Those candidates that mentioned energy losses to the surroundings were in the minority, and of these few mentioned the energy transferred to the spring system.

This response gained full marks.

(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.

(3)

Her conclusion is wrong. Amplitude of the mass increases to maximum is ~~due to~~ because of when resonance occurs, there is a maximum energy transfer, and less energy dissipated to surroundings. Energy is always conserved, maximum amplitude is formed by large energy in the system and less energy dissipated to surroundings.

ResultsPlus
Examiner Comments

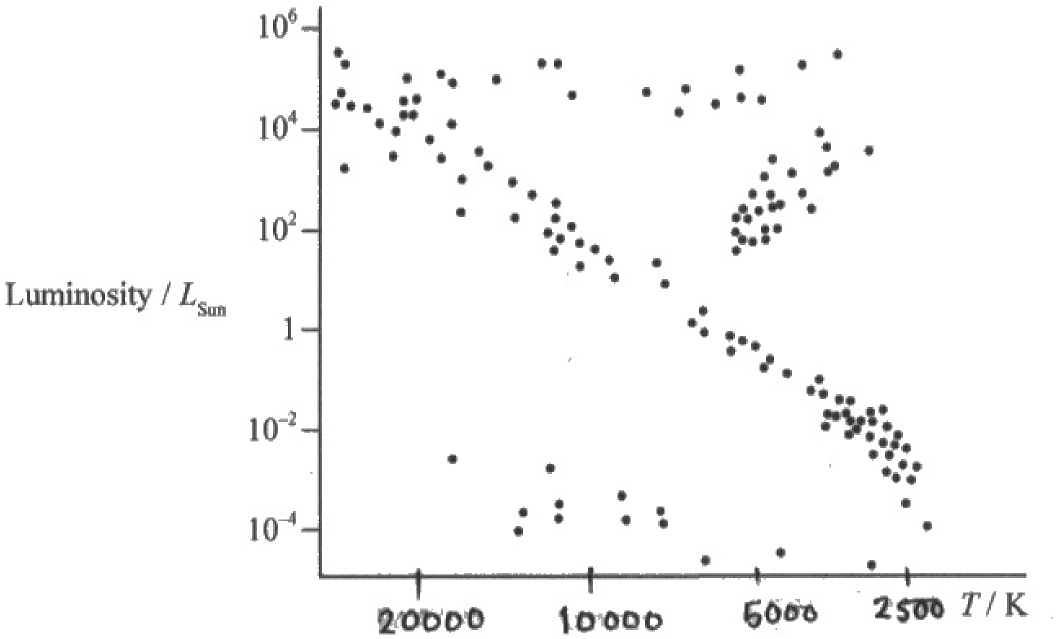
The basic ideas of each of the marking points are included in this response. Although the response does not explicitly state MP2, the statement that there is a maximum energy transfer and less energy dissipated to the surroundings at resonance was taken as just about enough for this marking point.

Question 20 (a)

Nearly all responses included a reverse scale. However, not all had the right values in the right places. 12000 K – 6000 K – 3000 K was common, with 6000 K corresponding with the luminosity of the Sun.

Both marks were awarded to this response.

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



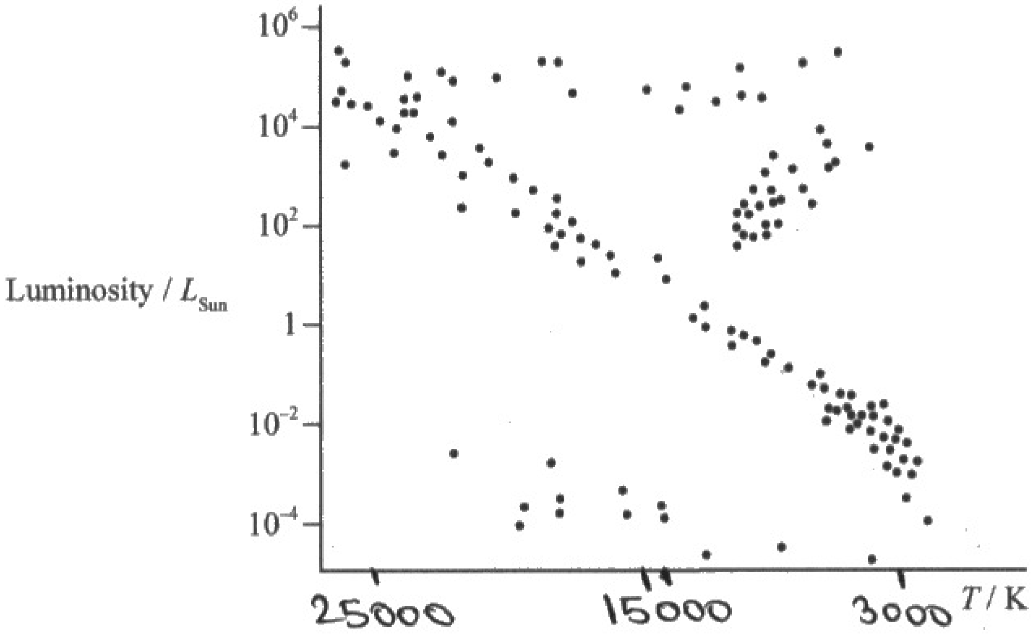
(a) Add a scale to the horizontal axis.

ResultsPlus
Examiner Comments

The temperature is a reverse scale and the values are realistic.

Only the mark for a reverse scale was credited in this response.

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



(a) Add a scale to the horizontal axis.

ResultsPlus
Examiner Comments

Although the scale may look logarithmic, it is very close to being linear.

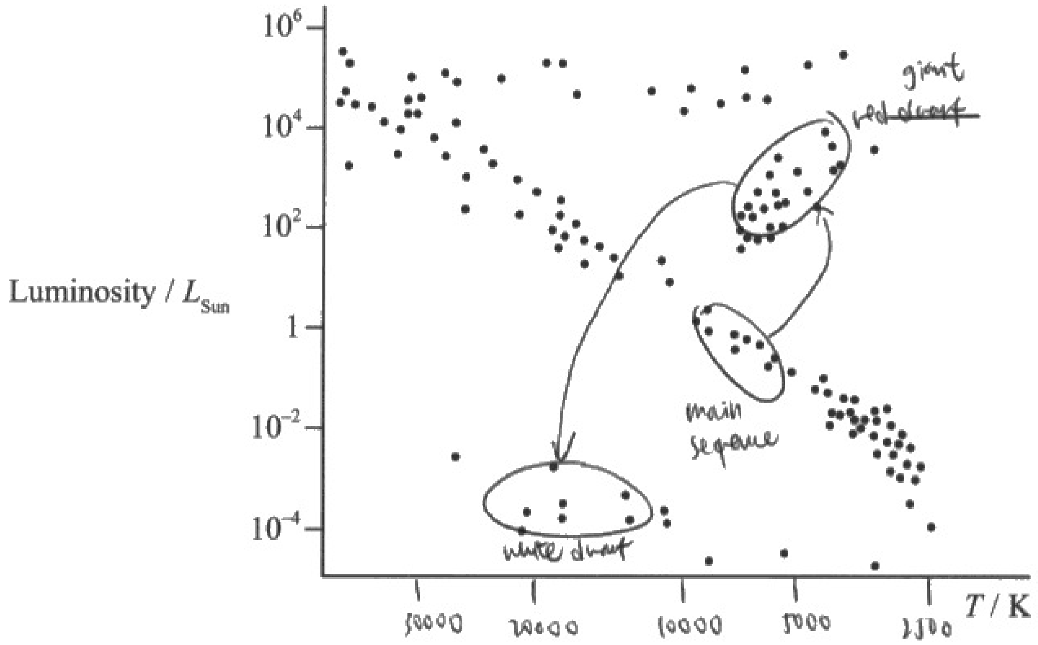
Question 20 (b)

A significant minority clearly did not understand what is meant by a 'star cluster'. These candidates often struggled to make sense of the HR-diagram.

Surprisingly few candidates annotated their graphs, but those that did often scored well in their answer. The main issue for some candidates was not stating the positions of the red giants and white dwarves on the HR diagram. We did not accept 'giants' for MP1, as there are blue giants at the top of the main sequence. We accepted 'red super giants'. We did not accept 'dwarves' for MP2, as there are dwarfs at the bottom of the main sequence.

This response scores all 3 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.

(3)

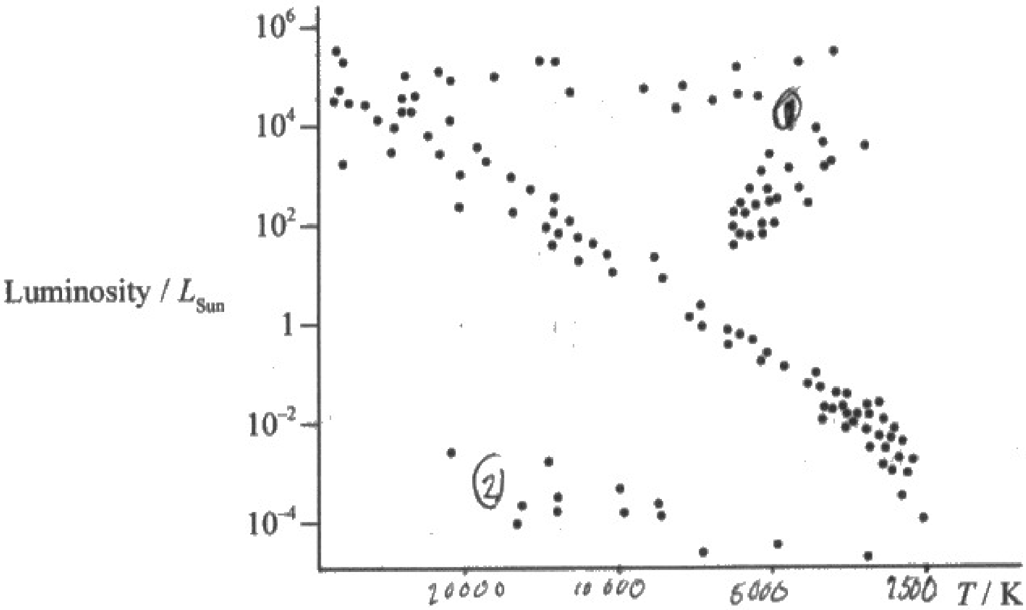
There are stars that have already gone off the main sequence and ~~becomes~~ become ~~a red dwa~~ red ~~dwarfs.~~ giants. In these stars, hydrogen fuels have already been used up that fusion of hydrogen stops, temperature decreases consequently which causes the contraction of star due to gravitational force, which releases energy for the star to expand to form red ~~dwarfs,~~ giants. This can be deduced from the diagram as there is a group of stars with higher luminosity than main sequence stars. Another piece of evidence is that there is even a few white dwarfs formed from red giant, which shows that the fusion of helium is stopped in red giants, the star cluster is therefore not a young star cluster.

ResultsPlus
Examiner Comments

Groups of stars are identified on the Hertzsprung-Russell diagram, and a relatively detailed evolution of a main sequence star is given. The existence of red giants and white dwarfs is correctly cited as evidence that this is not a young star cluster.

This response scores all 3 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.

(3)

A young star cluster would not have stars in their later stages such as red giants and white dwarfs. The stars at the top right ① of the H-R-diagram indicate red giants and those at the bottom left ② indicate white dwarfs. These would not have had time yet to develop in a young star cluster, so this is not a young star cluster.

ResultsPlus
Examiner Comments

Groups of stars are identified on the Hertzsprung-Russell diagram, and the existence of red giants and white dwarfs is correctly cited as evidence that this is not a young star cluster. The detail of the fusion processes taking place in the star for each group is not given, but this is not required for this question.

Question 20 (c)

The big steer was the ‘standard candle’ in the question, yet many then went on to explain the parallax method. A few candidates gave a circular argument of finding the luminosity of VI from the inverse square law and then using it again to find the distance. A few also measured the intensity from Andromeda.

Some candidates could not decide whether V1 was a standard candle in the Andromeda Nebula or was a prospective standard candle nearer to us. V1 appeared to oscillate between both roles in some responses.

A significant minority of candidates referred to the equation for the inverse square law but did not define the symbols L and I in the same section of their answer and thus did not gain MP3. Some did use the words Luminosity and Intensity elsewhere in the response, but this was not sufficient.

The last marking point was not often seen. A small minority suggested if the distance was many times the known diameter of the Milky Way then V1 must be too far away, or stated that they would compare the distance to a known nearby star cluster.

This response scored 3 marks.

(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.

(4)

· Standard candles are stellar objects with known luminosity
· Locate the standard candle in adromeda
· measure its intensity and use inverse square law to find its distance
· Locate the standard candle in our galaxy
· Measure its intensity and use inverse square law to find its distance
· Compare the 2 results

ResultsPlus
Examiner Comments

Each of the first 3 marking points are seen in this response. The reference to use of the inverse square law avoids the need to define *L* and *I* in the relevant equation, but this is acceptable. The response comes close to scoring MP4, but the final sentence, "compare the two results", is not strong enough for this marking point.

This response scored 3 marks.

(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.

(4)

$I = \frac{L}{4\pi d^2}$

~~① by using trigonometric parallax~~

① standard candle are stars with known luminosity

② by measuring the intensity of V1, using $I = \frac{L}{4\pi d^2}$, I = intensity, L = luminosity

③ d can be calculated

④ cannot use trigonometric parallax as it is too far

ResultsPlus
Examiner Comments

This is a minimalist response, but nonetheless the first 3 marking points are stated. The intensity expression is quoted, but *L* and *I* are defined, so this is fine. The final bullet point refers to the use of trigonometric parallax not being possible, but this is not strong enough for MP4.

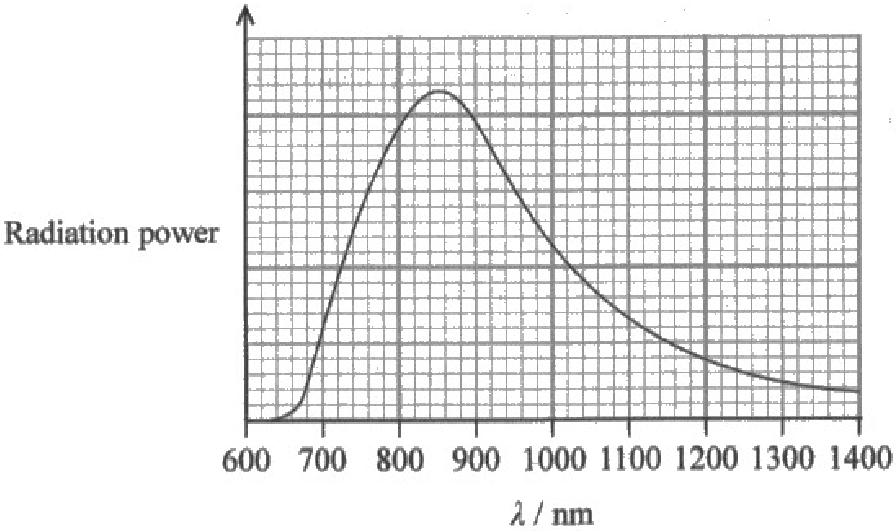
Question 21 (a)(i)-(ii)

(a)(i): This question presented no difficulties for most candidates. Some candidates mis-read the graph or had power of ten errors.

(a)(ii): On the whole this was very well answered. Numerical slips, carelessness with units and/or a lack of a proper final comparison and conclusion were the main reasons for not attaining full marks. An error, seen less frequently, was the use of an incorrect formula for the area.

This response scored full marks for both parts of the question.

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 λ.



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

(3)

$\lambda_{max} = 852$ nm

$T = \frac{2.89 \times 10^{-3} \text{ mK}}{852 \text{ nm}}$

$= \frac{2.898 \times 10^{-3}}{8.52 \times 10^{-7}}$ K

$= 3.4 \times 10^{3}$ K

≈ 3000 K

(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 = 1.18×10^{8} m
$L_{Sun} = 3.83 \times 10^{26}$ W

(5)

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

$= 4\pi (1.18 \times 10^8)^2 \cdot 5.67 \times 10^{-8} \times (3.4 \times 10^3)^4$

$= 1.33 \times 10^{24}$ W

$\frac{L}{L_{Sun}} = \frac{1.33 \times 10^{24} W}{3.83 \times 10^{26} W} = 0.00347 = 0.347\% < 0.5\%$

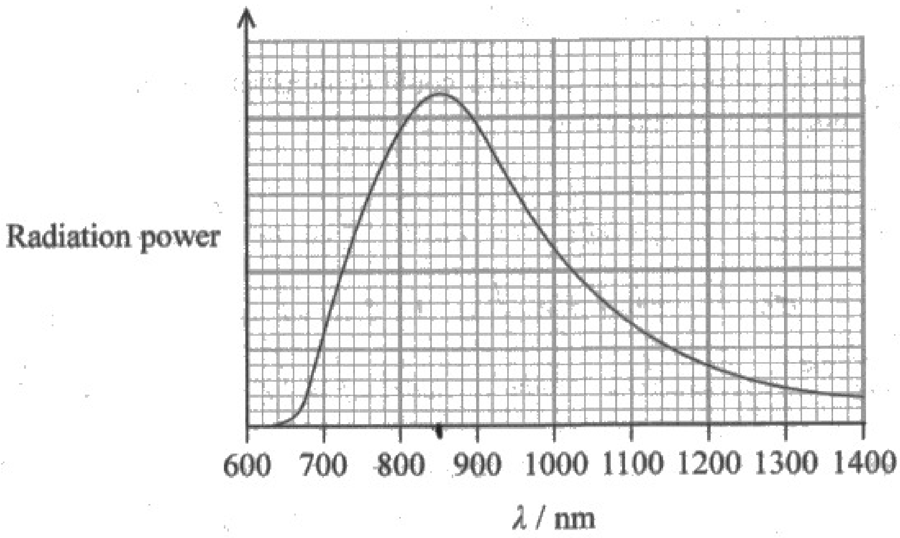
So it is correct.

ResultsPlus
Examiner Comments

The correct ratio of the two luminosities is obtained, and a comparison with 0.5% made with a valid conclusion.

This response scored full marks for both parts of the question.

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 λ.



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

(3)

$\lambda_{max} = 850\,nm$

$T = \frac{2.898 \times 10^{-3}}{\lambda_{max}} = \frac{2.898 \times 10^{-3}}{850 \times 10^{-9}} = 3400\,K \approx 3000\,K$

(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 = 1.18×10^{8} m

$L_{Sun} = 3.83 \times 10^{26}$ W

(5)

$L = \sigma A T^4 \quad \sigma 4\pi r^2 T^4$ $\quad 8.036 \times 10^{23}$

$= 5.67 \times 10^{-8} \times 4\pi \times (1.18 \times 10^{8})^2 \times 3000^4 =$ ~~[illegible]~~ W

~~[illegible] $\frac{\ 8.98 \times 10^{23}}{3.83 \times 10^{26}} \times 100 = 7.78 \times 10^{-12}$ % < < 0.5%~~

~~so statement is correct~~

$\frac{L_{ross}}{L_{Sun}} = \frac{8.036 \times 10^{23}}{3.83 \times 10^{26}} \times 100 = 0.21\% << 0.5\%$

so the luminosity of Ross-154 is less than 0.5% of L of Sun

so statement is correct

ResultsPlus
Examiner Comments

The correct ratio of the two luminosities (using the 'show that' value for the temperature) is obtained, and a comparison with 0.5% made with a valid conclusion.

ResultsPlus
Examiner Tip

Take care with powers of 10 when entering data into your calculator.

Question 21 (b)

This was well answered. If mistakes were made it was usually for trying to do the whole calculation in one go. Forgetting to square the π occurred often.

This response score all 3 marks.

(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 = 1.50×10^{11} m
mass of Ross-154 = 3.38×10^{29} kg

(3)

Centripetal Force = Gravitational force

$m\omega^2 r = \frac{GMm}{r^2}$ $\quad \omega^2 r^3 = \frac{GMm}{m}$ $\quad \omega^2 = \frac{GM}{r^3}$

$\frac{4\pi^2}{T^2} = \frac{GM}{r^3}$ $\quad \frac{4\pi^2 r^3}{GM} = T^2$ $\quad T^2 = \frac{4\pi^2 \times (0.096 \times 1.5 \times 10^{11})^3}{6.67 \times 10^{-11} \times 3.38 \times 10^{29}}$

$T^2 = 5.23 \times 10^{12}$ s $\quad T = 2.3 \times 10^6$ s

Time for one orbit = 2.3×10^6 seconds

ResultsPlus
Examiner Comments

The expression $a = \omega^2 r$ is used to obtain a correct answer in this response.

This response score all 3 marks.

(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 = 1.50×10^{11} m
mass of Ross-154 = 3.38×10^{29} kg

(3)

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

s = d/t

t = d/s

$v^2 = \frac{(6.67 \times 10^{-11})(3.38 \times 10^{29})}{0.096 \times (1.5 \times 10^{11})}$

$v =$ ~~3.4~~ 3.9×10^4 ms^{-1}

~~A~~ $2\pi(0.096 \times 1.5 \times 10^{11}) / (3.9 \times 10^4) = 2.3 \times 10^6$ s

Time for one orbit = 2.29×10^6 s

ResultsPlus
Examiner Comments

The expression $a = v^2/r$ is used to obtain a correct answer in this response.

This response scored all 3 marks.

(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)

$F = \frac{mv^2}{r}$ $F = \frac{GMm}{r^2}$ $\frac{GMm}{r^2} = \frac{mv^2}{r}$ $v^2 = \left(\left(\frac{2\pi}{T}\right)r\right)^2$

$GM = \frac{r^3 4\pi^2}{T^2}$ $T^2 = \frac{4r^3\pi^2}{GM}$ $T = \sqrt{\frac{4\pi^2 r^3}{GM}}$ $\sqrt{\frac{1.1788 \times 10^{32}}{(6.67 \times 10^{-11}) \times (3.38 \times 10^{29})}}$

$0.096 \times (1.5 \times 10^{11}) = 1.44 \times 10^{10}$ $T = 2.29 \times 10^6$ seconds

$T = 26.45$ days

Time for one orbit = 26.5 days

ResultsPlus
Examiner Comments

In this response $a = v^2/r$ is used to obtain a correct expression for the orbital period. Values are then substituted into this expression to obtain a correct answer. This is fine, although if an incorrect expression had been obtained before values were substituted then no marks would be available. The orbital period is unnecessarily converted into days.

ResultsPlus
Examiner Tip

Always substitute vales before re-arranging or combining equations. ‘Use of’ marks are only available for substitutions into a physically correct equation.

Paper Summary

Based on their performance on this paper, candidates should:

- ensure they have a thorough knowledge of the physics for this unit.
- read the question carefully and answer what is asked.
- formulate a response that is consistent with the command word used in the question.
- be particularly careful to use appropriate scientific terminology in questions which ask for a description or explanation.
- include all substitutions and all stages in the working in ‘show that’ questions.

Grade boundaries

Grade boundaries for this, and all other papers, can be found on the website on this link:

https://qualifications.pearson.com/en/support/support-topics/results-certification/grade-boundaries.html

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