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# Examiners' Report
# June 2019

## IAL Physics WPH05 01

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# Introduction

The assessment structure of WPH05 mirrors that of other units in the specification. It consists of 10 multiple choice questions, a number of short answer questions and some longer, less structured questions. As 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.

This paper gave candidates the opportunity to demonstrate their understanding of a wide range of topics from this unit, with all of the questions eliciting responses across the range of marks. However, marks for Q18(b)(i) and Q18(c) tended to be clustered at the lower end of the scale.

Calculation and ‘show that’ questions gave candidates an opportunity to demonstrate their problem solving skills to good effect. Some very good responses were seen for such questions, with accurate solutions which were clearly set out. Occasionally in calculation questions the final mark was lost due to a missing unit. Candidates understood the convention that in the 'show that' questions it was necessary to give the final answer to at least one more significant figure than the value quoted in the question. Not all candidates recognised the importance of showing all stages in their working in this type of question.

Once again there were examples of candidates disadvantaging themselves by not actually answering the question, or by not expressing themselves using suitably precise language. This was particularly the case in extended answer questions such as Q12, Q13(b), Q18(b)(i) and Q18(c) where candidates sometimes had knowledge of the topic, but could not express it accurately and succinctly. Candidates could most improve by ensuring they describe all aspects in sufficient detail and always use appropriate specialist terminology when giving descriptive answers.

The space allowed for responses was sufficient for almost all candidates. Candidates should be encouraged to consider the number of marks available for a question, and to use this to inform their response. If candidates either need more space or want to replace an answer with a different one, they should indicate clearly where that response is to be found.

The response to the multiple choice questions was acceptable, with 9 of the questions having 50% or more correct answers. In order of highest percentage correct they were Q08 (98%), Q03 (90%), Q02 (79%), Q07 (76%), Q04 (68%), Q05 (64%), Q10 (58%), Q01 (55%), Q06 (54%) and Q09 (39%). A few candidates omitted to answer all 10 questions. Since there is no penalty for an incorrect answer, candidates should be encouraged to attempt all questions.

There was some evidence of candidates learning previous schemes in the expectation of earning marks but less so than in previous exam series. Candidates should be encouraged to work with mark schemes in preparation for their exam. However, it is important that they understand that 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)*

Almost all candidates were able to use both equations successfully, scoring at least 2 of the 3 marks. A common mistake was to overlook that there were 44 people in the carriage, not just 1. A small minority are muddled about the use of Celsius and Kelvin temperatures. Some of these do not realise that because the size of a degree is the same on both scales, a temperature difference is the same whichever scale is used and therefore there is no need to convert before subtracting. There were a few that calculated the temperature difference correctly, but then attempted to convert to Kelvin by adding 273.

$E = mc\Delta\theta$

$E = 110 \times 720 \times (28 - 16)$

$E = 950\,400\ \text{J}$

$85\ \text{W} \times 44 = 3740\ \text{W}$

$P = \frac{E}{t}$ $\quad 3740 = \frac{950400}{t}$

$t = 254.1\ \text{s}$

Time taken = 254 s

**Examiner Comments**

This is an example of a response that scores all 3 marks. The working has been clearly set out. We can see that the energy required for this temperature rise has been calculated using the specific heat capacity. The total power for all 44 people has been found and this value substituted into the power equation. The final answer is correct and the unit included.

$E = mc\Delta T$
$= 110 \times 720 \times ((28+273)-(16+273))$
$= 950400 \text{ J}$

$W = Pt$
$85 \times 44 = 950400\, t$
$t = 254 \text{ s}$

Time taken = 254 s

**ResultsPlus**
**Examiner Comments**

This candidate has unnecessarily changed the two Celsius temperatures to Kelvin before calculating the temperature difference. The calculation has been done correctly and full marks are scored.

**ResultsPlus**
**Examiner Tip**

When doing a calculation using specific heat capacity it is not necessary to change temperatures to Kelvin.

$\Delta E = mc\Delta\theta$

$= 110 \times 720 \times (28-16)$

$= 9.504 \times 10^5 J$

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

$85 = \frac{9.504 \times 10^5}{\Delta t}$

$\Delta t = 1.1 \times 10^4 s$

Time taken = $1.1 \times 10^4 s$

**ResultsPlus**
**Examiner Comments**

This candidate has not taken the 44 people into account and so has an incorrect time as their answer. The first two marks have been scored.

**ResultsPlus**
**Examiner Tip**

Make sure that you include all relevant data from the question in your calculation.

## *Question 11 (b)*

This question requires a response that shows a greater understanding of the physics of this particular situation than the typical 'energy lost to the surroundings' answer. The question has already asked candidates to calculate how long it takes the energy from the people to raise the temperature of the air by 12°C and the air is part of the surroundings. We are looking for an answer that makes it clear that some of the energy emitted by the people is heating the seats, windows, wall etc of the carriage itself. In other words we wanted to see a named place where the energy was going rather than the air. Despite the question telling them that the doors and windows were closed we would have given credit to candidates who told us that **warm** air escaped. Unfortunately, those who attempted this argument usually failed to tell us that the escaping air was warm, or above its initial temperature.

children on board may dissipate thermal energy at a lower rate, so all 44 passengers may not have a rate of 85 W. ~~Instead, it may be less~~ The air ~~m~~ would thus be heated up at a slower rate.

**ResultsPlus**
**Examiner Comments**

This is an example of a response that has focused on the fact that not all the people in the carriage will heat the air at the same rate. Whilst this is a correct statement, the question says that 85 W is the **average** rate so the comment is not relevant and no credit is given.

**ResultsPlus**
**Examiner Tip**

Take careful note of all the information given in the question.

## *Question 12*

It was clear that many candidates could link the ultimate fate of the universe to its density and how the value of the density compares with the critical density. Many were also able to link an absence of dark matter to a reduced value of the density of the universe. Expressing these ideas with sufficient clarity and drawing the correct conclusion that the universe may continue to expand forever was more challenging. It did not occur to some candidates that it was necessary to identify that dark matter has mass and so the first mark could not be awarded.

The mention of dark matter in the question encouraged some candidates to include additional material that the question did not require about dark matter not interacting via electromagnetic radiation. Others tried to discuss the role of dark energy rather than dark matter. A knowledge of dark energy is not required by the specification.

If there is no dark matter, that means the mass of the universe is less than initially thought ∴ the density of the universe will be less. If the density is less than the critical density, the universe is an open universe and will continue to expand.

**ResultsPlus**
**Examiner Comments**

A succinct, very clearly expressed answer that has all the points we are looking for.

**12** Most scientists believe that dark matter is spread throughout the whole universe.
Recent observations indicate that there may be galaxies in which there is no dark matter.

Discuss how the absence of dark matter in parts of the universe might affect the ultimate fate of the universe.

**(4)**

Dark matter increases the mass of the universe. ~~galaxy~~ If dark matter is not present in some of the ~~galaxy~~ galaxies then the mass of universe, hence the average ~~average~~ density of the ~~to~~ universe would be smaller. ~~th~~ The ultimate ~~of~~ fate of the universe depends on the average density compared to a critical density of the universe. If the average ~~less~~ density is less than the critical density than the universe will keep on expanding forever.

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

ResultsPlus
Examiner Comments

An example of a well constructed but lengthier response that scores all the marks.

Dark matter affects the critical density of the universe. If there is no dark matter, if the ~~critical~~ density of the universe is less than the critical density, the universe will keep on expanding indefinitely forever. This kind of universe is an open universe. If the density of the universe is equal to the critical density, the universe will expand to a maximum size and stop expanding. This is a flat universe. If the density is greater than critical density, it will be a closed universe.

**ResultsPlus**
**Examiner Comments**

The candidate's first statement is incorrect and shows muddled understanding. However, the second sentence is well expressed and scores both the third and fourth marks. The candidate stated that "the density of the universe is equal to the critical density" and the response continued to tell us about the fate if the density is equal to or greater than the critical density. This adds nothing to the answer and no more marks can be awarded.

## *Question 13 (a) (i)*

Almost all candidates realised that the air in the tyre could be treated as an ideal gas and hence the ideal gas equation could be used. They have used this sufficiently often that they could begin with a statement that $p/T$ is constant without deriving the expression. This is acceptable, as is a statement that $p_1/T_1 = p_2/T_2$ .

The most common error was a failure to convert the initial temperature to Kelvin. These candidates could only be awarded the first marking point. Candidates should be encouraged to notice that when the symbol used for temperature is *T*, this represents a Kelvin temperature and applies in all calculations involving ideal gases.

There were a few candidates that started with pressure proportional to temperature which is incorrect physics. These responses could only be awarded the second mark for converting the temperature to Kelvin.

(a) (i) Calculate the temperature of the air in the tyre at the end of the race.

(3)

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\Rightarrow \frac{5.52\times10^5}{295} = \frac{5.60\times10^5}{T_2}$$

Temperature of air = 299.2K

**ResultsPlus Examiner Comments**

A clearly set out solution starting from $p_1/T_1 = p_2/T_2$ that shows the correct substitution of the two pressures and the initial temperature which has been converted to Kelvin. The candidate has rearranged the equation in their head and used their calculator to reach the answer which has been given the correct unit.

Note that the result of this calculation, as displayed on the calculator would be 299.275362..... and therefore this candidate should have written their 4 significant figure answer as 299.3 K. We generally award the final mark in a calculation if the candidate's value rounds to the value in the mark scheme, as this does.

This response is an example of the most common error for this calculation.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{5.52 \times 10^5}{22°} = \frac{5.60 \times 10^5}{T_2}$$

$$T_2 = \frac{5.60 \times 10^5 \times 22}{5.52 \times 10^5} = 22.3\,°C$$

Temperature of air = 22.3 °C

ResultsPlus
Examiner Comments

In this solution the candidate has forgotten that they need to convert the initial air temperature from Celsius to Kelvin. We award the first mark for substituting values into $p_1/T_1 = p_2/T_2$, but no more marks can be awarded.

## Question 13 (a) (ii)

A significant number of candidates didn't realise that the information at the beginning of Q13 still applied. In other words, that the pressure at the end of the bicycle race was $5.52 \times 10^5$ Pa just as it was for part (i). The candidates that had understood the question usually realised that the only variables were *N* and p. They were able to make a logical argument using the ideal gas equation to reach the conclusion that the result of the calculation would be that the temperature would be greater.

The most common mistake was to say that since air had escaped, the pressure in the tyre would be less and so the temperature would be less.

(ii) During the race, a small amount of air escapes from the tyre.

Explain how the value of the temperature calculated in (i) would be affected if allowance were made for this escaped air.

**(2)**

when air leaves the type the number of air molecules decreases

the temperature of air inside the type increases since

$N \propto \frac{1}{T}$ number of molecules is inversely proportional to

temperature

$$\frac{(\uparrow p)V}{(\downarrow N)k} = T\uparrow\uparrow$$

**ResultsPlus**
**Examiner Comments**

This candidate has identified that the number of air molecules decreases and has then used their knowledge of the ideal gas equation in order to say that the number of molecules is inversely proportional to the temperature. This is sufficient to be awarded the first mark. They have also drawn the correct conclusion, that the temperature would be higher, and hence are also awarded the second mark.

(2)

Temperature calculated will be ~~less~~ higher as $\frac{PV}{Nk} = T$, 'N' ~~de~~, number of particles, decreases, temperature would increase.

**ResultsPlus**
**Examiner Comments**

In this response the ideal gas equation has been rearranged to make temperature the subject of the equation. This is then used to justify the statement that the temperature will be higher as the number of particles decreases. This is sufficient to be awarded both marks.

If air escapes, the number of molecules decreases so presure exerted by gas at that temperature is decreased, so to reach the same pressure with less molecules a greater temperature is needed so temperature of tyre air would be higher.

**ResultsPlus**
**Examiner Comments**

This is a well argued explanation but there is no mathematical justification included for the stated relationship between temperature and pressure. However, this includes good physics and is awarded the **Max 1** mark noted in the mark scheme.

## *Question 13 (b)*

Questions asking candidates to explain pressure changes in terms of molecular momentum and kinetic energy have been set previously and most candidates were able to access at least some of the marks. Many responses included the right physics principles but either lacked sufficient detail, failed to make their points with sufficient clarity or did not use the correct terminology. References to increased kinetic energy rather than increased **mean** kinetic energy, particles instead of atoms or molecules, collisions between molecules rather than with the tyre wall and the change in momentum rather than the rate of change of momentum were seen all too frequently.

To construct a logical argument in response to the question asked it is necessary to realise that an increased molecular kinetic energy means that the momentum change in every collision, whether with another molecule or with the tyre walls, will be greater. This is the second marking point and it was rarely awarded.

***(b) Explain why the pressure exerted by the air in the tyre increases as the temperature of the air increases.**

**Your answer should include reference to molecular momentum and kinetic energy.**

**(4)**

Due to increase in temperature, the average kinetic energy of the air molecules increases. So the frequency of collision of air molecules with the walls of the tyre increases. There is greater momentum change per collision, hence rate of ~~colli~~ change of momentum ~~do~~ due to collisions at the wall increases. So force exerted on the wall of the tyre increases, hence force exerted per unit area increases. So pressure increases.

**ResultsPlus Examiner Comments**

An example of a well argued answer that has all the relevant physics and uses the correct terminology.

As temperature increases, average kinetic energy of molecules of air inside the tyre also increases as $E_k = \frac{3}{2}kT$.

Therefore, the frequency of collision between the air molecules and the inner walls of the tyre increases.

As a result, the rate of change of momentum of the air molecules increases

So the force exerted on the inner walls of the tyre increases so pressure ~~increases~~ exerted by air increases.

**ResultsPlus**
**Examiner Comments**

This is an example of a typical good response that is only missing the second mark. The candidate has not realised that an essential part of this argument is that the change in momentum for every collision is larger.

When the temperature of the air increases, the mean kinetic energy of the molecules will also increase.
The rate of collision is increased, which exerts a greater force.
Due to this the rate of change of momentum of particles is also greater, with larger force.
Hence the pressure increases.

**ResultsPlus**
**Examiner Comments**

This response shows both a knowledge of the topic and some understanding of the kind of argument that we are looking for, but lacks sufficient detail.

The first mark is awarded for the first sentence. The second sentence goes part of the way towards the third mark but has not specified that it is the rate of collision between the molecules and the tyre wall that has increased. The third sentence goes part of the way towards the fourth mark but does not make it clear that it is the rate of change of momentum at the tyre walls that increases, therefore increasing the force.

**ResultsPlus**
**Examiner Tip**

If a question is worth four marks always try to think about what four physics points the examiners might be looking for.

An example of a response which includes some correct physics but scores no marks.

- As the temperature increase, kinetic energy of the air molecules also increases.
- The molecules ~~collide~~ ~~is~~ move faster and collide harder with each other ~~with a~~
- This increases the rate of change of momentum.
- Therefore, the force increases in turn increasing the pressure.

**ResultsPlus**
**Examiner Comments**

Although the response includes a statement that the kinetic energy of the molecules increases, it does not specify that it is the **mean** kinetic energy. The response only refers to collisions between molecules not molecules and the tyre walls and describes them as harder which in this context is not a correct use of terminology. There is a comment about an increased rate of change of momentum but as far as we can tell, this refers to collisions between molecules.

## Question 14 (a)

This is a straightforward nuclear equation for beta decay which most candidates were able to complete correctly. The most common errors were associated with not being able to write the correct proton and nucleon number for the beta minus particle.

$$^{137}_{55}\mathrm{Cs} \rightarrow {}^{138}_{55}\mathrm{Ba} + {}^{-1}_{0}\beta^{-}$$

**ResultsPlus**
**Examiner Comments**

In this response, the nucleon number and the proton number for the beta minus particle have been transposed. The candidate has then made the equation balance, but in the process has the incorrect numbers for the barium nucleus.

$$^{137}_{55}\mathrm{Cs} \rightarrow {}^{137}_{56}\mathrm{Ba} + {}^{0}_{1}\beta^{-}$$

**ResultsPlus**
**Examiner Comments**

This candidate has used the symbol for a beta plus particle with a proton number of +1, instead of the -1 that we should see for a beta minus particle. This has resulted in both the nucleon numbers being correct, but both proton numbers being incorrect. 1 mark is awarded.

## *Question 14 (b)*

This question enabled the majority of candidates to demonstrate their ability to successfully calculate the decay constant and to make some progress in calculating the final activity given an initial number of nuclei and using the exponential equation for radioactive decay.

There are three stages to this calculation and two methods, with a common first stage which is to find the decay constant using the value of half-life given in the introduction to the whole question. Most candidates could do this successfully, working either in seconds or years. Those who worked in seconds from the beginning were more likely to eventually reach the correct answer for the final activity.

Most candidates then used $A = \lambda N$ with their value of $\lambda$ and the number of nuclei given in the question to find the initial activity of the caesium-137. A significant minority thought that they had found what they had been asked to and did no more calculation. The final stage using this method is to use the exponential equation to find the activity after 20 years, remembering that the final answer has to be in Bq, so a conversion from years is required at some point.

An alternative approach is to first use the exponential equation to calculate the number of caesium-137 nuclei remaining after 20 years and then use $A = \lambda N$ to calculate the final activity.

Some candidates were muddled about the times given in the question, using 20 years as the half-life and some completely misread the question and thought that they were being asked to calculate the activity after 13,720 years.

An example of one of the two methods for this question.

(b) When it is removed from a fission reactor, a fuel rod contains $1.36 \times 10^{24}$ nuclei of caesium-137.

Calculate the activity of the fuel rod due to the decay of the caesium-137 20 years after removal from the reactor.

1 year = $3.15 \times 10^7$ s

**(4)**

$\lambda = \frac{\ln 2}{30.2 \times 3.15 \times 10^7}$

$= 7.286 \times 10^{-10}$

$N = N_0 e^{-\lambda t}$

$N = 1.36 \times 10^{24} \times e^{-7.286 \times 10^{-10} \times 20 \times (3.15 \times 10^7)}$

$= 8.59 \times 10^{23}$

$A = -\lambda N$

$= 7.286 \times 10^{-10} \times 8.59 \times 10^{23}$

$= 6.26 \times 10^{14}$ Bq

Activity of fuel rod = $6.26 \times 10^{14}$ Bq

**ResultsPlus**
**Examiner Comments**

The decay constant has been calculated in $s^{-1}$, then the exponential equation used to find the number of nuclei remaining after 20 years. Finally the activity after 20 years is calculated. The answer is correct and has the right unit.

This response illustrates the other route through the calculation.

Initial activity : $A = \lambda N$

$\lambda = \frac{\ln 2}{30.2 \times 36}$ (crossed out) $= \frac{\ln 2}{30.2 \times 365 \times 24 \times 3600} \times 1.36 \times 10^{24} = 9.90 \times 10^{14}$ Bq ~~nuclei~~

$A = A_0 e^{-\lambda t}$

$A = 9.90 \times 10^{14} e^{-7.28 \times 10^{-10} \times 20 \times 3.15 \times 10^{7}}$

$= 6.26 \times 10^{14}$ Bq

Activity of fuel rod = $6.26 \times 10^{14}$ Bq

**ResultsPlus**
**Examiner Comments**

The first two stages have been done in one calculation, then substitution for the decay constant is seen as part of the calculation of the initial activity. Then the exponential equation has been used to find the final activity. The candidate has used time in seconds consistently therefore the final answer in Bq is correct.

$t_{1/2} = \frac{\ln 2}{\lambda}$

$3.15 \times 10^7 \times 30.2 = \frac{\ln 2}{\lambda}$

$\lambda = 7.28 \times 10^{-10}$ m

$\therefore$ $A = \lambda N$

$A = 7.28 \times 10^{-10} \times 1.36 \times 10^{24}$

$A = 9.91 \times 10^{14}$ Bq

Activity of fuel rod = $9.91 \times 10^{14}$ Bq

**ResultsPlus**
**Examiner Comments**

This response shows the correct calculation of the decay constant and then the initial activity, but has gone no further. The first 2 marks have been awarded.

$\lambda = \frac{\ln 2}{30.2 \times \text{yrs}}$ ~~$\times 365 \times 24 \times 3600$~~ $= 0.02295 \text{ yrs}^{-1}$

$A_0 = \lambda N = 0.02295 \times (1.36 \times 10^{24}) = 3.12 \times 10^{22} \text{ Bq}$

$A = A_0 e^{-\lambda t}$

$= (3.12 \times 10^{22}) \times e^{-0.02295 \times 20}$

$= 1.97 \times 10^{22} \text{ Bq}$

Activity of fuel rod = $1.97 \times 10^{22}$ Bq

**ResultsPlus Examiner Comments**

This candidate has worked throughout in years. Their final answer therefore has units $\text{years}^{-1}$, not Bq. The first 3 marks are awarded. Since they were asked to find the final activity we require SI units for the final answer.

## *Question 14 (c)*

In order to explain why the emission of gamma radiation is a more serious hazard than the emission of beta radiation we expect candidates to realise that it is the much greater penetrating ability of gamma compared to that of beta which is the key piece of physics. A discussion of what stops beta, eg a few mm Al and statements like gamma will be not be completely stopped by thick concrete or several cm Pb were often seen but are insufficient for the first mark. Many candidates told us, as they have in other questions on this topic in the past, that gamma is weakly ionising and highly penetrating but beta is moderately ionising and moderately penetrating. These were awarded the first mark because the comparison of penetrating powers is included.

It was rare to see responses where we could award the second mark. Descriptions of how radiation affects cells, causes mutations in DNA, causes cancer etc are not answering the question. Gamma is a more serious hazard because it is much more difficult to protect people from it and this is what the two alternatives for the second mark are about.

**(c) When caesium-137 decays it also emits gamma radiation.**

**Explain why the emission of gamma radiation is a more serious hazard than the emission of beta radiation.**

**(2)**

gamma radiation is more penetrating but less ionizing

but a lot of gamma radiation can cause halm to cells

**ResultsPlus**
**Examiner Comments**

The statement 'gamma radiation is more penetrating' was awarded the first mark. This is a minimum for that mark. The use of a comparative word like 'more' is essential.

(c) When caesium-137 decays it also emits gamma radiation.

Explain why the emission of gamma radiation is a more serious hazard than the emission of beta radiation.

**(2)**

gamma radiation has infinite range, harder to stop or block

it is very penetrating, causes cancer

**ResultsPlus**
**Examiner Comments**

Although this response tells us that gamma is very penetrating, there is no comparison of penetrating power with beta so the first mark cannot be awarded. The comment about 'infinite range' and 'harder to stop or block' goes some way towards the second mark but is insufficient.

# Question 15 (a) (i)

In general, this question was well answered with most candidates realising that the centripetal force required to keep the satellite in orbit is provided by the gravitational force between the satellite and the Earth, hence they needed to begin by equating the two expressions for force. This could be done either using *v* or *ω*. The other piece of required physics is the relationship between T and either *v* or *ω*. Almost all could then use algebra to manipulate the equations to give the required expression.

One of the many responses that scored all 3 marks.

$$\omega = \frac{2\pi}{T}$$

$$F = \frac{GMm}{r^2} = m\omega^2 r$$

$$\frac{GM}{r^2} = \omega^2 r$$

$$\frac{GM}{r^2} = \left(\frac{2\pi}{T}\right)^2 r$$

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

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

**ResultsPlus**
**Examiner Comments**

The two expressions for force have been equated, using angular velocity. It is clear that '*m*' has been cancelled. The expression relating angular velocity has been quoted and then substitution made for the angular velocity. The expression has then been rearranged to give the required equation.

$v = r\omega$  $\omega = v/r$

**15** Navstar 1 was a navigation satellite placed in a circular orbit about the Earth in 1978. It was the first Global Positioning System satellite to be launched.

(a) (i) Show that the orbital time $T$ for a satellite in a circular orbit of radius $r$ about the Earth of mass $M$ is given by

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

$T = \frac{2\pi}{\omega}$  $\omega = v/r$.

**(3)**

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

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

**ResultsPlus**
**Examiner Comments**

The two equations for force have been quoted, more than once, but then equated and therefore the first mark is awarded. In their rough working above the answer lines we can see the relationship between orbital time and angular velocity, but this has not been used. No further marks are awarded.

## *Question 15 (a) (ii)*

Almost all candidates could successfully use the equation given in part (i) to find a value for the orbital time of the satellite. Working out how to use that value to determine the number of times the satellite crosses the equator proved more challenging. Most were able to work out that there would be 2 orbits in one day but only a minority took the extra step that in every orbit the satellite crosses the equator twice which means that the answer to the question is 4.

An example of a clearly set out response that follows the mark scheme.

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}} = \sqrt{\frac{4\pi^2 \times (2.66 \times 10^7)^3}{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}}$$

$$= 43088.7 \text{ s}$$

One day = 24 hours = $(24 \times 3600)$ s = 86400 s

Number of rotations each day = $\frac{86400}{43088.7}$ = 2.0

∴ The satellite crosses the equator $(2 \times 2) = 4$ times a day.

Number of times satellite crosses equator = 4

**ResultsPlus**
**Examiner Comments**

The substitutions into the given equation are clearly seen and the correct value for *T* calculated. They have shown us that they have calculated the number of seconds in one day and how they have found that the number of rotations in one day is 2. Finally, we can see how they have arrived at the correct final answer of 4.

**ResultsPlus**
**Examiner Tip**

Always make it clear how you are doing a calculation.

This response illustrates the common error of failing to complete the question.

**(3)**

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

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

$$= \sqrt{\frac{4\pi^2 \times (2.66\times10^7)^3}{6.0\times10^{24}\times 6.67\times10^{-11}}}$$

$$= 43089\ \text{s}$$

$$\therefore N = \frac{60\times60\times24\ \text{s}}{43089\ \text{s}} = 2$$

Number of times satellite crosses equator = 2

**ResultsPlus**
**Examiner Comments**

In this response we can see the correct calculation of the number of orbits in one day. The value of *T* has been correctly calculated and they have divided the number of seconds in one day by *T*. The final stage has not been tackled. The first 2 marks are awarded.

**ResultsPlus**
**Examiner Tip**

It is worth double checking what the question asks.

(3)

$$T^2 = \frac{4\pi^2 r^3}{GM} = \frac{4\pi^2 (2.66\times10^7)^3}{6.67\times10^{-11}\times 6\times10^{24}}$$

$$T = 43088.7$$

Number of times satellite crosses equator = 43089

ResultsPlus
Examiner Comments

The substitution into the given expression has been done, scoring the first mark. The value of *T* has been calculated correctly but no use made of the value.

## *Question 15 (b)*

It would seem that many candidates did not appreciate that the question requires them to think about the calculation itself: that if potential energy is calculated using the given expression, *g* is assumed to be constant and will be taken as the value at the Earth's surface. In fact, the value of *g* will decrease significantly. We were looking for a mathematical description of this decrease for the first mark.

A range of responses were seen which did not address this and hence were awarded no marks. These included: suggesting that the satellite would change mass as fuel was used (the satellite has no fuel), the orbit being included to the equator would affect the potential energy, and energy would be lost to the surroundings, expressed in various ways.

The actual value for $\Delta E$ is smaller than the calculated value. Because $g = \frac{GM}{r^2}$. As r increase, g will decrease.

**ResultsPlus**
**Examiner Comments**

An example of a response that scores both marks.

The actual value would be less than calculated using the equation because as we go up higher the gravitational field strength decrease following an inverse square law: $g = \frac{GM}{r^2}$.

**ResultsPlus**
**Examiner Comments**

This also scores both marks. Although it is not expressed in the same way as is given in the mark scheme, the meaning is clear.

$g = \frac{GM}{r^2}$, where r is the radius of Earth. The radius is not accounted for in the potential energy calculation.

ResultsPlus
Examiner Comments

The first mark is awarded.

This candidate has not told us that the actual value of the energy will be less, and has just said that the radius is not accounted for. The second mark is not given.

The actual value for $\Delta E_{grav}$ is less than the calculated value.
This is because g is not constant. It decreases with increasing distance from centre of Earth. This is not accounted for in the equation he used.

ResultsPlus
Examiner Comments

The second mark is awarded but there is no mathematical justification given and so the first mark is not given.

ResultsPlus
Examiner Tip

Always try to back up a description of a relationship like this, between *g* and distance, with an appropriate equation.

## *Question 16 (a) (i)*

Many candidates were able to describe the position of $^{56}Fe$ as meaning that this isotope has the largest binding energy per nucleon. There were some who omitted ‘per nucleon’ and so were not awarded the first mark. The most common way to score the second mark was by saying that $^{56}Fe$ is the most stable. Those who attempted to explain that fusion of nuclei less massive than $^{56}Fe$ releases energy and fission of nuclei more massive than $^{56}Fe$ releases energy, rarely gave sufficient detail.

It has the highest binding energy per nucleon.
There is an increased leading upto it and a decrease afterwards.
Fusion can only happen with nucleons before $^{56}Fe$ and fission can only happen with nucleons after $^{56}Fe$.

**ResultsPlus**
**Examiner Comments**

The first sentence scores the first mark. The rest of the response has insufficient detail for the second mark to be awarded.

(2)

It has greater Binding energy. It is the most stable ~~element~~ nucleus
The final product of fusion and fission.

**ResultsPlus**
**Examiner Comments**

The first mark is not awarded because 'per nucleon' has been omitted, but they have said that it is the most stable nucleus. From the way the question is worded it is understood that 'it' refers to $^{56}Fe$, therefore the second mark is awarded.

**ResultsPlus**
**Examiner Tip**

In questions about binding energy take care to notice whether it is binding energy or binding energy per nucleon that is relevant.

(2)

$^{56}Fe$ is on the highest point of binding energy per nucleon, which $^{56}Fe$ has highest binding energy per nucleon, so highest energy is required to split ~~nucleons in~~ a $^{56}Fe$ nucleus into its component nucleons, which means $^{56}Fe$ nucleus is the most stable nucleus, after $^{56}Fe$, binding energy per nucleon decreases, so energy input is required to have ~~nucleus~~ nuclei ~~which ha~~ that have larger nucleon number than $^{56}Fe$ ~~to~~ to undergo fusion.

**ResultsPlus**
**Examiner Comments**

This response scores both marks. The first mark is awarded for the first statement. The candidate then has a clear description of the meaning of the highest binding energy per nucleon, telling us that the highest energy is required to split the nucleus into its component nucleons. This is the second alternative on the mark scheme for the second mark. They then go on to say that this means that the $^{56}Fe$ nucleus is the most stable. This in itself would have scored the second mark.

## *Question 16 (a) (ii) - (iii)*

(ii) This question asked candidates to **show that** the binding energy per nucleon is about 9 MeV. When asked to 'show that' it is necessary to show all the stages in the calculation and to give the final answer to more significant figures that are given in the question. Almost everyone began this question in the right way by attempting to calculate the mass defect. Some failed to work out that there are 26 protons and 30 neutrons in every nucleus of $^{56}$Fe. As long as the calculation included at least 1 proton and 1 neutron and the mass of the nucleus, this mark could be awarded, although the final answer would be incorrect. Many responses showed substitution into $\Delta E = c^2 \Delta m$ and the conversion to eV, arriving at an answer of 494 MeV. Because the question asked candidates to show that, most candidates who got this far realised that to get the correct answer they would have to divide by the number of nucleons.

(iii) The y-axis of the graph in the question shows that $^{2}$He is 1 square up from the origin and $^{56}$Fe is 9 squares up from the origin. This means that the value of the binding energy per nucleon for $^{2}$He must be equal to the value for $^{56}$Fe divided by 9. Many candidates could do this by inspection.

(ii) Show that the binding energy per nucleon of $^{56}_{26}$Fe is about 9 MeV.

proton mass = $1.673 \times 10^{-27}$ kg
neutron mass = $1.675 \times 10^{-27}$ kg
mass of $^{56}$Fe nucleus = $9.287 \times 10^{-26}$ kg

**(4)**

$(26 \times 1.673 \times 10^{-27}) + (30 \times 1.675 \times 10^{-27}) = 9.3748 \times 10^{-26}$ kg

$(9.3748 - 9.287) \times 10^{-26} = 0.0878 \times 10^{-26}$ kg.

$E = mc^2$

$= 0.0878 \times 10^{-26} \times (3 \times 10^8)^2$

$= 7.902 \times 10^{-11}$ J. $\quad$ 1 eV = $1.60 \times 10^{-19}$ J

$E = \dfrac{7.902 \times 10^{-11}}{1.60 \times 10^{-19}} = 493.875 \times 10^{6}$ eV

494

Binding Energy per nucleon $= \dfrac{493.875 \times 10^{6}}{56} = 8.82 \times 10^{6}$ eV

$= 8.8$ MeV.

(iii) Deduce a value for the binding energy per nucleon of $^2H$.
You should use your value from (ii) and the graph.

(2)

~~$\frac{494}{9} = 54$~~ $\frac{493.875 \times 10^6}{9} = 54.88 MeV$

Binding energy per nucleon = 27.4 MeV.

Binding energy per nucleon = ..................................

ResultsPlus
Examiner Comments

(ii) This scores all 4 marks. All stages in the calculation are shown, the correct final value for binding energy per nucleon has been reached, and it has been quoted to more significant figures than the 'show that' value of 9MeV.

(iii) The response shows the correct method, ie divide by 9, but has used the value they calculated for binding energy, 494 MeV, instead of 8.8 MeV. The answer is not correct therefore the second mark cannot be not awarded.

$\therefore$ ~~$m_{Fe}$~~ $\Delta m = m_{Fe} - (m_p + m_n)$

$= 9.287\times10^{-26} - (1.673\times10^{-27} + 1.675\times10^{-27})$

$= 8.952\times10^{-26}$ kg

$\therefore E =$ ~~mem~~ $\Delta mc^2$

$= (8.952\times10^{-26})\times(3\times10^8)^2$

$= 8.06\times10^{-9}$ J

$\therefore$ Binding energy = $\frac{\text{B.E/nucleon}}{\text{nucleon number}}$

$\Rightarrow$ ~~8.6~~ $8.06\times10^{-9} = \frac{\text{BE/nucleon}}{56}$

$\Rightarrow$ BE/nucleon = $4.52\times10^{-7}$

(iii) Deduce a value for the binding energy per nucleon of $^2H$.
You should use your value from (ii) and the graph.

**(2)**

Binding energy per nucleon of $^2H$ is 0

Binding energy per nucleon = 0

**ResultsPlus**
**Examiner Comments**

(ii) An attempt at calculating the mass defect has been made. The value calculated is incorrect because only 1 proton and 1 neutron have been included, but this is sufficient to award the first mark. The candidate has then shown their substitution into $\Delta E=c^2\Delta m$ to find the energy equivalent of the mass. This means that the second mark can be awarded. They have not attempted to convert their energy into eV and although they have realised that they need to divide their energy by 56, this is insufficient to be awarded any further marks.

(iii) Nothing creditworthy.

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

~~$\Delta m = (1.673\times10^{-27}\times26) + (1.675\times10^{-27}\times30) + (9.287\times10^{-26})$~~

$\Delta m = (9.287\times10^{-26}) - (1.673\times10^{-27}\times26) - (1.675\times10^{-27}\times30)$

mass deficit $= -8.78\times10^{-28}$

$E = -8.78\times10^{-28}\times(3\times10^{8})^2$

$E = -7.902\times10^{-11}$ J

$\frac{-7.902\times10^{-11}}{-1.6\times10^{-19}} \times 10^{6}$

$=$ ~~4293~~ 493875000 eV

494 MeV

(iii) Deduce a value for the binding energy per nucleon of $^2H$.
You should use your value from (ii) and the graph.

(2)

~~3.5 block $\frac{9\text{meV}}{3.5}$ = 2.57~~ 9 blocks = 9MeV

1 block = 1MeV

Binding energy per nucleon = 1 MeV

ResultsPlus
Examiner Comments

(ii) The first 3 marks are awarded. The candidate has forgotten to divide their value of energy by the number of nucleons. In this kind of calculation we ignore the minus signs.

(iii) The candidate has taken the 'show that' value and divided by 9, reaching an acceptable answer of 1 MeV, scoring two marks.

## *Question 16 (b)*

From their responses it was clear that whilst many candidates realised that the release of energy is associated with conservation laws, they did not express their ideas with sufficient clarity to be awarded more than the first mark, and sometimes not even that one. It was acceptable to answer either in terms of the conservation of mass-energy or the conservation of energy.

The question refers to the production of 'less massive' isotopes and for the mark to be awarded it was necessary for the response to make it clear that it is the total mass of these less massive isotopes that is less than the mass of the uranium-235. The equivalent approach is to refer to the increase in binding energy that occurs during the fission process. Since both the binding energy and the binding energy per nucleon increase either are acceptable.

For the second mark on both alternative schemes, it was necessary to name the conservation law that featured, either the conservation of mass-energy associated with the decrease in total mass, or the conservation of energy associated with the increase in binding energy. It was insufficient to simply mention $\Delta E = c^2 \Delta m$.

A rare example of a complete answer that scores both marks.

(b) The isotope uranium-235 undergoes fission into less massive isotopes.

Explain how fission of uranium-235 leads to a release of energy.

(2)

The mass of the daughter nuclei of the fission in total is less than the mass of uranium-235

$\Delta E = c^2 \Delta m$, mass-energy is conserved so 'lost mass' is released as energy. This is all due to the daughter nuclei having a higher binding energy per nucleon than uranium-235

**(Total for Question 16 = 10 marks)**

**ResultsPlus**
**Examiner Comments**

This response is awarded the marks for the comment about mass and the explanation which includes that 'mass-energy is conserved'.

The sum of the masses of the daughter nuclei formed from the fission of Uranium - 235 is less than the mass of uranium - 235. Due to this mass deficit, using ~~Δm~~ $E = \Delta mc^2$ it can be seen that mass is turned to energy.

**ResultsPlus**
**Examiner Comments**

This response includes a correct comment about the total mass of the daughter nuclei and is awarded the first mark. There is no mention of the conservation of mass-energy: the reference to the equation is insufficent for the second mark.

When uranium-235 decays, the binding energy per nucleon increases and therefore energy is ~~releases~~ released.

**ResultsPlus**
**Examiner Comments**

A minimum answer for the first mark on the alternative mark scheme.

## Question 17 (a)

Candidates have been asked many times in the past to make a statement about the meaning of simple harmonic motion. It is a standard definition and one that candidates should be ready to state without difficulty. In this question they have been given an incomplete definition and asked to rewrite it.

For the first mark it is essential to specify where the displacement is measured from. 'Equilibrium' is a technical word in physics and means a state not a position. The definition given in the question is meaningless unless the word 'position' or something similar is added. It is also necessary to include something about the direction of the acceleration for the second mark. This mark was more commonly awarded than the first.

Simple harmonic motion occurs when the acceleration of an object is directly proportional to it's displacement from the equilibrium position. Acceleration is always acting towards the equilibrium position.

**ResultsPlus Examiner Comments**

An answer that is awarded both marks.

A typical response, one that is awarded only the second mark.

Simple harmonic motion occurs when the acceleration of an object is ~~d~~ proportional ~~t~~ to it's displacement from equilbrium and it acts towards the equilbrium position.

**ResultsPlus Examiner Comments**

The candidate has copied the given incomplete definition but added a correct statement about the direction of the acceleration which means that the second mark is awarded. They have not made a correct statement about where the displacement is measured from.

(2)

It is when the resultant force is directly proportional to the displacement from equilibrium and this force is a restoring force which is trying to bring the object to its equilibrium position.

**ResultsPlus**
**Examiner Comments**

It is acceptable to define simple harmonic motion in terms of the force rather than acceleration, but this candidate has copied the given statement about displacement replacing 'acceleration' with 'force' but not saying the place where the displacement is measured from. Their comment about the force's direction is however sufficient to be awarded the second mark.

## *Question 17 (b) (i)*

It was clear from the vast majority of responses that candidates had done this experiment or a similar one and so knew the methods that are used to enable an accurate value of the time period to be obtained. For the third mark we were looking for **either** using a marker to indicate the timing position **or** that the timing should be done from the equilibrium position. Ideally, the marker should be at the equilibrium position. For this mark it was not necessary to state 'equilibrium position' as long as it was clear that this was the place the candidate was referring to.

Measure the time for about 20T and divide the time by 20.
Repeat and calculate the average time.
Use a marker to mark the centre of oscillation to determine one T more accurately.

**ResultsPlus**
**Examiner Comments**

An example of a clearly set out response that is awarded all the marks.

(i) A student uses a stopwatch to measure the period of oscillation $T$ of the test tube.

Describe the procedure she should follow to obtain an accurate value for $T$.

**(3)**

The student must first position herself in such a manner that she can observe the oscillation at eye level. She must then start the stopwatch when the test tube is at maximum amplitude or distance. Experiment must be repeated and average must be taken in order to get the most accurate result

**ResultsPlus**
**Examiner Comments**

This response is awarded the second mark for the comment that the 'experiment must be repeated and average taken'. This is not very well expressed but the meaning is clear.

The candidate is going to start the timing from the position of 'maximum amplitude or distance', which will not lead to an accurate result.

Measure the time taken for the test tube to complete 10 oscillations.
She should make sure she observes it at eye level.
Then divide the time measured by 10 to get the time period.
Repeat the experiment several times, and calculate a mean value for T.

**ResultsPlus**
**Examiner Comments**

This response is awarded the first and third mark.

The comment about observing at eye level is not credited in this situation.

## *Question 17 (b) (ii)*

The calculation was usually successfully completed. There were occasional instances of candidates who did not realise that the distance given is the amplitude, and divided it by 2. Those who tried to use the general equation for velocity in shm, $v = -A\omega\sin\omega t$, were usually unable to reach the correct answer because either they took the value of $t$ as 0.57 seconds, or they failed to set their calculator to radians.

An example of a response that scores full marks.

$v_{max} = A\omega$

$= \frac{2}{100} \times \frac{2\pi}{0.57}$

$= 0.22$ m/s

Maximum velocity = 0.22 m/s

**ResultsPlus**
**Examiner Comments**

This response shows the whole calculation done in one stage. The answer is correct and it is acceptable to write the unit as m/s.

$V = -A\omega \sin \omega t$

$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.57} = 11.02 \text{ rad s}^{-1}$

$V = -2 \times 10^{-2} \times 11.02 \times \sin(11.02 \times 0.57)$

$= 0.024 \text{ m s}^{-1}$

Maximum velocity = ..............................

**ResultsPlus**
**Examiner Comments**

The calculation of *ω* has been done correctly and the first mark is awarded.

This candidate has then attempted to use the general expression for velocity in shm. The value for time that has been used, 0.57 s, will not give the maximum velocity, because the maximum value of a sine function occurs when *t* = *T*/4. The calculation has also been done with the calculator set to degrees instead of radians and so the wrong answer would have been obtained even if a correct value of time had been used. However, since the value of time has been taken from the question and all the substitutions can be seen, the second mark is awarded.

**ResultsPlus**
**Examiner Tip**

If asked for the maximum value of velocity in shm, remember that the maximum value of a sine function is 1. Therefore the equation becomes much simpler.

$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.57} = 11.02 \text{ rad s}^{-1}$

$\therefore$ ~~$V = -A\omega \sin \omega t$~~ $V = -A\omega \sin \omega t$

~~$= 0.024$ m/s~~ $= 0.024$ m/s

Maximum velocity = 0.024 m/s

**ResultsPlus**
**Examiner Comments**

This response is awarded the first mark only. We can see that the full equation for velocity has been quoted but the answer is incorrect and we can see no substitution of values into the equation and so cannot award the 'use of' mark.

**ResultsPlus**
**Examiner Tip**

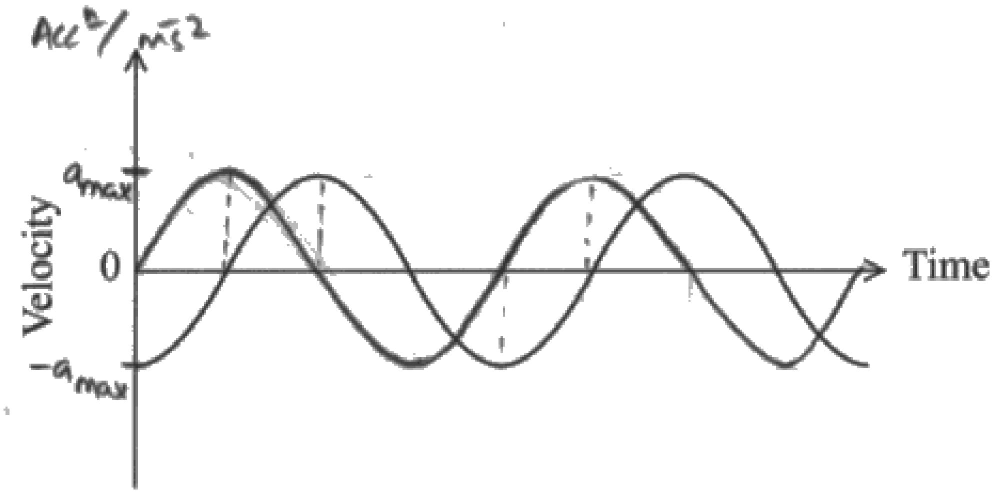
Marks are never awarded for simply quoting the equation you plan to use. Always rewrite the equation with appropriate numbers substituted.

## *Question 17 (b) (iii)*

Many candidates did not appreciate that because the graph shows the variation of velocity with time as a minus cosine function, the variation of acceleration with time must be a sine function. Those who drew a cosine function, ie a mirror image of the given graph, could score neither mark.

For the first mark, either a positive sine curve or a negative sine curve of any amplitude was accepted, provided that the amplitude was constant. For the second mark, it was necessary both to draw the curve so that it has the same period as the original and to draw it with the correct phase. Whilst we do not expect perfectly drawn freehand curves we do expect candidates to be able to show constant amplitude, the correct period and phase.

An example of a response that scored both marks.



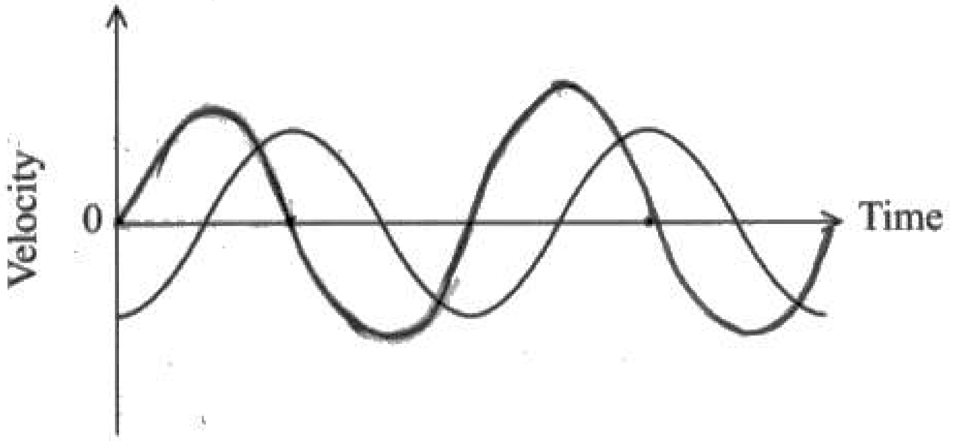

**ResultsPlus**
**Examiner Comments**

It was not necessary to label the axis in this question.

**ResultsPlus**
**Examiner Tip**

The use of guide lines to help draw the maxima at the correct points, as seen here, is very useful when drawing freehand curves

$$\frac{dv}{dt} = a$$




**ResultsPlus**
**Examiner Comments**

A sine curve has been drawn but its amplitude is not constant and therefore the first mark is not awarded.

The phase and time period are both correct and hence the second mark is awarded.

**ResultsPlus**
**Examiner Tip**

Use a ruler to draw some faint pencil guidelines to help keep the amplitude constant.

## *Question 17 (b) (iv)*

Whilst many candidates were able to identify that damping was taking place, very few could explain in sufficient detail what was happening in this particular situation.

Many made a general statement about energy being transferred to the surroundings or being dissipated. To answer this question about the oscillations of the loaded test tube, it is necessary to identify that there are forces acting on the tube by the water that result in the transfer of energy to the water. Air resistance and upthrust are not appropriate forces.

This is a typical response that is awarded the first mark only.

The amplitude will gradually decrease due to damping. This means that the energy is being dissipated from the oscillation.

**ResultsPlus**
**Examiner Comments**

The statement that energy is being dissipated is insufficient for the second mark.

The oscillation is damped - ie. the system has to do work against external ~~w~~ opposing forces eg water resistance and hence energy is dissipated to surroundings so amplitude decreases exponentially

**ResultsPlus**
**Examiner Comments**

A full answer that is awarded both marks.

## *Question 18 (a) (i)*

The vast majority of candidates had little difficulty in arriving at the correct answer and remembered to include the unit.

A few responses showed that whilst the correct equation had been identified, it was not copied down correctly and the constant of proportionality was written as $2.989 \times 10^{-3}$ instead of $2.898 \times 10^{-3}$. This is an incorrect use of the equation and so scores no marks.

$$\lambda_{max} T = 2.898 \times 10^{-3}$$

$$\Rightarrow \lambda_{max} = \frac{2.898 \times 10^{-3}}{3150}$$

$$= 9.2 \times 10^{-7} \text{ m}$$

Wavelength = $9.2 \times 10^{-7}$ m

**ResultsPlus**
**Examiner Comments**

An example of a well set out response that scores both marks.

This illustrates another error which has been seen a number of times.

$\lambda_{max} T = 2.898 \times 10^{-3}$ m K

$\lambda_{max} = \dfrac{2.898 \times 10^{-3} \times 10^{-3} \text{ K}}{3150 \text{ K}}$

$= 9.2 \times 10^{-10}$ m

Wavelength = $9.2 \times 10^{-10}$ m

**ResultsPlus**
**Examiner Comments**

The candidate has misunderstood the equation, and has interpreted 'm' as meaning x $10^{-3}$

This has resulted in an incorrect power of ten in the final answer. The first mark is awarded.

## *Question 18 (a) (ii)*

Whilst most candidates realised that the relevant equation is the Stefan-Boltzmann law, there were a variety of errors made in using it. A number forgot to raise the temperatures to the power 4, but many more failed to square all or part of their expression for radius.

There were a surprising number of errors made in expressing the final answer, even when the calculation had been done correctly. To 3 significant figures the value is 0.0107 which, when rounded to 2 significant figures is 0.011. A lot of candidates gave their final answer as 0.012.

(ii) The radius of Luyten's star is 35% of the radius of the Sun.

Calculate the ratio of the luminosity $L_L$ of Luyten's star to the luminosity $L_S$ of the Sun.

surface temperature of the Sun = 5800 K

**(2)**

$L_L : L_S$ $\quad L_S = 4\pi\sigma r_S^2 T_S^4 \quad L_S = r^2 \times 5800^4$

$L_L = 4\pi\sigma r_L^2 T_L^4 \quad L_L = \left(\frac{35}{100} r\right)^2 \times 3150^4$

$= \left(\frac{35}{100}\right)^2 r^2 \times 3150^4$

$L_L : L_S$

$= \dfrac{\left(\frac{35}{100}\right)^2 \times 3150^4}{1 \times 5800^4} = 0.0107$

$\dfrac{L_L}{L_S} = 0.0107$

**ResultsPlus**
**Examiner Comments**

A response that scores both marks.

~~$d_L = 0.35 d_s$ 0.35 $d_s$~~ $L_s = 4\pi(r_s)^2\sigma(5800)^4$

Sun, ~~$\frac{I_{sun}}{4\pi(d_s)^2}$~~ $L_L = 4\pi(0.35r_s)^2\sigma(3150)^4$

$$\frac{L_L}{L_s} = \frac{4\pi(0.35r_s)^2\sigma(3150)^4}{4\pi(r_s)^2\sigma(5800)^4}$$

$r_L = 0.35 r_s$

$$\frac{L_L}{L_s} = 0.012$$

$\frac{L_L}{L_s}$ = 0.012

**ResultsPlus**
**Examiner Comments**

This response shows values correctly substituted into the expressions for the luminosities, and the constants have been cancelled, but the answer is incorrect. Presumably this is because the candidate has incorrectly rounded the value displayed on their calculator. The first mark is awarded.

**ResultsPlus**
**Examiner Tip**

Write down your answer to 3 or 4 significant figures before rounding. If you then make a mistake you may still be awarded full marks.

$$\frac{L_L}{L_S} = \frac{4\pi \times (1 \times 0.35)m \times (3150K)^4}{4\pi \times (1m) \times (5800K)^4}$$

$= 0.03045077044$

$= 0.0305$

$\frac{L_L}{L_S} =$ 0.0305

**ResultsPlus**
**Examiner Comments**

In this response we can see that the candidate has a valid way to deal with the radius of Luyten's star being 35% of the radius of the Sun, but they have forgotten to square the radii. No marks can be scored because the equation has not been used correctly.

## *Question 18 (a) (iii)*

Most candidates realised that since they had been told that the atoms could be treated as an ideal gas, it would be possible to use the expression given at the back of the question paper for the mean kinetic energy of the atoms, 3/2 *kT.*

A few of these candidates looked up the value of the Boltzmann constant incorrectly and used the value for the Coulomb's Law constant instead. Some attempted to calculate kinetic energy using 1/2 $mv^2$, and because they didn't know the mean speed of the atoms used the speed of light. In neither of these is the equation being used correctly and no marks are awarded.

KE = $\frac{3}{2}kT$

$\frac{3}{2} \times 1.38 \times 10^{-23} \times 3150$

Mean kinetic energy = $6.5 \times 10^{-20}$ J

**ResultsPlus**
**Examiner Comments**

An example of a response that scores both marks.

$= \frac{1}{2} m \langle c^2 \rangle$

$= \frac{1}{2} \times 1.67 \times 10^{-27} \times (3 \times 10^8)^2 = 7.515 \times 10^{-11}$

Mean kinetic energy = $7.515 \times 10^{-11}$ J

**ResultsPlus**
**Examiner Comments**

This candidate has used the mass of a proton as the mass of a hydrogen atom which is sensible but they should have realised that an atom is not going to travel at the speed of light and therefore this method cannot be valid. No marks are awarded.

$E_k = \frac{3}{2} kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 3150$

Mean kinetic energy = $6.5 \times 10^{-20}$

**ResultsPlus**
**Examiner Comments**

The substitution and calculation have been done correctly but there is no unit. The second mark is only awarded if the answer is numerically correct and the unit is included. The response is awarded the first mark only.

## *Question 18 (b) (i)*

In order to answer this question it is necessary to bring understanding of several areas of physics to a new situation which has not been asked about before. Many realised that the Doppler shift was part of the explanation and so were awarded the first mark. For the second mark we were looking for some detail about what that meant about the motion of the atoms and the wavelength of light emitted by the atoms as observed on Earth. Statements about red or blue shift provided insufficient detail. A much smaller number of candidates realised that the motion of the atoms, behaving as an ideal gas with frequent collisions, would have a large range of different velocities and so this would lead to a large range of different wavelengths being observed.

Some candidates had clearly studied last year's paper, which is good practice as part of their exam preparation, but jumped to the conclusion that this question was very similar to one on that paper. They assumed that Luyten's star is spinning and so atoms on one side of the star would be receding from Earth and those on the other side approaching Earth. This question says nothing about the motion of Luyten's star so this approach could score a maximum of 2 marks.

When the atoms of the outer regions move randomly in the outer regions of the star, they all move at different velocities and is independent from each other. Some moves towards Earth, so the wavelength emitted by these atoms is shorter than 656.3 nm. Some recedes from Earth, the wavelength is stretched and is longer than 656.3 nm. With a combination of these motions, a thick line is obtained, and it becomes a range of wavelengths due to Doppler's effect, where $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$.

**ResultsPlus**
**Examiner Comments**

A very good answer that scores all 3 marks.

There is doppler effect occuring. when some atoms move towards the observer, wavelength decreases and if away, wavelength increases. so a range of EM spectrum line is produced

ResultsPlus
Examiner Comments

This response was awarded the first 2 marks. There is no discussion of how the atoms will have many different velocities and it is therefore insufficient to score the 3rd mark.

As the atom move in the region, the distance to ~~between~~ the atoms ~~and~~ from the Earth changes. By Doppler's effect, the wavelength observed at the ~~et~~ earth would change due to red shifts.

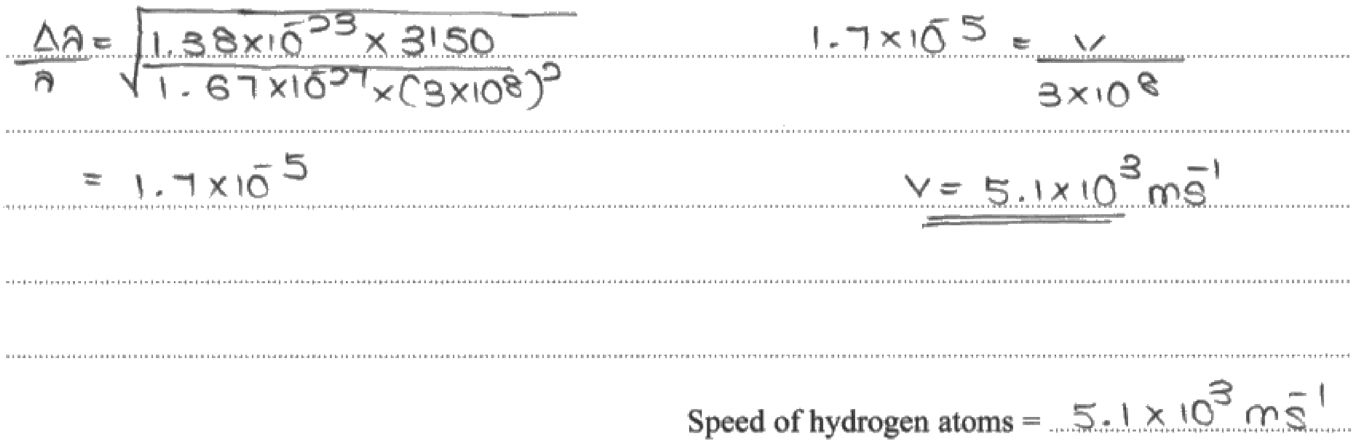
**ResultsPlus**
**Examiner Comments**

This response is not well written but there is mention of "Doppler's effect" with some correct context so the first mark is awarded. However, the candidate thinks that the Doppler shift occurs because of a changing distance from Earth which is incorrect physics and they have not specified whether the wavelength would be larger or smaller. No further marks are awarded.

## *Question 18 (b) (ii)*

The main challenge with this question was to realise that the final value of the speed of hydrogen atoms required that the left hand side of the given equation is equated with *v/c* , and it was not necessary to look for values of wavelength to substitute. However, many candidates were able to substitute appropriate values into the right hand side of the given equation and were awarded the first mark. There were a few responses in which the surface temperature of the Sun, 5800 K, was used instead of the surface temperature of Luyten's star, 3150 K.

A few candidates realised that when the two equations are equated, the expression can be simplified and the speed of light *c* cancels.This approach will of course, give the correct answer and is awarded full marks.



$$\frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1.38\times10^{-23}\times3150}{1.67\times10^{-27}\times(3\times10^{8})^2}}$$

$= 1.7\times10^{-5}$

$$1.7\times10^{-5} = \frac{v}{3\times10^{8}}$$

$v = 5.1\times10^{3}\ \text{m s}^{-1}$

Speed of hydrogen atoms = $5.1\times10^{3}\ \text{m s}^{-1}$

ResultsPlus
Examiner Comments

An example of a response that scored all three marks.

$\sqrt{\frac{kT}{mc^2}} = \frac{\Delta\lambda}{\lambda}$ $\qquad$ $v^2 = \frac{kT}{m}$

$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$ $\qquad$ $v^2 = \frac{1.38\times10^{-23} \times 3130}{1.67\times10^{-27}}$

$\sqrt{\frac{kT}{mc^2}} = \frac{v}{c}$

$\frac{kT}{mc^2} = \frac{v^2}{c^2}$ $\qquad$ $v = 5.1\times10^{3}\ ms^{-1}$

Speed of hydrogen atoms = $5.1\times10^{3}\ ms^{-1}$

**ResultsPlus**
**Examiner Comments**

This candidate has done the algebra first without making any mistakes, leading to the correct final answer, and is awarded full marks.

**ResultsPlus**
**Examiner Tip**

Unless you are very confident in your mathematical skills it is wiser to substitute values before rearranging equations.

$$\frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1.38 \times 10^{-23} \times 3150}{1.67 \times 10^{-27} \times (3 \times 10^{8})^2}} = 1.70 \times 10^{-5} m$$

$$V = \frac{1.70 \times 10^{-5} - 656.3 \times 10^{-9}}{656.3 \times 10^{-9}} \times 3 \times 10^{8}$$

$$= 7.5 \times 10^{9} ms^{-1}$$

Speed of hydrogen atoms = $7.5 \times 10^{9} ms^{-1}$

**ResultsPlus**
**Examiner Comments**

In this response we can see that the substitution into the right hand side of the given equation has been done correctly and so the first mark is awarded. The candidate got into a muddle when trying to use the Doppler shift equation so no further marks can be awarded.

## *Question 18 (c)*

This question asks for a comparison to be made between the two stars. It is essential therefore that comparison words like lower or smaller are used. The preceding parts of the question have introduced Luyten's star as having a lower surface temperature and lower luminosity than the Sun. This should have helped candidates to realise that Luyten's star has a smaller mass than the Sun and hence smaller gravitational forces acting.

These smaller gravitational forces result in a lower temperature, density and pressure in the **core** of the star compared to the core of the Sun. It is essential to identify that it is the core because this is where the main hydrogen fusion process takes place. Although many candidates mentioned the lower temperature of Luyten's star they often failed to identify that the core temperature must be lower.

Most responses attempted to relate what they knew about hydrogen fusion in a main sequence star to evolution of the star, but many could not express this with sufficient clarity, just repeating what was given in the question. We expected candidates to discuss hydrogen fusion rather than the more general nuclear fusion and to refer to hydrogen by name, not just refer to fuel.

An example of a response that scored all three marks.

Luyten's star ~~has a~~ is smaller than the Sun in mass, as both its luminosity and surface temperature is lower than the Sun's. This means gravitational force on the core is smaller and temperature and pressure in the core is smaller than the Sun's. ~~So~~ so rate of fusion is smaller and ~~so~~ it will burn it's reserve of hydrogen more slowly than the Sun ~~so~~, so will run of fuel slower. Star's remain in the main sequence only when they are burning hydrogen.

**(Total for Question 18 = 15 marks)**

**ResultsPlus**
**Examiner Comments**

In general, we accepted references to 'hydrogen burning' instead of the more accurate expression, 'hydrogen fusion'. This response includes both.

• The Luyten's star is less massive than the ~~sum~~ sun.
• It has lower gravitational force than sun has.
• Hence the rate of fusion is lower in Luyten's star.
• So it has a longer life-time.

**ResultsPlus**
**Examiner Comments**

The first mark is awarded for the candidate's second statement.

Their other comments are insufficient for the third mark although their response suggests that they understand the physics involved. They have not mentioned hydrogen and have not explained why a lower rate of fusion leads to a longer lifetime.

Temperature and mass of the Luyten's star is lower than the temperature and mass of the sun. Rate of fusion on the Luyton's star would be slower in compare to sun. Therefore will take longer time to run out of fuel and evolve to red giants.

ResultsPlus
Examiner Comments

This response suggests that the candidate understands the physics behind the third mark but has not expressed themselves well enough to be awarded the mark. It is meaningless to say that 'the rate of fusion is slower', a rate cannot be slower. The 'fuel' has not been identified as hydrogen.

# 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.
- Where questions ask for a description or explanation, be particularly careful to use appropriate scientific terminology.
- In 'show that' questions include all substitutions and all stages in the working.
- Show all their workings in calculations.

# Grade Boundaries

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

http://www.edexcel.com/iwantto/Pages/grade-boundaries.aspx