



Mark Scheme (Results)

June 2019

Pearson Edexcel GCE
In Physics (9PH0)
Paper 02 Advanced Physics II

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General Marking Guidance

- All candidates must receive the same treatment. Examiners must mark the first candidate in exactly the same way as they mark the last.
- Mark schemes should be applied positively. Candidates must be rewarded for what they have shown they can do rather than penalised for omissions.
- Examiners should mark according to the mark scheme not according to their perception of where the grade boundaries may lie.
- There is no ceiling on achievement. All marks on the mark scheme should be used appropriately.
- All the marks on the mark scheme are designed to be awarded. Examiners should always award full marks if deserved, i.e. if the answer matches the mark scheme. Examiners should also be prepared to award zero marks if the candidate's response is not worthy of credit according to the mark scheme.
- Where some judgement is required, mark schemes will provide the principles by which marks will be awarded and exemplification may be limited.
- When examiners are in doubt regarding the application of the mark scheme to a candidate's response, the team leader must be consulted.
- Crossed out work should be marked UNLESS the candidate has replaced it with an alternative response.

Quality of Written Communication

Questions which involve the writing of continuous prose will expect candidates to:

- write legibly, with accurate use of spelling, grammar and punctuation in order to make the meaning clear
- select and use a form and style of writing appropriate to purpose and to complex subject matter
- Organise information clearly and coherently, using specialist vocabulary when appropriate.

Full marks will be awarded if the candidate has demonstrated the above abilities. Questions where QWC is likely to be particularly important are indicated (QWC) in the mark scheme, but this does not preclude others.

Physics Specific Marking Guidance

Underlying principle

The mark scheme will clearly indicate the concept that is being rewarded, backed up by examples. It is not a set of model answers.

For example:

Horizontal force of hinge on table top

66.3 (N) or 66 (N) **and** correct indication of direction [no ue]

[Some examples of direction: acting from right (to left) / to the left / West / opposite direction to horizontal. May show direction by arrow. Do not accept a minus sign in front of number as direction.]

This has a clear statement of the principle for awarding the mark, supported by some examples illustrating acceptable boundaries.

Mark scheme format

- Bold lower case will be used for emphasis.
- Round brackets () indicate words that are not essential e.g. “(hence) distance is increased”.
- Square brackets [] indicate advice to examiners or examples e.g. [Do not accept gravity] [ecf].

Unit error penalties

- A separate mark is not usually given for a unit but a missing or incorrect unit will normally cause the final calculation mark to be lost.
- Incorrect use of case e.g. ‘Watt’ or ‘w’ will not be penalised.
- There will be no unit penalty applied in ‘show that’ questions or in any other question where the units to be used have been given.
- The same missing or incorrect unit will not be penalised more than once within one question but may be penalised again in another question.
- Occasionally, it may be decided not to penalise a missing or incorrect unit e.g. the candidate may be calculating the gradient of a graph, resulting in a unit that is not one that should be known and is complex.
- The mark scheme will indicate if no unit error penalty is to be applied by means of [no ue].

Significant figures

- Use of an inappropriate number of significant figures in the theory papers will normally only be penalised in ‘show that’ questions where use of too few significant figures has resulted in the candidate not demonstrating the validity of the given answer.
- Use of an inappropriate number of significant figures will normally be penalised in the practical examinations or coursework.
- Using $g = 10 \text{ m s}^{-2}$ **will** be penalised.

Calculations

- Bald (i.e. no working shown) correct answers score full marks unless in a ‘show that’ question.
- Rounding errors will not be penalised.
- If a ‘show that’ question is worth 2 marks then both marks will be available for a reverse working; if it is worth 3 marks then only 2 will be available.
- use of the formula means that the candidate demonstrates substitution of physically correct values, although there may be conversion errors e.g. power of 10 error.
- recall of the correct formula will be awarded when the formula is seen or implied by substitution.
 - The mark scheme will show a correctly worked answer for illustration only.

Question Number	Acceptable answer	Additional guidance	Mark
1	C	The only correct answer is C : main sequence – red giant – white dwarf A is not correct because it is white dwarf – red giant – main sequence B is not correct because it moves along the main sequence from large to small D is not correct because it moves along the main sequence from small to large	1
2	B	The only correct answer is B : for each spring, $\frac{1}{2}$ force, so $\frac{1}{2}$ extension, so $\frac{1}{2}Fx$ gives $\frac{1}{4}E$, so total is $\frac{1}{2}E$ A is not correct because it is the energy for one spring with this extension C is not correct because it only applies the factor of $\frac{1}{2}$ once D is not correct because it is the energy for two springs, each with the original extension	1
3	D	The only correct answer is D : the binding energy per nucleon curve shows an increase for both processes A is not correct because both processes show decreases B is not correct because fission shows a decrease C is not correct because fusion shows a decrease	1
4	C	The only correct answer is C : mass decrease by $20 \rightarrow 5\alpha$, which is a charge decrease of 10, but total charge decrease is 6, so 4β A is not correct because there are too few alpha and too many beta B is not correct because there are too few alpha and too many beta D is not correct because there are too many beta	1
5	B	The only correct answer is B : light leaving Y is polarised in its plane of polarisation and 135° is perpendicular to the plane of Y, so there will be maximum absorption by filter Z A is not correct because Z is not perpendicular to the plane of Y so some light is transmitted C is not correct because Z is not perpendicular to the plane of Y so some light is transmitted D is not correct because Z is not perpendicular to the plane of Y so some light is transmitted	1
6	D	The only correct answer is D : a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	1

7	C	The only correct answer is C: luminosity is proportional to temperature⁴ which means a 16-fold increase, and luminosity is proportional to area, which is proportional to diameter², and so means a 4-fold decrease, so there is a 4-fold increase overall A is not the correct answer because this only accounts for the decrease due to decreasing diameter B is not the correct answer because this is the answer obtained if the power applied to temperature is 2 instead of 4 D is not the correct answer because the effect of area is not included	1
8	B	The only correct answer is B: Upthrust is density of fluid $\times$ volume of object $\times$ g A is not the correct answer because density of object has been used, so this is the gravitational force acting on the object C is not the correct answer because this is the resultant force D is not the correct answer because this is the mean of the magnitude of the forces in A and B	1
9	D	The only correct answer is D: potential is proportional to $1/x$ A is not correct because electric fields do not cause a force on uncharged particles B is not correct because the force caused by gravitational field has only ever been shown to be attractive C is not correct because field strength is inversely proportional to x^2	1
10	D	The only correct answer is D: velocity is maximum when displacement is zero, and vice versa, and has positive and negative values since the direction reverses A is not correct because this shows maximum velocity when it should be minimum and vice versa B is not correct because this shows maximum velocity when it should be minimum and vice versa C is not correct because this does not show the change in direction of velocity during an oscillation	1

(Total for Multiple Choice Questions = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11	• Use of $\Delta Q = mc\Delta\theta$ (1) • ... for correct temperature change (1) • Use of $\Delta Q = L\Delta m$ (1) • Use of $P = E/t$ (1) • It is not transferred faster because: (1) 823 (W to water) < 2400 (W to iron) Or 46 100 (J to water) < 134 400 (J to iron) Or 19.2 (s to evaporate water at rate of 2400 W) < 56 (s taken)	<u>Example of calculation</u> mass of water = 0.0359 kg – 0.0182 kg = 0.0177 kg $\Delta Q = 0.0177 \text{ kg} \times 4190 \text{ J kg}^{-1} \text{ K}^{-1} \times (100 \text{ }^{\circ}\text{C} - 18 \text{ }^{\circ}\text{C})$ = 6100 J $\Delta Q = (0.0177 \text{ kg}) \times 2.26 \times 10^6 \text{ J kg}^{-1}$ = 40 000 J $P = (6100 \text{ J} + 40\,000 \text{ J}) / 56 \text{ s} = 823 \text{ W}$	5

(Total for Question 11 = 5 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	- Use of $n = c / v$ (1) $v = 2.0 \times 10^8 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $1.52 = 3.00 \times 10^8 \text{ m s}^{-1} / v$ $1.97 \times 10^8 \text{ m s}^{-1}$	2
12 (b) (i)	- the angle of incidence in an (optically) denser medium at which the angle of refraction (in the less dense medium) is 90° (1) Or - the greatest angle of incidence in an (optically) denser medium at which there is an emergent ray (into the less dense medium) Or - the greatest angle of incidence in an (optically) denser medium at which there is a refracted ray (in the less dense medium)	Other equivalent answers may be given Do not accept answers stating or implying that the critical angle is the smallest angle at which <u>total</u> internal reflection occur, e.g., ‘The smallest angle at which t.i.r. takes place’, but do not automatically exclude answers on the basis of mentioning internal reflection alone without the inclusion of ‘total’ ‘The greatest angle before t.i.r. takes place’ is not sufficient	1
12 (b) (ii)	- Use of $\sin C = 1 / n$ (1) $C = 41^\circ$ (1)	<u>Example of calculation</u> $\sin C = 1/1.52$ $C = 41.1^\circ$	2
12 (c)	- Light strikes the edges of the long crystals at angles greater than the critical angle (1) - It is repeatedly totally internally reflected along the crystal (1)		2

(Total for Question 12 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark																																
*13	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table border="1"> <thead> <tr> <th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table> The following table shows how the marks should be awarded for structure and lines of reasoning.	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).	6
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark																																
6	4	2	6																																
5	3	2	5																																
4	3	1	4																																
3	2	1	3																																
2	2	0	2																																
1	1	0	1																																
0	0	0	0																																

		Number of marks awarded for structure of answer and sustained line of reasoning			
	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2			
	Answer is partially structured with some linkages and lines of reasoning	1			
	Answer has no linkages between points and is unstructured	0			
	Indicative content • 720 Hz is the natural frequency of the bowl • The generator/hand causes forced/driven oscillations • When they don't match the natural frequency they are quiet because little/less energy is transferred • The loudness (at 720 Hz) is because of resonance • (Resonance occurs when) the driving frequency is equal/similar to the natural frequency • (When resonance occurs) there is maximum transfer of energy so the amplitude is maximum Or (When resonance occurs) there is maximum transfer of energy so the amplitude increases				Do not accept 'resonant frequency' for 'natural frequency'

(Total for Question 13 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14a	- The frequency/wavelength (of a line in the spectrum) emitted by the star must be measured (1) - Determine the difference between this frequency/wavelength and that emitted in the lab (1) (The Doppler equation is used to) determine the speed of the star (relative to the Earth) $v/c = \Delta f/f_0$ or $v/c = \Delta \lambda/\lambda_0$ (1) - Clear indication (stated in words or via a formula) that v is positive/approaching when the frequency has increased and negative/receding when it has decreased (1) Or corresponding statement about wavelength (1)	MP2 – accept in terms of difference between measured frequency/wavelength with average frequency/wavelength	4
bi	- Use of $\omega = 2\pi/T$ (1) - For at least 2 full cycles (1) $\omega = 6.5 \times 10^{-6}$ (radian s⁻¹) (1)	For MP3, accept correctly rounded answers in range 6.5×10^{-6} radian s⁻¹ to 6.6×10^{-6} radian s⁻¹ <u>Example of calculation</u> $\omega = 5 \times 2\pi / (56 \times 24 \times 60 \times 60) \text{ s}$ $= 6.49 \times 10^{-6} \text{ radian s}^{-1}$	3
bii	- Equates $F = Gm_1m_2/r^2$ and $F = m\omega^2r$ (1) Or $F = Gm_1m_2/r^2$ and $F = mv^2/r$ with $v = 2\pi r/T$ (1) - Correct rearrangement and substitution (e.g. in $r^3 = Gm_1/\omega^2$) (1) $r = 7.2 \times 10^9$ m (ecf from (b)(i))	<u>Example of calculation</u> $r^3 = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 0.12 \times 1.99 \times 10^{30} \text{ kg} / (6.5 \times 10^{-6} \text{ radian s}^{-1})^2$ $r = 7.2 \times 10^9 \text{ m}$ ($r = 7.6 \times 10^9$ m for ‘show that’ value)	3

(Total for Question 14 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15 (a)	- Use of $v = f\lambda$ (1) $\lambda = 0.013 \text{ m}$ (1)	<u>Example of calculation</u> $340 \text{ m s}^{-1} = 26.0 \text{ kHz} \times \lambda$ $\lambda = 0.013 \text{ m}$	2
15 (b)	- Two or more waves meet (1) - The (resultant) displacement (at a point) is the sum of the individual displacements from the individual waves (1)	Do not accept sum of amplitudes	2

15 (c)	- Wave and reflection will meet (1) - Superposition / interference occurs (1) - Where in antiphase, destructive interference (1) - Zero/minimum amplitude at nodes – so mice won't hear (1) Either - But node separation = $\frac{1}{2}$ wavelength = (about) 7 mm (1) - Too small a space for a mouse to avoid the ultrasound, so suggestion not correct (1) Or (MP5 and 6) - Wall absorbs some ultrasound so reflected wave has smaller amplitude than incident wave (1) - Incomplete cancellation, some ultrasound even at nodes, so suggestion (probably) incorrect (1) Or (MP5 and 6) - Waves also arrive from other walls/floor/ceiling/multiple reflection (1) - Complete cancellation unlikely so suggestion (probably) incorrect (1) Or (MP5 and 6) - A standing wave will only be formed if the length of the room is a whole number of half wavelengths - Otherwise there will be no nodes so no silent spots where the mouse won't hear (1)	<u>Example of calculation</u> $\lambda/2 = 0.013 \text{ m} / 2$ $= 0.0065 \text{ m}$	6
(Total for Question 15 = 10 marks)			

Question Number	Acceptable answers	Additional guidance	Mark
16(a)	- Determine period, T (1) - Use of $T = 2\pi\sqrt{l/g}$ (1) - Subtracts radius of mass (1) - Length of wire = 10.3 (m) (1)	<u>Example of calculation</u> $T = 52.2 \text{ s} / 8$ $= 6.53 \text{ s}$ $6.53 \text{ s} = 2\pi\sqrt{l/9.81 \text{ N kg}^{-1}}$ Length of pendulum to centre of mass = 10.6 m Length of wire = 10.6 m – 0.3 m = 10.3 m	4
16 (b)(i)	- Use of (breaking) stress = F/A (1) - Use of $A = \pi r^2$ (1) - Diameter = 1.06 mm and choose 1.22 mm because it is the thinnest wire with stress lower than the breaking stress (1)	<u>Example of calculation</u> For max stress, $3.10 \times 10^8 \text{ N m}^{-2} = 28 \text{ kg} \times 9.81 \text{ N kg}^{-1}/A$ $A = 8.86 \times 10^{-7} \text{ m}^2$ $8.86 \times 10^{-7} \text{ m}^2 = \pi r^2$ $r = 5.3 \times 10^{-4} \text{ m}$ diameter = 1.06 mm	3
16 (b)(ii)	- Use of stress = F/A and $A = \pi r^2$ (ecf for radius from (b)(i)) (1) - Use of Young modulus = stress / strain and strain = $\Delta x/x$ (1) - Extension = 1.3 cm (1)	Allow ecf for radius of wire chosen in part (b)(i), but not for the calculated radius or area <u>Example of calculation</u> stress = $28 \text{ kg} \times 9.81 \text{ N kg}^{-1} / \pi (1.22 \times 10^{-3} \text{ m} / 2)^2$ strain = $2.34 \times 10^8 \text{ Pa} / 200 \text{ GPa} = 0.00117$ extension = $0.00117 \times 11.2 \text{ m} = 0.0132 \text{ m}$	3

16 (c)	• There is (damping due to) air resistance and this (damping) force is the same for both (since they have the same shape, area and speed initially) (1) • For large mass the force due to air resistance produces a smaller negative acceleration since $a = F/m$ (1) • The speed will decrease less for each swing, so there is less effect on the amplitude Or It will take longer for the (maximum) speed to decrease (to zero) so the pendulum will oscillate for a longer time (1) OR • There is air resistance and the force is the same for both • The work done by air resistance per swing is the same for both masses (1) • Initially the larger mass has greater quantity of energy shared between its kinetic and potential energy stores, so the proportion of KE transferred to the thermal energy store of the sphere and the surroundings is less per swing, so there is less effect on the amplitude Or Larger mass has greater total energy so fraction dissipated per swing is smaller so the pendulum will oscillate for a longer time (1)		3
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	OR There is air resistance and this force is the same for both (1) • For both masses the change in momentum per swing is the same (1) • The larger mass has greater initial momentum so it will take longer for the (maximum) momentum to decrease (to zero) so the pendulum will oscillate for a longer time (1)		
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(Total for Question 17 = 13 marks)

Question Number	Acceptable answers	Additional guidance	Mark
17 (a)	• Use of lens equation $1/f = 1/v + 1/u$ (1) • Use of magnification $= v/u$ (1) • Magnification = 15 (1)	<u>Example of calculation</u> $1/17.9 \text{ mm} = 1/v + 1/16.7 \text{ mm}$ $v = (-)249 \text{ mm}$ magnification = $249 \text{ mm} / 16.7 \text{ mm}$ = 14.9	3
17 (b)(i)	• The electrons/atoms can only exist in discrete/specific energy levels (in the sodium atoms) (1) • Electrons/atoms become excited Or Electrons/atoms move to higher energy levels (1) • The electrons/atoms then move to lower energy levels, giving out energy in the form of <u>photons</u> (1) • The energy of the photon is equal to the energy difference between the energy levels (1) • $E = hf$ and $\lambda = c/f$ so wavelength depends on the photon energy (1) • There are only certain energy transitions possible (between discrete levels) so only certain frequencies/wavelengths are visible. (1)	accept $E = hc / \lambda$ MP6 – Allow reference to few or limited number for ‘certain’. Allow reference to discrete differences in energy levels.	6

17 (b)(ii)	• Use of $n\lambda = d \sin \theta$ (1) • $d = 1.77 \times 10^{-6} \text{ m}$ (1) • Choose $d = 2.0 \times 10^{-6} \text{ m}$ as a smaller value than $d = 1.77 \times 10^{-6} \text{ m}$ would cause greater diffraction angles so the third order would not be seen, but $3.3 \times 10^{-6} \text{ m}$ would produce smaller angles than $2.0 \times 10^{-6} \text{ m}$, causing larger relative uncertainty in measurement (1) Or • Use of $n\lambda = d \sin \theta$ (1) • A correct value of $\sin \theta$ or θ $d = 1.0 \times 10^{-6} \text{ m} \rightarrow 1.77$ $d = 1.7 \times 10^{-6} \text{ m} \rightarrow 1.04$ $d = 2.0 \times 10^{-6} \text{ m} \rightarrow 0.88 \quad 62.^{\circ}$ $d = 3.3 \times 10^{-6} \text{ m} \rightarrow 0.535 \quad 32.^{\circ}$ (1) • Choose $d = 2.0 \times 10^{-6} \text{ m}$. $1.7 \times 10^{-6} \text{ m}$ would give a sine value greater than 1, so no 3rd order is visible, and $3.3 \times 10^{-6} \text{ m}$ would produce smaller angles than $2.0 \times 10^{-6} \text{ m}$, causing larger relative uncertainty in measurement (1)	<u>Example of calculation</u> $3 \times 5.89 \times 10^{-7} \text{ m} = d \sin 90^{\circ}$ $d = 1.77 \times 10^{-6} \text{ m}$	3
17 (c)	• Use of $E = hf$ and $c = f\lambda$ (1) • Convert J to eV (1) • 2.1 eV (1) • Arrow drawn on diagram from -3.04 eV to -5.14 eV (1)	<u>Example of calculation</u> $E = 6.63 \times 10^{-34} \text{ Js} \times 3.00 \times 10^8 \text{ m s}^{-1} / 5.89 \times 10^{-7} \text{ m}$ $= 3.38 \times 10^{-19} \text{ J}$ $3.38 \times 10^{-19} \text{ J} / 1.60 \times 10^{-19} \text{ C} = 2.11 \text{ eV}$	4

(Total for Question 17 = 16 marks)

Question Number	Acceptable answers	Additional guidance	Mark
18 (a)	- Alpha won't penetrate the plastic so the gas can't escape (1) - Alpha won't penetrate the plastic so there is no risk (1)	For MP1, accept answers in terms of the small range of alpha particles in the air in the bag	2
18(b)(i)	- Calculate no of nuclei (1) - Use of $\ln 2 = t \frac{1}{2} \times \lambda$ (1) - Use of $A = \lambda N$ (1) $A = 3.97 \times 10^4 \text{ Bq}$ (1)	<u>Example of calculation</u> $N = (5.18 \times 10^{-5} \text{ g} / 230 \text{ g}) \times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7) \text{ s} = \ln 2$ $\lambda = 2.92 \times 10^{-13} \text{ s}^{-1}$ $A = 2.92 \times 10^{-13} \text{ s}^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4 \text{ Bq}$	4
18 (b)(ii)	- Calculates decays in one year (ecf from (b)(i)) (1) - Use of $pV = NkT$ (1) - uses $T = 295 \text{ K}$ (1) $V = 5.09 \times 10^{-14} \text{ m}^3$ (1)	<u>Example of calculation</u> ecf λ from (a) decays in one year $= 3.97 \times 10^4 \text{ Bq} \times 3.15 \times 10^7 \text{ s}$ $= 1.25 \times 10^{12}$ $1.00 \times 10^5 \text{ Pa} \times V = 1.25 \times 10^{12} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 295 \text{ K}$ $V = 5.09 \times 10^{-14} \text{ m}^3$	4
18 (b)(iii)	- Use of $\frac{1}{2} m \langle c^2 \rangle = 3/2 kT$ (1) - Or Use of $pV = \frac{1}{3} Nm \langle c^2 \rangle$ (allow ecf for N, V from (b)(ii)) (1) - uses $m = 4u$ (1) $\sqrt{\langle c^2 \rangle} = 1360 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\frac{1}{2} m \langle c^2 \rangle = 3/2 kT$ $\frac{1}{2} \times (4 \times 1.66 \times 10^{-27} \text{ kg}) \times \langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 295 \text{ K}$ $\langle c^2 \rangle = 1\,840\,000 \text{ m}^2 \text{ s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 1360 \text{ m s}^{-1}$ Accept the use of proton/neutron mass instead of u	3

(Total for Question 18 = 13 marks)