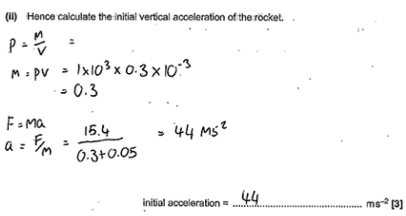
Mark scheme – Thermal Physics

Question			Answer/Indicative content	Marks	Guidance
1			C	1	**Examiner's Comments** As a substance melts, the PE of the molecules increases, ruling out answers B and D. The temperature of a melting substance does not change and so the KE of the molecules cannot change, as the temperature and mean KE of molecules are directly proportional. This means that C must be correct. A cannot be correct since the internal energy is the sum of the KE and PE of the molecules. The KE is constant and the PE increases, meaning the internal energy must also increase.
			Total	**1**	
2			A	1	
			Total	**1**	
3			The energy required per unit mass to change the temperature by 1 K / 1°C.	B1	**Allow**: $c = E/m\,\Delta\theta$, where E = energy, m = mass and $\Delta\theta$ = change in temperature.
			Total	**1**	
4			The sum of (the random distribution of) the KE and PE of (its) molecules	**B1**	**Not** if no clear indication of particulate nature, i.e. allow particles or atoms for molecules **Examiner's Comments** The correct answer for this item was a direct reference to specification point 5.1.2 (d) and required the association with the particles of a system. Many more than half of the candidates would have scored this mark had they included this association.
			Total	**1**	
5	a		pV/T = constant	B1	
			$(1.0 \times 10^5 V)/290 = (1.0 \times 10^3 \times 1.0 \times 10^6)/230$	B1	
			$V = 1.26 \times 10^4$ (m^3)	B1	
	b	i	$n = pV/RT = 1.0 \times 10^5 \times 1.26 \times 10^4/(8.31 \times 290)$	B1	**ecf**
		i	$n = 5.2 \times 10^5$	B1	**allow** 5.4×10^5 using 1.3×10^4
		ii	$4.0 \times 10^{-3} \times 5.2 \times 10^5 = 2.1 \times 10^3$ (kg)	B1	**ecf (i)**
	c		(internal energy $\propto$ T) $E = 1900 \times 230/290 = 1500$ (MJ)	B1	
	d		$U = \rho V g = 1.3 \times 1.26 \times 10^4 \times 9.81 = 1.61 \times 10^5$	C1	**or** $1.3 \times 1.3 \times 10^4 \times 9.81 =$

			Ma = U − Mg	C1	1.66×10^5
			27 M = 1.6×10^5 − Mg giving M = 4.3×10^3 kg	A1	M = 4.6×10^3 kg
			Total	**10**	
6			The sum of the (random) kinetic and potential energy of atoms or molecules in a substance	B1	**Allow** 'particles' **Examiner's Comments** This is a simple definition that many candidates recalled well. Lower level responses missed out that this is to do with the kinetic energy and potential energy of **particles**.
			Total	**1**	
7			D	1	
			Total	**1**	
8			**D**	**1**	**Examiner's Comments** The unit J mol^{-1} K^{-1} is the same unit as the molar gas constant, such that pV = nRT. It follows that the unit of R must be the same as the unit of pV/T as 'n' has no units.
			Total	**1**	
9			B	1	
			Total	**1**	
10			B	1	
			Total	**1**	
11			C	1	
			Total	**1**	
12			**A**	**1**	
			Total	**1**	
13			A	1	
			Total	**1**	
14			**B**	**1**	
			Total	**1**	
15			**C**	1	**Examiner's Comments**

					In this question, candidates should consider the equation pV = nRT. If the pressure and volume remain the same, this gives nT as a constant also. If the number of particles decreases to two thirds of the original number, then the temperature in kelvin, and thus the total kinetic energy and hence mean square speed must have increased by a factor of 1.5, giving option C. This question provided opportunities for middle-grade candidates.
			Total	**1**	
16			D	1	
			Total	**1**	
17			B	1	
			Total	**1**	
18			C	1	
			Total	**1**	
19			$E = mc\Delta\theta$ (any subject) <u>and</u> gradient is larger for CD The specific heat capacity of the liquid is less than that of the solid.	M1 A1	**ORA** **Allow**: $\Delta\theta$ is larger for liquid in the same time interval or same energy supplied for "gradient" **Allow** $c \propto$ gradient^{-1} **Not:** c = 1 / gradient **<u>Examiner's Comments</u>** Many candidates realised that the gradients of the lines AB and CD were related to the specific heat capacities of the solid and liquid states. Higher level responses included the formula relating energy change, mass, specific heat capacity and the temperature change, and how that formula related to the gradient of the line on a temperature-time graph. Once that link was established, the lower gradient indicates a larger specific heat capacity.
			Total	**2**	
20			when pressure or volume of an ideal gas tends to zero, the temperature must tend to zero;	B1	
			the temperature scale with this zero of temperature is the kelvin scale / AW	B1	
			Total	**2**	
21			number of moles = 0.327 / 0.018 = 18.17	C1	
			number of molecules = 18.17 × N_A		

			number of molecules = 1.1×10^{25}	A1	
			Total	**2**	
22			Smoke particles show random / haphazard motion (wtte)	B1	Accept a correctly labelled diagram for this B1 mark.
			This is because of collisions with air molecules / particles.	B1	
			Total	**2**	
23			*n* (= *pV/RT*) = $2.4 \times 10^5 \times 1.2 \times 10^{-3} / 8.31 \times$ <u>290</u> *n* = 0.12 (mol)	C1 A1	**Allow** any correct rearrangement of the equation **Allow** use of $pV = NkT$ and $n = Nk/R$ or $n = N/NA$ (n = 0.1195)
			Total	**2**	
24			Any **three** from: • Forces between particles are negligible except during collisions • Collisions are perfectly elastic • Time of a collision is negligible compared to time between collision • Particles / atoms / molecules occupy negligible volume compared to volume of gas • Large number of molecules in random motion.	B1 × 3	
			Total	**3**	
25	a		energy input = $mc\Delta\theta$ = $0.327 \times 4200 \times 80$ = 110 kJ	C1 M1	Allow 0.3 kg in the calculation
			energy input = power × time	C1	
			time = 220 (s)	A0	
	b		Thermal losses to kettle and surroundings	B1	
			Lagging the kettle	B1	
			Cover to prevent evaporation	B1	
			Total	**6**	

26	a		pV = constant (or $p_1V_1 = p_2V_2$) p_{final} = 2.4 x 10^5 x 1.2/1.5 = 1.9(2) x 10^5 (Pa)	C1 C1 A1	<u>Alternative method:</u> $p = nRT/V$ (p must be the subject) **Allow** use of $p = NkT/V$ (with N = 7.2 x 10^{22} and k = 1.38 x 10^{-23}) Substitute p = 0.12 x 8.31 x 290 / 1.5 x 10^{-3} ECF from 1a for incorrect n and/or T p = 1.9(3) x 10^5 (Pa) **<u>Examiner's Comments</u>** Questions 1(a) and 1(b) took the ideal gas equation and applied it to an unfamiliar situation, that of a toy rocket. Most candidates answered these questions well, remembering to convert the temperature from 17°C to 290K.
	b	i	Δp = (2.4 – 1.0) - 10^5 = 1.4 x 10^5 (Pa) upwards force *(= ΔpA)* = (2.4 – 1.0) x 10^5 x 1.1 x 10^{-4} = 15 (N)	C1 C1 A0	<u>Alternative method:</u> Downwards force (from trapped air) = pA = 2.4 x 10^5 x 1.1 x 10^{-4} = 26.4 (N) **and** upwards force (from atmosphere) = pA = 1.0 x 10^5 x 1.1 x 10^{-4} = 11.0 (N) So total upwards force = 26.4 – 11.0 = 15.4 (N) **Ignore** any attempt to calculate weight **Special case: Allow** 1/2 for the use of Δp = 2.4 x 10^5 (Pa) giving upwards force = 26.4 (N) **<u>Examiner's Comments</u>** Most candidates realised that a difference in air pressure between the inside and outside of the bottle would force the water downwards, producing an upwards force on the bottle which could be calculated using p = F/A.
		ii	m = 0.3 + 0.05 (= 0.35) (kg) (Resultant force = upwards force – $W = ma$) 15.4 – (0.35 x 9.81) = 0.35a **or** a = 12/0.35 a = 34 (m s^{-2})	C1 C1 A1	0.050 + (10^3 x 0.3 x 10^{-3}) <u>Alternative approach</u>: a = (15.4/m) - g ECF for incorrect value of m **No** ECF ci (since we are told that upwards force = 15(.4)(N)) Upwards force = 15 (N) gives a = 33 (m s^{-2}) **<u>Examiner's Comments</u>** This question, although a simple F = ma problem, challenged many candidates. **Exemplar 1**  Exemplar 1 shows the most common incorrect response. The correct value for mass (m = 0.35kg) has been used, but the value for the upwards force (15.4N) rather than the resultant force (15.4 – mg) has been used for F.

			Total	**8**	
27	a	i	$E = m \times c \times \Delta\theta = 0.15 \times 4200 \times 55$ $E = 3.5 \times 10^4$ (J)	A1	**Note** answer to 3 s.f. is 3.47×10^4 (J)
		ii	(Energy transferred from water = energy transferred to glycerol) $0.150 \times 4200 \times (75 - \theta)$ or $0.020 \times 2400 \times (\theta - 20)$	C1	
		ii	$0.150 \times 4200 \times (75 - \theta) = 0.020 \times 2400 \times (\theta - 20)$	C1	
		ii	$\theta = 71$(°C)	A1	
		iii	The temperature is less / different because of thermal energy of the water is also used to warm up the boiling tube. (AW)	B1	
	b		Graph showing constant temperatures during phase changes.	B1	
			Temperature increases linearly for the solid and the liquid.	M1	
			Steeper slope for the solid state.	A1	
			Total	**8**	
28	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) **<u>Examiner's Comments</u>** **Misconception** Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut

					• the ISS orbits in a vacuum where there is no gravity.
b	i		M = 5.97 x 10^{24}(kg) **or** ISS orbital radius R = 6.78 x 10^6(m) **or** $g \propto 1/r^2$ (gr^2 = constant so) g x (6.78 x $10^6)^2$ = 9.81 x (6.37 x $10^6)^2$ g = 8.66 (N kg^{-1})	C1 C1 A1	**or** g (= GM/R^2) = 6.67 x 10^{-11} x 5.97 x 10^{24} / (6.78 x $10^6)^2$ **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) **Examiner's Comments** The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating (6.37 × 10^6 + 4.1 × 10^5) incorrectly.
	ii		$2\pi r/T = v$ **or** T = 2 × 3.14 × 6.78 × 10^6 / 7.7 × 10^3 T = 5.5 × 10^3 s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**
c			½Mc^2 (½$N_A mc^2$) = $\frac{3}{2}RT$ c^2 = 3 × 8.31 × 293 / 2.9 × 10^{-2} = 2.52 × 10^5 $\sqrt{c^2}$ = 500 (m s^{-1}) (= 7.7 × 10^3 / 15)	C1 C1 A1 A0	**or** ½$mc^2 = \frac{3}{2}kT$ **or** $c^2 = 3kT/m$ **or** c^2 = 3 ×1.38 x 10^{-23} × 6.02 x 10^{23} x 293/2.9 × 10^{-2} = 2.52 × 10^5 **not** (7.7 × 10^3 / 15) = 510 (m s^{-1}) **Examiner's Comments** The success in this question depended on understanding the meaning of the term m in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took m to be the mass of one mole (the molar mass, M) whereas m is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
d			power reaching cells (= IA) = 1.4 × 10^3 × 2500 = 3.5 × 10^6 W power absorbed = 0.07 × 3.5 × 10^6 = 2.45 × 10^5 W cells in Sun for (92 – 35 =) 57 minutes	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using T = 90 minutes **ECF** value of T from **b(ii)** 55/90 × 2.45 × 10^5 = 1.5 × 10^5 (W) using T = 90 minutes

			average power = 57/92 × $2.45 \times 10^5 = 1.5 \times 10^5$ (W)		**Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	**13**	
29			P = (m/t)cθ = 0.070 × 4200 × (30 − 14)	C1	
			= 4700	A1	or 4.7
			unit = W or J s^{-1}	B1	**allow** kW if consistent with the value for P.
			Total	**3**	
30			Energy used to heat water to 100 °C = 0.60 × 4200 × 80 (= 201.6 kJ) Energy remaining to vaporise water = 528 (kJ) − 201.6 (kJ) (= 326.4 (kJ) mass vaporised = $326.4 \times 10^3 / 2.3 \times 10^6$ = 0.1419 (kg) mass of water left = 0.60 − 0.1419 mass of water left = 0.46 (kg)	**C1** **C1** **C1** **A1**	Possible ecf from **(a)** **Examiner's Comments** This was a challenging multi-step calculation that differentiated between the candidates well. A method employed by many high-scoring candidates began with a word equation "Total energy transferred = energy required to heat water to boiling point + energy required to vaporize water". This made it clear to award the mark for substituting into the specific heat capacity equation and clear to the candidate how to find the mass of vaporized water. A minority of candidates forgot to subtract the mass of vaporized water from the initial mass.
			Total	**4**	
31		i	($pV = nRT$) $100 \times 10^3 \times (0.46)^3 = n \times 8.31 \times (273 + 20)$ n = 4.0	C1 A1	**Note** T = 20 is XP **Not** 1 SF answer of 4 **Note** answer is 4.00 to 3SF
		ii		C1	**Note** T = 1300 is XP

			$\frac{100}{293} = \frac{p}{1573}$ or $p \times (0.46)^3 = n \times 8.31 \times 1573$ pressure = 540 (kPa)	A1	**Allow** use of correct, unrounded *n*
			Total	**4**	
3 2			No change in KE because temperature is constant (during melting) PE of (the molecules) increases (during melting) The internal energy increases	M1 A1 M1 A1	**Allow** 'KE is not changing' **Not** 'KE is not increasing' **Note:** This A1 mark can only be scored if both M1 marks have been awarded. **Examiner's Comments** This question was designed to lead the candidates into thinking about both KE and PE of the particles contained within the paraffin. The stem of the question includes a reference to constant temperature, so credit could only be awarded to linking this idea to that of the molecules' constant average KE, since average KE is directly proportional to absolute temperature. KE not changing was an acceptable alternative wording to constant average KE, but 'KE not increasing' was not. Candidates often picked up a mark for correctly stating that the PE of the molecules increased but would only gain the final mark for stating that the internal energy increased if they had already got the correct ideas for both PE and KE. Examiners commented that some candidates assumed conservation of energy and so if PE went up then KE went down or vice versa. Candidates wasted time and effort by describing what happened either before or after melting, which was not required.
			Total	**4**	
3 3			Section **AB** Any <u>two</u> from • Particles close together • Particle spacing increase with increasing time or increasing temperature • Particles in a fixed structure/(regular) lattice • Particles vibrate/perform SHM	B1 x 2 B1 x 2	**Not**: 'vibrates more'

			• Particles vibrate with increasing amplitude (from A to B) Section **CD** Any <u>two</u> from • Particles close together /(slightly) further apart (than in AB) • No regular structure /AW • Particles (are free to) move around / move past each other / flow • Particles move with increasing speed from C to D / greater KE		
			Total	**4**	
3 4	a		Use a thermometer (with ± 1 °C) Stir water bath / avoid parallax (for glass thermometer)	**B1** **B1**	**Allow** 'temperature sensor / gauge' **Allow** 'avoid touching sides of water bath with thermometer' **Allow** 'take temperature in several places / times and average' **Allow** idea of 'leave thermometer for long time (to reach thermal equilibrium)' **Not** idea of 'use thermometer with finer resolution' **Examiner's Comments** A large majority included a correct measuring device, such as a thermometer. Significantly fewer described a technique for accurate measurements such as stirring the water or taking the temperature at several points and calculating a mean temperature.
	b	i	Smaller (spacing between) divisions / increments (AW)	**B1**	**Ignore** any reference to accuracy or precision **Allow** 'less uncertainty' **Allow** better or smaller or greater or higher resolution **Examiner's Comments** Approximately half of the candidature made a correct comment regarding resolution or that the smaller intervals on the psi scale made it a sensible choice of scale.
		ii	$p = 37.0 \times 4.448 / (1000 \times 0.0254^2)$ 255 (kPa) uncertainty = 3 (kPa)	**B1** **B1**	**Allow** clearly identified correct answer in table or in working area. Must be 3sf Must be 1sf **Allow** 255.1 ± 3.4 scores mark 1 **Examiner's Comments** The vast majority of candidates correctly calculated the pressure in kPa and

					stated that the absolute uncertainty was 3 kPa. A very small number of responses were rounded inappropriately.
	c	i	Point plotted at (44, 255)	B1	ECF from **(b)(ii)** Plot to with ± half a small square **Ignore** checking error bars **Examiner's Comments** Most candidates correctly plotted the point with error bars. In this instance during marking Examiners were instructed to ignore the error bars as they were too difficult to view when scanned.
		ii	**Level 3 (5–6 marks)** Clear explanation, description **and** determination *There is a well-developed line of reasoning which is clear and logically structured.* *The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation, description **and** determination Or Some explanation and clear determination *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation or description or determination *The information is basic and communicated in an unstructured way.* *The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Indicative scientific points may include:** **Explanation and Description** • Absolute zero is the minimum possible temperature / at absolute zero KE is zero • At absolute zero *p* is zero • At absolute zero, the internal energy is minimum (allow 0) • Absolute zero should be (about) −273 °C • Reference to $pV = nRT$ or $pV = NkT$ or $p \propto T$ • A graph of *p* against *θ* is a straight line / straight line drawn on graph • Intercept of straight line with *x*-axis or *θ*-axis is absolute zero calculated by using y= mx + c **Determination** • Gradient in the range 0.7 to 0.9 (kPa K^{-1}) • $y = mx + c$ used to determine the intercept *c* or absolute zero • Absolute zero in the range −320 °C to −240 °C Use only L1, L2 and L3 in RM Assessor. **Examiner's Comments** It was clear that the majority of candidates had either performed this experiment themselves or had otherwise seen it before. The concept of absolute zero was very successfully described and many knew that an extrapolation or calculation involving the equation of a straight line was required to find absolute zero as the x-intercept of the straight line. Common errors included mis-calculating the gradient, inability to rearrange the

					equation or inappropriate conversion to kelvin. Re-plotting the graph was not required and merely wasted time for little reward.
	d		Draw the worst fit line (through all the error bars) (AW). Determine the new value for absolute zero and find the difference between the value in **(c)(ii)** and this new intercept. (AW)	B1 B1	**Examiner's Comments** Many candidates realised that drawing a line of worst fit was sensible. Far fewer were clear that using the line of worst fit to find a new x-intercept, leading to a spread in values for absolute zero was the correct procedure. Many incorrectly suggested finding the difference in gradients, or percentage differences in gradients.
	e		Cooling gas value of absolute zero is lower than **(c)(ii)** (Whilst cooling, the) temperature of gas lags behind the temperature of water (AW, ORA) Graph is shifted to the left Stir water / <u>wait</u> for temperatures to be the same / attempt at measuring temperature of gas directly (AW)	B1 B1 B1 B1	**Allow:** gradient is too shallow **Allow:** *p* measured is higher than expected for incorrect measurement of *T* (so affects the graph) (AW, ORA) **Not** insulation of water bath **Not** heat losses **Examiner's Comments** The first mark for this item was intended to be for a straightforward comparison that the repeated experiment yielded a lower value than that from part **c(ii)**. Many candidates calculated a percentage difference yet did not refer to the direction of difference. Some candidates successfully suggested that the water would always be cooler than the gas and so the thermometer reading would be systematically lower than the true temperature of the gas. Rather fewer discussed that the pressure reading would therefore be higher than it should be for the thermometer reading. Very few candidates linked this idea to the effect on the graph, namely that the points would all be shifted to the left, causing a lower x-intercept or a less steep line of best fit. There were three acceptable experimental approaches to avoid this systematic error. Stirring the water and waiting until the gas and water equilibrated would have reduced the effects of the rapid cooling. A sensible approach employed by some candidates was to take the temperature of the gas directly using a thermometer or temperature inside the flask.
			Total	**18**	
35		i	Fission reactors produce radioactive by-products which affect future generations and the environment in terms of possible contamination /	B1	

			exposure to humans and animals.		
6		ii	No of particles in 1000 g U = 1000/235 × 6.02 × 10^{23} = 2.56 × 10^{24} No of reactions for U = 2.56 × 10^{24}	B1	Appreciate that the key to the answer is the difference in numbers of atoms / nuclei **or** equal number of nucleons involved scores one mark if nothing else achieved.
		ii	Energy from U = 2.56 × 10^{24} × 200 = 5.12 × 10^{26} MeV	B1	
		ii	No of particles in 1000g H = 6.02 × 10^{26} No of reactions = 6.02 × 10^{26}/4 Energy from H = 6.02 × 10^{26}/4 × 28 = 42.14 × 10^{26} MeV	B1	
		ii	Hence energy 42/5 = 8.2 times higher	B1	
		ii	*second method* 235 g of U and 4 g of H / He contain 1 mole of atoms	or B1	
		ii	there are 4.26 moles of U and 250 moles of He	B1	
		ii	so at least 58 times as many energy releases in fusion ratio of energies is only 7 fold in favour of U	B1	
		ii	therefore 58/7 times as much energy released by 1 kg of H	B1	
		ii	*similar alternative argument,* e.g. For U each nucleon 'provides' 0.85 MeV	B1	
		ii	For H each nucleon 'provides' 7 MeV	B1	
		ii	(Approx) same number of nucleons per kg of U or H	B1	
		ii	so 8.2 times as much energy from H	B1	
			Total	**5**	
36			**Level 3 (5–6 marks)** Clear description and clear calculations of energy per kg *There is a well-developed line of reasoning which is*	B1×6	**Indicative scientific points may include:** **Description** • Energy is produced in both reactions

			clear and logically structured. The information presented is relevant and substantiated. **Level 2 (3–4 marks)** Clear description **OR** Clear calculations of energy per kg **OR** Some description **and** some calculations *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **OR** Limited calculations *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit		• More energy produced (per reaction) in fission • The (total) binding energy of 'products' is greater • In fusion, nuclei repel (each other) • Fusion requires high temperatures / high KE • Fission reactions are triggered by (slow-)neutrons • Chain reaction possible in fission **Calculations** • 1 kg of uranium has 4.26 mols / 2.56×10^{24} nuclei • 1 kg of deuterium has 500 mol / 3.01×10^{26} nuclei / 1.50×10^{26} 'reactions' • 200 MeV = 3.2×10^{-11} J • 4 MeV = 6.4×10^{-13} J • Uranium: ~ 10^{14} (J kg^{-1}) (actual value 8.2×10^{13}) • Deuterium: ~ 10^{14} (J kg^{-1}) (actual value 9.6×10^{13}) • The energy per kg is roughly the same **Examiner's Comments** This is the second LoR question. This is designed to assess knowledge of the two nuclear energy reactions and to calculate energy release using some given data. The differences between the fission and fusion reactions were generally well answered although many candidates explained differences in design, operation and waste more than the reactions. The similarities were often not as clear however several candidates gave excellent responses in terms of binding energies and mass differences. Candidates were also expected to complete a calculation to show which produces more energy output per kilogram. This is challenging calculation to follow through fully, but most candidates were able to make some attempt, even if it was only converting MeV to J. Only better candidates realised 2 nuclei of deuterium were used for one fusion reaction. While a small number of candidates did correctly calculate the energy per kilogram, they tended to state that fusion produced more energy rather than a feeling that they are basically equivalent. As usual with LoR questions, a holistic approach is taken to the marking and candidates can access higher levels without necessarily reaching all the marking points. Even so, relatively few candidates were able to access Level 3, generally due to poor calculations and/or descriptions.
			Total	**6**	
37			**Level 3 (5 - 6 marks)** Clear explanation using kinetic theory ideas **and either** a clear proof using formulae **or** a correct calculation *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)**	B1 x 6	**Indicative scientific points may include:** **Explanation using kinetic theory** • pressure = force/area • force is caused by air molecules colliding with oven walls • Newton's 2nd Law states force = rate of momentum change • increased temperature means each molecule has greater KE • hence greater velocity and hence greater momentum • and more collisions with walls per second • hence greater rate of momentum change on hitting walls. • This would lead to greater pressure if *N* remained constant • so number of molecules in oven must decrease (air escapes) • so fewer but 'harder' collisions at higher temperatures giving constant pressure.

			A partial explanation using kinetic theory ideas **and either** a partial proof using formulae **or** a partial calculation *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** An attempt at either explanation **or** proof **or** calculation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• Rms velocity c increases with temperature but number *N* decreases and so effects balance out to keep total KE (½Nmc^2) constant **Proof using formulae** • equate $pV = NkT$ and $E = \frac{3}{2}NkT$ to show $E = \frac{3}{2}pV$ • in an ideal gas, all internal energy *E* is kinetic energy • so *E* is independent of temperature **Calculation** • Internal energy $= \frac{3}{2}pV$ = 1.5 x 0.065 x 1.0 x 10^5 = 9.8 kJ • At *T* = 293K, $N = pV/kT$ = 1.6 x 10^{24} and *n* = 2.7 moles • At *T* = 473K, *N* = 1.0 x 10^{24} and *n* = 1.7 moles • so we can show that *NT* (and/or *nT*) remain constant
			Total	**6**	
38		i	Molecules in **X** vibrate about fixed positions /AW Molecules in **Z** are free to move/random/AW	B1 B1	**Allow** references to ice for **X** and water / liquid for **Z** **Allow** <u>one</u> correct for **B1** from: Molecules in **X** have lower <u>K</u>E/speed/velocity Speed/velocity of molecules increases with temp/time Amplitude or frequency increases with temp/time in **X**
		ii	<table><tr><th>Region</th><th>Physical quantity, or quantities, that increase as time increases</th><th>Physical quantity, or quantities, that remain constant as time increases</th></tr><tr><td>X</td><td>K</td><td>P</td></tr><tr><td>Y</td><td>P</td><td>K</td></tr><tr><td>Z</td><td>K</td><td>P</td></tr></table>	B1×3	**Note** that each B1 mark is for a correct row **Allow** KP/- for both X and Z
		iii	Absolute zero / 0 <u>K</u> / - 273 <u>°C</u>	B1	
			Total	**6**	

39			**Level 3 (5 – 6 marks)** Clear expansion of three statements *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.* **Level 2 (3 – 4 marks)** Clear expansion of two statements **or** Limited attempt at all three *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited attempt at one or two statements *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2ˆ for 3 marks, etc.** **Indicative scientific points may include:** **statement 1** • fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2\Delta m$ • Δm per second = luminosity / c^2 **statement 2** • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\varepsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\varepsilon_0 r$ • r is approximately 3fm **statement 3** • k.e. $\propto T$ so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4 x 10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter **<u>Examiner's Comments</u>** This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally

					had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	**6**	
40	a		Ensure largest possible proportion of flask is immersed.	B1 × 4	
			Make volume of tubing small compared to volume of flask.		
			Remove heat source and stir water to ensure water at uniform temperature throughout.		
			Allow time for heat energy to conduct through glass to air before reading temperature.		
	b	i	Pressure is caused by collisions of particles with sides.	B1	
		i	Velocity of particles (and volume of gas) are not zero at 0 °C.	B1	
		ii	**1:** Gradient of graph 0.75 × 10^2 / 100 = 0.75		
		ii	Number of moles of gas = gradient / R = 0.75 / 8.31 = 0.09	C1	Alternative method Internal energy = 3/2 × p × V
		ii		A1	
		ii	Mass of gas = 0.09 × 6.02 × 10^{23} × 4.7 × 10^{-27} = 2.5 × 10^{-4} (kg)		At θ = 100°C pV = 2.73 × 10^2
		ii	**2:** Internal energy = 3/2 × NkT		Internal energy = 1.5 × 2.73 × 10^2 = 410 (J)
		ii	= 1.5 × 0.09 × 6.02 × 10^{23} × 1.38 × 10^{-23} × (100 + 273)	C1	
		ii	= 410 (J)	A1	
			Total	**10**	
41		i	½ $m\,c_{RMS}^2$= 3/2 kT c_{RMS}^2 = 3 x 1.38 x 10^{-23} x 523 / 4.8 x 10^{-26} (Any subject) root mean square speed = 670 (m s^{-1})	C1 C1 A1	**Allow** this mark even when T = 250 is used subsequently **Not** 250ºC **Allow** c^2 = 4.5 x 10^5 **Allow** 2 marks for 4.5 x 10^5; mean square speed calculated **Allow** 1 mark for 464; no conversion to kelvin

					Examiner's Comments The key to this question is equating 2 formulae. The first is the familiar ½ m v^2 for kinetic energy. In this case, the squared speed will be the mean squared speed of the particles. The second is the connection between average kinetic energy of a particle at absolute temperature, *T*, $E_k = 3/2\ k\ T$. If candidates did that, then they not only scored the first mark but also could go on to complete the question. A common error was to forget to find the square root, as the question asks for the root mean square speed.
		ii	(number of molecules =) 1.3 x 6.02 x 10^{23} or 7.83 x 10^{23} mean KE = $\frac{3}{2}$ x 1.38 x 10^{-23} x 523 or 1.08 x 10^{-20} total kinetic energy = 8.5 x 10^3 (J)	C1 C1 A1	**Not** 250°C **Allow** 8.4 x 10^3 for use of 670 m s^{-1} **Allow** full credit for use of total KE = 1.5n*RT* **Allow** full credit for use of E_k for one molecule = ½ m c_{RMS}^2 (which may include ECF for their c_{RMS} in (d)(i)) **Allow** 2 marks for 4.0(5...) x 10^3 (J) ; no conversion to kelvin. **Examiner's Comments** There were 2 ways to answer this question. The first was to find the kinetic of one particle using the mean square speed and the second was to find the kinetic energy of one particle using the absolute temperature. Lower level responses stopped at that point, or there was misunderstanding how to scale that value up to the whole gas. For either route, the value for one particle needed to be multiplied by the number of particles in the gas. This can be found by multiplying the number of moles by the Avagadro constant given in the data, formulae and relationship booklet.
			Total	**6**	
42		i	KE = ½*mv*^{2} **and** GPE = *GMm / r* ½*mv*^{2} = *GMm / r* then a valid step to *v* = √(2*GM / r*)	**C1** **A1**	**Allow** *m* = 1 (kg) if clearly defined **Examiner's Comments** Examiners were delighted that candidates proved the relationship for escape velocity very clearly indeed with the higher ability candidates correctly suggesting that 'KE + GPE = 0' was the condition for escape, although 'KE lost = GPE gained' would have been a clear way of reconciling any minus sign confusion. A minority of candidates tried, unsuccessfully, to invoke the expression for circular motion inappropriately.

		ii	($v^2 = 2 \times 6.67 \times 10^{-11} \times 0.131 \times 10^{23} / 1.19 \times 10^{6}$) v = 1200 (m s^{-1})	A1	Answer to 3.s.f. is 1210 **Examiner's Comments** Approximately four-fifths of all candidates calculated the escape velocity on Pluto correctly. Those that did not score the mark for this item did so because of improper calculator use or, more rarely, because they selected the wrong data from the question.
		iii	Mercury has a higher escape velocity than Pluto (ORA) Mercury is closer to sun **and** Mercury is hott<u>er</u> (ORA) Molecules on Mercury (are more likely to) have **speed** higher than the escape velocity	B1 M1 A1	**Allow** a supporting calculation (speed is about 4.2 km s^{-1}) **Allow** 'required speed' for 'escape velocity' **Allow** 'fast enough to escape' **Examiner's Comments** Candidates found this last item very challenging indeed, with only exceptional candidates gaining two or three marks. Many candidates suggested that the reason for Mercury's lack of atmosphere was the superior gravitational pull of the Sun, which is wholly incorrect. Others suggested that the solar wind or 'radiation' had burnt off the atmosphere. Rather fewer candidates correctly related Mercury's smaller mean distance to the Sun and its higher temperature or reasoned that Mercury's escape velocity was higher than Pluto's. Only a small minority of candidates recognised that even though Mercury has a higher escape velocity, its higher temperature gave the atmosphere's molecules a higher average speed which would have exceeded Mercury's escape velocity.
			Total	**6**	
43	a	i	Any **THREE** from: Atoms of metal vibrate (about fixed points) Water molecules have translational KE The motion of the water molecules is random	B1×3	**Allow** particles for atoms / molecules throughout **Allow** idea that water particles move past each other **Not** idea that the water molecules have more KE than metal atoms

			Metal atoms and water molecules have the same KE		
		ii	(E_{heater} =) 200 × 10 × 60 **or** 120000 (J) (E_{water} =) 0.5 × 4200 × 40 **or** 84000 (J) (energy transferred = 120000 – 84000) energy transferred = 3.6 ×10^4 (J)	C1 C1 A1	
	b		**Level 3 (5–6 marks)** Clear description and explanation **and** correct calculations leading to value of L_f *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description and explanation **or** Correct calculations leading to value of L_f **or** Some description or explanation **and** some correct calculations *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description or explanation **or** Limited calculations	B1×6	**Indicative scientific points may include:** **Description and explanation** • $m \propto t$ (for both) • Greater gradient for funnel with heater / greater rate of water from funnel with heater • Energy supplied to the ice is at a constant rate (for both beakers) • Idea that arrangement in Fig 17.2 is a control • Beaker in 17.2 heated just by surroundings / air / room • Arrangement in Fig. 17.1 gains energy from heater and surroundings / air / room **Calculation** • Gradient(s) calculated • $\Delta m = 45 \times 10^{-3}$ kg • $\Delta E = mL_{(f)}$ • $\Delta E = 5 \times 12 \times 240 = 14400$ J • $L_{(f)} = 14400 / 45 \times 10^{-3} = 3.2 \times 10^5$ • Units: J kg^{-1} **Note** : $L_{(f)}$ can be calculated using $L_{(f)} = VI \div \lvert\Delta\text{gradient}\rvert$

			The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear. **0 marks** No response or no response worthy of credit.		
			Total	**12**	
4 4			**Level 3 (5–6 marks)** Clear explanation and correct calculation. *There is a well–developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation and limited calculation, or limited explanation and correct calculation. *There is a line of reasoning presented with some structure.* *The information presented is in the most–part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation and missing or incomplete calculation. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks**	**B1x6**	**Indicative scientific points may include:** **Explanation** • At a certain temperature all atoms have the same <u>average</u> kinetic energy • Helium behaves as an ideal gas • $E_K = \frac{3}{2}kT$ • Mean / r.m.s speed of atoms is less than the escape velocity • Atoms have range of speeds / velocity or mention of Maxwell–Boltzmann distribution • Faster atoms have escaped the Earth (over long period of time) • Earth was significantly hotter in the (ancient) past **Calculation** • T = 283 K • $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ • $c_{r.m.s.} = \sqrt{\frac{3kT}{m}}$ • $c_{r.m.s}$ = 1.3 km s^{-1}

			No response (NR) or no response worthy of credit (0).		**Examiner's Comments** **Exemplar 6** $\frac{1}{2}m\bar{c}^2 = \frac{3}{2}kT$ $\bar{c}^2 = \frac{3KT}{m} = \frac{3\times1.38\times10^{-23}\times283}{6.64\times10^{-27}}$ $\bar{c}^2 = 1764487.95$ $\bar{c} = 1328.34$ $\approx 1330\ ms^{-1}$. Particles move around random with random speeds. Collisions a elastic so KE is not lost. Most part are moving at speeds around 1330 ms^{-1} a little less but given the rand motion of particles, which follow Boltzmann's distribution, a very little of those have speeds ≥ 11 kms^{-1}. Eventually all ~~particles~~ molecules should Earth's ~~atmosphere~~ helium But since heli nuclei are just alpha particles which in ~~nuclear~~ radioactive reactions, these constantly ~~been~~ being produced. Hence, w can still find small amounts of today on Earth In correctly calculating the root means square speed and by being clear about how that has been calculated, this candidate has gained L2 already. There is a correct comparison of this speed with the escape velocity. There is also reference to the Boltzmann distribution of speeds, suggesting that even though a small fraction will have a sufficient velocity, over time those particles will escape. Most candidates made good progress with the calculation or provided

					an alternative by calculating the mean KE of a particle and comparing that with the KE a particle with escape velocity would have. A significant fraction made a poor comparison of their value with escape velocity (e.g. that 1300 ms^{-1} was greater than 11 km s^{-1}) or compared the mean squared speed with the escape velocity.
			Total	**6**	
45		i	(energy =) 150 × 7 **or** 1050 (J) 1050 = 0.025 × c × 20 (c =) 2100 (J kg^{-1} K^{-1})	C1 C1 A1	**Allow** any correct re-arrangement
		ii	(energy=) 150 × (63 – 7) **or** 8400 (J) 8400 = $L_{(f)}$ × 0.025 (L_f =) 3.4 × 10^5 (J kg^{-1})	C1 A1	
		iii	Longer time to heat water (through the same temperature) / shorter time to heat (ice) through same temperature / gradient of graph is greater for ice / gradient of graph is smaller for water/AW Water has greater specific heat capacity	M1 A1	**Allow** calculation of gradients
			Total	**7**	
46		i	*T* = 293 K	M1	
		i	3/2 *kT* = ½ mv^2	C1	
		i	3/2 × 1.38 × 10^{-23} × 293 = ½ × 4.7 × 10^{-26} × v^2	M1	
		i	v = 510 (m s^{-1})	A0	Note answer is 509.8 m s^{-1} to 4 s.f.
		ii	**1.** Total vertical momentum after = 0 Total vertical momentum before = 0 (momentum is conserved)	B1 B1	
		ii	**2.** 4.7 × 10^{-26} × *v* × sin 88° = 1.4 × 10^{-24} × 23 × sin 45°	C1	
		ii	*v* = 480 (m s^{-1})	A1	**Allow** other correct methods.
			Total	**7**	
47		i	(*p* =) 6.6 × 10^{-26} × 990 **or** 6.5(3) × 10^{-23} (kg m s^{-1})	C1	

			(Δp =) 2 × 6.6 × 10^{-26} × 990 Δp = 1.3 × 10^{-22} (kg m s^{-1})	A1	**Ignore** sign of answer
		ii	990/[2 × 0.46] (= 1080) (F = Δp/Δt) (F =) 1.3 × 10^{-22} × 1000 F = 1.3 × 10^{-19} N	B1 C1 A1	Possible ECF from **(b)(i)** **Note** 1080 would give 1.4 × 10^{-19} (N)
		iii	Use of $p = F/A$ **or** pressure = (total) force / area Idea of multiplying by total number of atoms	B1 B1	**Allow** particles or molecules for atoms
			Total	**7**	
48		i	sin **or** cos wave with 1.5 wavelengths (between **C** and **R)** y-axis showing scale, i.e. (amplitude) 2.(0) × 10^{-6} (m) correct scale on x-axis showing λ = 0.2 (m) **X** and **Y** labelled at adjacent intercepts on x-axis	**B1** **B1** **B1** **B1**	unit must be present, e.g 10^{-6} m **NOT** if axis labelled time **Examiner's Comments** Most candidates correctly labelled the scale on the displacement axis of the sinusoidal graph that they drew. The points where the air particles were moving the fastest were also well known. Fewer labelled *distance* on the x-axis, many incorrectly writing *time.* Only the better candidates marked the correct scale on this axis and very few indicated that there were 1.5 wavelengths between the points **C** and **R.**
		ii	**1** v = Aω **or** 2πfA v = (2 × 10^{-6} × 2 × 3.14 × 1.7 × 10^3 =) 2.1 × 10^{-2} (m s^{-1}.) **2** ½Mv^2 = 3/2 RT and T = 290 v = √(3 × 8.31 × 290 / 0.029) v = 5(.0) × 10^2 (m s^{-1}.)	**C1** **A1** **C1** **A1**	**or** ½mv^2 = 3/2 kT so v^2 = 3 (k / m) 290 **N.B. remember to record a mark out of 4 here** **Examiner's Comments** Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled *path* and *phase*

					difference or referred to *nodes* and *antinodes* detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used *maxima* and *minima* in place of *antinodes* and *nodes* although most recognised this to be a *standing* wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.
			Total	**8**	
49		i	$-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$	B1	
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	Working must be shown
		ii	$v = \sqrt{(2 × 9.81 × 6.4 × 10^6)} = 11 × 10^3$ m s^{-1}	B1	allow 11(.2) km s^{-1}
		iii	$½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 × 10^{-27}$ kg	B1	**ecf (ii); allow** m = 4u or $4 × 1.67 × 10^{-27}$
		iii	$T = 6.6 × 10^{-27} × 121 × 10^6 / 3 × 1.38 × 10^{-23}$	C1	
		iii	$T = 1.9 × 10^4$ (K)	A1	**allow** 2 or 2.0
		iv	1 random motion and elastic collisions of particles	B1	**max** 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	
		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α-particle	B1	**max** 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	**13**	