PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



MARK SCHEME

TOPIC 9: THERMODYNAMICS

KINETIC THEORY AND IDEAL GASES

SCORE	PERCENTAGE
/176	%

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Mark Scheme

Q1.

Question Number	Answer		Mark
(a)	Use of $pV = NkT$ Pressure difference **Or** temperature conversion $\Delta N = 5.0 \times 10^{21}$ Example of calculation: $\Delta N = \frac{\Delta pV}{kT} = \frac{(6.5\times10^5 - 5.8\times10^5)\text{Pa} \times 2.9\times10^{-4}\text{m}^3}{1.38\times10^{-23}\text{JK}^{-1} \times (273+20)\text{K}} = 5.0\times10^{21}$	(1) (1) (1)	3
(b)	Use of $pV = NkT$ $T_2 = 307$ (K) stated or implied **Or** 293(K) subtracted $\Delta T = 14$ K Example of calculation: $\frac{p_1}{T_1} = \frac{p_2}{T_2}$ $T_2 = \frac{6.8\times10^5\text{Pa}}{6.5\times10^5\text{Pa}} \times 293\text{K} = 307\text{K}$ $\Delta T = (307 - 293)\text{ K} = 14\text{ K}$	(1) (1) (1)	3
(c)	**Max 3** (Average) kinetic energy of molecules/atoms is greater **Or** molecules/atoms move faster Collision rate with walls of container is greater There is more momentum (exchanged) per collision **Or** the rate of change of momentum is greater Therefore a greater force on the container walls (dependent upon mp2 or mp3)	(1) (1) (1) (1)	3
	Total for question		9

Q2.

Question Number	Answer	Mark
	B	1

Q3.

Question Number	Answers	Mark
	The only correct answer is C ***A*** *is incorrect because the mean kinetic energy is constant at constant temperature* ***B*** *is incorrect because collisions between molecules do not increase the force on the walls of the container* ***D*** *is incorrect because the momentum change depends upon the root mean square speed of the molecules*	**1**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	• Equates right hand sides (1) • Final E_k formula ($\frac{1}{2} m \langle c^2 \rangle = 3/2 kT$) and k is constant (1)		**2**

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	An explanation that makes reference to the following: • air molecules make collisions with the puck and transfer momentum to the puck (1) • according to Newton's 2nd law the change of momentum creates a force on the puck (1) • the rate of change of momentum by air molecules colliding with bottom of puck is greater than that due to the collisions on the top of the puck (1) • the net (upward) force balances the weight of the puck <u>OR</u> the greater air pressure below the puck allows the puck to be supported. (1)		**(4)**

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>* (b)</td><td>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><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr></table></td><td>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).</td><td></td></tr>
</table>

5 - 4	3
3 - 2	2
1	1
0	0

The following table shows how the marks should be awarded for structure and lines of reasoning.

	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:

- applying Newton's 3rd law one puck (A) exerts a force on the other puck (B) and vice versa (1)
- forces equal in magnitude and opposite and direction (1)
- forces act for same time (1)
- $F\Delta t_A = -F\Delta t_B$ (1)
- applying Newton's 2nd law $F\Delta t = \Delta p$ since F is a resultant force on each puck (1)
- total change in momentum = zero, so momentum is conserved (1)
  OR Δp for one puck = $-\Delta p$ for the other puck, so momentum is conserved

(6)

Question Number	Acceptable Answer		Additional Guidance	Mark
(c)(i)	• resolve velocities to find forward/sideways component	(1)	Example of calculation: Forwards velocity components: $v\cos 30^\circ = 0.866\,v$; $2\cos 60^\circ = 1\,\text{m s}^{-1}$ $4m = m \times 0.866v + m \times 1$ $\therefore v = \frac{(4-1)\,\text{m s}^{-1}}{0.866} = 3.46\,\text{m s}^{-1}$	**(3)**
	• apply principle of conservation of momentum	(1)		
	• v = 3.46 m s^{-1}	(1)		
(c)(ii)	• use $KE = \frac{1}{2}mv^2$	(1)	Example of calculation: $KE_i = \frac{1}{2}m \times 4^2 = 8m$ $KE_f = \frac{1}{2}m \times 3.46^2 + \frac{1}{2}m \times 2^2$ $= 6m + 2m = 8m$	**(3)**
	• show that final KE is equal to initial KE	(1)		
	• elastic collisions conserve KE, so collision is elastic	(1)		

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $pV = NkT$ **(1)** • Conversion of temperature to Kelvin **(1)** • $p = 95.4$ kPa **(1)** • Calculation of excess pressure **(1)** • Use of $p = F/A$ **(1)** • $\Delta F = 995$ N **(1)** • Sensible comment, e.g. this is a large force so could make the door hard to open **(1)**	Example of calculation: $\frac{p_1}{T_1} = \frac{p_2}{T_2}$ $p_2 = p_1 \times \frac{T_2}{T_1} = 102 \times 10^3\,\text{Pa} \times \frac{(273+3.3)\,\text{K}}{(273+22.5)\,\text{K}}$ $= 95.37 \times 10^3\,\text{Pa}$ $\Delta p = (102 - 95.37)\,\text{kPa} = 6.63\,\text{kPa}$ $\Delta F = A\Delta p = 0.15\,\text{m}^2 \times 6.63 \times 10^3\,\text{Pa} = 994.5\,\text{N}$	7

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $V = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3$ (1) • Use of $pV = NkT$ (1) • Conversion of temperature to kelvin (1) • $N = 6.5 \times 10^{17}$ (1)	Example of calculation: $V = \frac{4}{3}\pi(0.080\ \text{m})^3 = 2.14 \times 10^{-3}\ \text{m}^3$ $N = \frac{1.25\ \text{Pa} \times 2.14 \times 10^{-3}\ \text{m}^3}{1.38 \times 10^{-23}\ \text{N m K}^{-1} \times (273 + 25)\text{K}}$ $= 6.50 \times 10^{17}$	4

Q2.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	An explanation that makes reference to the following points: • The intercept represents the temperature of the air at which the volume occupied would be zero (1) • This is the absolute zero (of temperature) (1) • Absolute zero is the lowest attainable temperature **Or** absolute zero is the temperature at which the atoms/molecules of the gas have zero kinetic energy (1)	For MP3 accept atoms/molecules stop moving	3
(ii)	**MAX 4** **Resolution:** • It is correct that uncertainties would be reduced by using high resolution instruments (1) • But the instruments are not high resolution (1) • There could be a systematic error (in the measurements) (1) **Graph:** • The points do not lie on a perfect straight line **Or** the true relationship may not linear (1) • Temperature intercept may not be accurate **Or** there may be extrapolation errors (1) • More points are needed **Or** a wider range is needed (1)		4

Q3.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Calculation of number of half-lives elapsed **(1)** • Use of number of half-lives to calculate number of iodine nuclei remaining **(1)** • Calculation of number of iodine nuclei decayed **(1)** • Conversion of temperature to kelvin **(1)** • Use of $ppVV = NNNNTT$ **(1)** • Pressure is 1.1×10^5 Pa (compared with 1.0×10^5) and so there is sufficient gas **Or** 1.1×10^{28} gas atoms needed to give required pressure compared with 1.2×10^{28} actual gas atoms, so there is sufficient gas **(1)**	MP1 & MP2: Allow use of $\lambda = \frac{\ln 2}{t_{1/2}}$ and $A = A_0 e^{-\lambda t}$ Example of calculation $N = \frac{N_0}{2^4} = \frac{1.25 \times 10^{28}}{16} = 7.81 \times 10^{26}$ $N = 1.25 \times 10^{28} - 7.81 \times 10^{26} = 1.17 \times 10^{28}$ $p \times 450\ \text{m}^3 = 1.17 \times 10^{28} \times 1.38 \times 10^{-23}\ \text{J K}^{-1} \times (20 + 273)\text{K}$ $\therefore p = \frac{4.73 \times 10^7\ \text{J}}{450\ \text{m}^3} = 1.05 \times 10^5\ \text{Pa}$	**6**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $pV = NkT$ **(1)** • = 349 K (= 76 °C) (ecf from (a)) **(1)**	Example of calculation pV/T = constant $T = 1.957 \times 10^5\ \text{Pa} \times 6.7 \times 10^{-6}\ \text{m}^3 \times 292\ \text{K} / 1.0 \times 10^5\ \text{Pa} \times 1.1 \times 10^{-5}\ \text{m}^3$ = 349 K = 76 °C	**2**

Q5.

Question Number	Answer		Mark
(a)	(When the air is heated) the density (of air in) the balloon decreases	**(1)**	
	So the upthrust is greater than the weight of the balloon (plus occupants)	**(1)**	**2**
(b)	Use of $\rho = \frac{m}{V}$	**(1)**	
	Use of $\Delta E = mc\Delta\theta$ [$\Delta\theta$ must be a temperature difference]	**(1)**	
	$\Delta E = 1.3(5) \times 10^9$ J	**(1)**	**3**
	Example of calculation: $m = \rho V = 1.20\,\text{kg m}^{-3} \times 7.4\times10^4\,\text{m}^3 = 8.88\times10^4\,\text{kg}$ $\Delta E = mc\Delta\theta = 8.88\times10^4\,\text{kg} \times 1010\,\text{J kg}^{-1}\,\text{K}^{-1}(35-20)\text{K} = 1.345\times10^9\,\text{J}$		
(c)(i)	Use of $pV = NkT$ [temperature in either K or °C]	**(1)**	
	$p = 9.24 \times 10^4$ Pa	**(1)**	**2**
	Example of calculation: $\frac{p_2}{p_1} = \frac{T_2}{T_1}$ $p_2 = (1.01\times10^5)\text{Pa} \times \frac{(273-5)\text{K}}{(273+20)\text{K}} = 9.238\times10^4$ Pa		
(c)(ii)	**Max 2** Hydrogen/gas behaves as an ideal gas	**(1)**	
	Mass of hydrogen/gas in balloon stays constant [Accept amount of hydrogen/gas]	**(1)**	
	Or number of molecules/atoms/particles of hydrogen/gas in balloon stays constant	**(1)**	**2**
	Temperature of hydrogen/gas is the same as the temperature of the surroundings		
(c)(iii)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)		
	The average/mean kinetic energy of the molecules decreases	**(1)**	
	Molecules travel slower (on average) **Or** rate of collisions with walls is less	**(1)**	
	So rate of change of momentum (during collisions) with walls is less	**(1)**	**3**
	Total for question		**12**

Q6.

Question Number	Answer	Mark
	B	1

Q7.

Question Number	Answer		Mark
(a)	Pressure (of gas) Amount of gas **Or** mass of gas **Or** number of moles / molecules / atoms	(1) (1)	2
(b)	Extending/extrapolating the line backwards The volume occupied by a gas will be zero at a particular temperature **Or** The graphs for different gases All cut the x axis at the same temp	(1) (1) (1) (1)	2

Q8.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Calculate no of nuclei • Use of $\ln 2 = t\,½ \times \lambda$ • Use of $A = \lambda N$ • $A = 3.97 \times 10^4$ (Bq)	(1) (1) (1) (1)	Example of calculation $N = (5.18 \times 10^{-5}\text{ g}/230\text{ g}) \times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7)\text{ s} = \ln 2$ $\lambda = 2.92 \times 10^{-13}\text{ s}^{-1}$ $A = 2.92 \times 10^{-13}\text{ s}^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4$ Bq	4
(ii)	• Calculates decays in one year (ecf from (b)(i)) • Use of $pV = NkT$ • uses $T = 295$ K • $V = 5.09 \times 10^{-14}\text{ m}^3$	(1) (1) (1) (1)	Example of calculation ecf λ from (a) decays in one year = 3.97×10^4 Bq $\times$ 3.15×10^7 s $= 1.25 \times 10^{12}$ 1.00×10^5 Pa $\times V = 1.25 \times 10^{12} \times 1.38 \times 10^{-23}$ J K^{-1} $\times$ 295 K $V = 5.09 \times 10^{-14}\text{ m}^3$	4
(iii)	• Use of $½\,m\langle c^2\rangle = 3/2\,kT$ **Or** Use of $pV = \frac{1}{3}Nm\langle c^2\rangle$ (allow ecf for N, V from (b)(ii)) • uses $m = 4u$ • $\sqrt{\langle c^2\rangle} = 1360\text{ m s}^{-1}$	(1) (1) (1)	Example of calculation $½\,m\langle c^2\rangle = 3/2\,kT$ $½ \times (4 \times 1.66 \times 10^{-27}\text{ kg}) \times \langle c^2\rangle = 3/2 \times 1.38 \times 10^{-23}$ J K^{-1} $\times$ 295 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

Q9.

Question Number	Answer	Mark
(a)	Temperature (of gas) [treat references to oil/room as neutral] (1) Mass of air/gas **Or** number of atoms/molecules/moles of air/gas [accept amount of air/gas, number of particles of air/gas] (1)	**2**
(b)	Assumption: idea that volume occupied by trapped air ∝ length of air in tube [e.g. volume = cross-sectional area × length] (1) pL = a constant [accept pV = a constant] **Or** if p doubles, L halves (1) At least 2 pairs of p, L values correctly read from graph (1) Readings show that pL = 4500 (kPa cm) [± 100 kPa cm] **Or** Readings show that p doubles when L is halved (1) [Accept references to V instead of L] <u>Example of calculation</u> p = 400 kPa, L = 11.0 cm pL=400 × 11.0 = 4400 p = 200 kPa, L = 23.0 cm pL=200 × 23.0 = 4600	**4**
(c)	Use of pV=NkT [Allow use of pV=nRT **and** N=n.N_A] (1) Conversion of temperature to kelvin (1) $N = 8.4 \times 10^{20}$ [Accept answers in range 8.1×10^{20} to 8.4×10^{20}] (1) [Answer in range but with an incorrect temperature conversion score max 2] <u>Example of calculation</u> $N = \frac{450\times10^{3}\,\text{Pa}\times0.10\,\text{m}\times7.5\times10^{-5}\,\text{m}^2}{1.38\times10^{-23}\,\text{JK}^{-1}\times(273+20)\text{K}} = 8.35\times10^{20}$	**3**
(d)(i)	No change (1)	**1**
(d)(ii)	Similar curve (1) Shifted higher **Or** shifted to the right (1) [an annotated diagram can score full marks]	**2**
	Total for question	**12**

Q10.

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Question Number	Answer		Mark
(a)	Use of $pV = NkT$ Pressure difference **Or** temperature conversion $\Delta N = 5.0 \times 10^{21}$ Example of calculation: $\Delta N = \frac{\Delta p V}{kT} = \frac{(6.5\times10^{5} - 5.8\times10^{5})\text{Pa} \times 2.9\times10^{-4}\text{m}^{3}}{1.38\times10^{-23}\text{JK}^{-1} \times (273+20)\text{K}} = 5.0\times10^{21}$	(1) (1) (1)	3
(b)	Use of $pV = NkT$ $T_2 = 307$ (K) stated or implied **Or** 293(K) subtracted $\Delta T = 14$ K Example of calculation: $\frac{p_1}{T_1} = \frac{p_2}{T_2}$ $T_2 = \frac{6.8\times10^{5}\text{ Pa}}{6.5\times10^{5}\text{ Pa}} \times 293\text{K} = 307\text{K}$ $\Delta T = (307 - 293)\text{ K} = 14\text{ K}$	(1) (1) (1)	3
(c)	**Max 3** (Average) kinetic energy of molecules/atoms is greater **Or** molecules/atoms move faster Collision rate with walls of container is greater There is more momentum (exchanged) per collision **Or** the rate of change of momentum is greater Therefore a greater force on the container walls (dependent upon mp2 or mp3)	(1) (1) (1) (1)	3
	Total for question		9

Q11.

Question Number	Acceptable answers	Additional guidance	Mark
	The only correct answer is **D** because pressure is proportional to absolute temperature and inversely proportional to volume, so the effect of the volume change is to increase the pressure by 3/2 and the effect of the temperature change is to increase the pressure by 6/5, and 18/10 = 9/5 A is not correct because a pressure of 5/9 p would depend on pressure being proportional to volume and inversely proportional to absolute temperature rather than being proportional to absolute temperature and inversely proportional to volume B is not correct because this assumes that pressure is proportional to both volume and absolute temperature, giving an answer of 4/5 p, instead of assuming that pressure is proportional to absolute temperature and inversely proportional to volume C is not correct because this assumes that pressure is inversely proportional to both volume and absolute temperature, giving an answer of 5/4 p, instead of assuming that pressure is proportional to absolute temperature and inversely proportional to volume		1

Q12.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Use total mass / mass of D ion • Use of $pV = NkT$ • $p = 2.8 \times 10^4$ Pa	(1) (1) (1)	Example of calculation $N = 5.0 \times 10^{-6}$ kg / 3.3×10^{-27} kg = 1.5×10^{21} $p = 1.5 \times 10^{21} \times 1.38 \times 10^{-23}$ J K^{-1} × 130 000 000 K / 98 m^3 = 2.77×10^4 Pa	3
(ii)	• Use of ½ m $<c^2>$ = 3/2 kT **Or** pV = 1/3 ($Nm<c^2>$) (ecf for N and p from (i)) • $\sqrt{<c^2>} = 1.3 \times 10^6$ m s^{-1}	(1) (1)	Example of calculation ½ m $<c^2>$ = 3/2 kT ½ × (3.3×10^{-27} kg) × $<c^2>$ = 3/2 × 1.38×10^{-23} J K^{-1} × 130 000 000 K $<c^2> = 1.6 \times 10^{12}$ m^2 s^{-2} $\sqrt{<c^2>} = 1.28 \times 10^6$ m s^{-1}	2
(iii)	• Use of $\Delta\lambda / \lambda = v/c$ to determine $\Delta\lambda$ • Adds shift to original wavelength • 1.075×10^{-6} m	(1) (1) (1)	Example of calculation $\Delta\lambda$ / 1.064×10^{-6} m = 15×10^6 m s^{-1}/3.00×10^8 m s^{-1} $\Delta\lambda = 5.3 \times 10^{-9}$ m $\lambda + 2\Delta\lambda = 1.075 \times 10^{-6}$ m	3

Q13.

Question Number	Answer	Mark
	D	1

Q14.

Question Number	Acceptable answers	Additional guidance	Mark
	• Equates right hand sides (1) • Final E_k formula ($\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$) and k is constant (1)		2

Q15.

Question Number	Answer	Mark
	Use of $pV = NkT$ (1) Temperature conversion (1) $\Delta N = 5.1 \times 10^{23}$ (1) [allow use of $pV = nRT$ and use of $N = n \times N_A$ for mp1] Example of calculation: $\Delta N = \frac{V\Delta p}{kT} = \frac{0.052\,\text{m}^3 \times (2.0\times10^5 - 1.6\times10^5)\,\text{Pa}}{1.38\times10^{-23}\,\text{J K}^{-1}(273+22)\,\text{K}} = 5.11\times10^{23}$	3
	Total for Question	**3**

(Total for question = 3 marks)

Mark Scheme

Q1.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of ½ $m \langle c^2 \rangle = 3/2\ kT$ • $\sqrt{\langle c^2 \rangle} = 500\ \text{m s}^{-1}$	(1) (1)	Example of calculation ½ $m \langle c^2 \rangle = 3/2\ kT$ ½ × 4.8×10^{-26} kg × $\langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23}\ \text{J K}^{-1} \times 292\ \text{K}$ $\langle c^2 \rangle = 2.52 \times 10^5\ \text{m}^2\ \text{s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 502\ \text{m s}^{-1}$	2

Q2.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An answer that makes reference to the following: • because the helium atoms are moving, there is a change in frequency/ wavelength of the emitted light (1) • for particles moving away from the observer there will be an decrease in frequency and for particles moving towards the observer there will be an increase in frequency OR for particles moving away from the observer there will be an increase in wavelength and for particles moving towards the observer there will be an decrease in wavelength (1)		**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(1)	• use of $v/c = \Delta\lambda/\lambda$ • $v = 1530\ \text{m s}^{-1}$	Example of calculation: $v / 3 \times 10^{8}\ \text{m s}^{-1} = 3 \times 10^{-3}\ \text{nm} / 587\ \text{nm}$ $v = 1530\ \text{m s}^{-1}$	**(2)**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)(2)	• mass of helium atom = 4u • use of $\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$ • $T = 375\ \text{K}$	Example of calculation: Mass of He atom = $4 \times 1.66 \times 10^{-27}\ \text{kg} = 6.64 \times 10^{-27}\ \text{kg}$ $\frac{1}{2}\ 6.64 \times 10^{-27}\ \text{kg} \times (1530\ \text{m s}^{-1})^2 = 3/2 \times 1.38 \times 10^{-23}\ \text{J K}^{-1} \times T$ $T = 375\ \text{K}$	**(3)**

Q3.

Question Number	Answer		Mark
(a)	(When the air is heated) the density (of air in) the balloon decreases	**(1)**	
	So the upthrust is greater than the weight of the balloon (plus occupants)	**(1)**	**2**
(b)	Use of $\rho = \frac{m}{V}$	**(1)**	
	Use of $\Delta E = mc\Delta\theta$ [$\Delta\theta$ must be a temperature difference]	**(1)**	
	$\Delta E = 1.3(5) \times 10^9$ J	**(1)**	**3**
	Example of calculation: $m = \rho V = 1.20\,\text{kg m}^{-3} \times 7.4 \times 10^4\,\text{m}^3 = 8.88 \times 10^4\,\text{kg}$ $\Delta E = mc\Delta\theta = 8.88 \times 10^4\,\text{kg} \times 1010\,\text{J kg}^{-1}\,\text{K}^{-1}\,(35-20)\text{K} = 1.345 \times 10^9\,\text{J}$		
(c)(i)	Use of $pV = NkT$ [temperature in either K or °C]	**(1)**	
	$p = 9.24 \times 10^4$ Pa	**(1)**	**2**
	Example of calculation: $\frac{p_2}{p_1} = \frac{T_2}{T_1}$ $p_2 = (1.01 \times 10^5)\text{Pa} \times \frac{(273-5)\text{K}}{(273+20)\text{K}} = 9.238 \times 10^4\,\text{Pa}$		
(c)(ii)	**Max 2** Hydrogen/gas behaves as an ideal gas	**(1)**	
	Mass of hydrogen/gas in balloon stays constant [Accept amount of hydrogen/gas]	**(1)**	
	Or number of molecules/atoms/particles of hydrogen/gas in balloon stays constant	**(1)**	**2**
	Temperature of hydrogen/gas is the same as the temperature of the surroundings		
(c)(iii)	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)		
	The average/mean kinetic energy of the molecules decreases	**(1)**	
	Molecules travel slower (on average) **Or** rate of collisions with walls is less	**(1)**	
	So rate of change of momentum (during collisions) with walls is less	**(1)**	**3**
	Total for question		**12**

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	• Equate $pV = NkT$ and $pV = \frac{1}{3}Nm < c^2 >$ • Suitable algebra		2

Q5.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• Calculate no of nuclei • Use of $\ln 2 = t\,½ \times \lambda$ • Use of $A = \lambda N$ • $A = 3.97 \times 10^4$ (Bq)	(1) (1) (1) (1)	Example of calculation $N = (5.18 \times 10^{-5}\text{ g}/230\text{ g}) \times 6.02 \times 10^{23}$ $= 1.36 \times 10^{17}$ $\lambda \times (75\,400 \times 3.15 \times 10^7)\text{ s} = \ln 2$ $\lambda = 2.92 \times 10^{-13}\text{ s}^{-1}$ $A = 2.92 \times 10^{-13}\text{ s}^{-1} \times 1.36 \times 10^{17}$ $A = 3.97 \times 10^4$ Bq	4
(ii)	• Calculates decays in one year (ecf from (b)(i)) • Use of $pV = NkT$ • uses $T = 295$ K • $V = 5.09 \times 10^{-14}\text{ m}^3$	(1) (1) (1) (1)	Example of calculation 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
(iii)	• Use of $½\,m\,\langle c^2\rangle = 3/2\,kT$ Or Use of $pV = \frac{1}{3}Nm < c^2 >$ (allow ecf for N, V from (b)(ii)) • uses $m = 4u$ • $\sqrt{\langle c^2\rangle} = 1360\text{ m s}^{-1}$	(1) (1) (1)	Example of calculation $½\,m\,\langle c^2\rangle = 3/2\,kT$ $½ \times (4 \times 1.66 \times 10^{-27}\text{ kg}) \times \langle c^2\rangle = 3/2 \times 1.38 \times 10^{-23}\text{ J K}^{-1} \times 295\text{ K}$ $\langle c^2\rangle = 1\,840\,000\text{ m}^2\text{ s}^{-2}$ $\sqrt{\langle c^2\rangle} = 1360\text{ m s}^{-1}$ Accept the use of proton/neutron mass instead of u	3

Q6.

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*</td><td>
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 table shows how the marks should be awarded for indicative content and structure and lines of reasoning.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>

<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
</td><td>
<table>
<tr><th>IC Points</th><th>IC Mark</th><th>Max linkage mark avail.</th><th>Max final mark</th></tr>
<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>
</table>

IC3 and IC4 must include a mention of the walls/container
</td><td>6</td></tr>
</table>

<table>
<tr><td></td><td>
Indicative content:

1. As the temperature of the gas increases the (average) speed/E_k of the atoms increases

2. Greater speed/E_k so the momentum of the atoms increases

3. The rate/frequency of collision of atoms with the container walls increases Or the time between collisions with the walls decreases

4. The rate of change of momentum at the walls increases

5. Rate of change of momentum is equal to the force

6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater
</td><td></td><td></td></tr>
</table>

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Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• Use of $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ (1) • mean kinetic energy $= 6.4\times10^{-20}$ J (1)	Example of calculation: $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ $= \frac{3}{2}\times1.38\times10^{-23}\,\text{J K}^{-1}\times3100\,\text{K} = 6.42\times10^{-20}\,\text{J}$	2

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• There are electron transitions between energy levels in the atoms, (1) • When electrons return to a lower level they emit energy in the form of photons (1)		2

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• Use total mass / mass of D ion (1) • Use of $pV = NkT$ (1) • $p = 2.8 \times 10^4$ Pa (1)	Example of calculation $N = 5.0 \times 10^{-6}$ kg / 3.3×10^{-27} kg = 1.5×10^{21} $p = 1.5 \times 10^{21} \times 1.38 \times 10^{-23}$ J K^{-1} × 130 000 000 K / 98 m^3 $= 2.77 \times 10^4$ Pa	3
(ii)	• Use of ½ m <c^2> = 3/2 kT **Or** pV = 1/3 (Nm<c^2>) (ecf for N and p from (i)) (1) • $\sqrt{<c^2>} = 1.3 \times 10^6$ m s^{-1} (1)	Example of calculation ½ m <c^2> = 3/2 kT ½ × (3.3×10^{-27} kg) × <c^2> = 3/2 × 1.38×10^{-23} J K^{-1} × 130 000 000 K <c^2> = 1.6×10^{12} m^2 s^{-2} $\sqrt{<c^2>} = 1.28 \times 10^6$ m s^{-1}	2
(iii)	• Use of $\Delta\lambda / \lambda = v/c$ to determine $\Delta\lambda$ (1) • Adds shift to original wavelength (1) • 1.075×10^{-6} m (1)	Example of calculation $\Delta\lambda / 1.064 \times 10^{-6}$ m = 15×10^6 m s^{-1}/3.00×10^8 m s^{-1} $\Delta\lambda = 5.3 \times 10^{-9}$ m $\lambda + 2\Delta\lambda = 1.075 \times 10^{-6}$ m	3

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• Equates right hand sides (1) • Final E_k formula ($\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$) and k is constant (1)		2

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$ (1) • with T in Kelvin (1) • $\sqrt{\langle c^2 \rangle} = 497\ \text{m s}^{-1}$ (1)	Example of calculation $\frac{1}{2} m \langle c^2 \rangle = 3/2\ kT$ $\frac{1}{2} \times 5.0 \times 10^{-26}\ \text{kg} \times \langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23}\ \text{J K}^{-1} \times 298\ \text{K}$ $\langle c^2 \rangle = 247\,000\ \text{m}^2\ \text{s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 497\ \text{m s}^{-1}$	3