Q1.

2	(a)		<u>mean</u> (value of the) <u>square</u>	M1	
			of the speeds (velocities) of the atoms/particles/molecules	A1	[2]
	(b)	(i)	$p = \frac{1}{3}\rho < c^2 >$	C1	
			$<c^2> = 3 \times 2 \times 10^5/2.4 = 2.5 \times 10^5$	C1	
			r.m.s speed = 500 ms^{-1}	A1	[3]
		(ii)	new $<c^2> = 1.0 \times 10^6$ or $<c^2>$ increases by factor of 4	C1	
			$<c^2> \propto T$ or $3/2\ kT = 1/2\ m<c^2>$	C1	
			$T = \{(1.0 \times 10^6) / (2.5 \times 10^5)\} \times 300$		
			= 1200 K	A1	[3]
			Total		[8]

Q2.

2	(a)		obeys the law pV/T = constant <u>or</u> any <u>two</u> named gas laws	**M1**	
			at all values of p, V and T	**A1**	**[2]**
			<u>or</u> two correct assumptions of kinetic theory of ideal gas **(B1)**		
			third correct assumption **(B1)**		
	(b)	(i)	mean square speed	**B1**	**[1]**
		(ii)	mean kinetic energy = $\frac{1}{2}m<c^2>$	**M1**	
			$\rho = Nm/V$ and algebra leading to [do not allow if takes N = 1]	**M1**	
			$\frac{1}{2}m<c^2> = 3/2\ kT$	**A0**	**[2]**
	(c)	(i)	$\frac{1}{2} \times 6.6 \times 10^{-27} \times (1.1 \times 10^4)^2 = 3/2 \times 1.38 \times 10^{-23} \times T$	**C1**	
			$T = 1.9 \times 10^4$ K	**A1**	**[2]**
		(ii)	Not all atoms have same speed/kinetic energy	**B1**	**[1]**

Q3.

2	(a)		e.g. fixed mass/ amount of gas		
			ideal gas		
			(*any two, 1 each*)	B2	[2]
	(b)	(i)	$n = pV / RT$	C1	
			$= (2.5 \times 10^7 \times 4.00 \times 10^4 \times 10^{-6}) / (8.31 \times 290)$	C1	
			= 415 mol	A1	[3]
		(ii)	volume of gas at 1.85×10^5 Pa $= (2.5 \times 10^7 \times 4.00 \times 10^4) / (1.85 \times 10^5)$		
			$= 5.41 \times 10^6\ cm^3$	C1	
			so, $5.41 \times 10^6 = 4.00 \times 10^4 + 7.24 \times 10^3\ N$	C1	
			N = 741	A1	[3]
			(answer 740 or fails to allow for gas in cylinder, max 2/3)		

Q4.

2 **(a)** molecule(s) rebound from wall of vessel / hits walls — B1
change in momentum gives rise to impulse / force — B1
either (many impulses) averaged to give constant force / pressure
or the molecules are in random motion — B1 [3]

(b) **(i)** $p = \frac{1}{3}\rho\langle c^2\rangle$ — C1

$1.02 \times 10^5 = \frac{1}{3} \times 0.900 \times \langle c^2\rangle$

$\langle c^2\rangle = 3.4 \times 10^5$ — C1
$c_{RMS} = 580 \text{ m s}^{-1}$ — A1 [3]

(ii) *either* $\langle c^2\rangle \propto T$ *or* $\langle c^2\rangle = 2 \times 3.4 \times 10^5$ — C1
$c_{RMS} = 830 \text{ m s}^{-1}$ (allow 820) — A1 [2]

(c) c_{RMS} depends on temperature (alone) — B1
so no effect — B1 [2]

Q5.

2 **(a)** *either* the half-life of the source is very long
or decay constant is very small
or half-life >> 40 days
or decay constant << 0.02 day^{-1} — B1 [1]

(b) number of helium atoms $= 3.5 \times 10^6 \times 40 \times 24 \times 3600$ — C1
$= 1.21 \times 10^{13}$
either $pV = NkT$ *or* $pV = nRT$ and $n = N / N_A$ — C1
$1.5 \times 10^5 \times V = 1.21 \times 10^{13} \times 1.38 \times 10^{-23} \times 290$
$V = 3.2 \times 10^{-13} \text{ m}^3$ — A1 [3]
(if uses T/°C or $n = 1$ or $n = 4$, then 1 mark max for calculation of number of atoms)

Q6.

2	**(a)**	**(i)**	27.2 + 273.15 or 27.2 + 273.2	C1	
			300.4 K	A1	[2]
		(ii)	11.6 K	A1	[1]
	(b)	**(i)**	($\langle c^2 \rangle$ is the) mean / average square speed	B1	[1]
		(ii)	$\rho = Nm/V$ with <u>N explained</u>	B1	
			so, $pV = 1/3\, Nm\langle c^2 \rangle$	B1	
			and $pV = NkT$ with <u>k explained</u>	B1	
			<u>so mean kinetic energy / $\langle E_K \rangle = ½m\langle c^2 \rangle = 3/2\, kT$</u>	B1	[4]
	(c)	**(i)**	$pV = nRT$		
			$2.1 \times 10^7 \times 7.8 \times 10^{-3} = n \times 8.3 \times 290$	C1	
			$n = 68$ mol	A1	[2]
		(ii)	mean kinetic energy $= 3/2\, kT$		
			$= 3/2 \times 1.38 \times 10^{-23} \times 290$	C1	
			$= 6.0 \times 10^{-21}$ J	A1	[2]
		(iii)	realisation that total internal energy is the total kinetic energy	C1	
			energy $= 6.0 \times 10^{-21} \times 68 \times 6.02 \times 10^{23}$	C1	
			$= 2.46 \times 10^5$ J	A1	[3]

Q7.

2	**(a)**	number of atoms of carbon-12	M1	
		in 0.012 kg of carbon-12	A1	[2]
	(b)	$pV = NkT$ or $pV = nRT$	C1	
		substitutes temperature as 298 K	C1	
		either $1.1 \times 10^5 \times 6.5 \times 10^{-2} = N \times 1.38 \times 10^{-23} \times 298$		
		or $1.1 \times 10^5 \times 6.5 \times 10^{-2} = n \times 8.31 \times 298$ and $n = N / 6.02 \times 10^{23}$	C1	
		$N = 1.7 \times 10^{24}$	A1	[4]

Q8.

2	**(a)**	amount of substance	M1	
		containing same number of particles as in 0.012 kg of carbon-12	A1	[2]
	(b)	$pV = nRT$	C1	
		amount = $(2.3 \times 10^5 \times 3.1 \times 10^{-3}) / (8.31 \times 290)$		
		$+ (2.3 \times 10^5 \times 4.6 \times 10^{-3}) / (8.31 \times 303)$	C1	
		= 0.296 + 0.420	C1	
		= 0.716 mol	A1	[4]
		(*give full credit for starting equation $pV = NkT$ and $N = nN_A$*)		

Q9.

2	**(a) (i)** *either* random motion *or* constant velocity until hits wall/other molecule	B1	[1]
	(ii) (total) volume of molecules is negligible compared to volume of containing vessel *or* radius/diameter of a molecule is negligible compared to the average intermolecular distance	M1 A1 (M1) (A1)	[2]
	(b) *either* molecule has component of velocity in three directions *or* $c^2 = c_X^2 + c_Y^2 + c_Z^2$ random motion and averaging, so $\langle c_X^2\rangle = \langle c_Y^2\rangle = \langle c_Z^2\rangle$ $\langle c^2\rangle = 3\langle c_X^2\rangle$ so, $pV = \frac{1}{3}Nm\langle c^2\rangle$	 M1 M1 A1 A0	[3]
	(c) $\langle c^2\rangle \propto T$ or $c_{rms} \propto \sqrt{T}$ temperatures are 300 K and 373 K $c_{rms} = 580\,m\,s^{-1}$ *(Do not allow any marks for use of temperature in units of °C instead of K)*	C1 C1 A1	[3]

Q10.

2	**(a)** obeys the equation pV = constant × T or $pV = nRT$ p, V and T explained at all values of p, V and T/fixed mass/n is constant	M1 A1 A1	[3]
	(b) (i) $3.4 \times 10^5 \times 2.5 \times 10^3 \times 10^{-6} = n \times 8.31 \times 300$ $n = 0.34$ mol	M1 A0	[1]
	(ii) for total mass/amount of gas $3.9 \times 10^5 \times (2.5 + 1.6) \times 10^3 \times 10^{-6} = (0.34 + 0.20) \times 8.31 \times T$ $T = 360$ K	 C1 A1	[2]
	(c) when tap opened gas passed (from cylinder B) to cylinder A work done <u>on</u> gas in cylinder A (and no heating) so internal energy and hence temperature increase	 B1 M1 A1	[3]

Q11.

2 (a) (i) 1. $pV = nRT$
$1.80 \times 10^{-3} \times 2.60 \times 105 = n \times 8.31 \times 297$ C1
$n = 0.19$ mol A1 [2]

2. $\Delta q = mc\Delta T$
$95.0 = 0.190 \times 12.5 \times \Delta T$ B1
$\Delta T = 40$ K A1 [2]
(allow 2 marks for correct answer with clear logic shown)

(ii) p/T = constant
$(2.6 \times 10^5) / 297 = p / (297 + 40)$ M1
$p = 2.95 \times 10^5$ Pa A0 [1]

(b) change in internal energy is 120 J / 25 J B1
internal energy decreases / ΔU is negative / kinetic energy of molecules decreases M1
so temperature lower A1 [3]

Q12.

2 (a) obeys the law pV = constant $\times$ T ………………………………… M1
at all values of p, V and T ………………………………… A1 **[2]**

(b) $n = (2.9 \times 10^5 \times 3.1 \times 10^{-2}) / (8.31 \times 290)$ ………………………… C1
$= 3.73$ mol ………………………………… A1 **[2]**

(c) at new pressure, $n_n = 3.73 \times \frac{3.4}{2.9} \times \frac{290}{300}$
$= 4.23$ mol ………………………………… C1
change = 0.50 mol ………………………………… C1
number of strokes = 0.50 / 0.012 = 42 (must round up for mark) ……. A1 **[3]**

Q13.

2 (a) (i) $pV = nRT$
$V = (8.31 \times 300)/(1.02 \times 10^5)$ ………………………………… C1
$= 0.0244$ m^3 (if uses Celsius, then 0/2) ………………………………… A1 [2]

(ii) volume occupied by one atom = $0.0244 / (6.02 \times 10^{23}) = 4.06 \times 10^{-26}$ m^3 ………… M1
separation $\approx \sqrt[3]{4.06 \times 10^{-26}}$ ………………………………… A1
$= 3.44 \times 10^{-9}$ m ………………………………… A0 [2]

(b) (i) $F = GMm / r^2$ ………………………………… C1
$= (6.67 \times 10^{-11} \times \{4 \times 1.66 \times 10^{-27}\}^2) / (3.44 \times 10^{-9})^2$ ………………… C1
$= 2.49 \times 10^{-46}$ N ………………………………… A1 [3]

(ii) ratio $= (4 \times 1.66 \times 10^{-27} \times 9.8) / 2.49 \times 10^{-46}$ ………………… C1
$= 2.6 \times 10^{20}$ ………………………………… A1 [2]

(c) assumption that forces between atoms are negligible ………………………… B1
comment e.g. ratio shows gravitational force to be very small
e.g. force is very much less than weight
e.g. if there are forces, they are not gravitational ………………… B1 [2]

Q14.

5 (a) change/loss in kinetic energy = change/gain in electric potential energy B1

$2 \times \frac{1}{2}mv^2 = q^2 / 4\pi\varepsilon_0 r$ C1

$2 \times \frac{1}{2} \times 2 \times 1.67 \times 10^{-27} \times v^2$

$= (1.6 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times 1.1 \times 10^{-14})$ M1

$v = 2.5 \times 10^6 \text{ m s}^{-1}$ A0 [3]

(b) $pV = \frac{1}{2}Nm\langle c^2\rangle$ and $pV = NkT$ C1

$\frac{1}{2} m\langle c^2\rangle = \frac{3}{2} kT$ (*award 1 mark of first two if $\langle c^2\rangle$ not used*) C1

$\frac{1}{2} \times 2 \times 1.67 \times 10^{-27} \times (2.5 \times 10^6)^2 = \frac{3}{2} \times 1.38 \times 10^{-23} \times T$ C1

$T = 5 \times 10^8$ K A1 [4]

(c) e.g. this is <u>very</u> high temperature
temperature found in stars
(*any sensible comment, 1 mark*)
(*if $T < 10^6$ K, should comment that too low for fusion to occur*) B1 [1]

Q15.

2 (a) *either* $pV = NkT$ *or* $pV = nRT$ *<u>and</u>* $n = N / N_A$ C1

clear correct substitution e.g.

$2.5 \times 10^5 \times 4.5 \times 10^3 \times 10^{-6} = N \times 1.38 \times 10^{-23} \times 290$ M1

$N = 2.8 \times 10^{23}$ .... A0 [2]

(*allow 1 mark for calculation of n = 0.467 mol*)

(b) (i) volume $= (1.2 \times 10^{-10})^3 \times 2.8 \times 10^{23}$ *or* $\frac{4}{3}\pi r^3 \times 2.8 \times 10^{23}$ C1

$= 4.8 \times 10^{-7}$ m^3 $\quad 2.53 \times 10^{-7}$ m^3 ....A1 [2]

(ii) *either* 4.5×10^3 cm^3 >> 0.48 cm^3 *or* ratio of volumes is about 10^{-4} B1

justified because volume of molecules is negligible ....B1 [2]

[Total: 6]

Q16.

2	(a)	(i)	no forces (of attraction or repulsion) between atoms / molecules / particles	B1	[1]
		(ii)	sum of kinetic and potential energy of atoms / molecules due to random motion	M1 A1	[2]
		(iii)	(random) kinetic energy increases with temperature no potential energy (so increase in temperature increases internal energy)	M1 A1	[2]
	(b)	(i)	zero	A1	[1]
		(ii)	work done $= p\Delta V$ $= 4.0 \times 10^5 \times 6 \times 10^{-4}$ $= 240$ J *(ignore any sign)*	C1 A1	[2]

(iii)

change	work done / J	heating / J	increase in internal energy / J
P → Q	**+240**	−600	**−360**
Q → R	0	+720	**+720**
R → P	**−840**	+480	**−360**

(*correct signs essential*)
(*each horizontal line correct, 1 mark – max 3*) B3 [3]

Q17.

2	(a)		atoms / molecules / particles behave as elastic (identical) spheres volume of atoms / molecules negligible compared to volume of containing vessel time of collision negligible to time between collisions no forces of attraction or repulsion between atoms / molecules atoms / molecules / particles are in (continuous) random motion (*any four, 1 each*)	(1) (1) (1) (1) (1) B4	[4]
	(b)		$pV = \frac{1}{3}Nm<c^2>$ and $pV = nRT$ *or* $pV = NkT$ $\frac{1}{3}Nm<c^2> = nRT$ or $= NkT$ and $<E_K> = ½m<c^2>$ $n = N/N_A$ *or* $k = R/N_A$ $<E_K> = \frac{3}{2} \times R/N_A \times T$	B1 B1 B1 A0	[3]
	(c)	(i)	reaction represents *either* build-up of nucleus from light nuclei *or* build-up of heavy nucleus from nuclei so fusion reaction	 M1 A1	[2]
		(ii)	proton and deuterium nucleus will have equal kinetic energies $1.2 \times 10^{-14} = \frac{3}{2} \times 8.31 / (6.02 \times 10^{23}) \times T$ $T = 5.8 \times 10^8$ K (*use of* $E = 2.4 \times 10^{-14}$ *giving* 1.16×10^9 K *scores 1 mark*)	B1 C1 A1	[3]
		(iii)	*either* inter-molecular / atomic / nuclear forces exist *or* proton and deuterium nucleus are positively charged / repel	 B1	[1]

Q18.

2 **(a)** e.g. moving in random (rapid) motion of <u>molecules/atoms/particles</u> no intermolecular forces of attraction/repulsion volume of <u>molecules/atoms/particles</u> negligible <u>compared</u> to volume of container time of collision negligible to time between collisions *(1 each, max 2)*	B2	[2]
(b) **(i)** **1.** number of (gas) <u>molecules</u>	B1	[1]
2. mean square speed/velocity (of gas molecules)	B1	[1]
(ii) either $pV = NkT$ *or* $pV = nRT$ and links n and k and $\langle E_K \rangle = \frac{1}{2}m\langle c^2 \rangle$	M1	
clear algebra leading to $\langle E_K \rangle = \frac{3}{2}kT$	A1	[2]
(c) **(i)** sum of potential energy and kinetic energy of <u>molecules/atoms/particles</u>	M1	
reference to random (distribution)	A1	[2]
(ii) no intermolecular forces so no potential energy	B1	
(change in) internal energy is (change in) kinetic energy and this is proportional to (change in) T	B1	[2]

Q19.

(c) **(i)** $\frac{1}{2} \times 2 \times 1.66 \times 10^{-27} \times (5.03 \times 10^{3})^{2} = \frac{3}{2} \times 1.38 \times 10^{-23} \times T$	C1	
$T = 2030$ K	A1	[2]
(ii) *either* because there is a range of speeds	M1	
some molecules have a higher speed	A1	
or some escape from point above planet surface	(M1)	
so initial potential energy is higher	(A1)	[2]

Q20.

2 **(a)** **(i)** sum of potential energy and kinetic energy of atoms/molecules/particles	M1	
reference to random	A1	[2]
(ii) no intermolecular forces	B1	
no potential energy	B1	
internal energy is kinetic energy (of random motion) of molecules (*reference to random motion here then allow back credit to **(i)** if M1 scored*)	B1	[3]
(b) kinetic energy $\propto$ thermodynamic temperature	B1	
either temperature in Celsius, not kelvin so incorrect *or* temperature in kelvin is not doubled	B1	[2]

Q21.

1	(a)	(i)	number of molecules	B1	[1]
		(ii)	mean square speed	B1	[1]
	(b)	(i)	1. $pV = nRT$	C1	
			$n = (6.1 \times 10^5 \times 2.1 \times 10^4 \times 10^{-6}) / (8.31 \times 285)$	C1	
			$n = 5.4$ mol	A1	[3]
			2. *either* $N = nN_A$		
			$= 5.4 \times 6.02 \times 10^{23}$	C1	
			$= 3.26 \times 10^{24}$	A1	
			or		
			$pV = NkT$		
			$N = (6.1 \times 10^5 \times 2.1 \times 10^4 \times 10^{-6}) / (1.38 \times 10^{-23} \times 285)$	(C1)	
			$N = 3.26 \times 10^{24}$	(A1)	[2]
		(ii)	*either* $6.1 \times 10^5 \times 2.1 \times 10^{-2} = {}^1/_3 \times 3.25 \times 10^{24} \times 4 \times 1.66 \times 10^{-27} \times \langle c^2 \rangle$	C1	
			$\langle c^2 \rangle = 1.78 \times 10^6$	C1	
			$c_{RMS} = 1.33 \times 10^3$ m s^{-1}	A1	
			or		
			${}^1/_2 \times 4 \times 1.66 \times 10^{-27} \times \langle c^2 \rangle = {}^3/_2 \times 1.38 \times 10^{-23} \times 285$	(C1)	
			$\langle c^2 \rangle = 1.78 \times 10^6$	(C1)	
			$c_{RMS} = 1.33 \times 10^3$ m s^{-1}	(A1)	[3]

Q22.

2	(a)	(i)	N: (total) number of molecules	B1	[1]
		(ii)	$\langle c^2 \rangle$: mean square speed/velocity	B1	[1]
	(b)		$pV = ⅓Nm\langle c^2 \rangle = NkT$		
			(mean) kinetic energy = $½ m\langle c^2 \rangle$	C1	
			algebra clear leading to $½ m\langle c^2 \rangle = (3/2)kT$	A1	[2]
	(c)	(i)	*either* energy required = $(3/2) \times 1.38 \times 10^{-23} \times 1.0 \times 6.02 \times 10^{23}$	C1	
			= 12.5 J (*12J if 2 s.f.*)	A1	[2]
			or energy = $(3/2) \times 8.31 \times 1.0$	(C1)	
			= 12.5 J	(A1)	
		(ii)	energy is needed to push back atmosphere/do work against atmosphere	M1	
			so total energy required is greater	A1	[2]

Q23.

2	(a) (i)	sum of kinetic and potential energies of the molecules	M1	
		reference to random distribution	A1	[2]
	(ii)	for ideal gas, no intermolecular forces	M1	
		so no potential energy (only kinetic)	A1	[2]
	(b) (i)	*either* change in kinetic energy $= 3/2 \times 1.38 \times 10^{-23} \times 1.0 \times 6.02 \times 10^{23} \times 180$	C1	
		$= 2240$ J	A1	[2]
		or $R = kN_A$		
		energy $= 3/2 \times 1.0 \times 8.31 \times 180$	(C1)	
		$= 2240$ J	(A1)	
	(ii)	increase in internal energy = heat supplied + work done on system	B1	
		2240 = energy supplied – 1500	C1	
		energy supplied = 3740 J	A1	[3]

Q24.

2	(a)	the number of atoms	M1	
		in 12 g of carbon-12	A1	[2]
	(b) (i)	amount = 3.2/40		
		= 0.080 mol	A1	[1]
	(ii)	$pV = nRT$		
		$p \times 210 \times 10^{-6} = 0.080 \times 8.31 \times 310$	C1	
		$p = 9.8 \times 10^5$ Pa	A1	[2]
		(do not credit if T in °C not K)		
	(iii)	*either* $pV = 1/3 \times Nm \langle c^2 \rangle$		
		$N = 0.080 \times 6.02 \times 10^{23}$ $(= 4.82 \times 10^{22})$		
		<u>and</u> $m = 40 \times 1.66 \times 10^{-27}$ $(= 6.64 \times 10^{-26})$	C1	
		$9.8 \times 10^5 \times 210 \times 10^{-6} = 1/3 \times 4.82 \times 10^{22} \times 6.64 \times 10^{-26} \times \langle c^2 \rangle$	C1	
		$\langle c^2 \rangle = 1.93 \times 10^5$		
		$c_{RMS} = 440$ m s^{-1}	A1	[3]
		or $Nm = 3.2 \times 10^{-3}$	(C1)	
		$9.8 \times 10^5 \times 210 \times 10^{-6} = 1/3 \times 3.2 \times 10^{-3} \times \langle c^2 \rangle$	(C1)	
		$\langle c^2 \rangle = 1.93 \times 10^5$		
		$c_{RMS} = 440$ m s^{-1}	(A1)	
		or $1/2\, m\langle c^2 \rangle = 3/2\, kT$	(C1)	
		$1/2 \times 40 \times 1.66 \times 10^{-27} \langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23} \times 310$	(C1)	
		$\langle c^2 \rangle = 1.93 \times 10^5$		
		$c_{RMS} = 440$ m s^{-1}	(A1)	
		*(if T in °C not K award max 1/3, unless already penalised in **(b)(ii)**)*		

Q25.

2	(a)	use of kelvin temperatures		B1	
		both values of (V/T) correct (11.87), V/T is constant so pressure is constant		M1	[2]
		(allow use of n = 1. Do not allow other values of n.)			
	(b) (i)	work done	$= p\Delta V$		
			$= 4.2 \times 10^5 \times (3.87 - 3.49) \times 10^3 \times 10^{-6}$	C1	
			$= 160$ J	A1	[2]
		(do not allow use of V instead of ΔV)			
	(ii)	increase/change in internal energy	= heating of system		
			+ work done on system	C1	
			$= 565 - 160$		
			$= 405$ J	A1	[2]
	(c)	internal energy = sum of kinetic energy and potential energy/ $E_K + E_P$		B1	
		no intermolecular forces		M1	
		no potential energy (so $\Delta U = \Delta E_K$)		A1	[3]

Q26.

3	(a)	obeys the equation pV/T = constant *(accept pV = nRT)*	B1	[1]
	(b) (i)	$pV = nRT$	C1	
		$5.0 \times 10^7 \times 3.0 \times 10^{-4} = n \times 8.31 \times 296$ giving $n = 6.1$ mol	A1	[2]
	(ii)	pressure ∝ amount of substance		
		loss = $0.40/100 \times 6.1$ mol = 0.0244 mol	C1	
		$= 0.0244 \times 6.02 \times 10^{23}$ (atoms)	C1	
		$= 1.47 \times 10^{22}$ atoms	C1	
		rate = $(1.47 \times 10^{22})/(35 \times 24 \times 60 \times 60)$		
		$= 4.9 \times 10^{15}\ s^{-1}$	A1	[4]