

Q1.

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

Q2.

2 (a)	obeys the law $pV/T = \text{constant}$ or any two named gas laws at all values of p , V and T or two correct assumptions of kinetic theory of ideal gas (B1) third correct assumption (B1)	M1 A1	[2]
(b) (i)	mean square speed	B1	[1]
(ii)	mean kinetic energy = $\frac{1}{2}m <c^2>$ $\rho = Nm/V$ and algebra leading to [do not allow if takes $N = 1$] $\frac{1}{2}m <c^2> = 3/2 kT$	M1 M1 A0	[2]
(c) (i)	$\frac{1}{2} \times 6.6 \times 10^{-27} \times (1.1 \times 10^4)^2 = 3/2 \times 1.38 \times 10^{-23} \times T$ $T = 1.9 \times 10^4 \text{ K}$	C1 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)	$n = pV / RT$ $= (2.5 \times 10^7 \times 4.00 \times 10^4 \times 10^{-6}) / (8.31 \times 290)$ $= 415 \text{ mol}$	C1 C1 A1	[3]
(ii)	volume of gas at $1.85 \times 10^5 \text{ Pa} = (2.5 \times 10^7 \times 4.00 \times 10^4) / (1.85 \times 10^5)$ $= 5.41 \times 10^6 \text{ cm}^3$ so, $5.41 \times 10^6 = 4.00 \times 10^4 + 7.24 \times 10^3 N$ $N = 741$ (answer 740 or fails to allow for gas in cylinder, max 2/3)	C1 C1 A1	[3]

Q4.



2 (a) molecule(s) rebound from wall of vessel / hits walls change in momentum gives rise to impulse / force <i>either</i> (many impulses) averaged to give constant force / pressure <i>or</i> the molecules are in random motion	B1 B1 B1 [3]
(b) (i) $p = \frac{1}{3} \rho \langle c^2 \rangle$	C1
$1.02 \times 10^5 = \frac{1}{3} \times 0.900 \times \langle c^2 \rangle$	
$\langle c^2 \rangle = 3.4 \times 10^5$ $c_{\text{RMS}} = 580 \text{ m s}^{-1}$	C1 A1 [3]
(ii) <i>either</i> $\langle c^2 \rangle \propto T$ <i>or</i> $\langle c^2 \rangle = 2 \times 3.4 \times 10^5$ $c_{\text{RMS}} = 830 \text{ m s}^{-1}$ (allow 820)	C1 A1 [2]
(c) c_{RMS} depends on temperature (alone) so no effect	B1 B1 [2]

Q5.

2 (a) <i>either</i> the half-life of the source is <u>very long</u> <i>or</i> decay constant is <u>very small</u> <i>or</i> half-life $>> 40$ days <i>or</i> decay constant $\ll 0.02 \text{ day}^{-1}$	B1 [1]
(b) number of helium atoms $= 3.5 \times 10^6 \times 40 \times 24 \times 3600$ $= 1.21 \times 10^{13}$ <i>either</i> $pV = NkT$ <i>or</i> $pV = nRT$ <i>and</i> $n = N/N_A$ $1.5 \times 10^5 \times V = 1.21 \times 10^{13} \times 1.38 \times 10^{-23} \times 290$ $V = 3.2 \times 10^{-13} \text{ m}^3$ (if uses $T/\text{°C}$ or $n = 1$ or $n = 4$, then 1 mark max for calculation of number of atoms)	C1 C1 A1 [3]

Q6.

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

Q7.

- 2 (a) number of atoms of carbon-12
in 0.012 kg of carbon-12 M1
A1 [2]
- (b) $pV = NkT$ or $pV = nRT$
substitutes temperature as 298 K C1
either $1.1 \times 10^5 \times 6.5 \times 10^{-2} = N \times 1.38 \times 10^{-23} \times 298$ C1
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
containing same number of particles as in 0.012 kg of carbon-12 M1
A1 [2]
- (b) $pV = nRT$
amount = $(2.3 \times 10^5 \times 3.1 \times 10^{-3}) / (8.31 \times 290)$ C1
+ $(2.3 \times 10^5 \times 4.6 \times 10^{-3}) / (8.31 \times 303)$ 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 M1
or A1
radius/diameter of a molecule is negligible compared to the average intermolecular distance (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 $\langle c_x^2 \rangle = \langle c_y^2 \rangle = \langle c_z^2 \rangle$ M1
 $\langle c^2 \rangle = 3\langle c_x^2 \rangle$ M1
so, $pV = \frac{1}{3}Nm\langle c^2 \rangle$ A1
A0 [3]
- (c) $\langle c^2 \rangle \propto T$ or $c_{ms} \propto \sqrt{T}$ C1
temperatures are 300K and 373K C1
 $c_{ms} = 580 \text{ m s}^{-1}$ A1 [3]
(Do not allow any marks for use of temperature in units of °C instead of K)

Q10.

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

Q11.

- 2 (a) (i) 1. $pV = nRT$
 $1.80 \times 10^{-3} \times 2.60 \times 105 = n \times 8.31 \times 297$
 $n = 0.19 \text{ mol}$
2. $\Delta q = mc\Delta T$
 $95.0 = 0.190 \times 12.5 \times \Delta T$
 $\Delta T = 40 \text{ K}$
(allow 2 marks for correct answer with clear logic shown)
- (ii) $p/T = \text{constant}$
 $(2.6 \times 10^5) / 297 = p / (297 + 40)$
 $p = 2.95 \times 10^5 \text{ Pa}$
- (b) change in internal energy is 120 J / 25 J
internal energy decreases / ΔU is negative / kinetic energy of molecules decreases so temperature lower

C1
A1 [2]B1
A1 [2]M1
A0 [1]B1
M1
A1 [3]**Q12.**

- 2 (a) obeys the law $pV = \text{constant} \times T$
at all values of p , V and T
- (b) $n = (2.9 \times 10^5 \times 3.1 \times 10^{-2}) / (8.31 \times 290)$
= 3.73 mol
- (c) at new pressure, $n_n = 3.73 \times \frac{3.4}{2.9} \times \frac{290}{300}$
= 4.23 mol
change = 0.50 mol
number of strokes = $0.50 / 0.012 = 42$ (must round up for mark)

M1
A1 [2]C1
A1 [2]C1
C1
A1 [3]**Q13.**

- 2 (a) (i) $pV = nRT$
 $V = (8.31 \times 300) / (1.02 \times 10^5)$
= 0.0244 m³ (if uses Celsius, then 0/2)
- (ii) volume occupied by one atom = $0.0244 / (6.02 \times 10^{23}) = 4.06 \times 10^{-26} \text{ m}^3$
separation $\approx (4.06 \times 10^{-26})^{1/3}$
= $3.44 \times 10^{-9} \text{ m}$
- (b) (i) $F = GMm / r^2$
= $(6.67 \times 10^{-11} \times \{4 \times 1.66 \times 10^{-27}\}^2) / (3.44 \times 10^{-9})^2$
= $2.49 \times 10^{-46} \text{ N}$
- (ii) ratio = $(4 \times 1.66 \times 10^{-27} \times 9.8) / 2.49 \times 10^{-46}$
= 2.6×10^{20}
- (c) assumption that forces between atoms are negligible
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

C1
A1 [2]M1
A1
A0 [2]C1
C1
A1 [3]C1
A1 [2]B1
[2]



Q14.

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

$$2 \times \frac{1}{2}mv^2 = q^2 / 4\pi\epsilon_0 r$$
 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
 $T = 5 \times 10^8 \text{ K}$ A1 [4]

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

Q15.

- 2 (a) either $pV = NkT$ or $pV = nRT$ and $n = N / N_A$ 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 $n = 0.467 \text{ mol}$)

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

(ii) either $4.5 \times 10^3 \text{ cm}^3 \gg 0.48 \text{ cm}^3$ 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 = $p\Delta V$
 $= 4.0 \times 10^5 \times 6 \times 10^{-4}$
 $= 240 \text{ J} \quad (\text{ignore any sign})$ 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 (1)
volume of atoms / molecules negligible compared to volume of containing vessel (1)
time of collision negligible to time between collisions (1)
no forces of attraction or repulsion between atoms / molecules (1)
atoms / molecules / particles are in (continuous) random motion (1)
(any four, 1 each) B4 [4]
- (b) $pV = \frac{1}{3}Nm\langle c^2 \rangle$ and $pV = nRT$ or $pV = NkT$ B1
 $\frac{1}{3}Nm\langle c^2 \rangle = nRT$ or $\frac{1}{3}NkT$ and $\langle E_K \rangle = \frac{1}{2}m\langle c^2 \rangle$ B1
 $n = N/N_A$ or $k = R/N_A$ B1
 $\langle E_K \rangle = \frac{3}{2} \times \frac{R}{N_A} \times T$ 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 B1
 $1.2 \times 10^{-14} = \frac{3}{2} \times 8.31 / (6.02 \times 10^{23}) \times T$ C1
 $T = 5.8 \times 10^8 \text{ K}$ A1 [3]
(use of $E = 2.4 \times 10^{-14}$ giving $1.16 \times 10^9 \text{ K}$ scores 1 mark)
- (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 molecules/atoms/particles
no intermolecular forces of attraction/repulsion
volume of molecules/atoms/particles negligible compared to volume of container
time of collision negligible to time between collisions
(1 each, max 2) B2 [2]
- (b) (i) 1. number of (gas) molecules 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 molecules/atoms/particles
reference to random (distribution) M1
A1 [2]
- (ii) no intermolecular forces so no potential energy
(change in) internal energy is (change in) kinetic energy and this is proportional to (change in) T B1
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
 $T = 2030 \text{ K}$ A1 [2]
- (ii) either because there is a range of speeds
some molecules have a higher speed M1
or some escape from point above planet surface A1
so initial potential energy is higher (M1)
(A1) [2]

Q20.

- 2 (a) (i) sum of potential energy and kinetic energy of atoms/molecules/particles
reference to random M1
A1 [2]
- (ii) no intermolecular forces
no potential energy
internal energy is kinetic energy (of random motion) of molecules B1
B1
B1 [3]
(reference to random motion here then allow back credit to (i) if M1 scored)
- (b) kinetic energy \propto thermodynamic temperature
either temperature in Celsius, not kelvin so incorrect
or temperature in kelvin is not doubled B1
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
 $n = 5.4 \text{ mol}$ A1 [3]
2. either $N = nN_A$ C1
 $= 5.4 \times 6.02 \times 10^{23}$ A1
 $= 3.26 \times 10^{24}$
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 $6.1 \times 10^5 \times 2.1 \times 10^{-2} = \frac{1}{3} \times 3.25 \times 10^{24} \times 4 \times 1.66 \times 10^{-27} \times \langle c^2 \rangle$ C1
 $\langle c^2 \rangle = 1.78 \times 10^6$ C1
 $c_{\text{RMS}} = 1.33 \times 10^3 \text{ m s}^{-1}$ A1
or
 $\frac{1}{2} \times 4 \times 1.66 \times 10^{-27} \times \langle c^2 \rangle = \frac{3}{2} \times 1.38 \times 10^{-23} \times 285$ (C1)
 $\langle c^2 \rangle = 1.78 \times 10^6$ (C1)
 $c_{\text{RMS}} = 1.33 \times 10^3 \text{ m s}^{-1}$ (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) $pV = \frac{1}{3}Nm\langle c^2 \rangle = NkT$ C1
(mean) kinetic energy = $\frac{1}{2}m\langle c^2 \rangle$ A1
algebra clear leading to $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}NkT$ [2]
- (c) (i) either energy required = $(3/2) \times 1.38 \times 10^{-23} \times 1.0 \times 6.02 \times 10^{23}$ C1
 $\approx 12.5 \text{ J} \quad (12 \text{ J if 2 s.f.})$ A1 [2]
or energy = $(3/2) \times 8.31 \times 1.0$ (C1)
 $\approx 12.5 \text{ J}$ (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 reference to random distribution	M1 A1 [2]
(ii) for ideal gas, no intermolecular forces so no potential energy (only kinetic)	M1 A1 [2]
(b) (i) either change in kinetic energy = $3/2 \times 1.38 \times 10^{-23} \times 1.0 \times 6.02 \times 10^{23} \times 180$ = 2240 J or $R = kN_A$ energy = $3/2 \times 1.0 \times 8.31 \times 180$ = 2240 J	C1 A1 [2] (C1) (A1)
(ii) increase in internal energy = heat supplied + work done on system 2240 = energy supplied - 1500 energy supplied = 3740 J	B1 C1 A1 [3]

Q24.

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

(if T in °C not K award max 1/3, unless already penalised in (b)(ii))

Q25.

- 2 (a) use of kelvin temperatures
both values of (V/T) correct (11.87), V/T is constant so pressure is constant

B1
M1 [2](allow use of $n = 1$. Do not allow other values of n .)

(b) (i) work done = $p\Delta V$
 $= 4.2 \times 10^5 \times (3.87 - 3.49) \times 10^3 \times 10^{-6}$
 $= 160 \text{ J}$

C1
A1 [2](do not allow use of V instead of ΔV)

(ii) increase / change in internal energy = heating of system
+ work done on system
 $= 565 - 160$
 $= 405 \text{ J}$

C1
A1 [2]

- (c) internal energy = sum of kinetic energy and potential energy/ $E_K + E_P$
no intermolecular forces
no potential energy (so $\Delta U = \Delta E_K$)

B1
M1
A1 [3]**Q26.**

- 3 (a) obeys the equation $pV/T = \text{constant}$
(accept $pV = nRT$)

B1 [1]

(b) (i) $pV = nRT$
 $5.0 \times 10^7 \times 3.0 \times 10^{-4} = n \times 8.31 \times 296$ giving $n = 6.1 \text{ mol}$

C1
A1 [2]

(ii) pressure \propto amount of substance
loss = $0.40 / 100 \times 6.1 \text{ mol} = 0.0244 \text{ mol}$
 $= 0.0244 \times 6.02 \times 10^{23} (\text{atoms})$
 $= 1.47 \times 10^{22} \text{ atoms}$

C1
C1
C1

rate = $(1.47 \times 10^{22}) / (35 \times 24 \times 60 \times 60)$
 $= 4.9 \times 10^{15} \text{ s}^{-1}$

A1 [4]

