15. Ideal Gases

15.3 Kinetic theory of gases

Paper 4

Marking Scheme

Q1.

(a)(ii)	no intermolecular forces	**B1**
	(so) potential energy is zero	**B1**
(b)(ii)	$E_K = (3/2)\,kT$	**C1**
	$E_K = (3/2) \times 1.38 \times 10^{-23} \times 290$ $= 6.0 \times 10^{-21}$ J	**A1**

Q2.

(b)(iii)	• (molecular) kinetic energy is proportional to temperature **or** kinetic energy (of molecules) is same in both cylinders • kinetic energy proportional to mass × mean-square speed **or** temperature proportional to mass × mean-square speed **or** r.m.s. speed proportional to √(temperature / mass) • mean-square speed inversely proportional to mass **or** r.m.s. speed inversely proportional to √(mass) *Any two bulleted points, 1 mark each*	**B2**
	r.m.s. speed (of molecules) in X is half r.m.s. speed (of molecules) in Y	**B1**

Q3.

(b)(ii)	line passing through the origin and not returning to either axis	**B1**
	curve with positive decreasing gradient	**B1**

Q4.

(a)	• molecules are in (constant) random motion • (all) collisions between molecules are (perfectly) elastic • no forces between molecules (except during collisions) • volume of molecules is negligible (compared with volume of gas) • collisions involving molecules are instantaneous *Any three points, 1 mark each*	**B3**
(b)	• molecules collide with (walls of) container • momentum of molecule changes during collision (with walls) • change in momentum is caused by force on molecule by wall • molecule experiences force from wall so molecule exerts force on wall • many molecules exerting force across the area of the wall leads to pressure (on the wall) *Any three points, 1 mark each*	**B3**

Q5.

(a)	• particles are in (continuous) random motion • particles have negligible volume (compared with the gas) • negligible forces between particles (except during collisions) • (all) collisions (perfectly) elastic • time of collision negligible (in comparison with time between collisions) *Any two points, 1 mark each*	**B2**

Q6.

(b)(iii)	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	**C1**
	$3.34 \times 10^{-27} \times v^2 = 3 \times 1.38 \times 10^{-23} \times 500$	**C1**
	$v = 2490\ \text{m s}^{-1}$	**A1**
	or	
	$pV = \frac{1}{3}(Nm)\langle c^2\rangle$ and Nm = mass of gas	**(C1)**
	$0.0424 \times v^2 = 3 \times 1.37 \times 10^5 \times 0.640$	**(C1)**
	$v = 2490\ \text{m s}^{-1}$	**(A1)**
(c)	sketch: line from (0, 0) to (500, v)	**B1**
	line with decreasing positive gradient throughout	**B1**

Q7.

(a)(i)	N: number of molecules (of the gas)	**B1**
	m: mass of one molecule (of the gas)	**B1**
	$\langle c^2\rangle$: mean square speed (of molecules)	**B1**
(a)(ii)	$pV = NkT$	**M1**
	$NkT = \frac{1}{3}Nm\langle c^2\rangle$ **and** $E_K = \frac{1}{2}m\langle c^2\rangle$ leading to $E_K = (3/2)\,kT$	**A1**
(b)	$\frac{1}{2} \times 3.34 \times 10^{-27} \times 9300^2 = (3/2) \times 1.38 \times 10^{-23} \times T$	**C1**
	$T = 6980$ K	**A1**
(d)	(very high pressure so) molecules are (very) close together (*not just 'nearer'*)	**B1**
	forces between molecules are not negligible **or** volume of molecules not negligible compared with gas volume	**B1**

Q8.

(d)	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	**C1**
	$3.34 \times 10^{-27} \times \langle c^2\rangle = 3 \times 1.38 \times 10^{-23} \times 400$	**C1**
	$c_{\text{r.m.s.}} = 2200\ \text{m s}^{-1}$	**A1**
(e)	r.m.s. speed is an average so many molecules have speeds greater than the escape speed **or** there is a distribution of molecular speeds (around the r.m.s. value) so many molecules have speeds greater than the escape speed	**B1**

Q9.

(b)	($pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2\rangle$ leading to) $NkT = \frac{1}{3}Nm\langle c^2\rangle$	**M1**
	algebra leading to $(3/2)kT = \frac{1}{2}m\langle c^2\rangle$ **and** use of $\frac{1}{2}m\langle c^2\rangle = E_K$ leading to $(3/2)kT = E_K$	**A1**
(c)(i)	$T = 296$ K	**C1**
	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$ $\frac{1}{2} \times 5.31 \times 10^{-26} \times u^2 = (3/2) \times 1.38 \times 10^{-23} \times 296$	**C1**
	$u = 480\ \text{m s}^{-1}$	**A1**
(c)(ii)	line passing through (P, u)	**B1**
	horizontal straight line	**B1**

Q10.

(b)	speed of molecule decreases on impact with moving piston	**B1**
	mean square speed (directly) proportional to (thermodynamic) temperature **or** mean square speed (directly) proportional to kinetic energy (of molecules) **or** kinetic energy (of molecules) (directly) proportional to (thermodynamic) temperature	**B1**
	kinetic energy (of molecules) decreases (so temperature decreases)	**B1**

Q11.

(b)(ii)	($pV =$) $NkT = \frac{1}{3}Nm\langle c^2\rangle$ **or** $pV = NkT$ **and** $pV = \frac{1}{3}Nm\langle c^2\rangle$	**M1**
	leading to $\frac{1}{2}m\langle c^2\rangle = (3/2)kT$ and $\frac{1}{2}m\langle c^2\rangle = E_K$	**A1**

Q12.

(a)(i)	no loss of kinetic energy	**B1**
(a)(ii)	• molecules have negligible volume (compared with gas/container) • no forces between molecules (except during collisions) • molecules are in random motion • collisions are instantaneous *Any two points, 1 mark each*	**B2**
(b)(i)	$2mu$	**A1**
(b)(ii)	$2L / u$	**A1**
(b)(iii)	force = change in momentum / time = $2mu / (2L / u)$ $= mu^2 / L$	**A1**
(b)(iv)	pressure = force / area = $(mu^2 / L) / L^2$ $= mu^2 / L^3$	**A1**
(c)	$pV = NkT$	**C1**
	$NkT = \frac{1}{3}Nm\langle c^2\rangle$ leading to $\frac{1}{2}m\langle c^2\rangle = (3/2)kT$ and $\frac{1}{2}m\langle c^2\rangle = E_K$	**A1**
(d)	$\frac{1}{2} \times 3.34 \times 10^{-27} \times \langle c^2\rangle = (3/2) \times 1.38 \times 10^{-23} \times (25 + 273)$	**C1**
	r.m.s. speed = 1.9×10^3 m s^{-1}	**A1**

Q13.

(a)	ρ: Nm / V	**B1**
	⅓: molecules move in three dimensions (not one) so ⅓ in any (one) direction	**B1**
	$\langle c^2\rangle$: molecules have different speeds so take average	**M1**
	of (speed)^2	**A1**

Q14.

(a)	(total volume of molecules is) negligible	**M1**
	compared with volume occupied by the gas	**A1**
(b)(ii)	volume of one atom $= d^3$ ($= 2.7 \times 10^{-29}$ m^3)	**C1**
	volume of all atoms $= 2.7 \times 10^{-29} \times 2.7 \times 10^{24}$	**C1**
	$= 7 \times 10^{-5}$ m^3	**A1**
	or	
	volume of one atom $= (4/3)\pi r^3$ ($= 1.41 \times 10^{-29}$ m^3)	**(C1)**
	volume of all atoms $= 2.7 \times 10^{24} \times 1.41 \times 10^{-29}$	**(C1)**
	$= 4 \times 10^{-5}$ m^3	**(A1)**
(c)	numerical comparison between answer to **(b)(ii)** and 2.4×10^{-2} (m^3) showing **(b)(ii)** is <u>much</u> less than 2.4×10^{-2} (m^3)	**B1**

Q15.

(a)(i)	specks of light moving haphazardly	**B1**
(a)(ii)	(gas) molecules collide with (smoke) particles **or** random motion of the (gas) molecules	**M1**
	<u>causes</u> the (haphazard) motion of the smoke particles **or** <u>causes</u> the smoke particles to change direction	**A1**

Q16.

(a)	no intermolecular forces (so no potential energy)	**B1**
(b)(i)	mean square speed (of molecule(s))	**B1**
(c)(i)1.	$pV = NkT$	**C1**
	$4.7 \times 10^{-2} \times 2.6 \times 10^5 = N \times 1.38 \times 10^{-23} \times 446$	**C1**
	or	
	$pV = nRT$ **and** $N = nN_A$ $4.7 \times 10^{-2} \times 2.6 \times 10^5 = n \times 8.31 \times 446$ $n = 3.3$ (mol)	**(C1)**
	$N = 3.3 \times 6.02 \times 10^{23}$	**(C1)**
	$N = 2.0 \times 10^{24}$	**A1**
(c)(i)2.	average increase $= 2900 / (2.0 \times 10^{24})$ $= 1.5 \times 10^{-21}$ J	**A1**
(c)(ii)	$\Delta E_K = (3/2)k(\Delta)T$ $1.5 \times 10^{-21} = (3/2) \times 1.38 \times 10^{-23} \times (\Delta)T$	**C1**
	$(\Delta)T$ in range 70–72 K	**C1**
	$T = 173 + 273 + 70$ $= 520$ K	**A1**

Q17.

(b)(i)	$pV = \frac{1}{3} Nm\langle c^2 \rangle$ **and** $M = Nm$ (and so) $p = \frac{1}{3}\rho\langle c^2 \rangle$	**C1**
	$2.12 \times 10^7 = \frac{1}{3} \times [3.20 / (1.84 \times 10^{-2})] \times \langle c^2 \rangle$	**C1**
	$c_{r.m.s.} = 605\,\text{m s}^{-1}$	**A1**