Mark schemes

1 A **[1]**

2 B **[1]**

3 A **[1]**

4 C **[1]**

5 A **[1]**

6 D **[1]**

7 C **[1]**

8

(a) (i) (use of $n = \frac{pV}{RT}$ gives) $n = \frac{1.0 \times 10^5 \times 1.0}{8.31 \times 300}$ **(1)**

= 40(.1) moles **(1)**

(ii) $n = \frac{2.2 \times 10^4 \times 1.0}{8.31 \times 270}$ = 9.8**(1)** moles **(1)**

3

(b) (total) = (40 × 6 × 10^{23}) − (9.8 × 6 × 10^{23}) = 1.8(1) ×10^{25} **(1)**

(allow C.E. for incorrect values of *n* from (a))

(oxygen molecules) = 0.23 × 1.8 ×10^{25} = 4.2 × 10^{24} **(1)**

2

[5]

9 (a) (i) curve A below original, curve B above original **(1)**

(ii) both curves correct shape **(1)**

2

(b) (i) (use of $pV = nRT$ gives) $130 \times 10^3 \times 0.20 = n \times 8.31 \times 290$ **(1)**

$n = 11$ (mol) **(1)** (10.8 mol)

(ii) (use of $E_k = \frac{3}{2} kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**

$= 6.0 \times 10^{-21}$ J **(1)**

(iii) (no. of molecules) $N = 6.02 \times 10^{23} \times 10.8$ ($= 6.5 \times 10^{24}$)
total k.e. $= 6.5 \times 10^{24} \times 6.0 \times 10^{-21} = 3.9 \times 10^4$ J **(1)**
(allow C.E. for value of n and E_k from (i) and (ii))
(use of $n = 11$ (mol) gives total k.e. $= 3.9$ (7) $\times 10^4$ J)

5

[7]

10

(a) (i) $n = PV/RT = 3.2 \times 10^5 \times 1.9 \times 10^{-3}/8.31 \times 285$

$n = 0.26$ mol ✓ (0.257 mol)

1

(ii) $P_2 = \frac{T_2}{T_1} \times P_1 = \frac{295}{285} \times 3.20 \times 10^5$ ✓

3.31×10^5 Pa ✓(allow $3.30\text{-}3.35 \times 10^5$ Pa)

3 sig figs ✓sig fig mark stands alone even with incorrect answer

3

(b) similar -(rapid) **random** motion

- range of speeds

different - **mean** kinetic energy

- root **mean** square speed

- **frequency** of collisions

2

[6]

11 (a) (i) a collision in which kinetic energy is conserved **(1)**

(ii) molecules of a gas are identical
[or all molecules have the same mass] **(1)**
molecules exert no forces on each other except during impact **(1)**
motion of molecules is random
[or molecules move in random directions] **(1)**

volume of molecules is negligible (compared to volume of container)
[or very small compared to volume of container or point particles] **(1)**
time of collision is negligible (compared to time between collisions) **(1)**
Newton's laws apply **(1)**
large number of particles **(1)** (any two)

3

(b) (i) the hot gas cools and cooler gas heats up
until they are at same temperature
hydrogen molecules transfer energy to oxygen molecules
until **average k.e.** is the same
(any two **(1)** **(1)**)

(ii) (use of $E_k = \frac{3}{2}kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 420$ **(1)**

$= 8.7 \times 10^{-21}$ J (8.69×10^{-21} J)

4

[7]

12 (a) (i) T (=273 + 22) = 295 (K) **(1)**

(ii) $pV = nRT$ **(1)**
$105 \times 10^3 \times 27 = n \times 8.31 \times 295$ **(1)**
n = 1160 (moles) **(1)** (1156 moles)
(allow C.E. for T (in K) from (i)

(iii) $N = 1156 \times 6.02 \times 10^{23} = 7.0 \times 10^{26}$ **(1)** (6.96×10^{26})

5

(b) (i) decreases **(1)**

because temperature depends on mean square speed (or $\overline{c^2}$)
[or depends on mean E_k] **(1)**

(ii) decreases **(1)**
as number of collisions (per second) falls **(1)**
rate of change of momentum decreases **(1)**

[or if using $pV = nRT$
decreases **(1)**
as V constant **(1)**
as n constant **(1)**]

[or if using p = $1/3\rho\overline{c^2}$
decrease **(1)**
as ρ is constant **(1)**
as $\overline{c^2}$ is constant **(1)**]

max 4

[9]

13 (a) (i) $pV = nRT$ **(1)**

(ii) all particles identical or have same mass **(1)**
collisions of gas molecules are elastic **(1)**
inter molecular forces are negligible (except during collisions) **(1)**
volume of molecules is negligible (compared to volume of container) **(1)**
time of collisions is negligible **(1)**
motion of molecules is random **(1)**
large number of molecules present
(therefore statistical analysis applies) **(1)**
monamatic gas **(1)**
Newtonian mechanics applies **(1)**

max 4

(b) $E_k = \frac{3RT}{2N_A}$ or $\frac{3}{2}kT$ **(1)**

$= \frac{3 \times 8.31 \times 293}{2 \times 6.02 \times 10^{23}}$ **(1)**

$= 6.1 \times 10^{-21}$ J **(1)** (6.07×10^{-21} J)

3

(c) masses are different **(1)**
hence because E_k is the same,
mean square speeds must be different **(1)**

2

[9]

14

(a) the number of atoms in 12g of carbon-12
or the number of particles / atoms / molecules in one mole of substance ✓

not – N_A quoted as a number

1

(b) (i) mean kinetic energy (= 3 / 2 *kT*) = 3 / 2 × 1.38 × 10^{-23} × (273 + 22)
= 6.1 × 10^{-21} (J) ✓

6 × 10^{-21} J is not given mark

1

(ii) mass of krypton atom
= 0.084 / 6.02 × 10^{+23} ✓
(= 1.4 × 10^{-25} kg)
$\overline{c^2}$ (= 2 × mean kinetic energy / mass

= 2 × 6.1 × 10^{-21} / 1.4 × 10^{-25})
= 8.7 - 8.8 × 10^4 ✓
$m^2\ s^{-2}$ or J kg^{-1} ✓

1st mark is for the substitution which will normally be seen within a larger calculation.
allow CE from (i)
working must be shown for a CE otherwise full marks can be given for correct answer only
no calculation marks if mass has a physics error i.e. no division by N_A note for CE
answer = (i) × 1.43 × 10^{25}

3

(c) (at the same temperature) the mean kinetic energy is the same
or

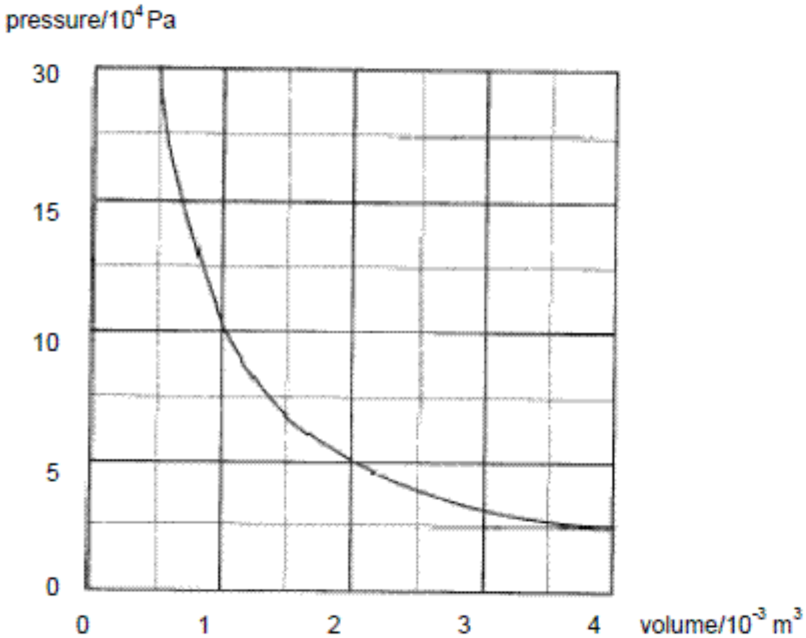
gases have equal $\frac{1}{2}mc_{rms}^2$
or
mass is inversely proportional to mean square speed / m ∝ 1 $/\overline{c^2}$ ✓
$\overline{c^2}$ or mean square speed of krypton is less ✓

1st mark requires the word <u>mean / average</u> or equivalent in an algebraic term
2nd mark 'It' will be taken to mean krypton. So, 'It is less' can gain a mark
allow 'heavier' to mean more massive'
allow vague statements like speed is less for 2nd mark but not in the first mark

2

[7]

15 (a)



3

curve with decreasing negative gradient that passes through the given point which does not touch the *x* axis **(1)**

designated points	
pressure/10^4 Pa	volume/10^{-3} m^3
10	1.0
5.0	2.0
4.0	2.5
2.5	4.0

2 of the designated points **(1)(1)** (one mark each)

(b) (i) $N = PV/kT = 5 \times 10^4 \times 2 \times 10^{-3}/1.38 \times 10^{-23} \times 290$ **(1)**

[or alternative use of $PV = nRT$
$5 \times 10^4 \times 2.0 \times 10^{-3}/8.31 \times 290 = 0.0415$ moles]
$= 2.50 \times 10^{22}$ molecules **(1)**

2

(ii) (mean) kinetic energy of a molecule

$= \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)** (= 6.00×10^{-21} J)

(total kinetic energy = mean kinetic energy × *N*)

= $6.00 \times 10^{-21} \times 2.50 \times 10^{22}$ **(1)**

= 150 (J) **(1)**

3

(c) all molecules/atoms are identical

molecules/atoms are in random motion

Newtonian mechanics apply

gas contains a large number of molecules

the volume of gas molecules is negligible (compared to the volume occupied by the gas) or reference to point masses

no force act between molecules except during collisions or the speed/velocity is constant between collisions or motion is in a straight line between collisions

collisions are elastic or **kinetic** energy is conserved

and of negligible duration

any 4 ***(1)(1)(1)(1)***

max 4

[12]

16 (a) molecules have negligible volume
collisions are elastic
the gas cannot be liquified
there are no interactions between molecules (except during collisions)
the gas obeys the (ideal) gas law / obeys Boyles law etc.
at all temperatures/pressures
any two lines ✓ ✓

a gas laws may be given as a formula

2

(b) (i) *n (= PV / RT)* = $1.60 \times 10^{6} \times 0.200 / (8.31 \times (273 + 22))$ ✓
= 130 or 131 mol ✓ (130.5 mol)

2

(ii) mass = 130.5 × 0.043 = 5.6 (kg) ✓
(5.61kg)

allow ecf from bi

density (= mass / volume) = 5.61 / 0.200 = 28 ✓ (28.1 kg m^{-3})
kg m^{-3} ✓

a numerical answer without working can gain the first two marks

3

(iii) *($V_2 = P_1 V_1 T_2 / P_2 T_1$)*
V_2 = 1.6 × 10^6 × .200 × (273 – 50) / 3.6 × 10^4 × (273 + 22) or 6.7(2) (m^3) ✓

allow ecf from bii

[reminder must see bii]
look out for

mass remaining = 5.61 × 0.20 / 6.72 = 0.17 (kg) ✓ (0.167 kg)
or
n = (PV / RT = 3.6 × 10^4 × 0.200 / (8.31 × (273 − 50)) = 3.88(5) (mol) ✓

mass remaining = 3.885 × 4.3 × 10^{-2} = 0.17 (kg) ✓
2 sig figs ✓

any 2 sf answer gets the mark

3
[10]

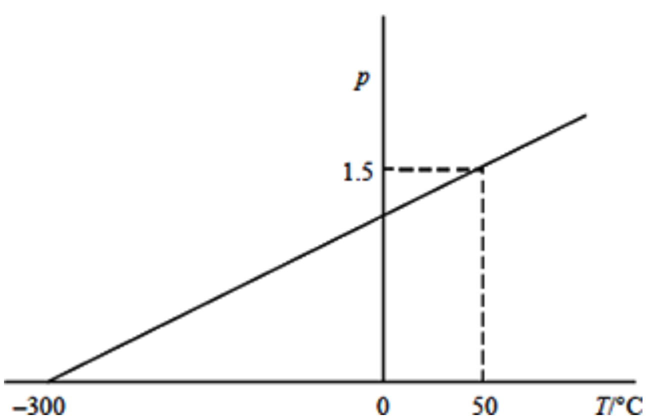
17

(a) $n\left(=\frac{pV}{RT}\right)=\frac{1.5\times10^5\times1.2\times10^{-5}}{8.31\times323}$ **(1)** = (6.71 × 10^4 mol)

number of molecules = nN_A **(1)** = 6.71 × 10^{-4} × 6.02 × 10^{23}
= 4.04 × 10^{20} **(1)**
[or equivalent solution using $pv = NkT$]

(3)

(b)



straight line with positive gradient **(1)**
through (50, 1.5) **(1)**
crosses temperature axis between –250 and –300°C **(1)**

(3)

(c) number of moles left in container after valve opens

$$n\left(=\frac{pV}{RT}\right) = \frac{2.0 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 573}$$ **(1)** (= 5.04×10^{-4} mol)

∴ number of molecules left in container = $5.04 \times 10^{-4} \times 6.02 \times 10^{23}$
= 3.03×10^{20} **(1)**

∴ number of molecules that escape = $4.04 \times 10^{20} - 3.03 \times 10^{20}$
= 1.01×10^{20} **(1)**

[*alternative (c)*
∴ number of moles that escape (= $6.71 \times 10^{-4} - 5.04 \times 10^{-4}$)
= 1.67×10^{-4}
∴ number of molecules that escape = $1.67 \times 10^{-4} \times N_A$
= 1.01×10^{20} **(1)**]

(3)

[9]

18 (a) number of molecules in a gas is very large
duration of collision much less than time between collisions
total volume of molecules small compared with gas volume
molecules are in random motion
collisions are (perfectly) elastic
there are no forces between molecules (any four) **(4)**

(any 4)

(b) (i) heat (energy) transferred to gas from warmer air outside
mean kinetic energy of gas molecules increases
or molecules move faster
momentum of molecules increases
more collisions per second
each collision (with container walls) transfers more momentum
force (per unit area) on container wall increases (any four) **(4)**

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part.

(ii) $T = 273 + 27 = 300$K **(1)**

mean kinetic energy = $\frac{3}{2}kT$

= $1.5 \times 1.38 \times 10^{-23} \times 300 = 6.2 \times 10^{-21}$ J **(1)**

(allow e.c.f. for incorrect T)

(6)

[10]

19 (a) (i) Use of $V = \pi r^2 L$

3.47×10^{-2} or 3.5×10^{-2} (m)

Sub including V and L (condone L=18)

Or rearrangement to make r subject of correct equation

Condone power 10 error on L

1 mark for following answers

1.7×10^{-2}, 1.7×10^{-3}, 3.5×10^{-3} (m)

2

(ii) Use of $pV = NkT$ or $T = 19 + 273$ or $T = 292$ seen

Allow rearrangement making N subject $N = \frac{pV}{kT}$

Correct use of $pV = NkT$ substitution

4.26×10^{21} seen or 4.3×10^{21} seen

Condone sub of 19 for T for 1st mark in either method

Or (N =) $\frac{1.01 \times 10^5 \times 1.7 \times 10^{-4}}{1.38 \times 10^{-23} \times 292}$ seen with $pV = NkT$ seen

*Alternative use of $pV = nRT$ **and** $N = nN_A$ in first and second marks*

First mark condone $T = 19$

Second mark $pV = nRT$ seen with use of and $7(.08) \times 10^{-3} \times 6(.02) \times 10^{23}$ seen

3

(iii) (NV=)$1.7 \times 10^{-4} \times 7 \times 10^{-4}$ or 1.19×10^{-7} seen

2.76×10^{-29} to 3.0×10^{-29} (m3) condone 1 sf here

Penalise where product does not equal 1.19×10^{-7}

2

(iv)

- the volume of molecule(s) is negligible **compared to** volume occupied by gas
- the particles are far apart / large spaces between particles (compared to their diameter)
- **Therefore** Time during collisions is negligible compared to time between collision
- **Therefore** intermolecular forces are negligible

Allow volume of one molecule is negligible compared to total volume

Max 3

(b) Use of ½ $m\langle c^2\rangle = 3/2\ kT$ sub or rearrangement
Condone c_{rms} as subject for 1 mark
Condone power 10 error
Condone T = 19 in 1st MP
Correct sub with $\langle c^2\rangle$ as subject including correct power 10
2.57×10^5 or 2.6×10^5 (on answer line)
m2 s^{-2}

Alternatively:

use of pV=1/3 $Nm\langle c^2\rangle$ sub or rearrangement

Condone c_{rms} as subject for 1 mark

Condone power 10 error

Condone T = 19 in 1st MP

Correct sub with $\langle c^2\rangle$ as subject including correct power 10

2.7(4) × 10^5 (from N = 4 × 10^{21}) (on answer line)

2.57×10^5 for N = 4.26×10^{21}

2.5(48) × 10^5 for N = 4.3×10^{21}

$m^2\ s^{-2}$

condone alternative units where correct:

Pa $m^3\ kg^{-1}$

J kg^{-1}

4

(c) (i) $p_1L_1 = k_1$ and $p_2L_2 = k_2$

(consistent power 10)

i.e. 2 sets of **correct** data
seen in sub
allow incomplete sub with 2
similar k (18×10^3) values seen

$p_1L_1 = k_1$, $p_2L_2 = k_2$ and $p_3L_3 = k_3$

(consistent power 10)

i.e. 3 sets of **correct data**
seen in sub

Comparison of k values followed by conclusion

Presents a factorial of L leading to an inverse of the factorial change in P (correct data)

*Repeats this process for **second** data set for same factorial change (correct data)*

***States** the relationship seen and **states** the conclusion*

3

(ii) Temperature or internal energy

Allow mass / number of particles / mean square speed (of molecules)

1

(d) L decreases then volume decreases (therefore more particles in any given volume) / V = πr^2 L / V is (directly) proportional to L

Decreased volume Increases number of collisions (with walls every second)

Decreased volume causes <u>Rate of change</u> of momentum to increase

Increased <u>rate of change</u> of momentum causes <u>force</u> (exerted on walls) to <u>increase</u> (causing an increase in pressure)

Allow converse argument but must be consistent

$p = \frac{\frac{1}{3} Nm\overline{c^2}}{\pi r^2 L}$, *or equivalent*

must be correct equation with V in terms of L

with p as subject

4

[22]

20 (a) The molecules (continually) move about in random motion✓

Collisions of molecules with each other and with the walls are elastic✓

Time in contact is small compared with time between collisions✓

The molecules move in straight lines between collisions✓

ANY TWO

Allow reference to 'particles interact according to Newtonian mechanics'

2

(b) Ideas of pressure = F / A and F = rate of change of momentum✓

Mean KE / rms speed / mean speed of air molecules increases✓

More collisions with the inside surface of the football each second✓

Allow reference to 'Greater change in momentum for each collision'

3

(c) Radius = 690 mm / 6.28) = 110 mm or T = 290 K ✓ seen

volume of air = 5.55×10^{-3} m^3✓

$n \times 29$(g) = 11.4 (g)✓ n = 0.392 mol

Use of $pV = nRT = \frac{0.392 \times 8.31 \times 290}{5.55 \times 10^{-3} \text{ m}^3}$ ✓

$p = 1.70 \times 10^5$ Pa ✓

Conclusion: Appropriate comparison of their value for p with the requirement of the rule, ie whether their pressure above 1×10^5 Pa falls within the required band✓

Allow ecf for their n V and T✓

6

[11]

21 (a) (i) $PV = NkT$ **(1)**

223×10^5 Pa **(1)**

2

(ii) pV = const or repeat calculation from (i) **(1)**

3.5×10^{-3} m^3 **(1)**

2

(iii) kinetic energy = 3/2 kT **(1)**

$5.9(0) \times 10^{-21}$ J **(1)**

2

(b) (i) volume increase **(1)**)
time between collisions increases **(1)**)
speed constant as temp constant **(1)**)
rate of change of momentum decreases **(1)**)

max 3

(ii) volume smaller in cylinder **(1)**

molecules occupy significantly greater proportion of the volume **(1)**

molecules closer so intermolecular forces greater **(1)**

3

(c) internal energy stays the same **(1)**

gas does work in expanding so W is negative **(1)**

gas must be heated to make U positive **(1)**

U and W equal and opposite **(1)**

4

[16]

22 (a) (i) $pV = nRT$ **(1)**

$V = \frac{15 \times 8.13 \times 290}{500 \times 10^3}$ **(1)** (gives $V = 7.2 \times 10^{-2} m^3$)

(ii) (use of $E_k = \frac{3}{2}kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**

$= 6.0 \times 10^{-21}$ (J) **(1)**

4

(b) (use of $pV = nRT$ gives) $n = \frac{420 \times 10^3 \times 7.2 \times 10^{-2}}{8.31 \times 290}$ **(1)**
[or use $p \propto n$]

$n = 13$ moles **(1)** (12.5 moles)

2

(c) pressure is due to molecular bombardment [or moving molecules] **(1)**
when gas is removed there are fewer molecules in the cylinder
[or density decreases] **(1)**

(rate of) bombardment decreases **(1)**
molecules exert forces on wall **(1)**

$\overline{c^2}$ is constant **(1)**

[or $pV = \frac{1}{3} Nm (c^2)$ **(1)**

V and m constant **(1)**

(c^2) constant since T constant **(1)**

$p \propto N$ **(1)**]

[or $p = \frac{1}{3}$ p(c^2) **(1)**

explanation of ρ decreasing **(1)**

(c^2) constant since T constant **(1)**

p (c^2) ρ **(1)**]

max 4

[10]

23 (a) (i) pV / T = constant in any form

C1

correct substitution including absolute temperatures / 345K

C1

72°C **not** 345K
condone no unit and condone just °

A1

(3)

(ii) $pV = nRT$

C1

correct substitution: $n = \frac{1.9 \times 10^5 \times 5.8 \times 10^{-5}}{8.3 \times 345}$ **or** $\frac{1.91 \times 10^5 \times 8.5 \times 10^{-5}}{8.3 \times 345}$

C1

3.8(5) × 10^{-3} (mol) **or** 3.8(4) × 10^{-3} (mol)

A1

e.c.f. for their (i)

(3)

(iii) $pV = \frac{1}{3} Nm<c^2$ **or** $p = \frac{1}{3} \rho<c^2$

C1

3.0 × 10^5 m^2 s^{-2} condone subsequent calculation of rms speed

A1

(2)

(iv) no heat transfer / $\Delta Q = 0$ / no energy loss

B1

process too quick (for conduction to take place) /
glass is poor (thermal) conductor / the system is isolated

B1

(2)

(v) molecules move faster / have more KE

B1

greater number of collisions (per second) (between molecules and wall)
not between molecules

B1

greater (rate of) change in momentum in each collision

B1

(3)

(b) (i) anticlockwise arrows correctly labelled - both arrows needed

B1

(3)

(ii) work done **on** the gas (during compression)

B1

(1)

[15]

24 (a) (i) correct p and V from graph **(1)**

$n = \frac{8.0 \times 10^4 \times 2.00 \times 10^{-3}}{8.31 \times 300}$ **(1)** (= 0.0064 mol)

(ii) $V_2 = V_1 \frac{T_2}{T_1}$ = 3.3 × 10^{-3} m^3 **(1)**

(3)

(b) (i) $\frac{3}{2}$ RT or $\frac{3}{2}$ $N_A kT$ **(1)**

(ii) total kinetic energy $\left(=\frac{3}{2}nRT\right)$ = 1.5 × 8.3 × 0.064 × 300 **(1)** = 239 J **(1)**

molecules have no potential energy **(1)**
no attractive forces [or elastic collisions occur] **(1)**

(max 4)

(c) ΔQ = heat entering (or leaving) gas

ΔU = change (or increase) in internal energy

ΔW = work done

[**(1) (1)** for three definitions, deduct one for each incorrect or missing]

(i) $\Delta Q = \Delta U$ **(1)**
temperature rises but no work done **(1)**

(ii) $\Delta Q = \Delta U + \Delta W$ **(1)**
temperature rises and work done in expanding **(1)**

(max 5)

(d) (i) $\Delta U = \frac{3}{2} nR(500 - 300)$ = 159 J **(1)** (= ΔQ)

(ii) $p\Delta V = 8.0 \times 10^4 \times (3.3 - 2.0) \times 10^{-3}$ = 104 J **(1)**
$\therefore \Delta Q = \Delta U + p\Delta V$ = 263 J **(1)**

(3)

[15]

25 (a) (i) they would collide with atoms of gas

M1

losing energy by:
ionising the gas

A1

exciting gas molecules

A1

allow 1 for stating inelastic collisions

(3)

(ii) $pV = nRT$

C1

$n = 2.8 \times 10^{-6}$

A1

(2)

(iii) 1.7×10^{18} B1

(their (ii) $\times 6.0 \times 10^{23}$) (1)

(b) (i) energy $\frac{1}{2}mv^2 = 3.3 \times 10^{-16}$ J B1 (1)

(ii) 1 volt = 1 Joule per coulomb C1

or p.d. = energy gained by electron / charge on electron

2070 V or 2100 V A1 (2)

(iii) number of electrons = current / e C1

3.1×10^{16} A1 (2)

(iv) it produces heating of the mica B1

it causes (rotation) kinetic energy of the mica paddle B1 (2)

(v) force = change in momentum per second C1

change in momentum per collision = 2.46×10^{-23} (N s) C1

force = their (iii) × their momentum (7.6×10^{-7} N) A1 (3)

(vi) moment = force × perpendicular distance C1

1.9×10^{-8} N m A1 (2)

[18]