A-Level Physics

Molecular Kinetic Theory

Mark Scheme

Time available: 64 minutes
Marks available: 60 marks

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Mark schemes

1. (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 × 29(g) = 11.4 (g)✓ n = 0.392 mol

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

$p = 1.70 \times 10^5$ 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]

2. (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 $m\langle c^2 \rangle = 3/2\ k$T 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

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

2.57×10^5 for $N = 4.26 \times 10^{21}$

$2.5(48) \times 10^5$ for $N = 4.3 \times 10^{21}$

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

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 Rate of change of momentum to increase
Increased rate of change of momentum causes force (exerted on walls) to increase (causing an increase in pressure)

Allow converse argument but must be consistent

$p = \frac{\frac{1}{3} N m \overline{c^2}}{\pi r2 \text{ L}}$, *or equivalent*

must be correct equation with V in terms of L

with p as subject

4

[22]

3. (a) The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).

High Level − Good to Excellent
An experiment with results and interpretation must be given leading to the measurement of absolute zero. The student refers to 5 or 6 points given below. However each individual point must stand alone and be clear.*The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*

6 clear points = 6 marks

5 clear points = 5 marks

5-6

Intermediate Level − Modest to Adequate
An experiment must be given and appropriate measurements must be suggested. For 3 marks the type of results expected must be given. 4 marks can only be obtained if the method of obtaining absolute zero is given.*The grammar and spelling may have a few shortcomings but the ideas must be clear.*

4 clear points = 4 marks

3 clear points = 3 marks

3-4

Low Level − Poor to Limited
One mark may be given for any of the six points given below. For 2 marks an experiment must be chosen and some appropriate results suggested even if the details are vague. Any 2 of the six points can be given to get the marks.
There may be many grammatical and spelling errors and the information may be poorly organised.

2 clear points = 2 marks

Any one point = 1 mark

1-2

The description expected in a competent answer should include:
1. Constant mass of gas (may come from the experiment if it is clear that the gas is trapped) <u>and</u> constant volume (or constant pressure).

For (point 1) amount / quantity / moles of gas is acceptable.

2. Record pressure (or volume) for a range of temperatures.(the experiment must involve changing the temperature with pressure or volume being the dependent variable).

For (point 2) no specific details of the apparatus are needed. Also the temperature recording may not be explicitly stated eg. record the pressure at different temperatures is condoned.

3. How the temperature is maintained / changed / controlled. (The gas must be heated uniformly by a temperature bath or oven − so not an electric fire or lamp).

4. Describe or show a graph of pressure against temperature (or volume against temperature) that is linear. The linear relationship may come from a diagram / graph or a reference to the Pressure Law or Charles' Law line of best fit is continued on implies a linear graph).

5. Use the results in a graph of pressure against temperature (or volume against temperature) which can be extrapolated to lower temperatures which has zero pressure (or volume) at absolute zero, <u>which is at 0 K or −273 °C</u> (a reference to crossing the temperature axis implies zero pressure or volume).

For (points 4 and 5) the graphs referred to can use a different variable to pressure or volume but its relationship to V or P <u>must</u> be explicit.

In (point 5) the graph can be described or drawn.

6. Absolute zero is obtained using any gas (provided it is ideal or not at high pressures or close to liquification)
Or Absolute temperature is the temperature at which the volume (or pressure or mean kinetic energy of molecules) is zero / or when the particles are not moving.

Discount any points that are vague or unclear

(Second part of point 6) must be stated not just implied from a graph.

(b) (i)
- The motion of molecules is random.
- Collisions between molecules (or molecules and the wall of the container) are elastic.
- The time taken for a collision is negligible (compared to the time between collisions).
- Newtonian mechanics apply (or the motion is non-relativistic).
- The effect of gravity is ignored or molecules move in straight lines (at constant speed) between collisions.

✓✓ any two

If more than 2 answers are given each wrong statement cancels a correct mark.

2

(ii) **Escalate if the numbers used are 4000, 5000 and 6000 giving 25666666 or similar.**

mean square speed
(= $(2000^2 + 3000^2 + 7000^2) / 3$ =
20.7×10^6)
= 2.1×10^7 ($m^2\ s^{-2}$)

Common correct answers

20.7×10^6

21×10^6

2.07×10^7

2.1×10^7

20 700 000

21 000 000.

***Possible escalation**.*

1

(c) **Escalate if the question and answer line requires a volume instead of a temperature.**

(using meanKE = $3RT / 2N_A$)
$T = 2N_A \times$ meanKE / $3R$
$=2 \times 6.02 \times 10^{23} \times 6.6 \times 10^{-21} / 3 \times 8.31$ ✓
= 320 (K) ✓ (318.8 K)
Or
(meanKE = $3kT / 2$)
$T = 2 \times$ meanKE / $3k$
$=2 \times 6.6 \times 10^{-21} / 3 \times 1.38 \times 10^{-23}$ ✓
= 320 (K) ✓ (318.8 K)

First mark for substitution into an equation.

Second mark for answer

***Possible escalation**.*

Answer only can gain 2 marks.

2

[11]

4.

(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]

5. (a) (i) $p\ V = nR\ T$ **(1)**

$V = \frac{15 \times 8.31 \times 290}{500 \times 10^3}$ **(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]