3.2
One tricky question + explanations
Two ideal gases are kept at the same temperature in two containers separated by a valve, as shown in the diagram. Estimate the pressure when the valve is opened. (The temperature stays the same.)
23. Two ideal gases are kept at the same temperature in two containers separated by a valve, as shown in the diagram. Estimate the pressure when the valve is opened. (The temperature stays the same.)

Let there be \( n_1 \) moles of the gas in the left container and \( n_2 \) in the right. Then it must be true \( (\text{using } n = \frac{PV}{RT}) \) that

\[
n_1 = \frac{12 \times 10^5 \times 6.0 \times 10^{-3}}{RT} \quad \text{and} \quad n_2 = \frac{6.0 \times 10^5 \times 3.0 \times 10^{-3}}{RT}.
\]

When the gases mix we will have \( n_1 + n_2 \) moles in a volume of 9.0 dm\(^3\) and so

\[
n_1 + n_2 = \frac{P \times 9.0 \times 10^{-3}}{RT}.
\]

Hence

\[
\frac{12 \times 10^5 \times 6.0 \times 10^{-3}}{RT} + \frac{6.0 \times 10^5 \times 3.0 \times 10^{-3}}{RT} = \frac{P \times 9.0 \times 10^{-3}}{RT}.
\]

This means that

\[
P = \frac{12 \times 10^5 \times 6.0 + 6.0 \times 10^5 \times 3.0}{9.0} = 10 \times 10^5 \text{ Pa} = 10 \text{ atm}.
\]
A container of volume $3.2 \times 10^{-6}$ m$^3$ is filled with helium gas at a pressure of $5.1 \times 10^5$ Pa and temperature 320 K. Assume that this sample of helium gas behaves as an ideal gas.

1a. The mass of a helium atom is $6.6 \times 10^{-27}$ kg. Estimate the average speed of the helium atoms in the container. \[ \frac{1}{2} m v^2 = \frac{3}{2} k T / n = \sqrt{\frac{3 k T}{m}} \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 320}{6.6 \times 10^{-27}}} \] \[ v = 1.4 \times 10^3 \text{ms}^{-1} \]

1b. Show that the number of helium atoms in the container is $4 \times 10^{20}$. \[ N = \frac{p V}{k T} / \frac{5.1 \times 10^5 \times 3.2 \times 10^{-6}}{1.38 \times 10^{-23} \times 320} \] \[ OR \]
\[ N = \frac{p V N_A}{R T} / \frac{5.1 \times 10^5 \times 3.2 \times 10^{-6} \times 6.02 \times 10^{23}}{8.31 \times 320} \]
\[ N = 3.7 \times 10^{20} \]

A helium atom has a volume of $4.9 \times 10^{-31}$ m$^3$.

1c. Calculate the ratio \[ \frac{\text{volume of helium atoms}}{\text{volume of helium gas}} \]. \[ \frac{4 \times 10^{20} \times 4.9 \times 10^{-31}}{3.2 \times 10^{-6}} = 6 \times 10^{-5} \]
1d. Discuss, by reference to the kinetic model of an ideal gas and the answer to (c)(i), whether the assumption that helium behaves as an ideal gas is justified.

«For an ideal gas» the size of the particles is small compared to the distance between them/size of the container/gas

OR

«For an ideal gas» the volume of the particles is negligible/the volume of the particles is small compared to the volume of the container/gas

OR

«For an ideal gas» particles are assumed to be point objects

calculation/ratio/result in (c)(i) shows that volume of helium atoms is negligible compared to/much smaller than volume of helium gas/container
«hence assumption is justified»
An ideal monatomic gas is kept in a container of volume $2.1 \times 10^{-4} \text{ m}^3$, temperature $310 \text{ K}$ and pressure $5.3 \times 10^5 \text{ Pa}$.

2a. State what is meant by an ideal gas.

<table>
<thead>
<tr>
<th>a gas in which there are no intermolecular forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
</tr>
<tr>
<td>a gas that obeys the ideal gas law/all gas laws at all pressures, volumes and temperatures</td>
</tr>
<tr>
<td>OR</td>
</tr>
<tr>
<td>molecules have zero PE/only KE</td>
</tr>
</tbody>
</table>

Accept atoms/particles.

2b. Calculate the number of atoms in the gas.

$$N = \frac{pV}{kT} = \frac{5.3 \times 10^5 \times 2.1 \times 10^{-4}}{1.38 \times 10^{-23} \times 310} \approx 2.6 \times 10^{22}$$

2c. Calculate, in J, the internal energy of the gas.

For one atom $U = \frac{3}{2} kT \times \frac{3}{2} \times 1.38 \times 10^{-23} \times 310 / 6.4 \times 10^{-21} \approx 170 \text{ J}$

$U = 2.6 \times 10^{22} \times \frac{3}{2} \times 1.38 \times 10^{-23} \times 310 \approx 170 \text{ J}$

Allow ECF from (a)(ii)

Award [2] for a bald correct answer

Allow use of $U = \frac{3}{2} pV$

[2 marks]
2d. Calculate, in Pa, the new pressure of the gas.

\[ p_2 = 5.3 \times 10^5 \times \frac{2.1\times10^{-4}}{6.8\times10^{-4}} = 1.6 \times 10^5 \text{ Pa} \]

[1 mark]

2e. Explain, in terms of molecular motion, this change in pressure. [2 marks]

«volume has increased and» average velocity/KE remains unchanged
«so» molecules collide with the walls less frequently/longer time between collisions with the walls
«hence» rate of change of momentum at wall has decreased
«and so pressure has decreased»

The idea of average must be included
Decrease in number of collisions is not sufficient for MP2. Time must be included.
Accept atoms/particles.
A closed box of fixed volume 0.15 m³ contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

3a. Calculate the pressure of the gas. 

\[
\text{Pressure} = \frac{3.0 \times 8.31 \times 290}{0.15} \approx 48 \text{ kPa}
\]

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg⁻¹ K⁻¹.

3b. Calculate, in kg, the mass of the gas. 

\[
\text{Mass} = \frac{860}{3100 \times 23} \approx 0.012 \text{ kg}
\]

3c. Calculate the average kinetic energy of the particles of the gas. 

\[
\frac{3}{2} \times 1.38 \times 10^{-23} \times 313 = 6.5 \times 10^{-21} \text{ J}
\]

3d. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. 

[3 marks]
3d. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure.

- Larger temperature implies larger (average) speed/larger (average) KE of molecules/particles/atoms
- Increased force/momentum transferred to walls (per collision) / more frequent collisions with walls
- Increased force leads to increased pressure because $P = \frac{F}{A}$ (as area remains constant)

*Ignore any mention of $PV = nRT$.*/