# Unit 13 · Ideal Gas

**HARDER PRACTICE QUESTIONS · ANSWER KEY**

Full marks 28

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

## 1 Spot the error

**ANSWER** U · 3

Charles's law, V ∝ T, uses the **absolute** temperature: 20 °C is 293 K and 40 °C is 313 K, a rise of under 7%, not a doubling.

$V_2 = 2.0 \times 313 \div 293 =$ **2.14 L**.

**MARKING SCHEME**

- ✓ The mistake: Celsius temperatures used in V ∝ T.
- ✓ $T_1 = 293$ K, $T_2 = 313$ K.
- ✓ $V_2 = 2.14$ L.

## 2 Read the data

**ANSWER** A · 4

i. $\gamma_V = \dfrac{P_\theta - P_0}{P_0 \theta} = \dfrac{109.3 - 80.0}{80.0 \times 100} =$ **$3.66 \times 10^{-3}$ K$^{-1}$**.

ii. $1/273.15 = 3.66 \times 10^{-3}$ K$^{-1}$: the same. Every gas has this pressure coefficient, whatever it is.

iii. $P = P_0(1 + \gamma_V\theta) = 0$ when $\theta = -1/\gamma_V =$ **−273 °C**, absolute zero.

**MARKING SCHEME**

- ✓ $\gamma_V = (P - P_0)/(P_0\theta)$.
- ✓ $3.66 \times 10^{-3}$ K$^{-1}$.
- ✓ Equal to 1/273.15: the same for all gases.
- ✓ Zero pressure at −273 °C.

## 3 Show that

**ANSWER** A · 3

For the two gases: $PV = \frac{1}{3} N_1 m_1 {c_1}^2$ and $PV = \frac{1}{3} N_2 m_2 {c_2}^2$, with the same P and V, so

$N_1 \cdot \frac{1}{2} m_1 {c_1}^2 = N_2 \cdot \frac{1}{2} m_2 {c_2}^2$.

At the same temperature the average kinetic energy per molecule is the same:

$\frac{1}{2} m_1 {c_1}^2 = \frac{1}{2} m_2 {c_2}^2 = \frac{3}{2} k_B T$.

So $N_1 = N_2$.

**MARKING SCHEME**

- ✓ PV = ⅓Nmc² written for both, equated.
- ✓ Same T means the same ½mc² per molecule.
- ✓ So $N_1 = N_2$.

## 4 Estimate it

**ANSWER** A · 3

$V = 10 \times 8 \times 3 = 240$ m³. From $PV = Nk_B T$:

$N = PV/(k_B T) = 1.0 \times 10^5 \times 240 \div (1.38 \times 10^{-23} \times 300) \approx$ **$5.8 \times 10^{27}$** molecules.

**MARKING SCHEME**

- ✓ V = 240 m³ and T = 300 K.
- ✓ $N = PV/(k_B T)$.
- ✓ About $5.8 \times 10^{27}$.



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## 5 Why the Moon has no air

**ANSWER** HA · 4

i. $crms = \sqrt{3RT/M}$, so $T = \dfrac{c^2 M}{3R} = \dfrac{2400^2 \times 0.0040}{3 \times 8.31} \approx$ **924 K**.

ii. The rms speed is only an average: the molecules' speeds are spread out from nearly zero to several times the rms speed. Some atoms always move faster than 2.4 km/s, and over millions of years these escape one by one, and collisions keep giving new atoms high speeds.

**MARKING SCHEME**

- ✓ $T = c^2M/(3R)$.
- ✓ About 924 K.
- ✓ Speeds are spread out: some atoms are much faster than the rms speed.
- ✓ Those escape, and over a long time the gas is lost.

## 6 Predict, then explain

**ANSWER** HA · 3

i. **No.**

ii. Temperature measures the average kinetic energy of the molecules' **random** motion, relative to the gas as a whole. Moving the whole tank adds the same velocity to every molecule, an ordered motion that doesn't change how fast they move about relative to each other. So the random motion, and the temperature, stay the same.

**MARKING SCHEME**

- ✓ No change.
- ✓ Temperature measures the random motion of the molecules, relative to the gas.
- ✓ The train's velocity is ordered motion shared by all molecules, so it adds nothing to the temperature.

## 7 Correct the misconceptions

**ANSWER** U · 3

1. At 0 °C (273 K) gas molecules move fast, hundreds of metres a second; only at absolute zero would they have their least possible energy.
2. At the same temperature every molecule has the same average kinetic energy, $(3/2)k_B T$; heavier ones simply move more slowly.
3. $P \propto T$ in **kelvin**: 283 K to 293 K raises the pressure by only about 3.5%.

**MARKING SCHEME**

- ✓ The molecules move at 0 °C; the least energy is at 0 K.
- ✓ The same average KE at the same temperature, whatever the mass.
- ✓ $P \propto T$ in kelvin, so only about 3.5% more.

## 8 Think

**ANSWER** HA · 3

i. **The same**: by Avogadro's law, equal volumes at the same T and P hold equal numbers of molecules.

ii. Nitrogen's mass is **7 times** helium's: the same number of molecules, each 28/4 = 7 times as heavy.

iii. Helium's rms speed is $\sqrt{7} \approx$ **2.6 times** nitrogen's: $c_{rms} \propto 1/\sqrt{M}$ at the same temperature.

**MARKING SCHEME**

- ✓ Equal numbers of molecules.
- ✓ Nitrogen 7 times the mass.
- ✓ Helium $\sqrt{7} \approx 2.6$ times as fast.



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## 9 Make your own

HA · 2

**ANSWER**

For example helium, M = 0.004 kg/mol: $T = c^2M/(3R) = 1000^2 \times 0.004 \div (3 \times 8.31) \approx$ **160 K**. Check: $\sqrt{(3 \times 8.31 \times 160 \div 0.004)} \approx 1000$ m/s. (Any gas: $T = c^2M/(3R)$.)

**MARKING SCHEME**

- ✓ $T = c^2M/(3R)$ with M in kg/mol.
- ✓ A temperature found and checked.

| Marks by level | Knowledge | Understanding | Application | Higher ability | Total |
|---|---|---|---|---|---|
| **Marks** | 0 | 6 | 10 | 12 | **28** |



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