Unit 7 · Gas Laws

ANSWER KEY · FOR TEACHERS

Full marks 45

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

1 Key words

1. absolute zero → **d.** −273 °C, the start of the kelvin scale
2. STP → **g.** 0 °C and 760 mmHg
3. molar volume → **f.** 22.4 L at STP
4. ideal gas → **b.** obeys the gas laws exactly; a model that doesn't exist
5. diffusion → **a.** a gas spreading by the random motion of its molecules
6. effusion → **e.** a gas leaking molecule by molecule through a tiny hole

Each carries 0.5 mark. K · 3

2 Label the diagram

1. cotton wool soaked in ammonia solution
2. white ring of ammonium chloride
3. NH_3 (M = 17)
4. 59.4 cm
5. cotton wool soaked in conc. hydrochloric acid
6. 40.6 cm

Each carries 0.5 mark. U · 3

3 Multiple choice

i. **b.** a straight line through the origin — U · 1

By Boyle's law, $P = k \times \frac{1}{V}$: P is directly proportional to $\frac{1}{V}$, and a direct proportion plots as a straight line through the origin. Against V itself, the graph would be a falling curve.

ii. **b.** $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ — K · 1

For a fixed mass of gas, $\frac{PV}{T}$ stays constant, since $V \propto \frac{1}{P}$ (Boyle) and $V \propto T$ (Charles).

iii. **c.** the volume of the gas molecules is negligible compared with the volume of the container — K · 1

The kinetic theory assumes the molecules are so small that their own volume can be ignored, that they don't attract each other, that collisions are perfectly elastic and that they are always moving.

iv. **c.** low pressure and high temperature — U · 1

At low pressure the molecules are far apart, so their volume doesn't matter; at high temperature they move fast, so their weak attraction hardly affects them.

v. **c.** 273 °C — A · 1

Doubling the volume needs double the **kelvin** temperature: 0 °C = 273 K, and 2 × 273 = 546 K, which is 546 − 273 = **273 °C**. (546 °C is the trap: 546 is the answer in kelvin, not in degrees Celsius.)

4 Very short answers

a. MARKING SCHEME — K · 1

✓ 360 K.

b. MARKING SCHEME — K · 1

✓ Daniel Bernoulli, 1738.

c. MARKING SCHEME — U · 1

✓ The temperature.

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d. MARKING SCHEME U · 1

✓ It doubles.

5 Short answers

a. MARKING SCHEME U · 2

✓ As it rises the air pressure around it falls, so the gas inside expands (Boyle's law).

✓ Filled full at the ground, it would burst soon after launch.

b. MARKING SCHEME U · 2

✓ By Graham's law, the rate of diffusion is inversely proportional to the square root of the molar mass.

✓ Ammonia (17 g/mol) is lighter than hydrogen chloride (36.5 g/mol).

c. MARKING SCHEME A · 2

✓ A tyre's volume hardly changes, so warm air in it has a higher pressure ($P \propto T$).

✓ A reading taken warm would be too high, and a tyre filled while warm would be too soft once cool.

d. MARKING SCHEME U · 2

✓ 0 °C (273 K) and 1 atm (760 mmHg).

✓ A volume alone doesn't tell how much gas there is, since it changes with temperature and pressure.

6 Long answers

a. ANSWER U · 4

Boyle's law: the volume of a fixed mass of a gas is inversely proportional to its pressure, provided its temperature stays the same: $PV =$ constant.

Explanation: the pressure of a gas is caused by its molecules hitting the walls of the container. At a constant temperature, their average kinetic energy, and so their average speed, stays the same. If the volume is halved, the same number of molecules, moving at the same speed, travel only half as far between one wall and the next, so they hit each part of the walls twice as often. Twice the number of hits each second on each unit area means twice the pressure. So halving the volume doubles the pressure.

MARKING SCHEME

✓ The statement of Boyle's law, with the fixed mass and fixed temperature.

✓ Pressure is caused by the molecules hitting the walls.

✓ At a fixed temperature, their average speed stays the same.

✓ With half the volume they hit each part of the walls twice as often, so the pressure doubles.

b. ANSWER A · 4

Let a fixed mass of gas go from (P_1, V_1, T_1) to (P_2, V_2, T_2).

First, at constant temperature T_1, change the pressure from P_1 to P_2; the volume becomes V. By Boyle's law, $P_1V_1 = P_2V$, so $V = \frac{P_1V_1}{P_2}$ … (i)

Then, at constant pressure P_2, change the temperature from T_1 to T_2; the volume goes from V to V_2. By Charles's law, $\frac{V}{T_1} = \frac{V_2}{T_2}$, so $V = \frac{V_2T_1}{T_2}$ … (ii)

From (i) and (ii), $\frac{P_1V_1}{P_2} = \frac{V_2T_1}{T_2}$. Multiplying both sides by $\frac{P_2}{T_1}$:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

This is the combined gas equation: $\frac{PV}{T}$ is constant for a fixed mass of gas.

MARKING SCHEME

✓ First step, Boyle's law: $V = \frac{P_1V_1}{P_2}$.

✓ Second step, Charles's law: $V = \frac{V_2T_1}{T_2}$.

✓ Equating the two values of V.

✓ $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$.

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7 Numerical problems

a. ANSWER A · 2

$T_1 = 7 + 273 = 280$ K, $T_2 = 147 + 273 = 420$ K

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{250 \times 420}{280} = 375 \text{ cm}^3$$

375 cm³.

MARKING SCHEME

✓ $T_1 = 280$ K and $T_2 = 420$ K.
✓ $V_2 = 375$ cm³.

b. ANSWER A · 3

$$V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{700 \times 500 \times 273}{300 \times 760} = 419.1 \text{ cm}^3$$

About 419 cm³ at STP.

MARKING SCHEME

✓ $T_1 = 300$ K; at STP 760 mmHg and 273 K.
✓ $V_2 = \frac{700 \times 500 \times 273}{300 \times 760}$.
✓ $V_2 = 419$ cm³.

c. ANSWER A · 3

$$\frac{t_{CO_2}}{t_{O_2}} = \sqrt{\frac{M_{CO_2}}{M_{O_2}}} = \sqrt{\frac{44}{32}} = 1.17$$

$t_{CO_2} = 40 \times 1.17 = 46.9$ s. **About 47 s.**

MARKING SCHEME

✓ $\frac{t_{CO_2}}{t_{O_2}} = \sqrt{\frac{44}{32}}$.
✓ The ratio is 1.17.
✓ About 47 s.

d. ANSWER A · 3

$$\frac{r_X}{r_{CH_4}} = \sqrt{\frac{16}{M_X}} \quad \Rightarrow \quad \frac{1}{2} = \sqrt{\frac{16}{M_X}} \quad \Rightarrow \quad \frac{1}{4} = \frac{16}{M_X}$$

$M_X = 64$ g/mol. **The molar mass is 64 g/mol** (it could be sulphur dioxide).

MARKING SCHEME

✓ $\frac{1}{2} = \sqrt{\frac{16}{M_X}}$.
✓ Squaring: $\frac{1}{4} = \frac{16}{M_X}$.
✓ $M_X = 64$ g/mol.

8 Think

ANSWER HA · 3

The student used degrees Celsius as if they were measured from zero volume. Charles's law needs the absolute (kelvin) temperature: 20 °C = 293 K and 40 °C = 313 K. The volume changes by the ratio $\frac{313}{293}$ = 1.068, so it grows by **only about 7%**, not 100%. To double the volume, the gas would have to be heated to $2 \times 293 = 586$ K, which is 313 °C.

MARKING SCHEME

✓ Charles's law needs kelvin, not °C: 293 K and 313 K.
✓ The volume changes by 313 ÷ 293 = 1.068.
✓ It grows by only about 7%, not 100%.

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9 Activity: Air in a bottle under a balloon (Practical 14)

(not marked)

WHAT STUDENTS SHOULD FIND

In hot water the balloon stands up and swells, because the air in the bottle expands. In cold water it goes limp and may be pulled into the bottle's neck, because the air contracts. It shows Charles's law: the balloon keeps the pressure inside close to the air's outside, and a higher temperature gives a bigger volume.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	17	18	3	**45**

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