3.6 Pressure in gases and work done on a gas

Name: _____ Class: _____ Date: _____ **Total: 27 marks**

KEY WORDS density

Objective

Use pV = constant for a fixed mass of gas at constant temperature, and explain (HT) how doing work on a gas raises its temperature. Physics only. Original questions for spec statements 4.3.3.2–4.3.3.3.

1 Key knowledge and worked examples

A gas can be compressed or expanded by pressure changes. The pressure produces a **net force at right angles** to any surface it touches. For a **fixed mass at constant temperature**:

$$pV = \text{constant} \qquad \text{so} \qquad p_1V_1 = p_2V_2$$

- p pressure in pascals, Pa (or keep kPa consistently); V volume in m^3 (or cm^3 consistently).
- Consistency is what matters: if both volumes are in cm^3, both pressures must be in the same unit.

Particle explanations of each direction:

- At constant temperature, average molecular speed stays the same.
- **Volume increases → pressure falls:** molecules collide with each unit area of wall less frequently.
- **Volume decreases → pressure rises:** molecules collide with each unit area of wall more frequently.

The piston's area need not change when volume changes. Explain collision rate per unit area, rather than assuming every wall area changes.

Worked example. A syringe holds 50 cm^3 of air at 100 kPa. It is compressed to 20 cm^3 at constant temperature.

- Known: both volumes and one pressure. Rearrange before substituting.

$$p_2 = \frac{p_1V_1}{V_2} = \frac{100\text{ kPa} \times 50\text{ cm}^3}{20\text{ cm}^3} = 250\text{ kPa}$$

- Check: compressing must raise the pressure ✓; cm^3 cancelled because both volumes used it.

Worked example (reversed, constant temperature). A bubble of volume 2.0 mm^3 rises from depth where the pressure is 300 kPa to the surface at 100 kPa.

$$V_2 = \frac{p_1V_1}{p_2} = \frac{300\text{ kPa} \times 2.0\text{ mm}^3}{100\text{ kPa}} = 6.0\text{ mm}^3$$

(HT) Doing work on a gas. Work is the transfer of energy by a force. Compressing a gas transfers energy to its particles:

1. the piston pushes on the molecules as it moves in – **work is done on the gas**;
2. the gas's **internal energy increases**;
3. the average kinetic energy of the molecules rises, so the **temperature increases**.

Rapid compression can warm the trapped gas because work transfers energy to it faster than energy leaves by heating. Expanding gas can cool while doing work if heating does not replace the transferred energy. A slow compression with heat exchange can instead keep temperature nearly constant; apply pV = constant only when its conditions hold.

2 Practice

2.1 A fixed mass of gas at constant temperature has $pV = 400\text{ kPa} \cdot \text{cm}^3$. Calculate the pressure when the volume is 25 cm^3. [2]

2.2 State the two conditions (about the gas) needed for $p_1V_1 = p_2V_2$ to apply. [2]

2.3 (HT) Explain why a bicycle pump warms when you pump a tyre quickly. [3]

3 Exam-style questions

3.1 A sealed flask of air at 101 kPa has volume 250 cm^3.

(a) The flask is compressed to 100 cm^3 at constant temperature. Calculate the new pressure. [3]

(b) Explain the pressure change using the particle model. [3]

3.2 When the plunger of a sealed syringe is pulled out slowly, the gas inside expands and its temperature stays constant.

(a) Explain, using the particle model, why the pressure inside decreases. [3]

(b) The gas pressure outside is 101 kPa. State the direction of the net force on the plunger immediately after it is released, and justify it. [2]

3.3 A diver's air bubble has volume 0.60 cm^3 at a depth where the pressure is 405 kPa. It rises to the surface at 101 kPa. The temperature stays constant.

(a) Calculate the bubble's volume at the surface. [3]

(b) Calculate the mass-proportional quantity $\frac{p_1V_1 - p_2V_2}{p_1V_1}$, i.e. the fraction by which pV changed. [1]

(c) The temperature did stay constant while the bubble expanded. Explain what happened to the energy the gas lost as it expanded. [2]

(d) (HT) Before air enters the cylinder, a piston rapidly compresses a fixed mass of air in a closed pump chamber, with little heat loss. Explain why the air in this chamber becomes warmer. [3]