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.

$$p_2 = \frac{p_1 V_1}{V_2} = \frac{100 \text{ kPa} \times 50 \text{ cm}^3}{20 \text{ cm}^3} = 250 \text{ kPa}$$

- 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.

$$V_2 = \frac{p_1 V_1}{p_2} = \frac{300 \text{ kPa} \times 2.0 \text{ mm}^3}{100 \text{ kPa}} = 6.0 \text{ mm}^3$$

(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 $p_1 V_1 = p_2 V_2$ 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]

Solutions

2.1

$$p = \frac{400 \text{ kPa} \cdot \text{cm}^3}{25 \text{ cm}^3} = \mathbf{16} \text{ kPa}$$

(rearrangement 1, answer with unit 1.)

2.2 The mass of gas is fixed (no gas enters or leaves) and the temperature is constant.

2.3 Pushing the plunger does work on the trapped air; the air's internal energy increases – its molecules gain kinetic energy; the temperature of the air rises, and the warm pump then heats your hand.

3.1 (a) Rearrange first.

$$p_2 = \frac{p_1 V_1}{V_2} = \frac{101 \times 250}{100} = \mathbf{253} \text{ kPa (3 s.f.)}$$

(rearrangement C1, substitution C1, answer A1.) (b) The same number of molecules now occupies a smaller volume; they collide with each unit area of wall more frequently at the same average speed; the force per unit area – the pressure – increases.

3.2 (a) The molecules spread through a larger volume at the same average speed (constant temperature); the same molecules occupy a larger volume; so collisions per second per unit area fall and the pressure decreases. (b) The net force acts **inward**, pushing the plunger back towards its original position: pulling it out lowers the inside pressure below the outside pressure of 101 kPa, so the outside force on the plunger is greater than the inside force.

3.3 (a)

$$V_2 = \frac{p_1 V_1}{p_2} = \frac{405 \times 0.60}{101} = \mathbf{2.4} \text{ cm}^3$$

(rearrangement C1, substitution C1, answer A1.) (b) Zero – $p_1 V_1 = p_2 V_2 = 243$ kPa $\cdot$ cm^3 for constant temperature; pV did not change. (c) The expanding gas **did work on the surrounding water** as it pushed it back; the energy transferred by that work was replaced by heat flowing in from the warmer surroundings, keeping the temperature – and pV – constant. (d) The moving piston does work on the fixed mass of air in the closed pump chamber; with little heat lost, this energy transfer increases its internal energy; average molecular kinetic energy increases, so temperature rises. Merely adding more air to a separate fixed-volume cylinder would not by itself prove a temperature rise.