2. Relationships Between Volume and Pressure, Temperature, and Amount

| Variable | Pressure | Temperature | Amount |
|---|---|---|---|
| Graph | inverse relationship: double is half ($v$ vs. $p$) | direct relationship above zero ($v$ vs. $T$) | direct relationship ($v$ vs. $n$) |
| Equation | $v = k_1/p$ and $p_1v_1 = p_2v_2$ | $v = k_2T$ and $v_1/T_1 = v_2/T_2$ | $v = k_3n$ and $v_1/n_1 = v_2/n_2$ |
| Variables controlled | temperature and amount | pressure and amount | pressure and temperature |

3. The ideal gas law

$pv = nRT$ $p$ is the gas pressure in, for example, kilopascals (kPa)
$v$ is the gas volume in, for example, litres (L)
$n$ is the amount in, for example, moles (mol)
$R$ is the gas constant in, for example, kPa·L/(mol·K)
$T$ is the kelvin (absolute) temperature in kelvins (K)

# CHAPTER 9 REVIEW

**(Page 456)**

## Understanding Concepts

1. At SATP chlorine is a gas, bromine is a liquid, and iodine is a solid, indicating that larger halogen molecules have stronger intermolecular forces.
2. (a) Water and ice are both colourless and odourless, have a specific volume, and are negligibly compressible.
   (b) Ice has a specific shape; water does not.
   (c) Gases (like water vapour) are highly compressible because there are very large spaces between their molecules.
   (d) In ice, $H_2O$ molecules are very ordered, with specific location and orientation; the only significant molecular motion is internal vibration. In liquid water, the molecules are free to rotate, and to slowly change location relative to each other; so the molecules are more disordered. In water vapour, rapid molecular change of location is a much greater effect; so the molecules are very much more disordered.
   (e) In ice, $H_2O$ molecules are held in a specific location and orientation by hydrogen bonds between molecules. In liquid water, the kinetic energy of the molecules is higher, overcoming the hydrogen bonding to the extent that the molecules are free to rotate and to change location relative to each other. In water vapour, the kinetic energy of the molecules has overcome the hydrogen bonds and the molecules are widely separated from each other, so the characteristics of this state are based on molecular motion.
   (f) The two major components of the atmosphere are nitrogen (about 78%) and oxygen (about 21%). Two minor components of the atmosphere are argon (about 1%) and water vapour (variable, usually around 1–3%).
   (g) Water is a very important component of Earth's atmosphere because it falls as rain, which is essential for plant and animal life, and the phase changes of water control the planet's weather.
3. (a) The volume of a gas sample decreases proportionally with its pressure, assuming the amount and temperature remain constant.
   (b) The volume of a gas sample increases proportionally with its absolute temperature, assuming the amount and pressure remain constant.
   (c) The volume of a gas sample is directly proportional to the product of its amount and its absolute temperature, and inversely proportional to its pressure.
4. (a) $v \times \frac{1}{3} \times \frac{2}{1} = 2/3\ v$, a final volume 2/3 of the original volume.
   (b) $v \times \frac{2}{1} \times \frac{2}{1} = 4\ v$, a final volume 4 times the original volume.

 

(c) $v \times \frac{1}{2} \times \frac{2}{1} = v$, a final volume equal to the original volume.

5. A law is a descriptive generalization based on evidence; Charles's Law is a statement of how the temperature of a gas sample is observed to affect its volume at constant pressure.
   A theory is a possible explanation based on reasoning; Charles's Law may be explained by postulating that gases expand when warmed because their molecules are moving faster, and thus will exert the same average pressure on container walls only if there are fewer collisions — that is, if they are farther apart.

6. (a) $745\ \cancel{\text{mm Hg}} \times \frac{101.325\ \text{kPa}}{760\ \cancel{\text{mm Hg}}} = 99.3\ \text{kPa}$

   (b) $150\ \cancel{\text{Pa}} \times \frac{1\ \text{kPa}}{1000\ \cancel{\text{Pa}}} = 0.150\ \text{kPa}$

   (c) $2.50\ \cancel{\text{atm}} \times \frac{101.325\ \text{kPa}}{1\ \cancel{\text{atm}}} = 253\ \text{kPa}$

7. (a) $0°\text{C} = (0 + 273) = 273\ \text{K}$

   (b) $21°\text{C} = (21 + 273) = 294\ \text{K}$

   (c) $37°\text{C} = (37 + 273) = 310\ \text{K}$

   (d) $-273°\text{C} = (-273 + 273) = 0\ \text{K}$

8. $p_1 = 100\ \text{kPa}$
   $v_1 = 28.8\ \text{L}$
   $p_2 = 350\ \text{kPa}$
   $v_{H_2} = ?$

$$p_1 v_1 = p_2 v_2$$

$$v_{H_2} = \frac{p_1 v_1}{p_2}$$

$$= \frac{100\ \cancel{\text{kPa}} \times 28.8\ \text{L}}{350\ \cancel{\text{kPa}}}$$

$$v_{H_2} = 8.23\ \text{L}$$

or

$$v_{H_2} = 28.8\ \text{L} \times \frac{100\ \cancel{\text{kPa}}}{350\ \cancel{\text{kPa}}}$$

$$v_{H_2} = 8.23\ \text{L}$$

The final volume of hydrogen gas will be 8.23 L, assuming amount and temperature are constant.

9. (a) Since the pressure and volume are inversely proportional, the new volume will be: $300\ \text{mL} \times \frac{1}{2} = 150\ \text{mL}$.

   (b) $p_1 = 125\ \text{kPa}$
   $T_1 = 7°\text{C} = 280\ \text{K}$
   $p_{CO_2} = ?$
   $T_2 = 30°\text{C} = 303\ \text{K}$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$p_{CO_2} = \frac{T_2 p_1}{T_1}$$

$$= \frac{303\ \cancel{\text{K}} \times 125\ \text{kPa}}{280\ \cancel{\text{K}}}$$

$$p_{CO_2} = 135\ \text{kPa}$$

or

$$p_{CO_2} = 125\text{ kPa} \times \frac{303\ \cancel{\text{K}}}{280\ \cancel{\text{K}}}$$

$$p_{CO_2} = 135\text{ kPa}$$

The final pressure of carbon dioxide will be 135 kPa, assuming amount and volume remain constant.

(c) A can of carbonated pop sometimes overflows when opened because bubbles form so rapidly from the saturated solution, that they can push liquid and foam out of the opening. This is due to the sudden drop in pressure above the liquid. The volume containing the gas above the liquid changes from small to huge (the size of the atmosphere) when the container is opened.

10. $p_1 = 96.7\text{ kPa}$

$T_1 = 19.5°\text{C} = 292.5\text{ K}$

$p_2 = 195\text{ kPa}$

$T_{gas} = ?$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$T_{gas} = \frac{T_1 p_2}{p_1}$$

$$= \frac{292.5\text{ K} \times 195\ \cancel{\text{kPa}}}{}$$

$$T_{gas} = 590\text{ K} = 317°\text{C}$$

or

$$T_{gas} = 292.5\text{ K} \times \frac{195\ \cancel{\text{kPa}}}{96.7\ \cancel{\text{kPa}}}$$

$$T_{gas} = 590\text{ K} = 317°\text{C}$$

The final gas temperature when the container breaks will be 317°C.

11. $p_1 = 600\text{ kPa}$

$T_1 = 150°\text{C} = 423\text{ K}$

$v_1 = 10.0\text{ kL}$

$p_{steam} = ?$

$T_2 = 110°\text{C} = 383\text{ K}$

$v_2 = 18.0\text{ kL}$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

$$p_{steam} = \frac{T_2 p_1 v_1}{T_1 v_2}$$

$$= \frac{383\ \cancel{\text{K}} \times 600\text{ kPa} \times 10.0\ \cancel{\text{kL}}}{423\ \cancel{\text{K}} \times 18.0\ \cancel{\text{kL}}}$$

$$p_{steam} = 302\text{ kPa}$$

or

$$p_{steam} = 600\text{ kPa} \times \frac{10.0\ \cancel{\text{kL}}}{18.0\ \cancel{\text{kL}}} \times \frac{383\ \cancel{\text{K}}}{423\ \cancel{\text{K}}}$$

$$p_{steam} = 302\text{ kPa}$$

The final pressure of the turbine steam will be 302 kPa.

 

12. (a) $p_1 = 103 \text{ kPa}$

$v_1 = 3000 \text{ m}^3$

$p_2 = 97 \text{ kPa}$

$v_{air} = ?$

$$p_1 v_1 = p_2 v_2$$

$$v_{air} = \frac{p_1 v_1}{p_2}$$

$$= \frac{103 \cancel{\text{kPa}} \times 3000 \text{ m}^3}{97 \cancel{\text{kPa}}}$$

$$v_{air} = 3.2 \times 10^3 \text{ m}^3$$

or

$$v_{air} = 3000 \text{ m}^3 \times \frac{103 \cancel{\text{kPa}}}{97 \cancel{\text{kPa}}}$$

$$v_{air} = 3.2 \times 10^3 \text{ m}^3$$

The air volume increases by $(3.2 - 3.000) \times 10^3 \text{ m}^3 = 2 \times 10^2 \text{ m}^3$.

(b) $p_1 = 103 \text{ kPa}$

$v_1 = 100 \text{ mL}$

$p_2 = 97 \text{ kPa}$

$v_{CH_4} = ?$

$$p_1 v_1 = p_2 v_2$$

$$v_{CH_4} = \frac{p_1 v_1}{p_2}$$

$$= \frac{103 \cancel{\text{kPa}} \times 100 \text{ mL}}{}$$

$$v_{CH_4} = 0.11 \text{ L}$$

or

$$v_{CH_4} = 100 \text{ mL} \times \frac{103 \cancel{\text{kPa}}}{97 \cancel{\text{kPa}}}$$

$$v_{CH_4} = 1.1 \times 10^2 \text{ mL} = 0.11 \text{ L}$$

The final volume of methane gas in the vegetation must be 0.11 L.

(c) If an advancing storm is accompanied by a low-pressure system, then air in caves will increase in volume and the excess will escape (detectable as wind), and gas bubbles in sunken vegetation might expand enough for it to become buoyant — thus indicating the oncoming storm.

13. $m = 4.54 \text{ kg}$

$p = 96.5 \text{ kPa}$

$T = 12°\text{C} = 285 \text{ K}$

$v_{C_3H_8} = ?$

$M = 44.11 \text{ g/mol}$

$R = 8.31 \text{ kPa·L/(mol·K)}$

$$n_{C_3H_8} = 4.54 \text{ k}\cancel{\text{g}} \times \frac{1 \text{ mol}}{44.11 \cancel{\text{g}}}$$

$$n_{C_3H_8} = 0.103 \text{ kmol}$$

$$pv = nRT$$

$$v_{C_3H_8} = \frac{nRT}{p}$$

$$= \frac{0.103 \text{ k}\cancel{\text{mol}} \times \dfrac{8.31 \text{ }\cancel{\text{kPa}}\cdot\text{L}}{\cancel{\text{mol}}\cdot\cancel{\text{K}}} \times 285 \cancel{\text{K}}}{96.5 \cancel{\text{kPa}}}$$

$$v_{C_3H_8} = 2.53 \text{ kL}$$

The volume of propane gas is 2.53 kL, or 2.53 $m^3$.

14. $m_{He}$ = ?

$p$ = 102.7 kPa

$T$ = 18°C = 291 K

$v$ = 7.5 × 5000 = 3.8 × $10^4$ L = 38 kL

$M$ = 4.00 g/mol

$R$ = 8.31 kPa·L/(mol·K)

$$pv = nRT$$

$$n_{He} = \frac{pv}{RT}$$

$$= \frac{102.7 \text{ }\cancel{\text{kPa}} \times 38 \text{ k}\cancel{\text{L}}}{\dfrac{8.31 \text{ }\cancel{\text{kPa}}\cdot\cancel{\text{L}}}{\text{mol}\cdot\cancel{\text{K}}} \times 291 \cancel{\text{K}}}$$

$$n_{He} = 1.6 \text{ kmol}$$

$$m_{He} = 1.6 \text{ k}\cancel{\text{mol}} \times \frac{4.00 \text{ g}}{1 \cancel{\text{mol}}}$$

$$m_{He} = 6.4 \text{ kg}$$

The mass of helium gas required is 6.4 kg.

15. $n_{air}$ = ? (total amount of the gases present)

$p$ = 99.5 kPa

$T$ = 21°C = 294 K

$v$ = 2.95 m × 3.50 m × 2.45 m = 25.3 $m^3$ = 25.3 kL

$R$ = 8.31 kPa·L/(mol·K)

$$pv = nRT$$

$$n_{air} = \frac{pv}{RT}$$

$$= \frac{99.5 \text{ }\cancel{\text{kPa}} \times 25.3 \text{ k}\cancel{\text{L}}}{\dfrac{8.31 \text{ }\cancel{\text{kPa}}\cdot\cancel{\text{L}}}{\text{mol}\cdot\cancel{\text{K}}} \times 294 \cancel{\text{K}}}$$

$$n_{air} = 1.03 \text{ kmol}$$

The amount of air present in the room is 1.03 kmol (of various gases).

## Applying Inquiry Skills

16. **Hypothesis**

(a) According to Boyle's Law, the volume of gas in the syringe should be inversely proportional to the pressure applied, and the product of the pressure and volume should be a constant value.

 

### Analysis

(b) For each trial the *pv* product is $5.0 \times 10^3$ kPa·L , thus verifying the relationship $pv = k$ (a constant value). This means that *p* and *v* are inversely proportional.

According to the evidence, the pressure and volume of the gas in this investigation are in inverse proportion.

### Evaluation

(c) Boyle's law is supported by the evidence gathered in this investigation. (Even though Boyle's law is not a hypothesis any more, it is used under that heading in the format provided herein. Every scientific concept has uncertainty associated with it; hypotheses have more uncertainty than other concepts.)

17. **Experimental Design**

A syringe is sealed at the tip and then placed inside a hot-water bath. The temperature of the syringe is gradually decreased by cooling the water bath. Temperature is the manipulated variable, and gas volume in the syringe is the responding variable. The results are graphed, and the theoretical temperature at zero volume is found by extrapolation.

## Making Connections

18. Two examples of natural phenomena involving gas laws are:
    (i) tornadoes — which are generated when warm air rises and abruptly cools and shrinks, and
    (ii) expansion in size or rupture of fish caught in deep water and brought to the surface, as the external pressure exerted on gases in their bodies decreases.

    Two examples of technological products involving gas laws are:
    (i) aerosol (spray) cans, which use volume increase caused by pressure decrease as a propellant system, and
    (ii) internal-combustion engines, which depend in part on energy from strongly heating gases, thus increasing the pressure exerted on the piston that drives the crankshaft.
19. Propane tanks have expiry dates, after which they may not be refilled, to forestall the possible problem of corrosion and leakage of an old tank. Old tanks must be disposed of according to strict regulations, because they almost always contain some residual propane. This remaining propane may be mixed with air inside the old tank, possibly creating a dangerous explosive device if the tank is exposed to flame or sparks.
20. Air bags are porous fabric bags that fill with gas extremely rapidly. They can cushion and/or prevent a person's impact on the interior of his/her own automobile in a crash, thus preventing or reducing injury and risk of death. Air bags inflate so rapidly that they can cause injury in individuals who are sitting too close to them. This risk is particularly serious for children, to the extent that some manufacturers have developed second-generation air bags that have adjustable inflation rates. Some vehicles (especially pickup trucks) allow the driver to switch off the passenger air bag circuit when transporting a child in a child safety seat.
21. (a) Some (of many) categories that can be used to classify the components of air are: *essential* (e.g., the oxygen we need to breathe); *inert* (e.g., the argon and nitrogen comprising 4/5 of the atmosphere); *important* (e.g., the water vapour content that affects weather); and *hazardous* (e.g., ground-level ozone, carbon monoxide, or nitrogen oxide).

    (b) An example of an atmospheric gas that may be discussed from several perspectives is carbon dioxide. Some perspective statements might include:

    **Scientific** — The atmospheric concentration of $CO_{2(g)}$ gas rose 7.4% from 1900 to 1970.

    **Technological** — Power plants designed to burn natural gas produce much less carbon dioxide than those that burn coal.

    **Economic** — Power plants that produce less carbon dioxide are often much more expensive to run than those that produce larger amounts.

    **Environmental** — The increase in atmospheric concentration of carbon dioxide may be accelerating the rate of warming of the atmosphere by enhancing the greenhouse effect, which may in turn be increasing the effects of climate change on all living things.

## Exploring

22. A typical answer might discuss argon (about 1% of the atmosphere), its uses (for example, in light bulbs to prevent reaction or evaporation of the filament and in welding to prevent corrosion during the joining process), and its commercial production (by fractional distillation of liquid air).

    GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.