4.

State	Properties	Explanations
solid	solids have definite shape and volume	the attractive force(s) between particles is sufficiently high to hold the particles in place
	are virtually incompressible	the particles are too close together to be compressed
	do not flow easily	the attractive force(s) between particles holds the particles in place
liquid	liquids assume the shape of the container but have a definite volume	attractive forces have been overcome so the particles can rotate and roll over each other and assume new shapes but maintain the same volume
	are virtually incompressible	the particles are still “touching each other” (repelling each other, electrostatically)
	flow readily	the particles can roll over each other
gas	gases assume the shape and volume of the container	the particles are independent of each other due to very small attractive forces; the particles are only contained by the container, not by intermolecular attractions
	are highly compressible	the distance between the particles is large relative to the size of the particle (20–30 times the diameter), so there is empty space for compression
	flow easily	there is little or no attractive force(s) among the particles, so they are free to move independently in any direction

Making Connections

5. Gas particles move very rapidly, so the flexible fabric air bag fills in an instant, before the motorist hits the steering wheel of the car. Gases have no definite shape, so the flexible bag can mould to the motorist’s shape and spread the restraining force evenly. Gases can move through small openings, so the gas from an air bag quickly diffuses through small holes to deflate the bag after a collision, freeing the motorist.

9.2 GAS LAWS

Try This Activity: A Simulation of Gas Properties

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(a) The order of gas cylinders from most likely to least likely to explode is 1, 5, 3, 2, 4. The order is based on the reasoning that smaller volumes and higher temperatures (for the same mass of gas) produce greater pressures. The higher the pressure, the more likely the cylinder will be to explode.
– Cylinder 1 has the smallest volume and the highest temperature and, therefore, should be at the highest pressure.
– Cylinder 5 is also at the highest temperature but has a greater volume than 1. Cylinder 5 has twice the volume of 3, but 5 has a temperature that is almost three times larger. Therefore, 5 likely has a higher pressure than 3.
– Cylinder 3 follows 5, as indicated above, but precedes 2 because 3 has a higher temperature and the same volume as 2.
– Cylinder 2 is at the same temperature as 4 but 2 has a smaller volume. Therefore, the pressure in 2 should be greater than in 4.
– Cylinder 4 has the greatest volume and the lowest temperature, and therefore, the least pressure.
Note: At this stage students would not know about the Kelvin temperature scale. Although the above reasoning is correct, the comparisons should be done using Kelvin, not Celsius, temperatures. If Kelvin temperatures are used, the order of 5 and 3 would likely be reversed.

(b) Variables that need to be considered are the amount of gas, and the volume, temperature, and maximum pressure for the cylinder.

PRACTICE

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Understanding Concepts

1. STP is 0°C and 101.325 kPa; SATP is 25°C and 100 kPa.
2. **Table 3:** Converting Pressure Units

Pressure (kPa)	Pressure (atm)	Pressure (mm Hg)
(a) 0.50	0.0049	3.8
(b) 96.5	0.952	724
(c) 110	1.09	825
(d) 253	2.50	1.90×10^3

(a) $0.50\ \cancel{\text{kPa}} \times \dfrac{1\ \text{atm}}{101.325\ \cancel{\text{kPa}}} = 0.0049\ \text{atm}$

$0.50\ \cancel{\text{kPa}} \times \dfrac{760\ \text{mm Hg}}{101.325\ \cancel{\text{kPa}}} = 3.8\ \text{mm Hg}$

(b) $96.5\ \cancel{\text{kPa}} \times \dfrac{1\ \text{atm}}{101.325\ \cancel{\text{kPa}}} = 0.952\ \text{atm}$

$96.5\ \cancel{\text{kPa}} \times \dfrac{760\ \text{mm Hg}}{101.325\ \cancel{\text{kPa}}} = 724\ \text{mm Hg}$

(c) $825\ \cancel{\text{mm Hg}} \times \dfrac{101.325\ \text{kPa}}{760\ \cancel{\text{mm Hg}}} = 110\ \text{kPa}$

$825\ \cancel{\text{mm Hg}} \times \dfrac{1\ \text{atm}}{760\ \cancel{\text{mm Hg}}} = 1.09\ \text{atm}$

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

$2.50\ \cancel{\text{atm}} \times \dfrac{760\ \text{mm Hg}}{1\ \cancel{\text{atm}}} = 1.90 \times 10^3\ \text{mm Hg}\ \ (= 1.90\ \text{m Hg})$

3. Using only one pressure unit facilitates communication, understanding, and comparison of pressures.

Making Connections

4. When the bulb is released, the pressure inside the tube is lower than that outside. The outside air pressure pushes down on the surface of the surrounding liquid, forcing the liquid into the tube.

PRACTICE

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Understanding Concepts

5. Atmospheric pressure is the force per unit area exerted by air on the surfaces of all objects.
6. $p_1 = 101\ \text{kPa}$

   $v_1 = 0.650\ \text{L}$

   $p_2 = ?$

   $v_2 = 0.250\ \text{L}$

$$p_1v_1 = p_2v_2$$
$$p_2 = \frac{p_1v_1}{v_2}$$
$$= 101 \text{ kPa} \times \frac{0.650 \cancel{\text{L}}}{0.250 \cancel{\text{L}}}$$
$$p_{\text{air}} = 263 \text{ kPa}$$

or

$$p_{\text{air}} = 101 \text{ kPa} \times \frac{0.650 \cancel{\text{L}}}{0.250 \cancel{\text{L}}}$$
$$p_{\text{air}} = 263 \text{ kPa}$$

The final pressure of the air must be 263 kPa.

7. $p_1 = 98.0$ kPa

$v_1 = 35.0$ L

$p_2 = 25.0$ kPa

$v_2 = ?$

$$p_1v_1 = p_2v_2$$
$$v_2 = \frac{p_1v_1}{p_2}$$
$$= 98.0 \cancel{\text{kPa}} \times \frac{35.0 \text{ L}}{25.0 \cancel{\text{kPa}}}$$
$$v_{\text{He}} = 137 \text{ L}$$

or

$$v_{\text{He}} = 35.0 \text{ L} \times \frac{98.0 \cancel{\text{kPa}}}{25.0 \cancel{\text{kPa}}}$$
$$v_{\text{He}} = 137 \text{ L}$$

The final volume of helium will be 137 L.

8. $p_1 = 3.0$ atm

$v_1 = 110$ mL

$p_2 = 2.0$ atm

$v_2 = ?$

$$p_1v_1 = p_2v_2$$
$$v_2 = \frac{p_1v_1}{p_2}$$
$$= 3.0 \cancel{\text{atm}} \times \frac{110 \text{ mL}}{2.0 \cancel{\text{atm}}}$$
$$v_{\text{balloon}} = 1.6 \times 10^2 \text{ mL} = 0.16 \text{ L}$$

or

$$v_{\text{balloon}} = 110 \text{ mL} \times \frac{3.0 \cancel{\text{atm}}}{2.0 \cancel{\text{atm}}}$$
$$v_{\text{balloon}} = 1.6 \times 10^2 \text{ mL} = 0.16 \text{ L}$$

The final volume of the balloon will be 0.16 L.

9. $p_1 = 98 \text{ kPa}$

$v_1 = 32 \text{ kL}$

$p_2 = 150 \text{ kPa}$

$v_2 = ?$

$$p_1 v_1 = p_2 v_2$$

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

$$= \frac{98 \cancel{\text{kPa}} \times 32 \text{ kL}}{150 \cancel{\text{kPa}}}$$

$$v_{air} = 21 \text{ kL}$$

or

$$v_{air} = 32 \text{ kL} \times \frac{98 \cancel{\text{kPa}}}{150 \cancel{\text{kPa}}}$$

$$v_{air} = 21 \text{ kL}$$

The final volume of air in the diving bell will be 21 kL.

10. The movement of air "masses" within the atmosphere, and thinning with altitude cause local air pressure to depend on your location and time.

Making Connections

11. Evangelista Torricelli (1608–1647), Blaise Pascal (1623–1662), Guillaume Amontons (1663–1705)

What follows is a brief summary of development:

Evangelista Torricelli (1608–1647)

At Galileo's urging, Torricelli first investigated the principle of air pressure scientifically and invented the mercury barometer (a tube of mercury inverted in a dish of mercury) in 1643. The basic question was why water could only be raised about 10 m by a vacuum pump. Torricelli's suggestion was that the weight of air pushed the water up, rather than the pump's "vacuum" pulling it up. (This was also the first vacuum known to science.)

Blaise Pascal (1623–1662)

Pascal continued investigating and verified Torricelli's hypothesis that air had definite weight that would necessarily decrease with increasing altitude. He carried a barometer up a mountain, Puy de Dôme. Pascal also made a barometer with wine (less dense than water) that had a height of over 13 m. (The wine experiment was done in the same year that Torricelli died. The SI unit of pressure, the pascal, Pa, is named after Blaise Pascal.)

Guillaume Amontons (1663–1705)

Amontons invented the first hygrometer (for measuring moisture in the air) in 1687 (the same year that Isaac Newton published his laws of motion and universal gravitation), and the first barometer that did not use mercury — so that it could be used on board ships at sea. He also invented an air thermometer that improved on Galileo's version by keeping the volume constant and measuring pressure (directly) and temperature (indirectly). Amontons, like Edison, was deaf.

Note: The SIRs computer program has some excellent simulations of barometers and manometers.

PRACTICE

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Understanding Concepts

12. Absolute zero is about –273°C, or 0 K

13. $T\text{ (K)} = T\text{ (°C)} + 273$

(a) $T\text{ (K)} = 0 + 273 = 273 \text{ K}$

(b) $\text{T (K)} = 100 + 272 = 373 \text{ K}$

(c) $T\text{ (K)} = -30 + 273 = 243 \text{ K}$

(d) $T\text{ (K)} = 25 + 273 = 298 \text{ K}$

14. $T\ (°C) = T\ (K) - 273$

(a) $T\ (°C) = 0 - 273 = -273°C$

(b) $T\ (°C) = 100 - 273 = -173°C$

(c) $T\ (°C) = 300 - 273 = 27°C$

(d) $T\ (°C) = 373 - 273 = 100°C$

15. Scientists have come very close to achieving absolute zero. One source quotes, for example, $< 2 \times 10^{-8}$ K by 1988. According to the quantum mechanics theory, molecules at absolute zero do not have zero kinetic energy, but rather a minimum possible amount called the "zero–point" energy. In theory, it seems that molecular motion would not cease altogether.

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PRACTICE

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Understanding Concepts

16. $v_1 = 12.7$ mL

$T_1 = 22°C = 295$ K

$v_2 = ?$

$T_2 = -11°C = 262$ K

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

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

$$= \frac{262\ \cancel{K} \times 12.7\ \text{mL}}{295\ \cancel{K}}$$

$$v_{\text{butane}} = 11.3\ \text{mL}$$

or

$$v_{\text{butane}} = 12.7\ \text{mL} \times \frac{262\ \cancel{K}}{295\ \cancel{K}}$$

$$v_{\text{butane}} = 11.3\ \text{mL}$$

The final volume of butane will be 11.3 mL.

17. $v_1 = 2.05$ L

$T_1 = 5°C = 278$ K

$v_2 = ?$

$T_2 = 21°C = 294$ K

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

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

$$= \frac{294\ \cancel{K} \times 2.05\ \text{L}}{278\ \cancel{K}}$$

$$v_{\text{air}} = 2.17\ \text{L}$$

or

$$v_{air} = 2.05\text{ L} \times \frac{294\ \cancel{\text{K}}}{278\ \cancel{\text{K}}}$$

$$v_{air} = 2.17\text{ L}$$

The final volume of the air initially in the bottle will be 2.17 L. The volume of air that will leave the bottle due to the volume increase will therefore be (2.17 − 2.05) L, or 0.12 L.

18. $v_1 = 1.5\text{ L}$
$T_1 = 22°\text{C} = 295\text{ K}$

$v_2 = ?$

$T_2 = 100°\text{C} = 373\text{ K}$

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

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

$$= \frac{373\ \cancel{\text{K}} \times 1.5\text{ L}}{295\ \cancel{\text{K}}}$$

$$v_{air} = 1.9\text{ L}$$

or

$$v_{air} = 1.5\text{ L} \times \frac{373\ \cancel{\text{K}}}{295\ \cancel{\text{K}}}$$

$$v_{air} = 1.9\text{ L}$$

The final volume of the 1.5 L of air initially in the pan will be 1.9 L. The increase in the volume of air will be (1.9 − 1.5) L, or 0.4 L.
(The 1.5 L is a description of the (nominal) pan size, not a measured volume. The above calculation assumed an initial volume of 1.5 L of air in this pan.)

$$\frac{0.40\ \cancel{\text{L}}}{1.500\ \cancel{\text{L}}} \times 100\% = 26\%$$

The percentage increase of the volume of air will be 26%.
(The same answer is obtained by early rounding or not. Rounding on paper, but no rounding in the calculator, is preferred.)

19. $v_1 = 1.00\text{ L}$

$T_1 = 20°\text{C} = 293\text{ K}$

$v_2 = ?$

$T_2 = 80°\text{C} = 353\text{ K}$

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

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

$$= \frac{353\ \cancel{\text{K}} \times 1.00\text{ L}}{293\ \cancel{\text{K}}}$$

$$v_{air} = 1.20\text{ L}$$

or

$$v_{air} = 1.00\text{ L} \times \frac{353\ \cancel{\text{K}}}{293\ \cancel{\text{K}}}$$

$$v_{air} = 1.20\text{ L}$$

The final volume of each litre of air will be 1.20 L.

Applying Inquiry Skills

20. The design of this experiment is judged inadequate. At typical room temperatures, a change of one degree only changes the volume by about 1/300th. It seems very unlikely that this would change the total volume enough to measure with a graduated cylinder. As well, the water will evaporate to some extent into the trapped air space, and the cylinder itself will expand and contract with temperature changes. Likely the biggest problem would be keeping the pressure of gas in the cylinder constant.

To work effectively, the gas would need to be trapped by a liquid with little tendency to evaporate (such as mercury) in a long thin tube (so small changes show up as visible motion) in an apparatus that kept the gas at constant pressure.

Note: Guillaume Amontons (1663–1705) invented just such a device, significantly improving an earlier design constructed by Galileo, which had suffered from all the drawbacks mentioned above.

21. (a) v_1 = assume 1.000 L

T_1 = –60°C = 213 K

v_2 = ?

T_2 = 540°C = 813 K

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

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

$$= \frac{813\ \cancel{\text{K}} \times 1.000\ \text{L}}{213\ \cancel{\text{K}}}$$

$$v_{N_2} = 3.82\ \text{L}$$

or

$$v_{N_2} = 1.000\ \text{L} \times \frac{813\ \cancel{\text{K}}}{213\ \cancel{\text{K}}}$$

$$v_{N_2} = 3.82\ \text{L}$$

The final volume of each litre of nitrogen will be 3.82 L.

The ratio of volume increase is $\frac{3.82\ \cancel{\text{L}}}{1.00\ \cancel{\text{L}}}$, or 3.82:1.00.

(b) The gas expansion in jet engines is also used to spin the turbine that powers the compressor that compresses the gas–fuel mix before ignition.

PRACTICE

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Understanding Concepts

22. p_1 = 97 kPa

T_1 = 22°C = 295 K

p_2 = 350 kPa (minimum; any higher pressure breaks the tank)

T_2 = ?

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

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

$$= \frac{295\ \text{K} \times 350\ \cancel{\text{kPa}}}{97\ \cancel{\text{kPa}}}$$

$$T_{air} = 1064\ \text{K} = 791°\text{C (maximum)}$$

or

$$T_{air} = 295 \text{ K} \times \frac{350 \cancel{\text{kPa}}}{97 \cancel{\text{kPa}}}$$

$$T_{air} = 1064 \text{ K} = 791°\text{C (maximum)}$$

The maximum final air temperature would have been 791°C.

23. Kinetic molecular theory postulates that pressure increases with temperature (for a fixed quantity and volume of a gas) because higher temperature means faster-moving molecules, which must then collide more frequently with container walls, and so with more force per unit area.

Applying Inquiry Skills

24. (a) $p_1 = 125 \text{ kPa}$

$T_1 = 300 \text{ K}$

$p_2 = ?$

$T_2 = 400 \text{ K}$

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

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

$$= \frac{400 \cancel{\text{K}} \times 125 \text{ kPa}}{300 \cancel{\text{K}}}$$

$$p_{Ne} = 167 \text{ kPa}$$

or

$$p_{Ne} = 125 \text{ kPa} \times \frac{400 \cancel{\text{K}}}{300 \cancel{\text{K}}}$$

$$p_{Ne} = 167 \text{ kPa}$$

The final pressure of neon gas is predicted to be 167 kPa.

(b) The difference is: $|162 \text{ kPa} - 167 \text{ kPa}| = 5 \text{ kPa}$

The % difference is: $\frac{5 \cancel{\text{kPa}}}{167 \cancel{\text{kPa}}} \times 100\% = 3\%$

Making Connections

25. (a) $p_1 = 310 \text{ kPa}$

$T_1 = 21°\text{C} = 294 \text{ K}$

$p_2 = ?$

$T_2 = 38°\text{C} = 311 \text{ K}$

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

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

$$= \frac{311 \cancel{\text{K}} \times 310 \text{ kPa}}{294 \cancel{\text{K}}}$$

$$p_{air} = 328 \text{ kPa}$$

or

$$p_{air} = 310 \text{ kPa} \times \frac{311 \cancel{\text{K}}}{294 \cancel{\text{K}}}$$

$$p_{air} = 328 \text{ kPa}$$

The final total air pressure in the tire will be 328 kPa.

(b) The final gauge pressure reading will be (328 − 100) kPa = 228 kPa.
(c) If the tire pressure is set when the tire is hot, the pressure will fall as the tire cools, and will be too low at ambient temperatures. This can cause tire failure and/or premature wear.

PRACTICE

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Understanding Concepts

26. $p_1 = 101 \text{ kPa}$

$v_1 = 50.0 \text{ mL}$

$p_2 = ?$

$v_2 = 12.5 \text{ mL}$

$$p_1 v_1 = p_2 v_2$$

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

$$p_2 = \frac{101 \text{ kPa} \times 50.0 \cancel{\text{mL}}}{12.5 \cancel{\text{mL}}}$$

$$p_{\text{gas}} = 404 \text{ kPa}$$

or

$$p_{\text{gas}} = 101 \text{ kPa} \times \frac{50.0 \cancel{\text{mL}}}{12.5 \cancel{\text{mL}}}$$

$$p_{\text{gas}} = 404 \text{ kPa}$$

The final pressure of the gas in the syringe will be 404 kPa.

27. $v_1 = 0.10 \text{ L}$

$T_1 = 25°\text{C} = 298 \text{ K}$

$v_2 = ?$

$T_2 = 190°\text{C} = 463 \text{ K}$

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

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

$$= \frac{463 \cancel{\text{K}} \times 0.10 \text{ L}}{298 \cancel{\text{K}}}$$

$$v_{CO_2} = 0.16 \text{ L}$$

or

$$v_{CO_2} = 0.10 \text{ L} \times \frac{463 \cancel{\text{K}}}{298 \cancel{\text{K}}}$$

$$v_{CO_2} = 0.16 \text{ L}$$

The final volume of the carbon dioxide will be 0.16 L.

28. $p_1 = 150 \text{ kPa}$

$T_1 = 35°\text{C} = 308 \text{ K}$

$p_2 = 250 \text{ kPa}$

$T_2 = ?$

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

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

$$= \frac{308 \text{ K} \times 250 \cancel{\text{kPa}}}{150 \cancel{\text{kPa}}}$$

$$T_{\text{butane}} = 513 \text{ K} = 240°\text{C}$$

or

$$T_{\text{butane}} = \frac{308 \text{ K} \times 250 \cancel{\text{kPa}}}{150 \cancel{\text{kPa}}}$$

$$T_{\text{butane}} = 513 \text{ K} = 240°\text{C}$$

The temperature of butane for which the valve will open is 240°C.

29. $p_1 = 100 \text{ kPa}$

$T_1 = 20°\text{C} = 293 \text{ K}$

$v_1 = 5.00 \text{ L}$

$p_2 = 90 \text{ kPa}$

$T_2 = 35°\text{C} = 308 \text{ K}$

$v_2 = ?$

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

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

$$= \frac{308 \cancel{\text{K}} \times 100 \cancel{\text{kPa}} \times 5.00 \text{ L}}{294 \cancel{\text{K}} \times 90 \cancel{\text{kPa}}}$$

$$v_{\text{balloon}} = 5.8 \text{ L}$$

or

$$v_{\text{balloon}} = 5.00 \text{ L} \times \frac{308 \cancel{\text{K}}}{294 \cancel{\text{K}}} \times \frac{100 \cancel{\text{kPa}}}{90 \cancel{\text{kPa}}}$$

$$v_{\text{balloon}} = 5.8 \text{ L}$$

The final total volume of the balloon will be 5.8 L.

30. $p_1 = 800 \text{ kPa}$

$T_1 = 30°\text{C} = 303 \text{ K}$

$v_1 = 1.0 \text{ L}$

$p_2 = 100 \text{ kPa}$

$T_2 = 25°\text{C} = 298 \text{ K}$

$v_2 = ?$

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

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

$$= \frac{298\ \cancel{\text{K}} \times 800\ \cancel{\text{kPa}} \times 1.0\ \text{L}}{303\ \cancel{\text{K}} \times 100\ \cancel{\text{kPa}}}$$

$$v_{\text{He}} = 7.9\ \text{L}$$

or

$$v_{\text{He}} = 1.0\ \text{L} \times \frac{298\ \cancel{\text{K}}}{303\ \cancel{\text{K}}} \times \frac{800\ \cancel{\text{kPa}}}{100\ \cancel{\text{kPa}}}$$

$$v_{\text{He}} = 7.9\ \text{L}$$

The volume occupied by the helium gas at SATP will be 7.9 L.

31. All the previous calculations are done assuming that all gases behave similarly, and that the relationships used predict behaviour for any gas.

32. $p_1 = 6.5$ atm

$T_1 = 10°\text{C} = 283$ K

$v_1 = 2.0$ mL

$p_2 = 0.95$ atm

$T_2 = 24°\text{C} = 297$ K

$v_2 = ?$

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

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

$$= \frac{297\ \cancel{\text{K}} \times 6.5\ \cancel{\text{atm}} \times 2.0\ \text{mL}}{283\ \cancel{\text{K}} \times 0.95\ \cancel{\text{atm}}}$$

$$v_{\text{bubble}} = 14\ \text{mL}$$

or

$$v_{\text{bubble}} = 2.0\ \text{mL} \times \frac{297\ \cancel{\text{K}}}{283\ \cancel{\text{K}}} \times \frac{6.5\ \cancel{\text{atm}}}{0.95\ \cancel{\text{atm}}}$$

$$v_{\text{bubble}} = 14\ \text{mL}$$

The final volume of the bubble will be 14 mL.

33. The most important assumption in all previous calculations is that in every case the amount of gas remains constant.

Making Connections

34. (a) As the temperature increases, the pressure must increase: they are directly related, as expressed by $\frac{p}{T} = \text{k}$.

(b) Pressure and volume are inversely related, as expressed by $pv = \text{k}$, so if the pressure drops to 1/9 the previous value, the volume should increase to 9 times its previous value.

Reflecting

35. The appropriate law is chosen by examining which variables change, and which remain constant. The combined gas law may always be used: unchanged variables simply cancel.

SECTION 9.2 QUESTIONS

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Understanding Concepts

1. **Table 6:** Using Pressure Units

	Pressure (kPa)	Pressure (atm)	Pressure (mm Hg)
(a)	**88.7**	0.875	**665**
(b)	25.0	**0.247**	**188**
(c)	**112**	**1.11**	842

(a) $0.875\ \cancel{\text{atm}} \times \dfrac{101.325\ \text{kPa}}{1\ \cancel{\text{atm}}} = 88.7\ \text{kPa}$

$0.875\ \cancel{\text{atm}} \times \dfrac{760\ \text{mm Hg}}{1\ \cancel{\text{atm}}} = 665\ \text{mm Hg}$

(b) $25.0\ \cancel{\text{kPa}} \times \dfrac{1\ \text{atm}}{101.325\ \cancel{\text{kPa}}} = 0.247\ \text{atm}$

$25.0\ \cancel{\text{kPa}} \times \dfrac{760\ \text{mm Hg}}{101.325\ \cancel{\text{kPa}}} = 188\ \text{mm Hg}$

(c) $842\ \cancel{\text{mm}}\ \cancel{\text{Hg}} \times \dfrac{101.325\ \text{kPa}}{760\ \cancel{\text{mm}}\ \cancel{\text{Hg}}} = 112\ \text{kPa}$

$842\ \cancel{\text{mm}}\ \cancel{\text{Hg}} \times \dfrac{1\ \text{atm}}{760\ \cancel{\text{mm}}\ \cancel{\text{Hg}}} = 1.11\ \text{atm}$

2. **Table 7:** Celsius and Kelvin

	t (°C)	*T* (K)
(a)	25	**298**
(b)	–35	**238**
(c)	**39**	312
(d)	**–65**	208

3. (a) inverse
   (b) direct
   (c) direct
   (d) amount

4. (a) $p_1 = 225\ \text{kPa}$

$v_1 = 27\ \text{L}$

$p_2 = 98\ \text{kPa}$

$v_2 = ?$

$$p_1v_1 = p_2v_2$$

$$v_2 = \frac{p_1v_1}{p_2}$$

$$= \frac{225\ \cancel{\text{kPa}} \times 27\ \text{L}}{98\ \cancel{\text{kPa}}}$$

$$v_{\text{air}} = 62\ \text{L}$$

or

$$v_{\text{air}} = 27\ \text{L} \times \frac{225\ \cancel{\text{kPa}}}{98\ \cancel{\text{kPa}}}$$

$$v_{\text{air}} = 62\ \text{L}$$

The final volume of the escaped air will be 62 L.

(b) The new volume is 62/27 = 2.3 times larger than before. The pressure has dropped by the inverse factor, and is 0.44 times its previous value. So, while the pressure has dropped, the volume has increased.

5. $p_1 = 1.00\ \text{atm}$

$T_1 = 40.0°\text{C} = 313\ \text{K}$

$v_1 = 500\ \text{mL}$

$p_2 = 35.0\ \text{atm}$

$T_2 = ?$

$v_2 = 23.0\ \text{mL}$

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

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

$$= \frac{313\ \text{K} \times 35.0\ \cancel{\text{atm}} \times 23.0\ \cancel{\text{mL}}}{}$$

$$T_{\text{fuel}} = 504\ \text{K} = 231°\text{C}$$

or

$$T_{\text{fuel}} = 313\ \text{K} \times \frac{35.0\ \cancel{\text{atm}}}{1.00\ \cancel{\text{atm}}} \times \frac{23.0\ \cancel{\text{mL}}}{500\ \cancel{\text{mL}}}$$

$$T_{\text{fuel}} = 504\ \text{K} = 231°\text{C}$$

The final temperature of fuel gases in the cylinder will be 231°C.

Applying Inquiry Skills

6. (a) **Hypothesis**

The pressure of a fixed volume of a gas is directly proportional to its absolute temperature. The reasoning is that increasing the temperature increases the average kinetic energy of the molecules which, in turn, increases the pressure exerted by collisions within the vessel.

(b) **Experimental Design**

The metal sphere is immersed in a bath of ice water at the freezing point, and is left there until the gas temperature has become equal to the temperature of the water bath. The water bath is slowly raised in temperature, and the gas pressure is measured at regular temperature intervals.

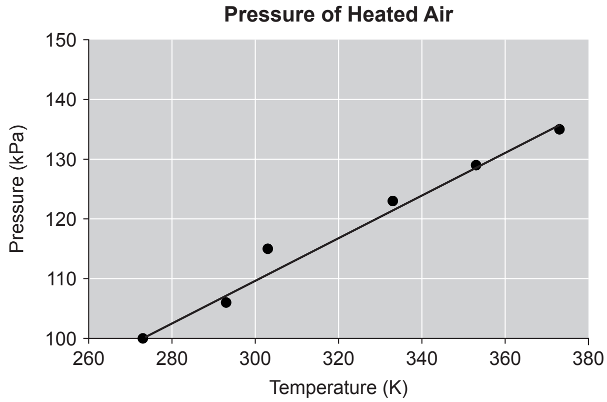
(c) **Analysis**

Converting temperatures in degrees Celsius to kelvin gives:

Table 8: Evidence

Temperature (°C)	Pressure (kPa)	Temperature (K)
0	100	**273**
20	106	**293**
40	115	**303**
60	123	**333**
80	129	**353**
100	135	**373**

Graphing pressure as a dependent variable against temperature as an independent variable gives:



A graph of the evidence clearly shows that the pressure–temperature relation is very close to a straight line. This means that, according to the evidence gathered in this investigation, pressure is directly proportional to the absolute (kelvin) temperature for the gas sample.

(d) **Evaluation**

The evidence is judged to be adequate. The design and materials are simple and straightforward, and provide evidence that enables the question to be answered easily and without ambiguity.

The hypothesis is supported by evidence gathered in the investigation and, therefore, verified.

Making Connections

7. (a) p_1 = 305 kPa

T_1 = 130°C = 403 K

v_1 = 1.0 L

p_2 = 101 kPa

T_2 = 93°C = 366 K

v_2 = ?

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

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

$$= \frac{366\ \cancel{K} \times 305\ \cancel{kPa} \times 1.0\ L}{403\ \cancel{K} \times 101\ \cancel{kPa}}$$

$$v_{bubble} = 2.7\ L$$

or

$$v_{bubble} = 1.0\ L \times \frac{305\ \cancel{kPa}}{101\ \cancel{kPa}} \times \frac{366\ \cancel{K}}{403\ \cancel{K}}$$

$$v_{bubble} = 2.7\ L$$

The final total volume of the water vapour bubble will be 2.7 L.

(b) The narrow shaft opening is necessary to restrict flow, so that pressure has the time to build up enough to spray the water high above the surface.

9.3 COMPRESSED GASES

PRACTICE

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Understanding Concepts

1. (a) $p_1 = 300$ kPa

$v_1 = 6.0$ L

$p_2 = 100$ kPa

$v_2 = ?$

$$p_1 v_1 = p_2 v_2$$

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

$$= \frac{300\ \cancel{kPa} \times 6.0\ L}{100\ \cancel{kPa}}$$

$$v_{air} = 18\ L$$

or

$$v_{air} = 6.0\ L \times \frac{300\ \cancel{kPa}}{100\ \cancel{kPa}}$$

$$v_{air} = 18\ L$$

The air volume at surface conditions will be 18 L.

(b) If you try to hold your breath while rising from a deep dive using scuba gear, the decrease in outside pressure can result in serious damage to the alveoli in your lungs, caused by the pressure differential inside and outside your chest.

(c) Temperature is assumed to be constant, as is the amount of gas.

2. The contents of aerosol cans are already under high pressure. If heating raises the temperature, the pressure will increase proportionally. If the pressure becomes too high, the can may rupture abruptly (explode), which could injure someone nearby.

Making Connections

3. Typical answers might include careers such as:
Trucks have braking systems that use compressed air to exert very high forces; drivers must be certified to operate vehicles using such systems.
Welders are trained to use a variety of pressurized gases: acetylene and oxygen that are mixed to form the fuel; inert gases such as argon that keep air away from a weld so that it does not oxidize.

