

Pneumatics

Gases

All gases have common physical properties.

- Compressibility: Unlike liquids, gases can be easily and highly compressed.
- Expandability: Like liquids, gases expand to fill their containers.
- Volume: Gases occupy more space than the liquids or solids from which they form.

Gases are affected by three variables: pressure (p), temperature (T), and volume (V).

Pressure

Pressure is the measure of force acting perpendicular to a unit area. For example, consider a book laying flat on a table. The book exerts a force on the table equal to its weight divided by the surface area of the book. If you stood that same book up on edge, it would exert a greater force on the table, since the same weight is divided by a much smaller surface area.

In pneumatics, a fluid in a cylinder exerts pressure on a piston equal to the force divided by the surface area of the piston. A perfect vacuum would have absolute zero pressure. The following definitions can help with understanding pressure, both qualitatively and quantitatively:

- Absolute pressure: The measure of pressure with respect to absolute zero pressure.
- Atmospheric pressure: The pressure within the atmosphere of the Earth, also known as air pressure or barometric pressure. Standard atmospheric pressure equals 14.7 lb/in², although it may be higher at higher elevations and lower at sea level.
- Gauge pressure: The relative pressure of the compressed air within a system. It is measured relative to the ambient atmospheric pressure.

Absolute pressure is calculated by adding gauge pressure to atmospheric pressure.

$$\text{Gauge Pressure} + \text{Atmospheric Pressure} = \text{Absolute Pressure}$$

Practice Problem: If a gauge reads 120.0 psi, what is the absolute pressure?

$$P_{gau} + P_{atm} = P_{abs}$$
$$120.0 \frac{lb}{in^2} + 14.7 \frac{lb}{in^2} = 134.7 \frac{lb}{in^2}$$

Temperature

Temperature is a measure of the average kinetic energy of a substance and reflects the movement of the atoms or molecules. Absolute zero is the theoretical temperature at which all atomic or molecular motion stops. An absolute temperature scale (like Kelvin or Rankine) is one in which a reading of zero coincides with absolute

zero. The Rankine scale is related to the Fahrenheit scale, as both scales have the same size unit of temperature. The following equation represents the relationship between the two scales:

$$^{\circ}R = ^{\circ}F + 460$$

In $^{\circ}R$, absolute zero is 0; in Fahrenheit, the same value is represented by $-460^{\circ}F$.

Practice Problem: If the temperature of the air in a system is $65^{\circ}F$, what is the absolute temperature?

$$^{\circ}R = ^{\circ}F + 460$$

$$^{\circ}R = 65^{\circ}F + 460$$

$$^{\circ}R = 525^{\circ}$$

Pascal's Law

The pressure of a pneumatic system follows Pascal's Law, just like in hydraulic systems. Recall that Pascal's Law states that when pressure is applied at any point to a confined, incompressible fluid, there is an equal increase in pressure at every other point of the container. Mathematically, Pascal's Law is written as:

$$P = \frac{F}{A}$$

Perfect Gas Laws

Boyle's Law

The relationship between temperature (T), pressure (p), and volume (V) is described by the perfect gas laws—Boyle's Law and Charles' Law. Boyle's Law states that the volume of a gas at constant temperature varies inversely with the pressure exerted on it. This law is represented mathematically by the following equation.

$$p_1 (V_1) = p_2 V_2$$

where:

p = pressure

V = Volume

Unit = in^3

Practice Problem: A cylinder is filled with 40 in³ of air at a pressure of 60 psi. The cylinder is compressed to 10 in³. What is the resulting absolute pressure?

1. Convert p_1 to absolute pressure.

$$p_1 = 60 \frac{\text{lb}}{\text{in}^2} + 14.7 \frac{\text{lb}}{\text{in}^2}$$

$$p_1 = 74.7 \frac{\text{lb}}{\text{in}^2}$$

2. Substitute values in Boyle's Law formula.

$$p_1 (V_1) = p_2 V_2$$

$$74.7 \frac{\text{lb}}{\text{in}^2} (40 \text{ in}^3) = p_2 (10 \text{ in}^3)$$

$$\frac{2988 \text{ in} \cdot \text{lb}}{10 \text{ in}^3} = p_2$$

$$p_2 = 298.8 \frac{\text{lb}}{\text{in}^2}$$

Charles' Law

Charles' Law states that the volume of gas increases or decreases as the temperature increases or decreases, provided that the amount of gas and pressure remain constant. This law is represented mathematically by the following equation.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Where:

V = volume

T = Absolute Temperature

Practice Problem: An expandable container is filled with 28 in³ of air and is sitting in ice water that is 32 °F. The container is removed from the icy water and then heated to 200 °F. What is the resulting volume?

1. Convert T to absolute temperature.

$$T_1 = 32^\circ\text{F} + 460 = 492^\circ\text{R}$$

$$T_2 = 200^\circ\text{F} + 460 = 660^\circ\text{R}$$

2. Substitute values into Charles' Law formula.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{28 \text{ in}^3}{492^\circ R} = \frac{V_2}{660^\circ R}$$

$$V_2 = \frac{18480 \text{ in}^3 \cdot ^\circ R}{492^\circ R}$$

$$V_2 = 38 \text{ in}^3$$

Ideal Gas Law

Gay-Lussac's Law

Gay-Lussac's Law states that the absolute pressure of a gas increases or decreases as the temperature increases or decreases, provided that the amount of gas and the volume remain constant. This law is represented mathematically by the following equation.

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

Where: p = Absolute Pressure and T = Absolute Temperature

Practice Problem: A 300 in.³ sealed air tank is sitting outside. In the morning, the temperature inside the tank is 62 °F, and the pressure gauge reads 120 $\frac{\text{lb}}{\text{in}^2}$. By afternoon, the temperature inside the tank is expected to be close to 90 °F. What will the absolute pressure be at that point?

1. Convert p_1 to absolute pressure.

$$p_1 = 120 \frac{\text{lb}}{\text{in}^2} + 14.7 \frac{\text{lb}}{\text{in}^2}$$

$$p_1 = 134.7 \frac{\text{lb}}{\text{in}^2}$$

2. Convert T_1 and T_2 to absolute temperature.

$$T_1 = 62^\circ F + 460 = 522^\circ R$$

$$T_2 = 90^\circ F + 460 = 550^\circ R$$

3. Substitute values in Gay-Lussac's Law formula.

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

$$\frac{134.7 \frac{lb}{in^2}}{522 \text{ } ^\circ R} = \frac{p_2}{550 \text{ } ^\circ R}$$

$$p_2 = \frac{74085 \frac{lb}{in^2} \times ^\circ R}{522 \text{ } ^\circ R}$$

$$p_2 = 141.9 \frac{lb}{in^2}$$

Additional Question: If the absolute pressure is $141.9 \frac{lb}{in^2}$, what is the pressure reading at the gauge?

$$P_{gau} + P_{atm} = P_{abs}$$

$$P_{gau} + 14.7 \frac{lb}{in^2} = 141.9 \frac{lb}{in^2}$$

$$P_{gau} = 141.9 \frac{lb}{in^2} - 14.7 \frac{lb}{in^2}$$

$$P_{gau} = 127.2 \frac{lb}{in^2}$$