The Mechanics of Breathing

Breathing is an essential physiological function. Through breathing, our bodies obtain oxygen for our cells and eliminate carbon dioxide, a cellular waste product. Breathing is involuntary—the autonomic nervous system regulates our breathing without the need for conscious effort. However, if we want to, we can take temporary control of our breathing function, inhaling or exhaling as forcefully as we like.

Boyle's Law

The mechanics of breathing can be explained in terms of gas laws. Boyle's law states that the pressure and the volume of a gas in a closed container are inversely proportional—as the volume of the container decreases, the pressure of the contained gas increases. As the volume increases, the pressure decreases.

Mathematically, Boyle's law can be stated this way:

$$pV = k$$

- p = the pressure, which can be measured in pascals (Pa) or in millimeters of mercury (mm Hg) (1 pascal = 1 newton per square meter)
- V = the volume, measured in liters, milliliters, or cubic centimeters
- k = constant

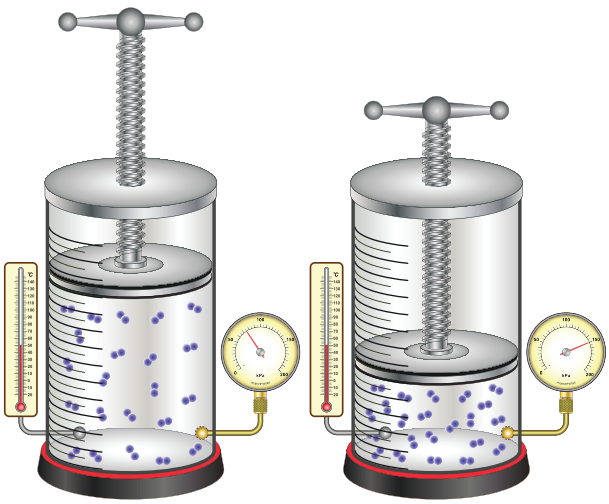
If the volume in a closed container is changed, the pressure changes along with the volume. The product of the two numbers remains the same value before and after the change:

$$p_1V_1 = p_2V_2$$

- p_1 = the initial pressure of the closed container
- V_1 = the initial volume of the closed container
- p_2 = the final pressure of the closed container
- V_2 = the final volume of the closed container

Cylinder and Piston

Many textbooks use the example of a cylinder and piston when introducing this law. As seen in the figure, as the piston moves downward, the volume decreases. The gas molecules inside the cylinder have less space to move and therefore strike the walls of the cylinder more often. As a result, the pressure increases. (Note: the pressure and volume of a gas also depend on temperature, and Boyle's law applies when temperature is constant.)



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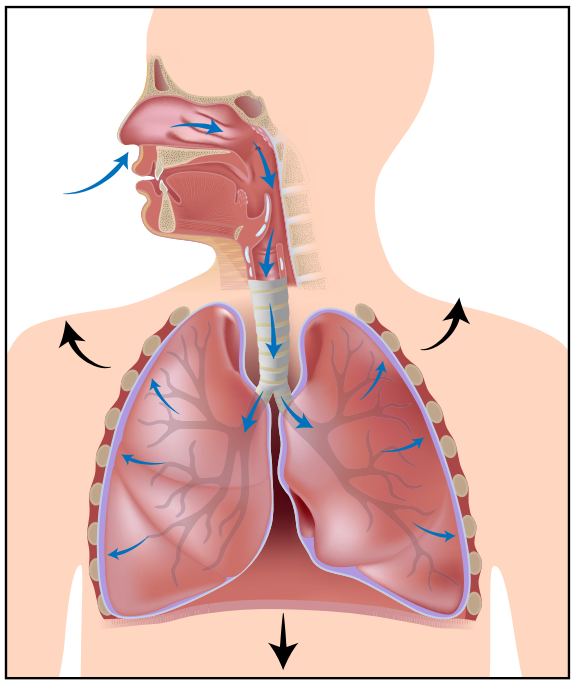
The key concept to understand is that the movement of air depends on a difference in pressure, or a pressure gradient. Even when you take a deep breath, you are not “sucking” air into your lungs. Instead, air moves due to a pressure gradient created by your respiratory system. Gases, like air, travel along a pressure gradient from high pressure to low pressure.

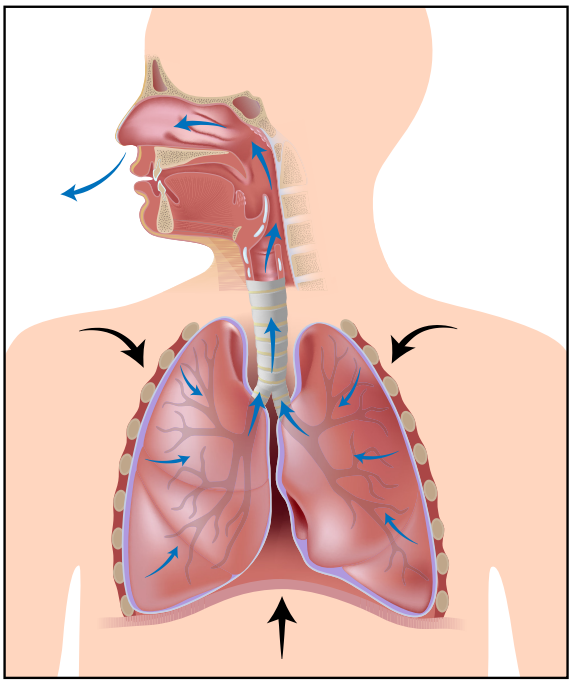
Inhaling and Exhaling

The structure of the human respiratory system functions well to create the pressure gradient needed for inhaling and exhaling. During inhalation, air is drawn in from the surroundings by a change in the volume of the lungs. This change in lung volume is due to a change in the volume of a closed container—the thoracic cavity. The thoracic cavity (also known as the chest cavity) is separated from the abdominal cavity by a domed sheet of skeletal muscle called the diaphragm. As the diaphragm contracts and is pulled down, the ribs expand, increasing the volume of the thoracic cavity.

As explained by Boyle’s law, when volume increases, the pressure in the thoracic cavity decreases. The lungs, which connect to the outside via the bronchi, trachea, nose, and mouth, provide the means for the internal and external pressure to equalize. Air rushes from the higher pressure of the surroundings into the mouth or nose and then to the lungs. Once pressure equilibrates, inhalation ends.



Inspiration



Expiration

The diaphragm relaxes, and the volume of the thoracic cavity and lungs decreases. Another pressure gradient forms, this time with higher pressure inside of the body (rather than outside of it). Air moves from the lungs out of the mouth or nose and into the surroundings during exhalation. Breathing depends on this back-and-forth pressure gradient caused by volume changes due to contraction and relaxation of the diaphragm.