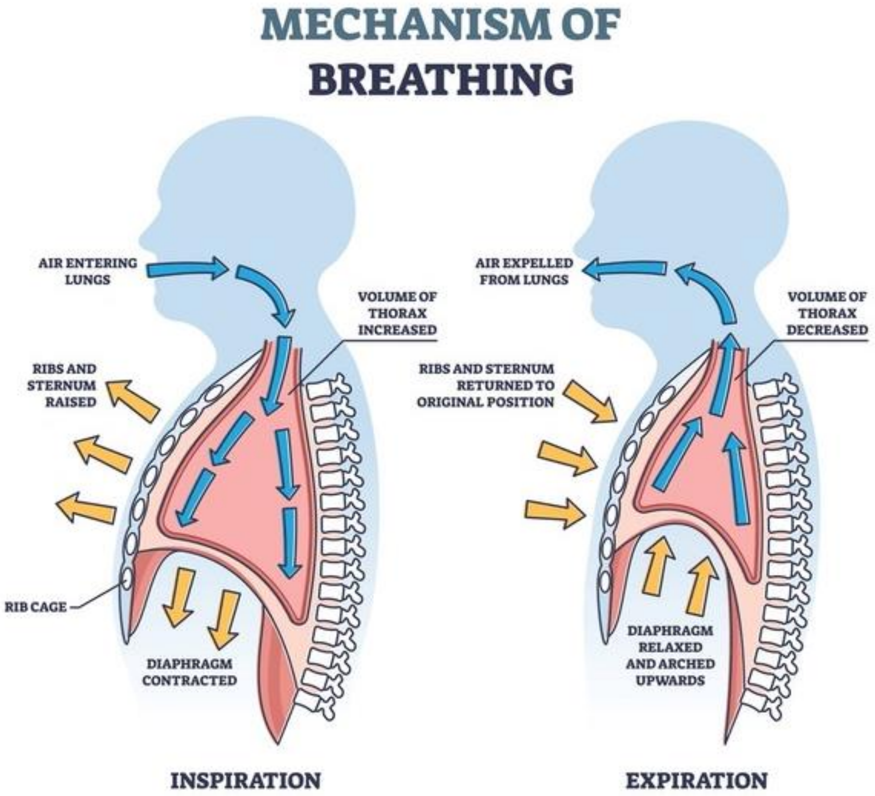
Ventilation and its Mechanism

Ventilation is the movement of air into and out of the lungs, driven by pressure gradients created by the respiratory muscles. During inspiration, the diaphragm contracts and lowers, and the intercostal muscles lift the rib cage, expanding the thoracic cavity, which decreases intrapulmonary pressure and draws air in. During expiration, the diaphragm and intercostal muscles relax, decreasing the thoracic volume, increasing intrapulmonary pressure, and forcing air out of the lungs.



Mechanism of Ventilation

Ventilation relies on the physical principles of air flowing from a high-pressure area to a low-pressure area, requiring the work of respiratory muscles to alter thoracic volume and pressure.

Components of the Ventilatory Pump

- **Lungs:**

  Housed in an airtight thoracic cavity, they are responsible for gas exchange with the bloodstream.

- **Thoracic Cavity:**

  Formed by the ribs, sternum, and vertebrae, this cavity encloses and protects the lungs.

- **Diaphragm:**

  A large, dome-shaped muscle forming the floor of the thoracic cavity, it is the primary muscle of inspiration.

- **Intercostal Muscles:**

Muscles located between the ribs that help lift and move the rib cage during breathing.

- **Pleura:**
  A thin layer of fluid-filled space (pleural space) between the lungs and the chest wall, acting as a lubricant.
  The Cycle of Breathing

1. **<u>Inspiration</u>:**

- **Muscle Contraction:** The diaphragm contracts and moves downward, while the external intercostal muscles contract to lift the rib cage upward and outward.
- **Volume Increase:** The combined movement expands the volume of the thoracic cavity.
- **Pressure Drop:** The increased thoracic volume creates a partial vacuum, reducing the pressure inside the lungs (intrapulmonary pressure).
- **Air Inflow:** Because the intrapulmonary pressure becomes lower than atmospheric pressure, air rushes into the lungs.

2. **<u>Expiration</u>:**

- **Muscle Relaxation:** During quiet breathing, the diaphragm and external intercostal muscles relax.
- **Volume Decrease:** The elastic recoil of the lungs and chest wall causes the thoracic cavity to decrease in volume.
- **Pressure Increase:** The decreased volume increases the pressure inside the lungs (intrapulmonary pressure).
- **Air Outflow:** As intrapulmonary pressure exceeds atmospheric pressure, air is forced out of the lungs.

<u>Intra Pleural Pressure:</u>

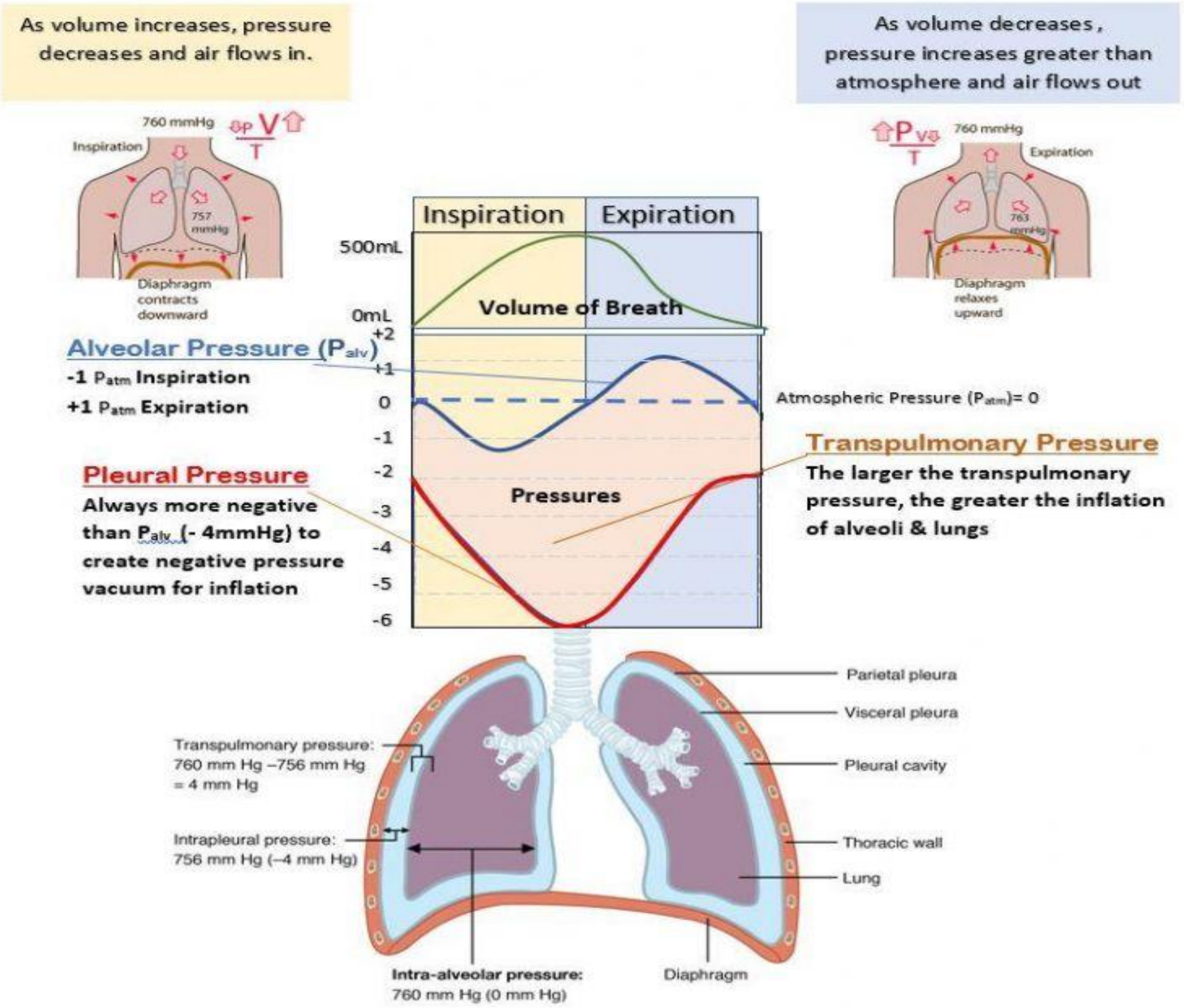
Respiratory pressures are always given in relation to **atmospheric pressure** (P_{atm}) which is the pressure exerted by the atmosphere around the body. To standardize numbers, we always set the atmospheric pressure to zero. It doesn't matter whether you are in Rexburg at nearly 5000 ft where atmospheric pressure is about 630 mmHg or at sea level which is 760 mmHg. All other pressures are compared to the atmospheric pressure of zero. Thus, a negative pressure such as -5 mm Hg describing any area in the respiratory system means that the particular respiratory area being described is 5 mm Hg lower than P_{atm}. When **alveolar pressure** (P_{alv}), the pressure inside the alveoli, is -1 mm Hg, inhalation will occur and air will flow into the lungs until alveolar pressure is zero (same as atmospheric pressure). Remember, there must be a pressure difference to have air flow. When P_{alv} is +1 mm Hg air will flow the opposite direction and exhalation will occur.

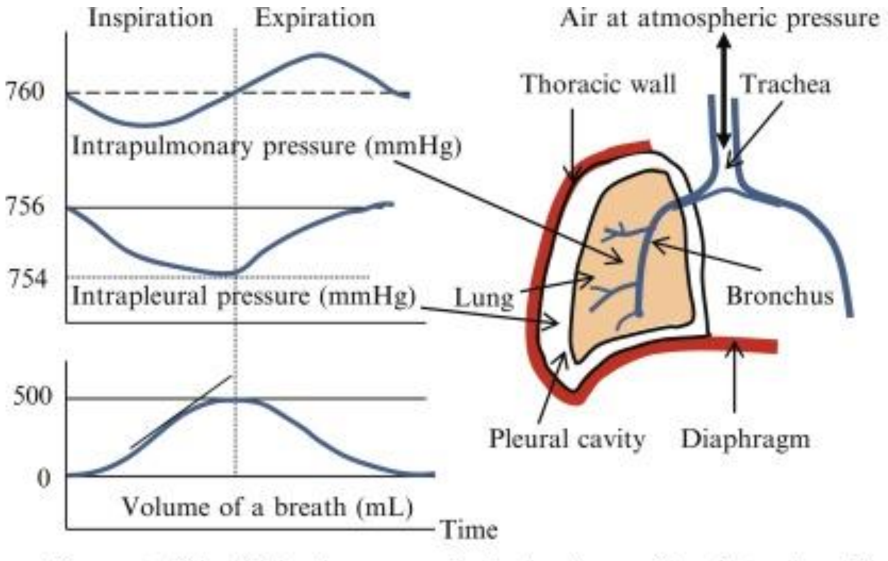
Pressure inside the pleural cavity or **pleural pressure** (also known as intrapleural pressure) is usually -4 mm Hg. Where does this negative pressure in relation to atmospheric come from? The fact that lymphatic vessels constantly suck fluid out of the pleural cavity, essentially creating a partial vacuum, contributes to a lower pleural pressure compared to alveolar pressure. There are also a couple of forces that attempt to pull the lungs away from the thoracic cavity wall and cause the lungs to assume the smallest size possible. The first is the lungs' inward elastic force. Think of a stretched rubber band - it would like to return to its resting state of not being stretched. The lungs are elastic and would like to be as small as possible. Secondly, there is surface tension exerted by water molecules inside the alveoli that are attracted to one another. This force attempts to make the alveoli as small as possible. The fact that our alveoli are placed in an environment (pleural cavity) that has a negative pressure makes it much easier for them to expand.

Imagine filling a balloon with air. In order to make it expand, it would be necessary to vigorously blow up the balloon. This would be an example of how **positive-pressure ventilation** works, in which you must force air in. In cases where a person is on a ventilator positive-pressure ventilation is used to force oxygen into the lungs. But is it also possible to get a balloon to expand by decreasing the pressure around it? Yes, it is. Put a balloon in a vacuum or take the balloon out to space and see if it expands (as long as the opening to the balloon is at atmospheric pressure). In the same way, it is easier to inflate the alveoli when they are surrounded by a partial vacuum like that in the pleural cavity. If it weren't for this lower pleural cavity pressure compared to alveolar pressure, the lungs would collapse. This is known as **negative-pressure ventilation** and is the way humans breathe under normal conditions. Unless there is an injury in the lining of the lungs that changes the pressures, there is always an area in the pleural space that is a lower pressure than the alveoli which creates a vacuum for air to flow from a high pressure to a low pressure inside the lungs.

The difference between the pleural pressure and alveolar pressure is called **transpulmonary pressure.** The larger the transpulmonary pressure the more the alveoli and the lungs will be inflated at any given moment.

Boyle's Ideal Gas Law and Pressures of Ventilation





Tangent of the tidal volume curve indicates the gas flow in trachea. The gas flow becomes zero at end-expiratory and end-inspiratory position when intrapulmonary pressure may be equal to the atmospheric pressure.

Compliance and factors affecting it

Compliance refers to the ability of the lungs and thoracic cavity to expand when pressure is applied. It's basically a measure of how easily the lungs can stretch or expand during breathing.

- **Lung Compliance** = Change in Lung Volume / Change in Transpulmonary Pressure
- High compliance means the lungs expand easily (less effort needed to breathe in).
- Low compliance means the lungs are stiff or less elastic, making breathing harder (more effort required).

Types of compliance:

1. **Lung compliance** — elasticity of lung tissue itself.
2. **Chest wall compliance** — elasticity of the rib cage and muscles involved in breathing.