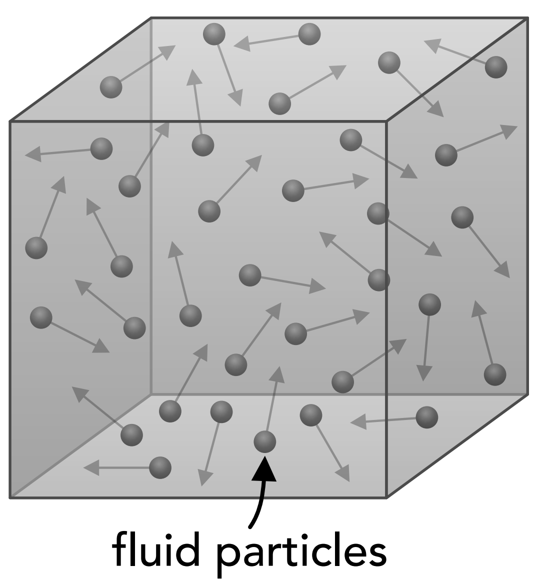
PRESSURE

Pressure

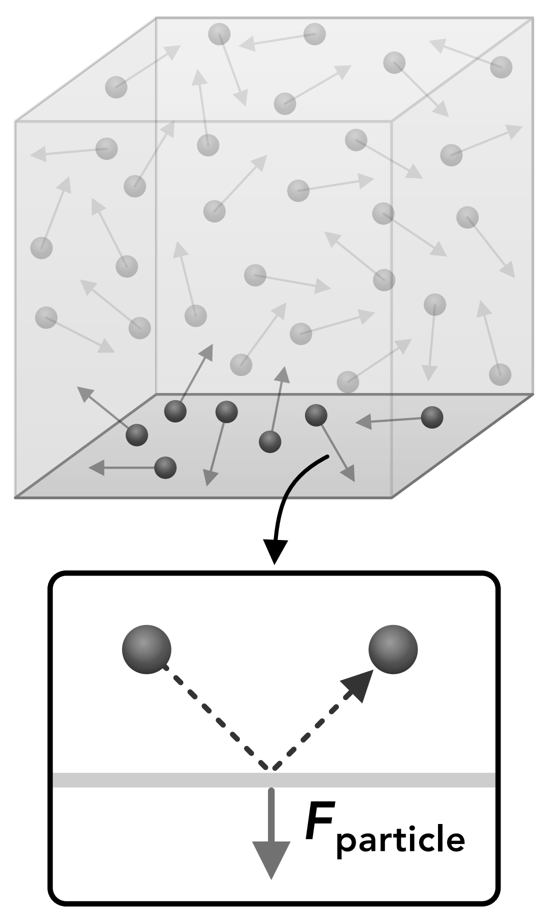
Variables		SI Unit
P	pressure	$\text{Pa} = \frac{\text{N}}{\text{m}^2}$
F	force	N
A	area	m^2

- **Pressure** is an amount of force exerted per unit of area.
- We can describe the pressure exerted on a surface by a fluid or on a fluid by a surface, and how the pressure relates to the total force and the surface area.
- The particles of a fluid (liquid or gas) are constantly moving around in random directions, and the pressure of a fluid is caused by the many **collisions** between fluid particles and between the fluid particles and the surfaces of its container.
- Because of these particle collisions **the pressure of a fluid acts in every direction**.
- Pressure is a scalar quantity (not a vector quantity) but the **force** from a pressure is a vector and always acts **perpendicular to the surface** that is in contact with the fluid.

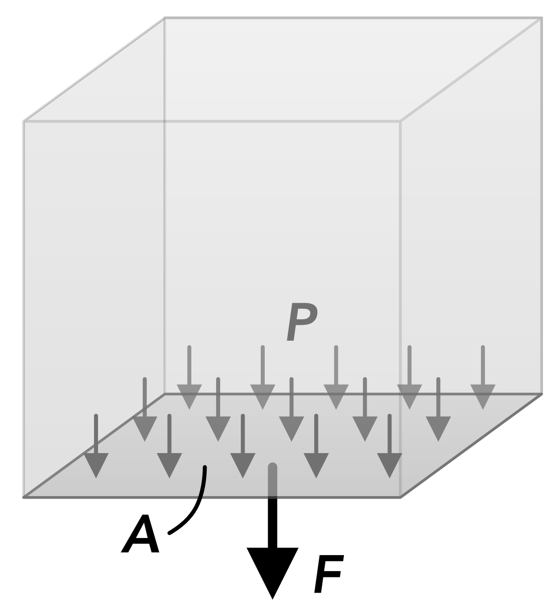
The pressure within a fluid and the pressure exerted on a surface is caused by the many fluid particle collisions



fluid particles move randomly, colliding with other fluid particles and the container walls



each time a particle collides with a wall it exerts a force on the surface

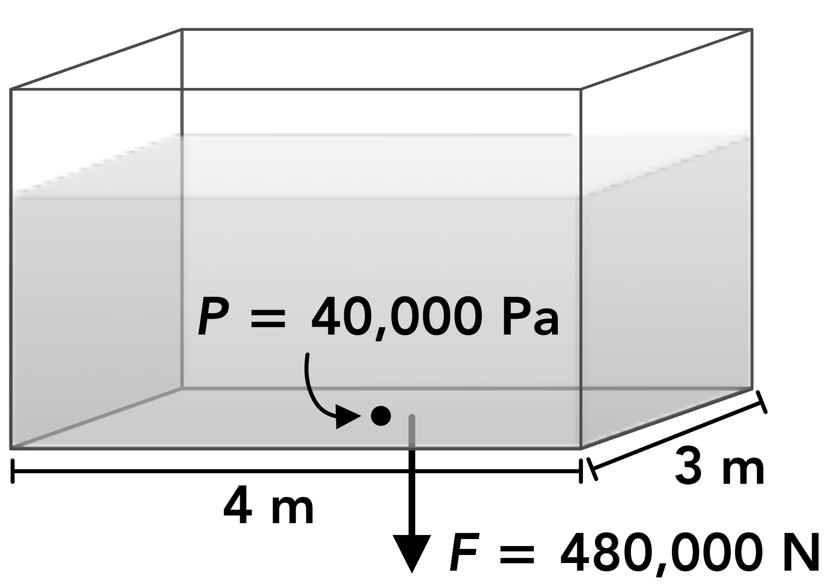


F is the net force acting on a surface of area A due to fluid pressure P

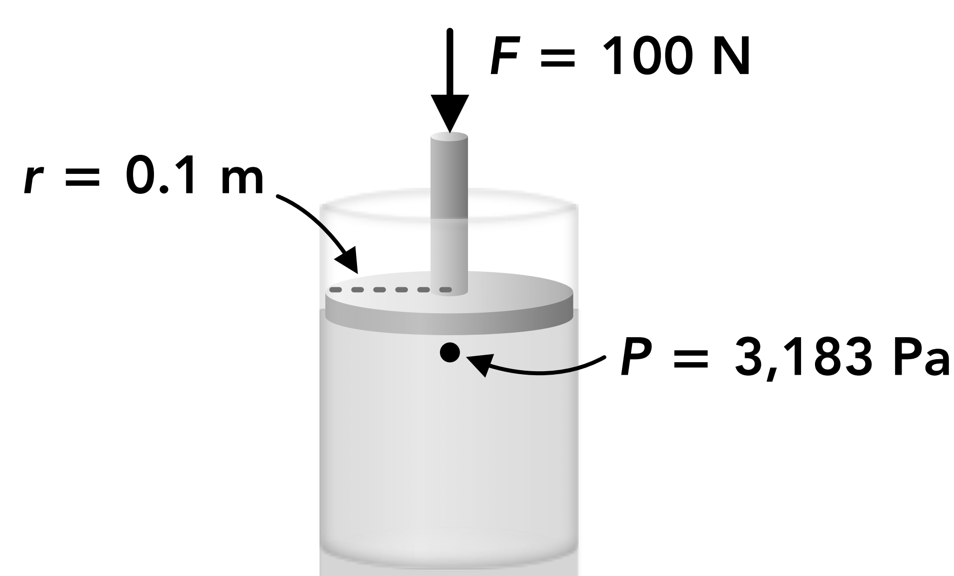
Pressure

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

Examples of a force exerted on a surface by a fluid, or on a fluid by a surface

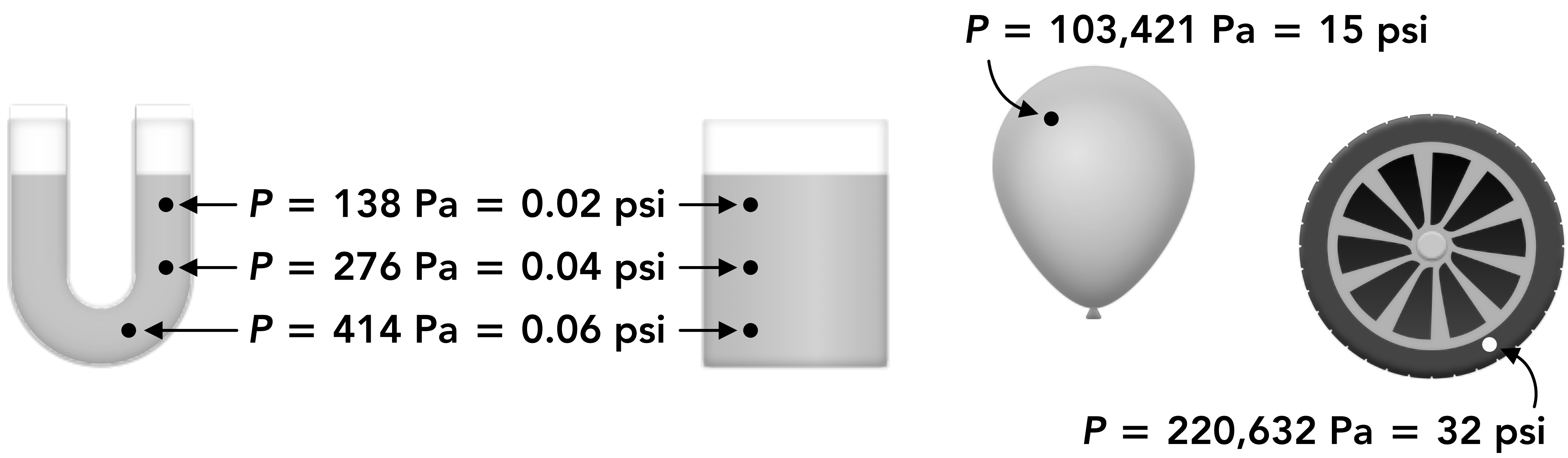


$$P = \frac{F}{A} \longrightarrow 40{,}000 \text{ Pa} = \frac{480{,}000 \text{ N}}{(4 \text{ m} \times 3 \text{ m})}$$



$$P = \frac{F}{A} \longrightarrow 3{,}183 \text{ Pa} = \frac{100 \text{ N}}{\pi(0.1 \text{ m})^2}$$

- In addition to describing the pressure acting on a surface, we can also describe the pressure at specific points within a fluid. In this case we are describing what the force per unit of area would be on a surface at that point.



- The SI unit of pressure is a **Pascal (Pa)** which is equal to 1 N/m² and named for physicist and mathematician Blaise Pascal who made important contributions to the study of fluids.
- There are many different units for pressure, some common units and conversion are listed below.

Pressure unit conversions:

1 bar = 100,000 Pa ⟵ Pa: Pascal (1 N/m²)

atm: standard atmosphere ⟶ **1 atm = 101,325 Pa**

psi: pounds/inch² ⟶ **1 psi ≈ 6,894.757 Pa**

1 Torr = 1 mmHg = 1/760 atm ≈ 133.322 Pa

inHg: inches of mercury ⟶ **1 inHg = 25.4 mmHg ≈ 3,386.38 Pa**

inH_2O: inches of water ⟶ **1 inH_2O = 2.54 cmH_2O ≈ 249.082 Pa**

Vacuums, Absolute Pressure and Gauge Pressure

Values		Unit	Name
P_{atm}	101,325	Pa	standard atmospheric pressure

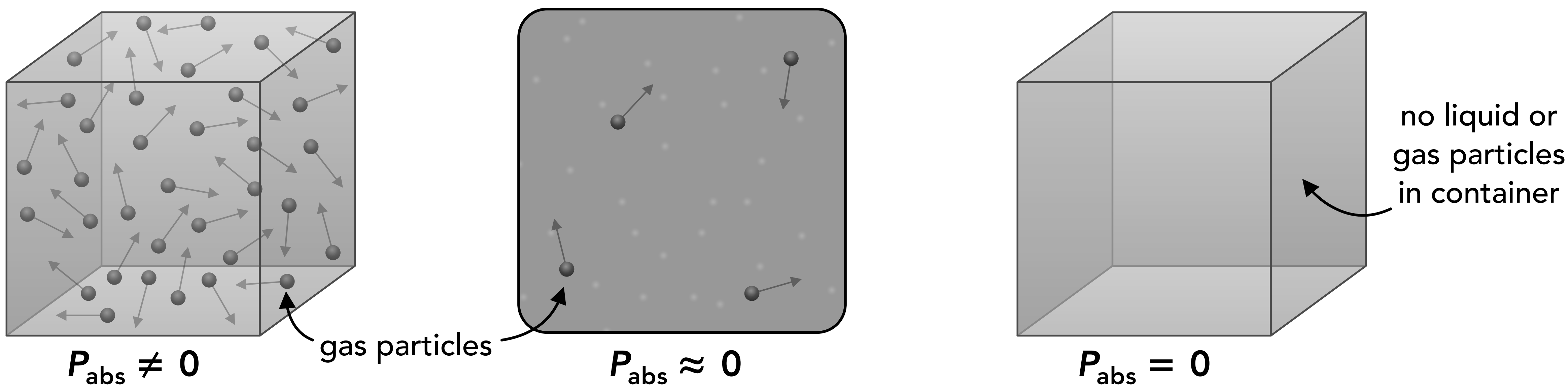
Variables		SI Unit
P_{abs}	absolute pressure	Pa
P_{gauge}	gauge pressure	Pa
P_0	reference pressure	Pa

- An **absolute vacuum**, also called a **perfect vacuum**, is when a space or container is completely empty. There are no fluid particles (liquid or gas) moving around so the space has **zero absolute pressure** because there is nothing that would create pressure.
- An absolute vacuum (zero absolute pressure) is more of a theoretical zero reference point. It's nearly impossible to create a perfect vacuum in a container, which requires removing every single gas particle using a "vacuum" pump. Outer space is nearly a perfect vacuum, but there are still some gas particles floating around.

A container filled with gas has pressure due to the gas particles

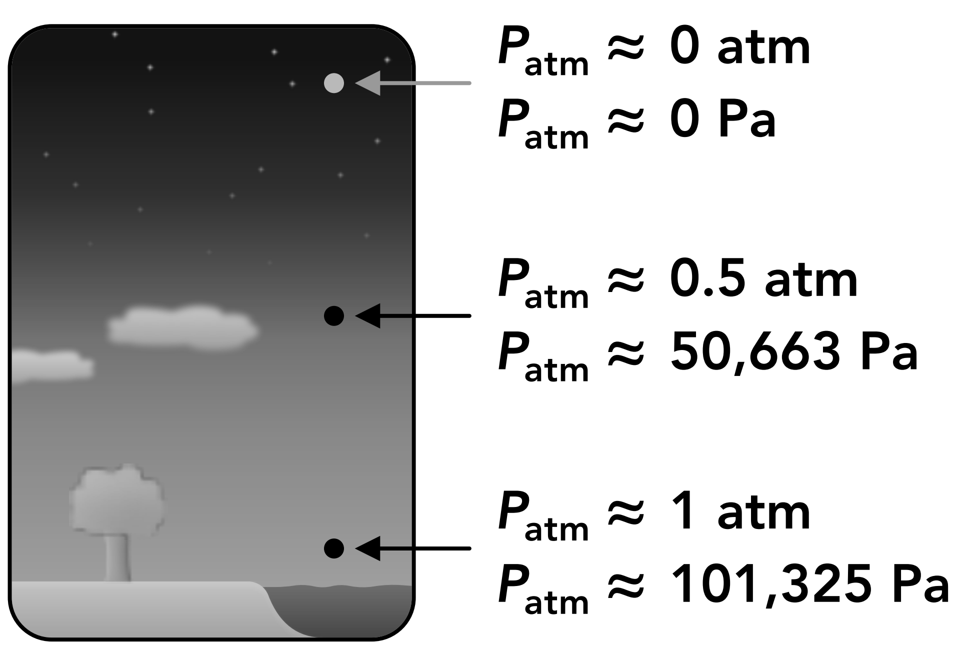
Outer space is nearly a perfect vacuum but there are still some gas particles floating around

A perfect vacuum would have no fluid particles and zero absolute pressure

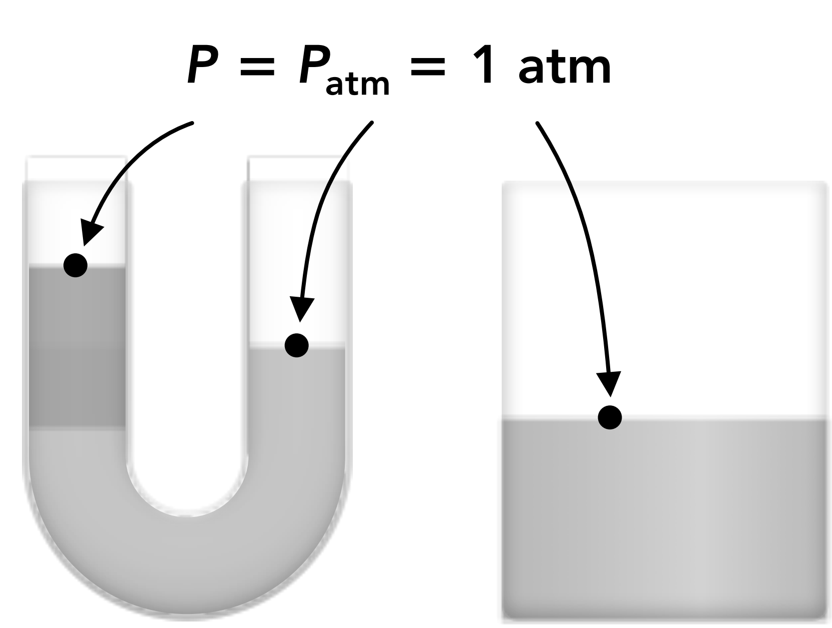


- **Atmospheric pressure** (P_{atm}) is often used as the reference pressure (P_0) when working with gauge pressures.
- Atmospheric pressure is the air pressure of the earth's atmosphere, and we usually use a value of 1 atm (equal to 101,325 Pa or 760 mmHg) which is the approximate average air pressure at sea level.
- The atmospheric pressure at sea level is due to the weight of the atmosphere above us, and atmospheric pressure decreases as you move upwards (see the following section on fluid pressure and depth).
- Anywhere that a liquid surface is exposed to atmospheric pressure, the pressure at the liquid's surface is equal to atmospheric pressure (1 atm). This fact can be used when analyzing the pressure in a fluid at different points.

Standard atmospheric pressure is 1 atm (101,325 Pa) at sea level and decreases with altitude



Any liquid surface that is exposed to the atmosphere will be at atmospheric pressure (1 atm)

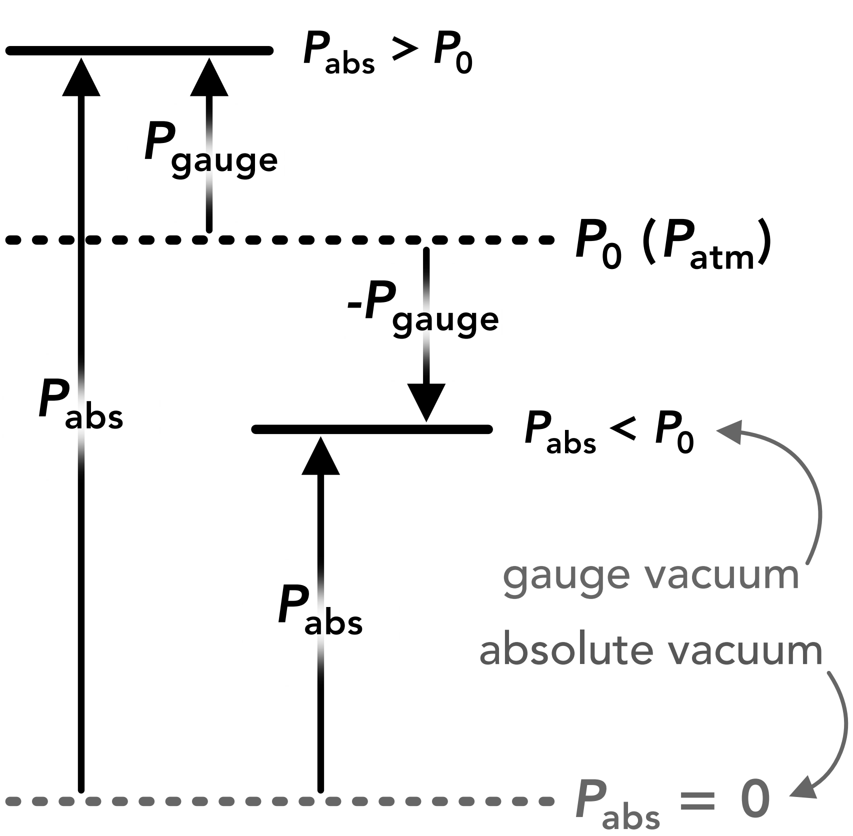


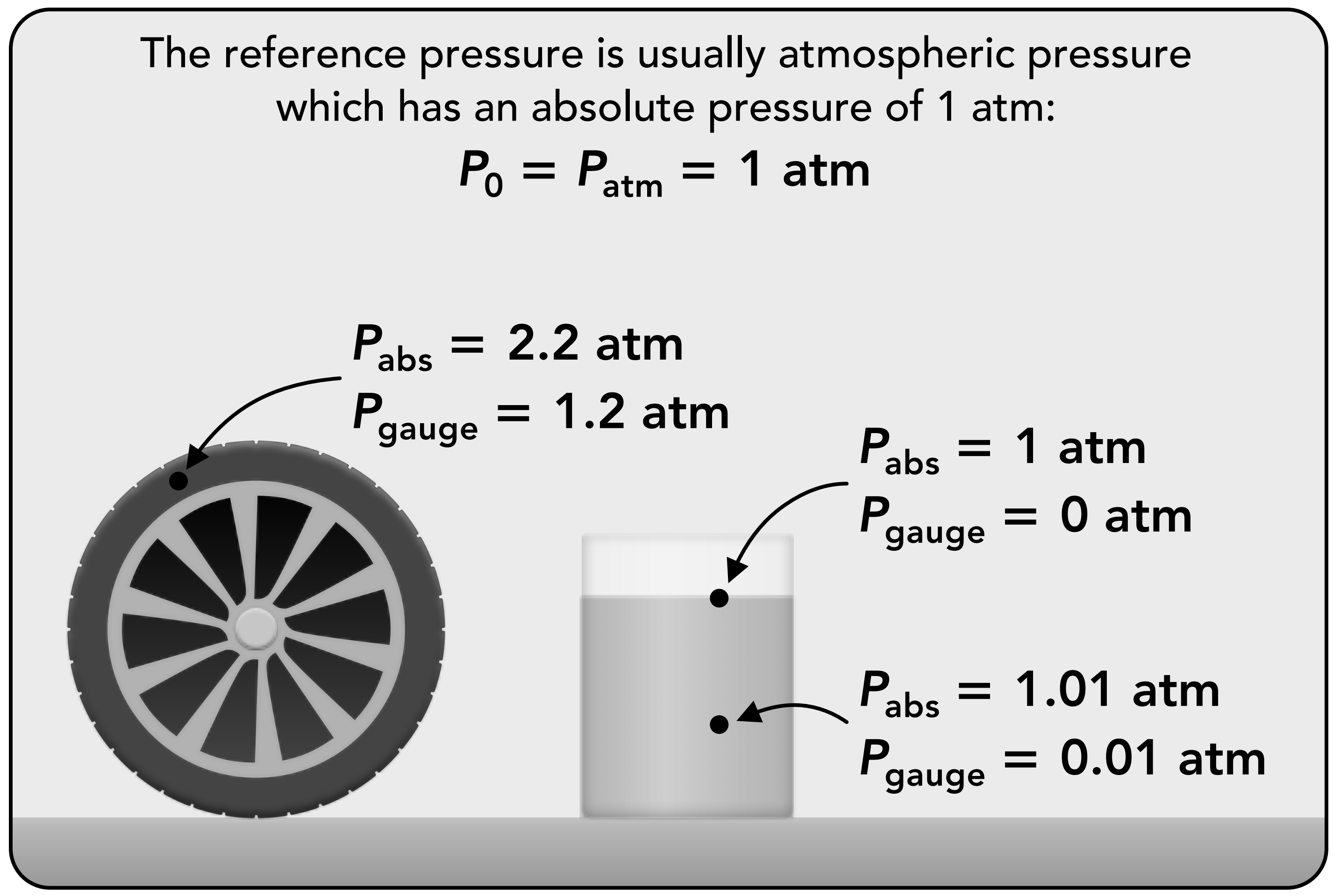
- When working with pressure it's important to specify between absolute pressure and a gauge pressure.
- **Absolute pressure** (P_{abs}) is measured relative to **zero absolute pressure** (a perfect vacuum). Absolute pressure might be referred to as the "true pressure" or the "total pressure" at a point in a fluid.
- **Gauge pressure** (P_{gauge}) is measured relative to a **reference pressure** (P_0). The reference pressure is often the absolute pressure of the surrounding environment, such as atmospheric pressure (P_{atm} = 1 atm = 101,325 Pa).
- If a pressure is less than the reference pressure (atmospheric pressure) then **the gauge pressure is negative.**
- The absolute pressure is equal to the gauge pressure plus the reference pressure. Put another way, the gauge pressure is equal to the absolute pressure minus the reference pressure.

$$P_{abs} = P_{gauge} + P_0 \longleftrightarrow P_{gauge} = P_{abs} - P_0$$

P_0 is usually P_{atm} (1 atm)

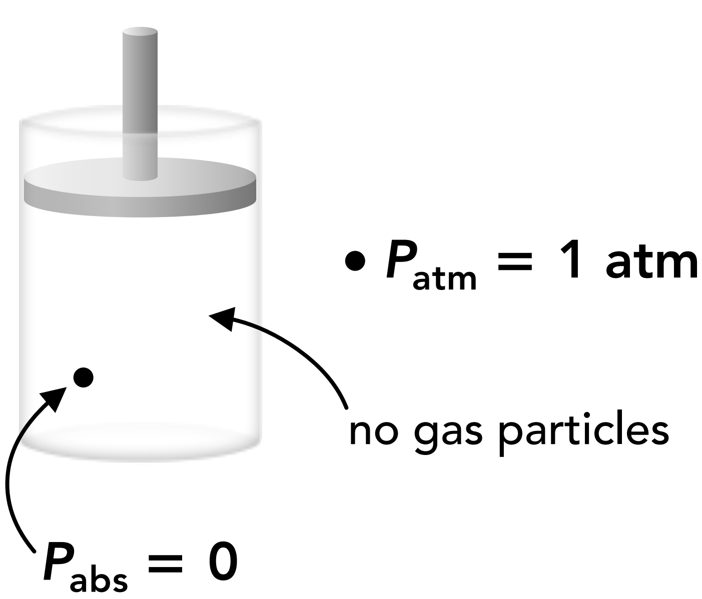
Absolute vs gauge pressure



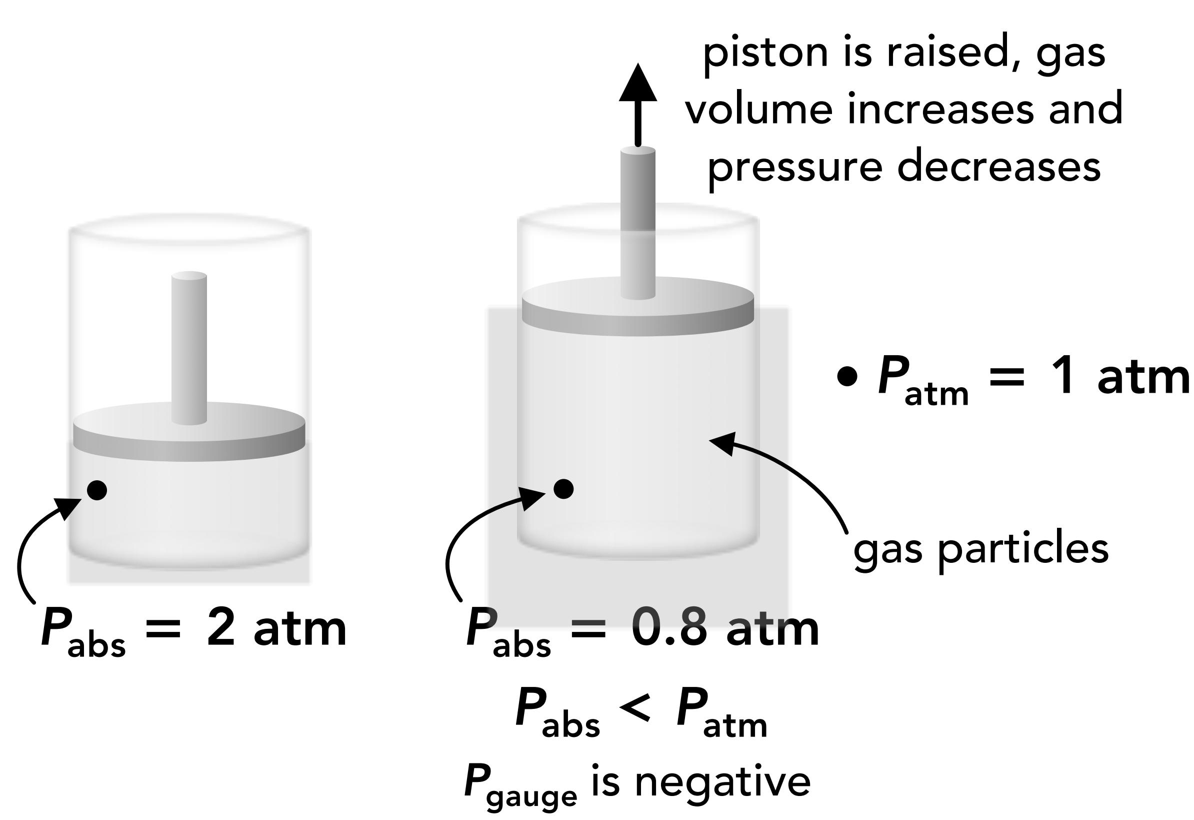


- The word "vacuum" is sometimes used to describe a gauge vacuum, which is when the gauge pressure is negative (the pressure is lower than the atmospheric pressure or reference pressure, see the diagram above). So it's important to be clear about the difference between "absolute/perfect vacuum" and "gauge vacuum".

An **absolute vacuum** is when the absolute pressure is zero and there are no fluid particles in the container.



A **gauge vacuum** is when the absolute pressure is less than atmospheric pressure and the gauge pressure is negative. There are still fluid particles present so this is not an absolute vacuum.



Pressure and Fluid Depth

Values		Unit	Name
ρ_{water}	1,000	$\frac{kg}{m^3}$	density of water (4°C)
ρ_{merc}	13,600	$\frac{kg}{m^3}$	density of mercury (0°C)
g	9.8	$\frac{m}{s^2}$	gravitational acceleration

Variables		SI Unit
ρ	fluid density	$\frac{kg}{m^3}$
h	depth below surface	m

- The pressure in a fluid **increases with depth** due to the weight of the fluid above that point pushing downwards. This is true for any fluid (liquid or gas).
- This is why the water pressure is greater at the bottom of a pool or at deeper points in the ocean, and why air pressure is lower at the top of a mountain or in a airplane (the atmosphere is like a pool of air).

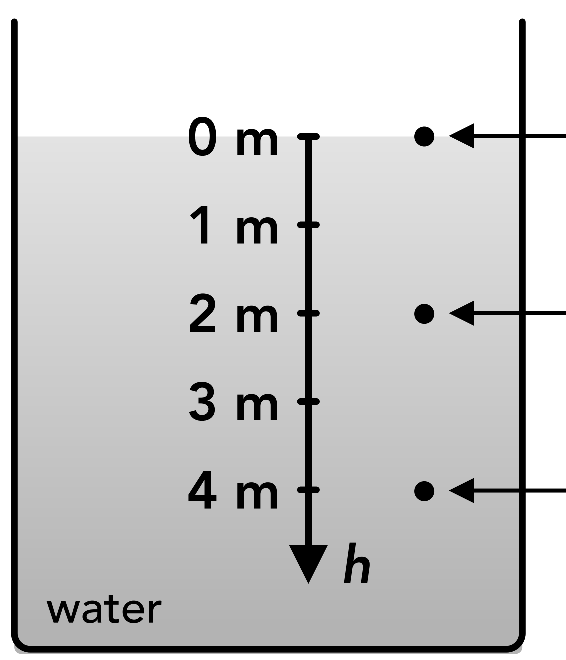
Gauge pressure at depth below surface

$$P_{gauge} = \rho g h$$

Absolute pressure at depth below surface

$$P_{abs} = \rho g h + P_0$$

$$P_{abs} = P_{gauge} + P_0$$

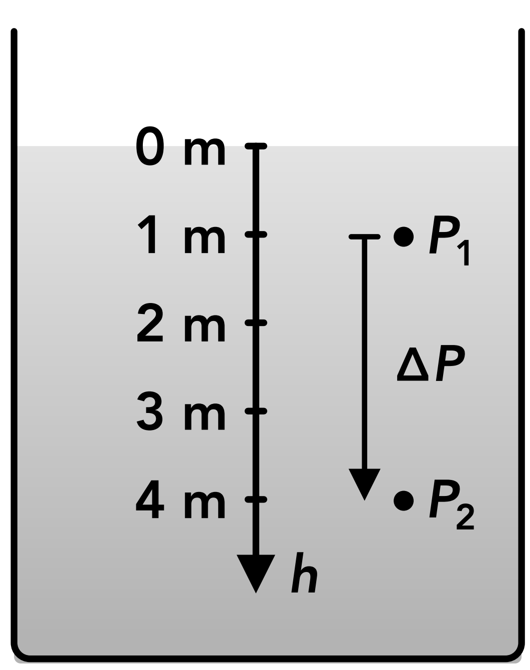


$P_{gauge} = \rho g h = (1000\ kg/m^3)(9.8\ m/s^2)(0\ m) = 0\ Pa$

$P_{gauge} = \rho g h = (1000\ kg/m^3)(9.8\ m/s^2)(2\ m) = 19{,}600\ Pa$

$P_{gauge} = \rho g h = (1000\ kg/m^3)(9.8\ m/s^2)(4\ m) = 39{,}200\ Pa$

h is depth below the surface of the fluid, down is positive



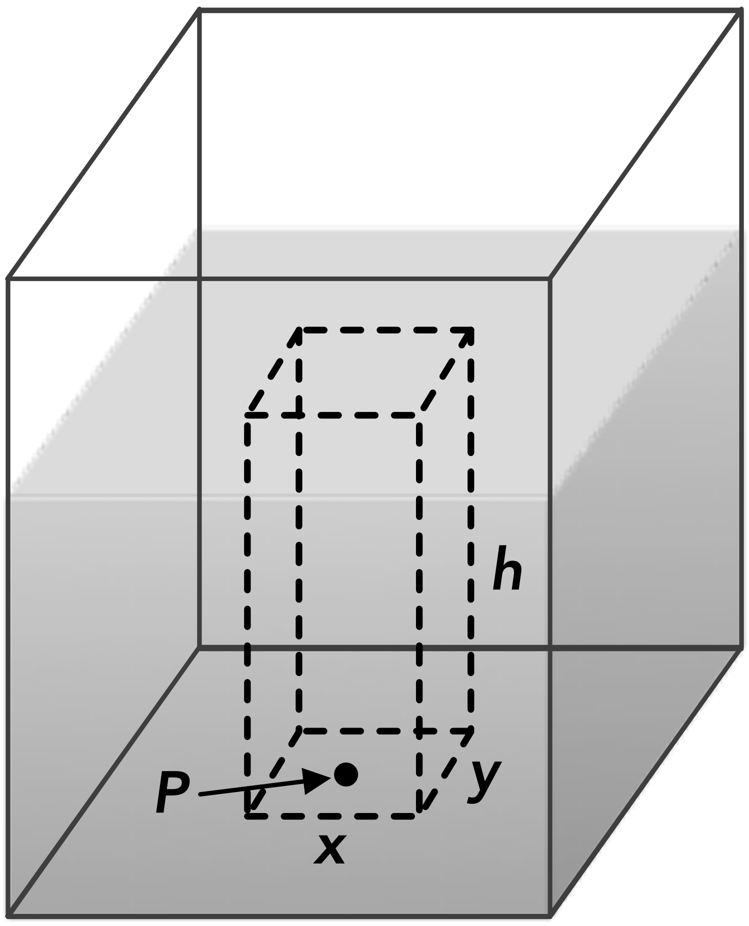
Pressure difference between two depths

$$\Delta P = \rho g \Delta h$$

$\Delta h = 4\ m - 1\ m = 3\ m$

$\Delta P = \rho g \Delta h = (1000\ kg/m^3)(9.8\ m/s^2)(3\ m) = 29{,}400\ Pa$

- The gauge pressure at a certain depth in a fluid is equal to the weight of the fluid above that point. We can derive the gauge pressure equation above by finding the weight force of a column of fluid on a specific surface area.
- The variable ***h*** is used in the equation because the pressure depends on the **height** of the column of fluid above a point, and the height of the column is the same as the depth below the surface.



weight of fluid column: $w = mg$

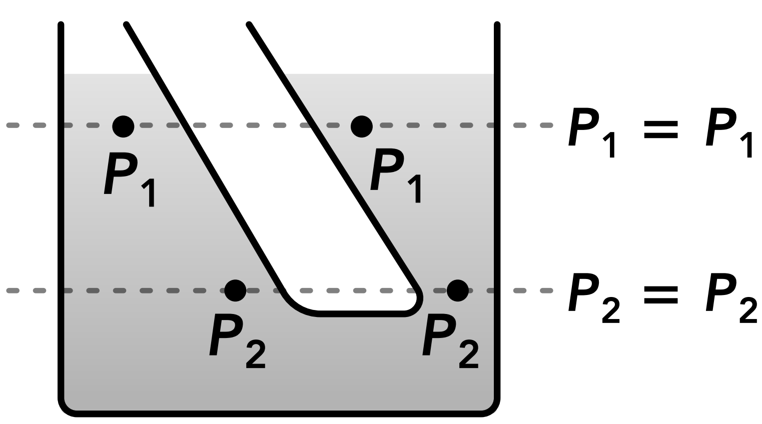
density and mass of fluid: $\rho = \frac{m}{V}$, $\rho V = m$

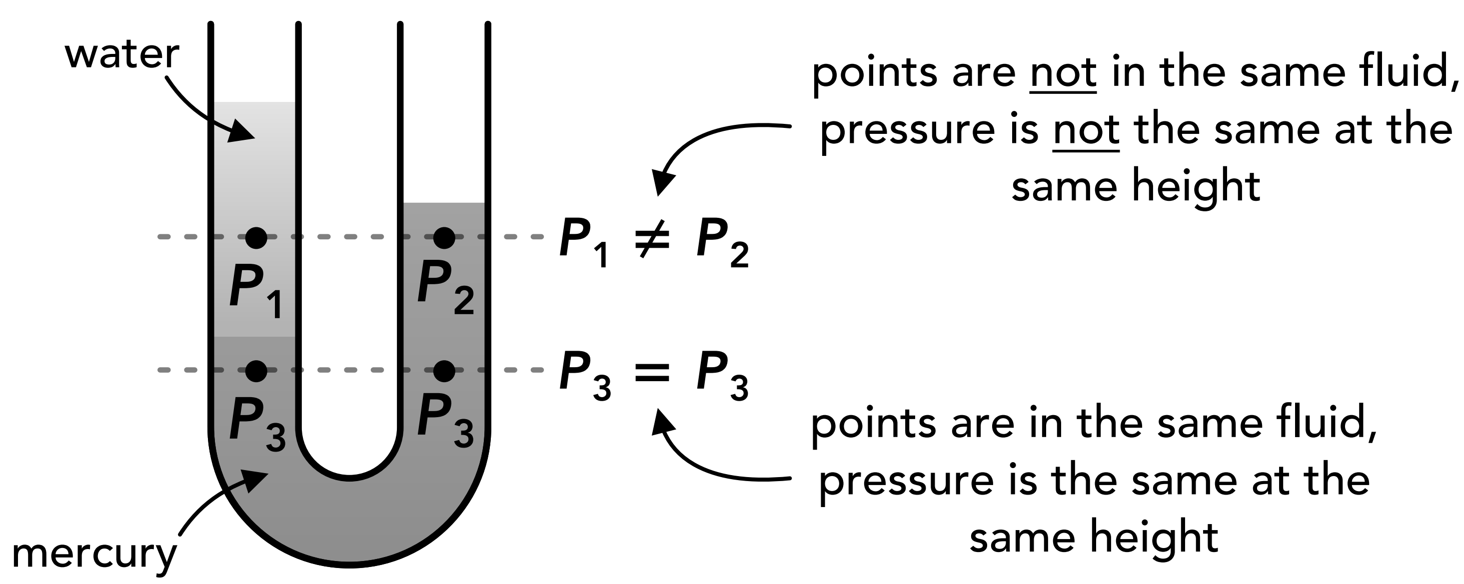
volume of fluid column: $V = xyh$

$$P = \frac{F}{A} = \frac{w}{A} = \frac{(mg)}{(xy)} = \frac{(\rho V)g}{xy} = \frac{\rho(xyh)g}{xy} = \rho g h$$

$A = xy$: area of column bottom

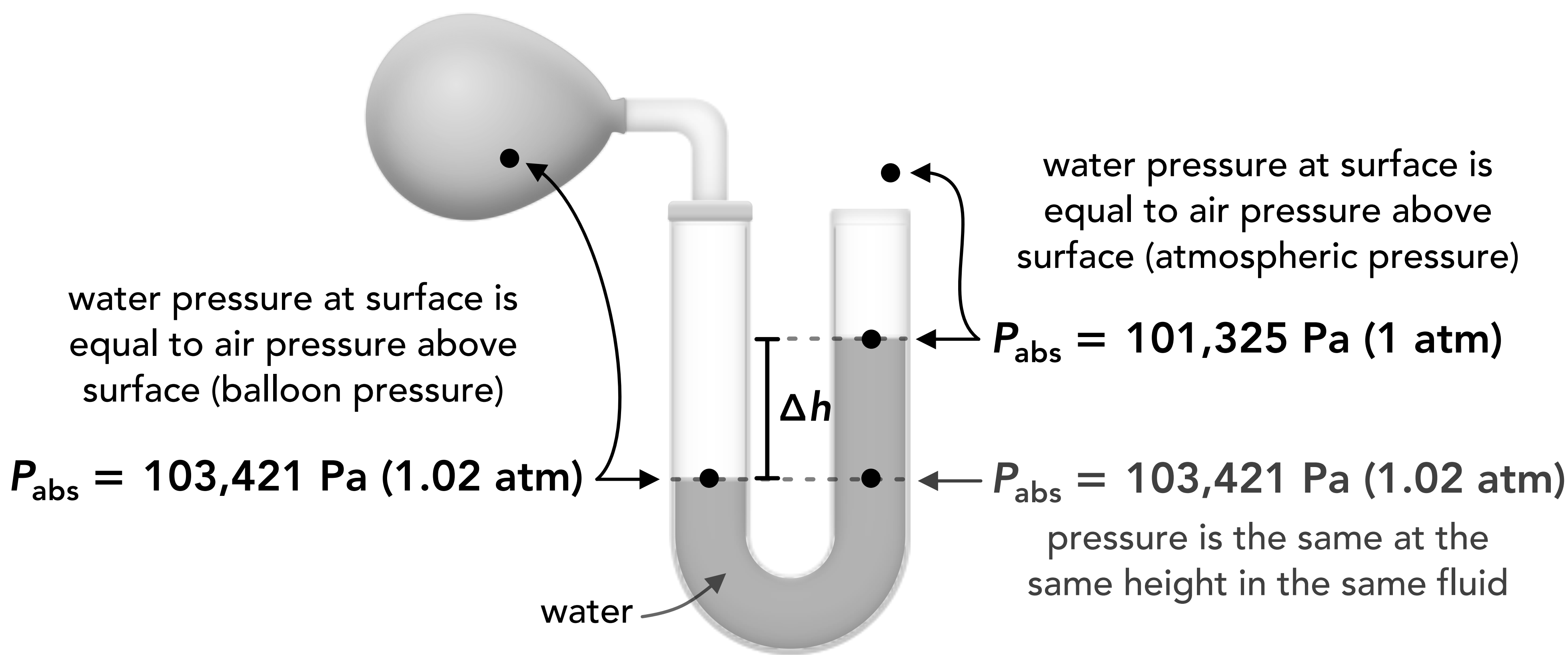
- An important fact is that **the pressure is the same everywhere in the same static fluid at the same height**. If this was not true the fluid would flow until it reached static equilibrium and the pressure was equal again.
- This fact is true regardless of the container shape, and is true even if part of the fluid is at a gauge vacuum.





- If we want to determine the absolute pressure in a fluid at a specific point we can use the equation above and the fact that any liquid surface exposed to the atmosphere will be at atmospheric pressure.
- This applies to containers with a single fluid and containers with multiple fluids like water, oil or mercury.
- Some common applications of these principles are **U-tubes**, **manometers** (pressure gauges) and **barometers** (devices used to measure true atmospheric pressure which fluctuates with the weather).
- By measuring the difference in the height of a fluid at two points we can measure things like the air pressure in a balloon or the true atmospheric pressure.

The difference in water height is caused by the difference between the balloon air pressure and the atmospheric air pressure

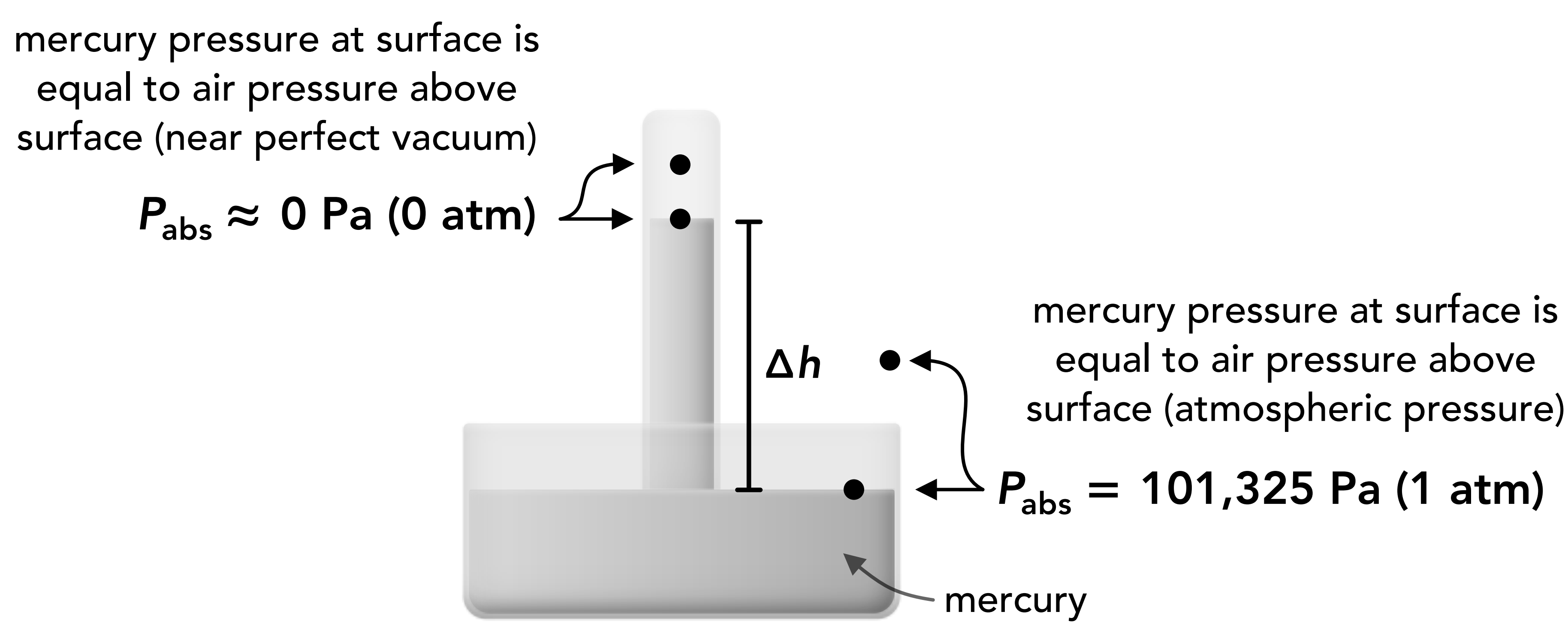


$$\Delta P = \rho g \Delta h$$

$$(103{,}421 \text{ Pa} - 101{,}325 \text{ Pa}) = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)\Delta h$$

$$0.21 \text{ m} = \Delta h$$

The height of the column of mercury in a barometer is determined by the atmospheric pressure, at 1 atm of atmospheric pressure the column will be 760 mm tall (1 atm = 760 mmHg)



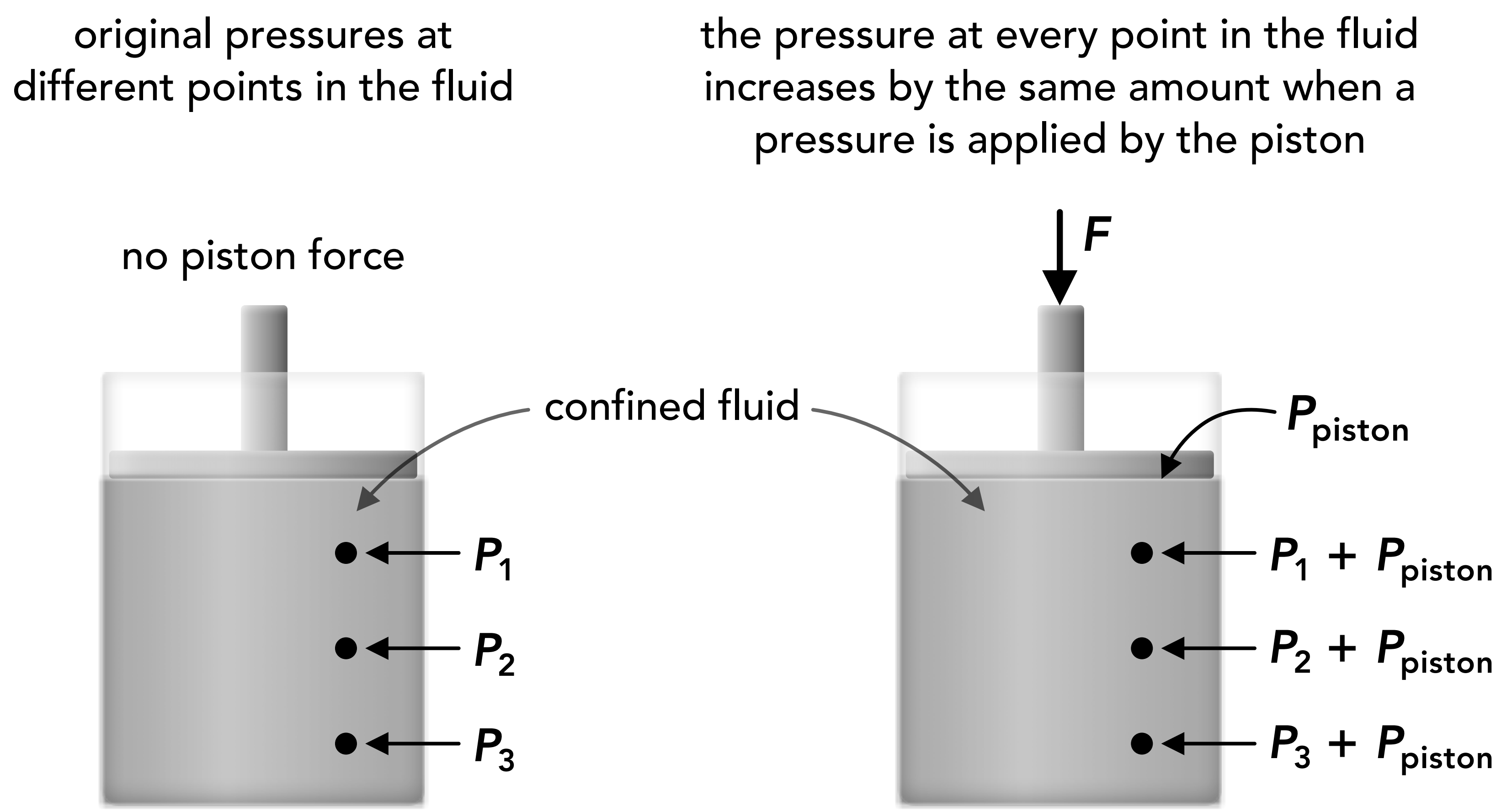
$$\Delta P = \rho g \Delta h$$

$$(101{,}325 \text{ Pa} - 0 \text{ Pa}) = (13{,}600 \text{ kg/m}^3)(9.8 \text{ m/s}^2)\Delta h$$

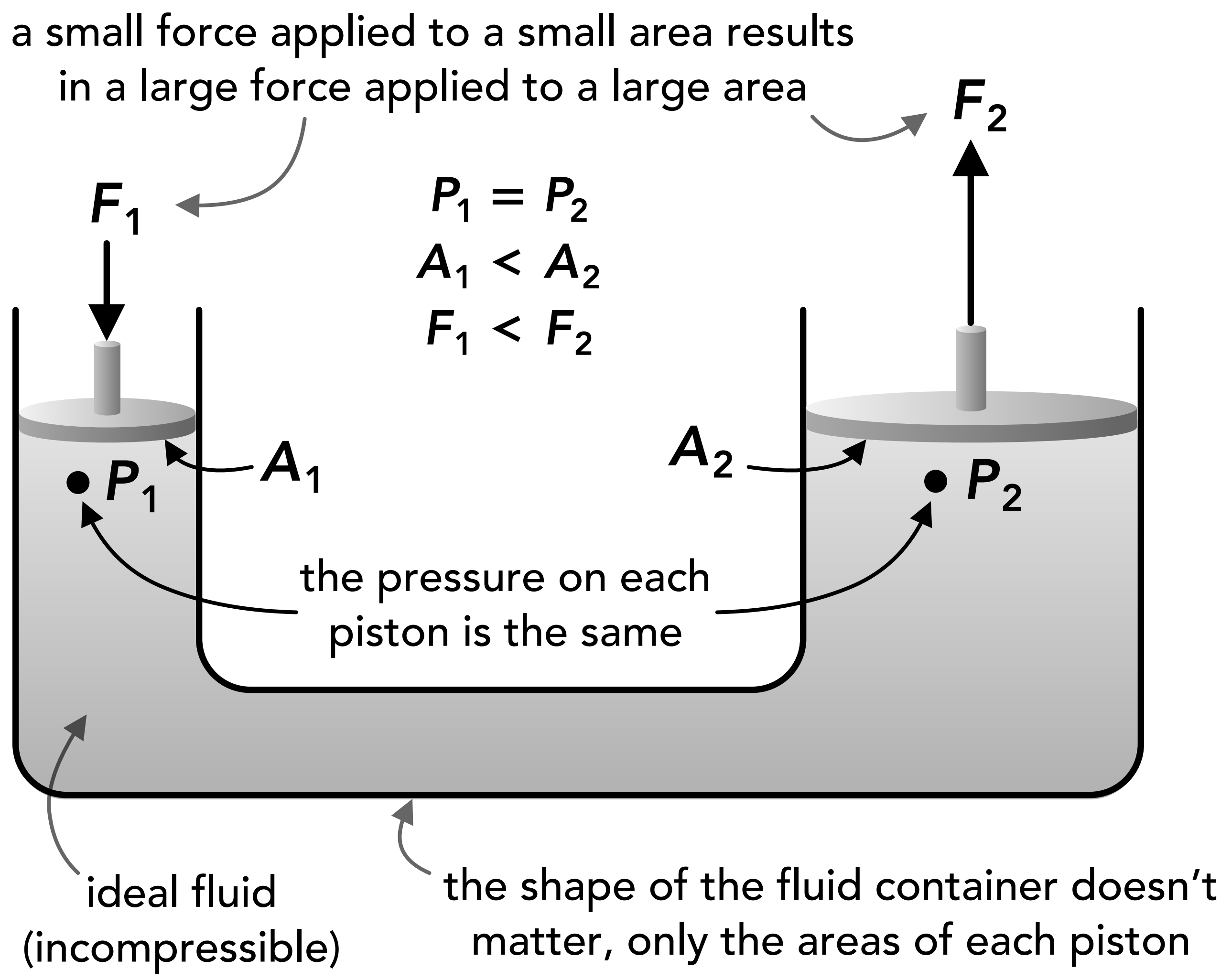
$$0.76 \text{ m} = \Delta h$$

Confined Fluids and Pascal's Principle

- If we have a container that is completely filled with a single fluid and the container is enclosed on all sides (not exposed to the atmosphere) the fluid is **confined**. If the fluid is a liquid, there cannot be any gas (air) in the container, so that the liquid is in contact with all walls of the container.
- **Pascal's principle** says that if we apply a change in pressure to any point in a confined fluid (at rest), the pressure at every point in the fluid will change by the same amount. We could say that the pressure change is "distributed" throughout the fluid in all directions.



- This principle is commonly applied to connected cylinders and pistons, which allows us to transmit forces in different directions often using a mechanical advantage (the output force is greater than the input force). These are often referred to as hydraulic systems (when using a liquid) and pneumatic systems (when using a gas).
- In this course we are going to assume the fluid in a piston system is an **ideal fluid** (an incompressible liquid).
- The change in pressure applied by one piston is transmitted to the other piston so **the change in pressures on each piston are equal**. The change in the **force** on each piston is dependent on the **surface area** of each piston.
- It's important to note that the pressure in the fluid still increases with depth, so if the pistons are at different heights then the pressure on each piston is not the same - the **change** in pressure on each piston is the same.



the pressure on each piston is the same (technically the **change** in pressure is the same but we often just say the pressure is the same)

$$P_1 = P_2$$

$$P_1 = \frac{F_1}{A_1} \qquad P_2 = \frac{F_2}{A_2}$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$F_1 \frac{A_2}{A_1} = F_2$$