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Pressure measurement

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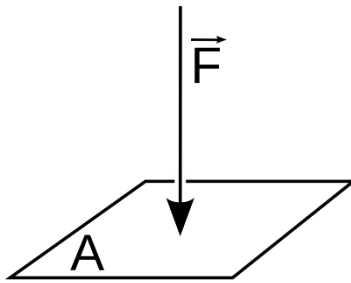
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Introduction

- The development of pressure measurement methods and techniques began with **Torricelli's experiment in 1643**, which showed that the Earth's atmospheric mantle presses the Earth's surface with a pressure corresponding to approximately 760 mm of Hg.
- Pressure is a physical quantity needed to describe the **thermodynamic state of a fluid**
- Pressure or **compressive stress** is a special form of stress, defined as a force acting on a unit area
- Often, pressure is measured to indirectly obtain the values of some other physical quantities (e.g. flow rate and fluid level).

Pressure definitions

Mechanics



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

p , Pa – pressure

F , N – force

A , m² – area

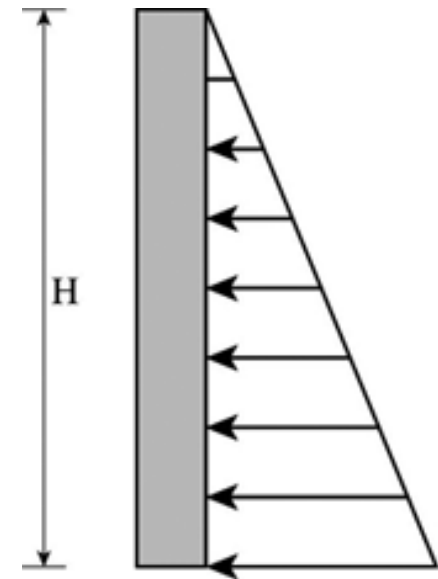
Fluid mechanics (hydrostatic pressure)

$$p = \rho gh$$

ρ , kg/m³ – fluid density

g , m/s² – gravitational acceleration

h , m – height of the liquid column (depth)



Hydrostatic pressure
on the wall

Pressure definitions

Thermodynamics:

According to the **kinetic theory of gases**, pressure is a measure of the total average kinetic energy of the translational motion of gas molecules in a volume V at a temperature T :

$$p = \frac{2}{3} Nk \frac{T}{V}$$

N – number of molecules

k – Boltzmann constant, $k = 1,38064852 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$

T, K – thermodynamic temperature

Pressure units

- 1) Pascal (Pa)
- 2) Bar atmosphere (atm)
- 3) Technical atmosphere (at)
- 4) Millimeter of water column
- 5) Millimeter of mercury column (mm Hg)
- 6) Inch of water column
- 7) Inch of mercury PSI (pounds per square inch)

Relationships between some pressure units

	Pa	bar	at	atm	mm Hg
Pa	1	1×10^{-5}	$1,0197 \times 10^{-5}$	$9,869 \times 10^{-6}$	$7,501 \times 10^{-3}$
bar	1×10^5	1	1,0197	$9,869 \times 10^{-1}$	$7,501 \times 10^2$
at	$9,807 \times 10^4$	$9,807 \times 10^{-1}$	1	$9,678 \times 10^{-1}$	$7,356 \times 10^2$
atm	$1,013 \times 10^5$	1,013	1,033	1	$7,60 \times 10^2$
mm Hg	$1,333 \times 10^2$	$1,333 \times 10^{-3}$	$1,360 \times 10^{-3}$	$1,316 \times 10^{-3}$	1

Atmospheric pressure

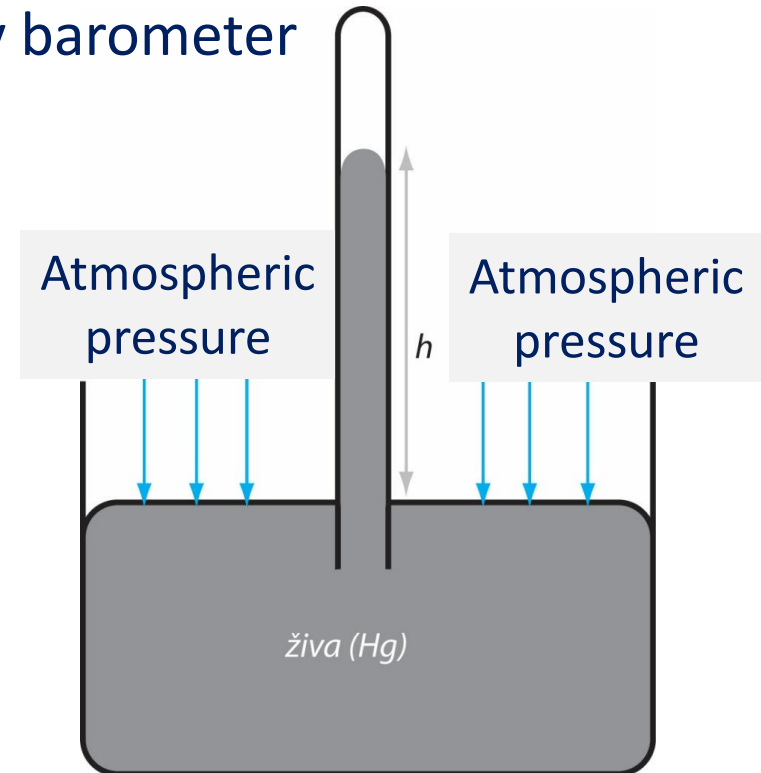
- ❑ **Atmospheric pressure** is the pressure on any part of the Earth's atmosphere
- ❑ It is equal to the **hydrostatic pressure** caused by the Earth's atmosphere located in the column above the point of measurement
- ❑ Areas of lower pressure have less mass of atmosphere above them, and areas of higher pressure have more
- ❑ **With the increase in altitude**, the column of atmosphere above decreases, and the atmospheric pressure is lower
- ❑ The weight of the air envelope is subject to many influences, so the atmospheric pressure changes constantly and irregularly
- ❑ **At sea level**, the atmospheric pressure is the highest, and the atmosphere is defined by that pressure

Measuring atmospheric pressure

Devices for measuring atmospheric pressure are called **barometers**

The working principle of a mercury barometer

$$1 \text{ atm} = 760 \text{ mm Hg} = 101325 \text{ Pa}$$



Measuring atmospheric pressure

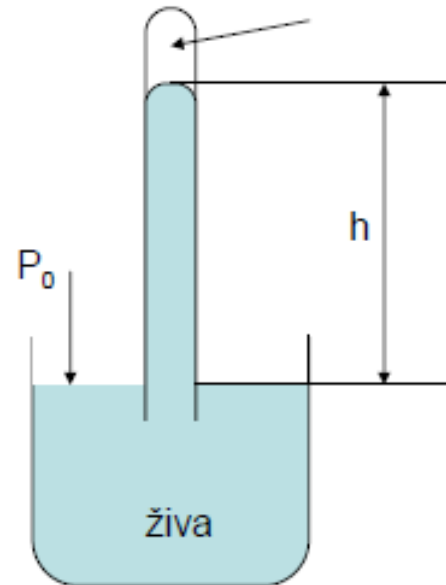
Torricelli's experiment

$$G = m \cdot g = V \cdot \rho \cdot g = A \cdot h \rho \cdot g$$

$$F = p_0 \cdot A$$

$$G = F$$

$$p_0 = h \rho \cdot g$$



$$P_0 = \rho g h$$

$$p_a = \rho g h = 13\,595,103 \cdot 9,80665 \cdot 0,76 = 101325 \text{ Pa}$$

Measuring atmospheric pressure

- The standard atmosphere** (symbol: atm) is an old unit of pressure
- It was originally defined as the pressure at which the height of the **mercury column in the barometer is 760 mm**
- This is also the air pressure measured at the mean altitude at the latitude of Paris
- This definition also depends on the density of mercury, which also depends on the pressure, it was later modified by prescribing the exact relationship according to Pascal

Technical atmosphere

- **Technical atmosphere** (sign: at) is a unit of measurement for pressure from the old technical system of units (MKpS). According to the definition, it is equal to one kilopound per square centimeter:

$$1 \text{ kp/cm}^2$$

As this definition also depends on the density of mercury, which also depends on the pressure, it was later changed by prescribing the exact relation to Pascal.

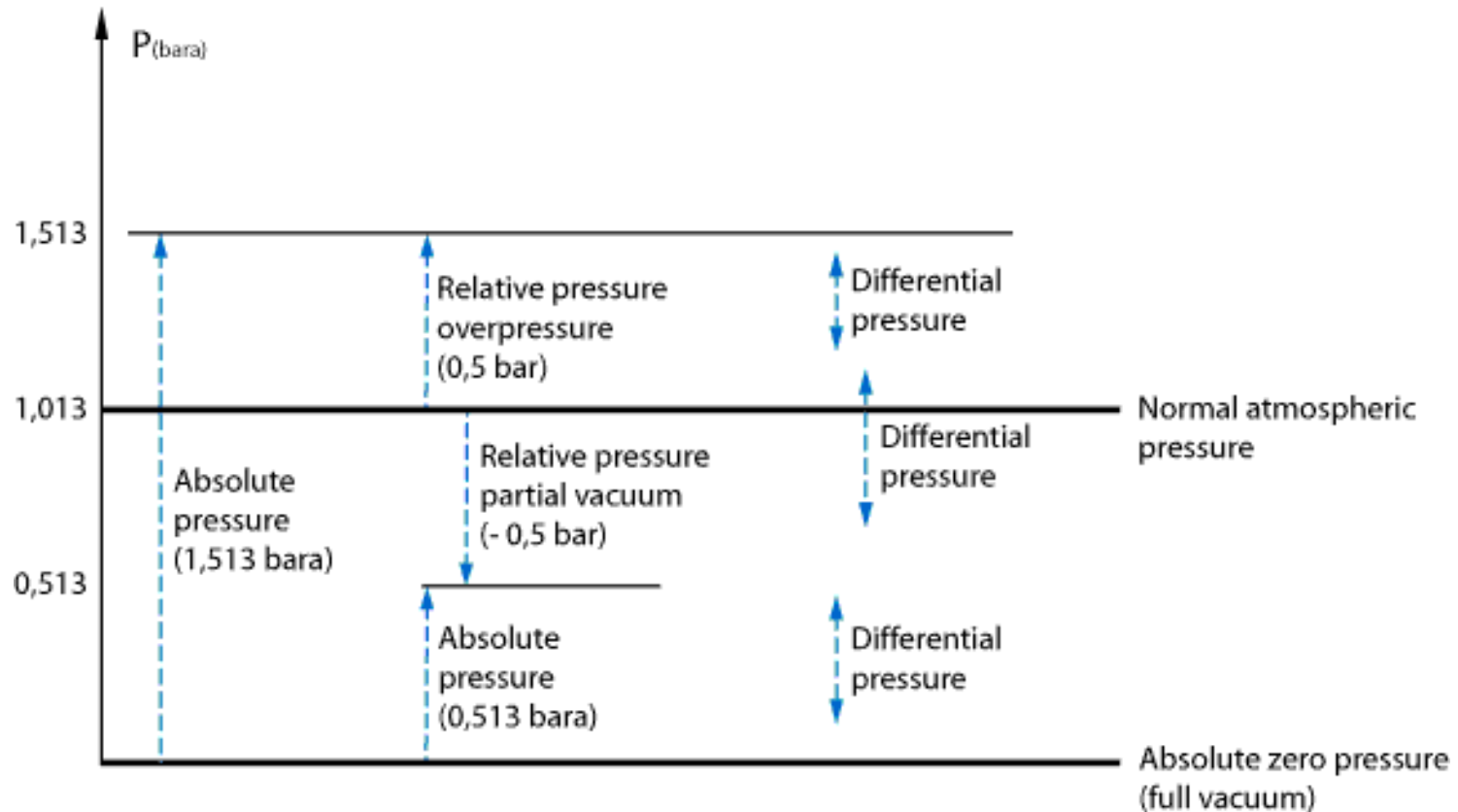
Types of pressures

- Atmospheric** pressure
- vacuum** (empty space)

If the container does not contain a single molecule, the pressure in it is zero (absolute zero = 100% vacuum). It is also used as a term for a very small pressure reduced to the smallest achievable value.

- Relative pressure** - pressure measured with respect to some reference pressure (often atmospheric)
- Absolute pressure** – pressure measured on a scale that uses absolute zero as a reference value
- Overpressure**
- Negative pressure**

Atmospheric, absolute and relative pressure



Pressure measurement methods

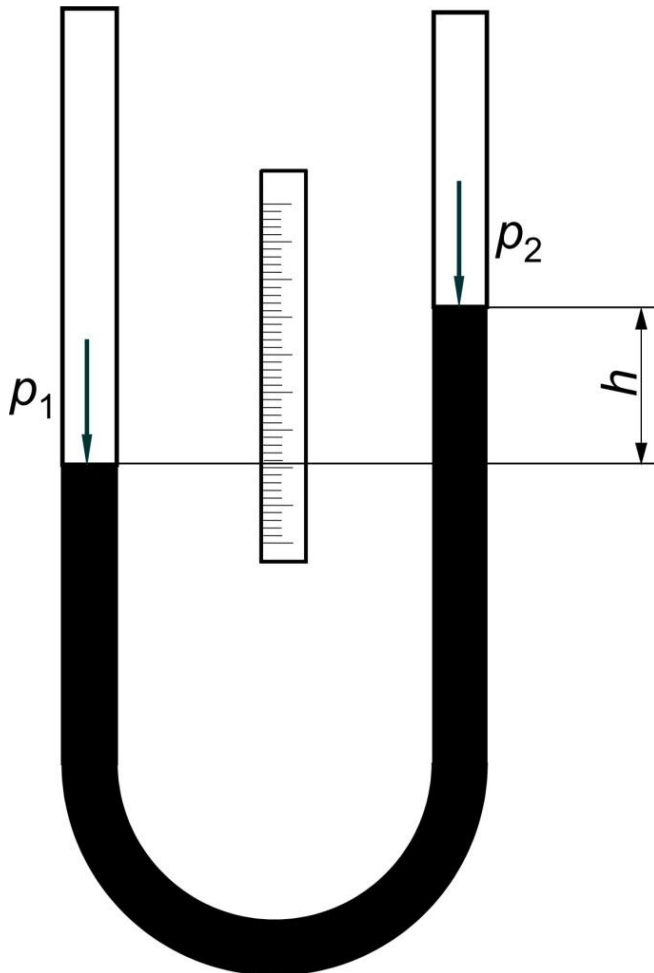
Categorization of pressure measurement methods:

1. **Liquid manometers** (U-manometers, piezometers, U-tubes)
2. Manometers with **elastic transducers** (tubes, membranes, bellows)
3. **Sensors** (inductive, capacitive, resistive, piezoelectric)

Liquid pressure gauges

- ❑ This group includes manometers that **contain liquid**
- ❑ A liquid column of certain height and cross-section acts as a "liquid weight" of known weight
- ❑ The weight of such a weight is usually measured by its **height in a calibrated glass tube**
- ❑ The weight of the weights, i.e. the force, is used for comparison with the force with which the measured pressure acts on a certain surface
- ❑ Thus, the height of the liquid column can be considered a measure of pressure

'U' – pressure gauge



Pressure difference:

$$\Delta p = p_1 - p_2 = \rho g h$$

- ρ – density of manometer liquid
 g – gravitational acceleration
- h – height difference between the liquid columns in the left and right arms