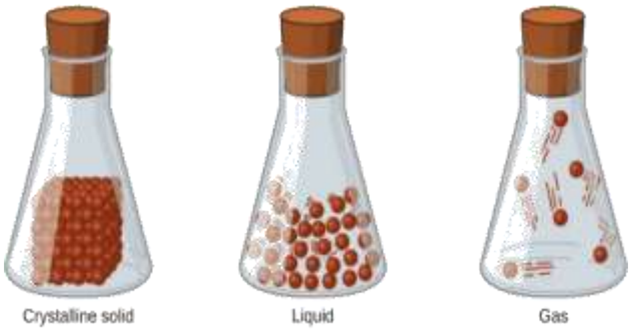
PRESSURE IN LIQUID AND GASES

FLUIDS

There are three known states of matter: solids, liquids and gases.

- Solids are described as having particles which are close together and unable to move far and as having their own shape and being hard to compress. (picture 1-a).
- Liquids are described as having particles which are also close together but free to move and as taking the shape of their container and being hard to compress (picture 1-b).
- Gases are described as having particles which are further apart and as having their own shape and being easy to compress (picture 1-c).

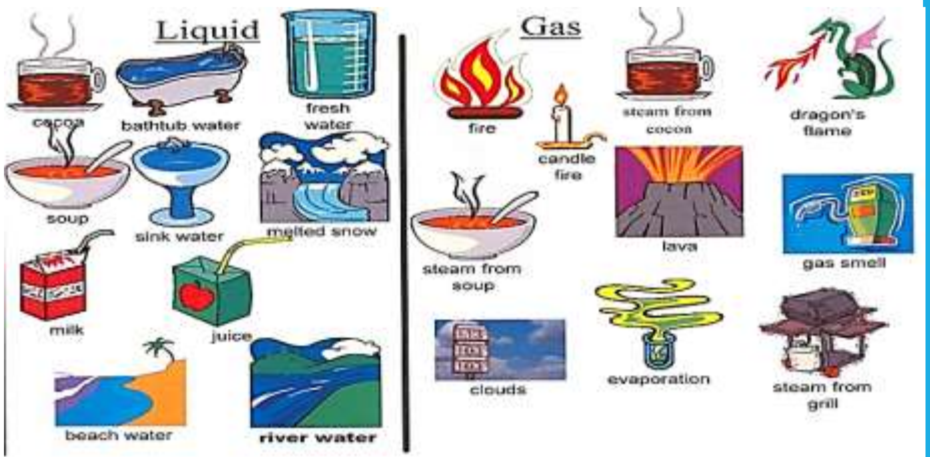


(a) (b) (c)

picture 1

A fluid is a substance that is a capable of flowing. Fluid has no permanent shape but takes up the shape of containing vessel or channel or is shaped by external forces (the atmosphere). Fluids are divided into homogeneous and heterogeneous.

A homogeneous fluid is a fluid that has uniform properties throughout a given sample. In some cases, it is mentioned as a fluid that as the same density throughout. Homogeneous fluids are normally divided into two classes, liquids and gases. Examples of homogeneous fluids are: milk, water, gas smell, fire etc (picture 2).



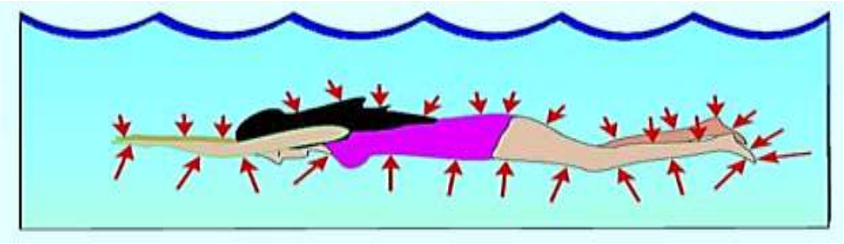
picture 2

● Compressible and incompressible fluids

If the density is constant (most liquids), the fluid is incompressible
If the density varies significantly (e.g. some gas flows), the fluid is compressible.

LIQUID PRESSURE

Liquid has its own weight, this causes pressure on the wall and on the bottom of the container in which liquid is held, it also causes pressure on any object immersed in the liquid.



picture 3

Example
If you dive into a swimming pools (picture 3), you will experience the pressure of the water on you. This pressure comes about because any object under water is being pressed down on by the weight of water above it.

The pressure is defined as a normal force exerted by a liquid per unit area.

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

A large force pressing on a small area gives a high pressure. Pressure is scalar quantity.

From the formula that defines the pressure follows:
The intensity of the force exerted by a liquid is equal to the product of the pressure and the surface on which this force operates $\boldsymbol{F = p \cdot A}$

Force is measured in newtons and area is measured in square metres. The units of pressure are thus newtons per square metres ($\frac{N}{m^2}$), which are given the special name of pascals (Pa).

$$\mathbf{1\ Pa = 1\ \frac{N}{m^2}}$$

The pressure unit pascal is too small for pressures encountered in practice. Therefore, its multiples kilopascal $(1 \text{ kPa} = 10^3 \text{ Pa})$ and megapascal $(1 \text{ MPa} = 10^6 \text{ Pa})$ are commonly used.

Some Pressures			
	Pressure (Pa)		**Pressure (Pa)**
Center of the Sun	$2x10^{16}$	**Automobile tire**	$2x10^5$
Center of Earth	$4x10^{11}$	**Atmosphere at sea level**	$1{,}0x10^5$
Highest sustained laboratory pressure	$1{,}5x10^{10}$	**Normal blood systolic pressure**	$1{,}6x10^4$
Deepest ocean trench (bottom)	$1{,}1x10^8$	**Best laboratory vacuum**	10^{-12}
Spike heels on a dance floor	10^6		

Snowshoes (picture 4) prevent the person from sinking into the soft snow because the force on the snow is spread over a larger area, reducing the pressure on the snow’s surface

Picture 4

LAWS OF FLUID PRESSURE


picture 5

In the static fluid we have three basic laws of fluid pressure.

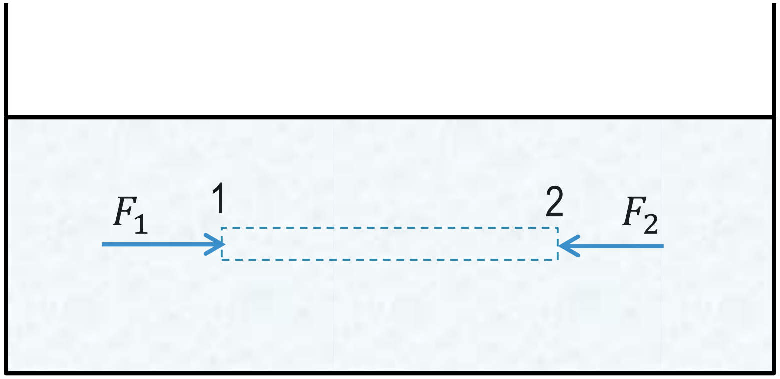
First law

Experiments show that in liquids and gases the pressure act equally in all directions.
An example - a small rubber balloon (picture 5) has a spherical shape in the air and in the water, if the pressure in some direction would be stronger than in the other, the balloon would deform.

We conclude that at an arbitrary point in a stationary homogeneous fluid pressure has the same magnitude in all directions.

Second law

Let's consider a piece of liquid in the form of a horizontal cylinder whose bases are small enough (picture 6). The cylinder is positioned between two arbitrary points 1 and 2. On the base of the cylinder, liquid exerts forces F_1 and F_2. Since the cylinder is stationary, this applies $F_1 = F_2$



picture 6

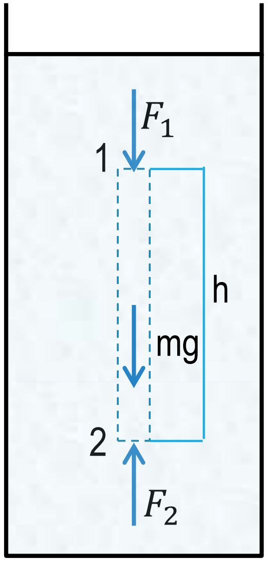
If S is the surface of the base of the cylinder, and p_1 and p_2 are liquids pressure at the places where the bases are, the previous equality will be: $p_1 \cdot A = p_2 \cdot A \Rightarrow p_1 = p_2$

We conclude that the pressure at two arbitrary points on the same horizontal level in a stationary homogeneous liquid is the same.

Third law

Increasing pressure with depth is a consequence of the weight of the liquid.
Measurements show that:
The pressure difference in two arbitrary points at different depths in a stationary homogeneous liquid is equal to the product of the density of the liquid, the gravitational acceleration and the height difference between the given points:

$\Delta p = p_2 - p_1 = \rho g h$ → This difference represent hydrostatic pressure.



picture 7

Let's consider a piece of liquid in the form of a vertical cylinder whose bases are small enough (picture 7). The cylinder is positioned between two arbitrary points 1 and 2. On the base of the cylinder, the remaining liquid exerts forces F_1 and F_2 and the force of the weight is acting on the cylinder. Since the cylinder is stationary, this applies:

$$F_1 + mg = F_2$$

If h is the height of the cylinder, and A of the base surface then:

$$F_1 = p_1 A \qquad F_2 = p_2 A \qquad m = \rho V = \rho A h$$

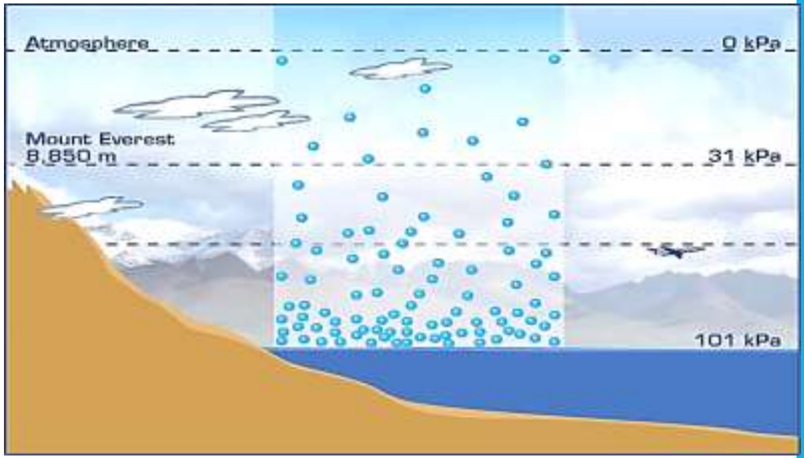
→ $p_1 A + \rho A h g = p_2 A$ → $p_2 - p_1 = \rho g h$

This law applies to gas pressures. The only difference is that the density of the gases is much smaller than the density of the liquid, so the change of pressure with depth (height) can be noticed only if it is a large depth (height).

ATMOSPHERIC PRESSURE

The earth is surrounded by an aircover called the atmosphere (a thickness of 200 km). Atmospheric pressure is a direct consequence of the weight of the air, the upper layers of air suppress the lower layers by their weight and it is transmitted to the Earth's surface, which causes atmospheric pressure.

Let's look at two layers of the atmosphere at different heights (second level and third level from the picture 7). It is clear that the pressure in the second layer will be higher than the pressure in the third layer, because we just have the weight of the air layer above the third layer, and the weight of the air layer between them also act on second layer From this it can be concluded that the pressure decreases with height. It is understandable then that the lowest layers of the atmosphere suffer the greatest pressure, therefore the atmospheric pressure is greatest at the sea level (picture 8).



picture 8

The mean sea level pressure is the average atmospheric pressure at sea. Average sea-level pressure is 101 kPa.(also called normal atmospheric pressure)

In meteorological reports, air pressure is expressed in other units - bars (millibars):

1 bar = 100 kPa

1 milibar = 10^{-3} bar = 100 Pa

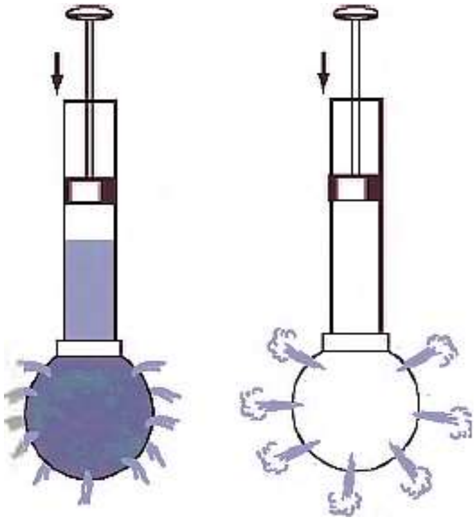
Sometimes as a unit is used the **millimeter of mercury** height of 1mm

1 mmHg = 13600 kg/m^3 ·9,81 m/s^2 ·0,001 m =133,4 Pa

Atmospheric pressure is measured with a **barometer**.

PASCAL'S LAW

We have seen in the previous section that the pressure difference between two points in a liquid at rest depends only on the difference in verticall height between the point. The difference is in fact $\rho g h$, where ρ is density of the liquid (assumed constant) and h is the difference in vertical height.



picture 9

Suppose by some means the pressure at one point of the liquid is increase. The pressure at all other points of the liquid must also increase by some amount because the pressure difference must be the same between two points. This is the content of Pascal's law which may be stated as fallows:

If the pressure in a liquid is changed at a particular point, the change is transmitted to the entire liquid without being diminished in magnitude (picture 9).

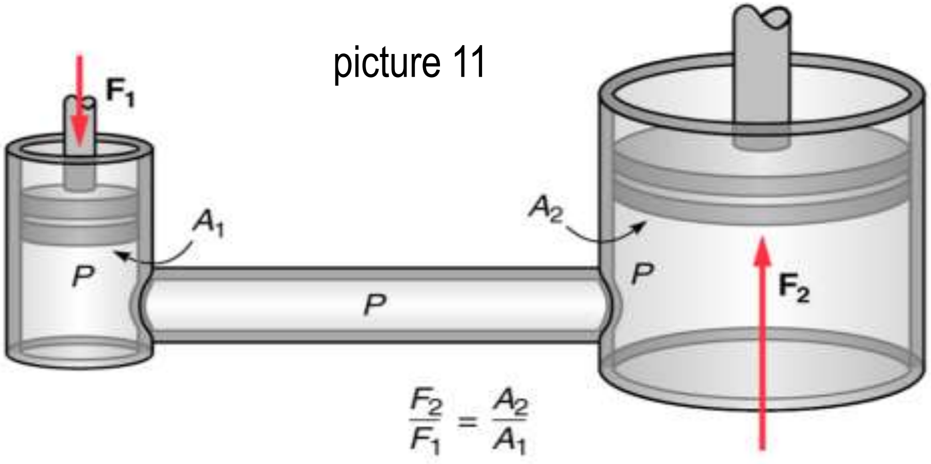
picture 10

Every time you squeeze a tube of toothpaste you demonstrate Pascal's law (picture 10). The pressure that your fingers exert at the bottom of the tube is transmitted through the toothpaste and forces the paste out at the top.

►Hydraulic press

A small force (F_1) is applied to piston with a small area (A_1) produces a much large force F_2 on the larger piston.. It is schematically illustrated in picture 11. A well known application of Pascal's law is the hydraulic lift is used to support or lift heavy objects.

picture 11



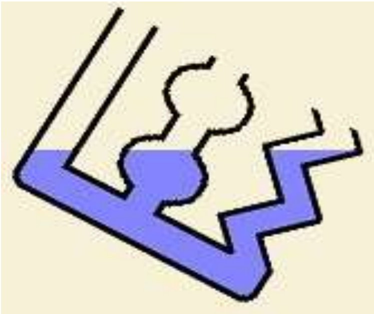
A piston with small cross section area A1, exerts a force F1 on the surface of a liquid such as oil. The applied pressure $p = F_1/A_1$ is transmitted through connecting pipe to a larger piston of area A_2. The applied pressure is the same in both cylinders, so

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

Where, P = pressure (Pa or N/m^2), F = force (N), A = area (m^2)

In the above picture $A_2 > A_1$, therefore, $F_2 > F_1$.
Thus, hydraulic life is a force multiplying device with multiplication factor equal to the ratio of the areas of the two pistons, car lifts and jacks, any elevators and hydraulic brakes all use pascal's law principle.

THE PRINCIPLE OF COMMUNICATING VESSELS



picture 12

Who has not yet experienced the fact that it is especially easy to spill out a very full teapot or watering can?
The reason is that the water in the spout is at the same level as the water in the rest of the can or pot. If you tilt the can, the water level remains in the same horizontal plane (picture 12). So, that spill it out you just have to tilt the can a little. This is called the principle of communicating vessels.

Communicating vessels is a name given to a set of containers containing a homogeneous fluid when the liquid settles, it balances out to the same level in all of the containers regardless of the shape and volume of the containers or how they are tilted. If additional liquid is added to one vessel, the liquid will again find a new equal level in all the connected vessels.

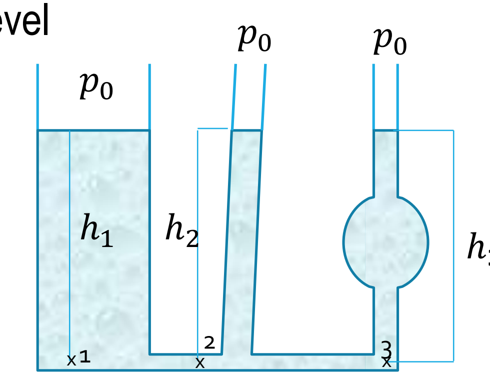
The principle of communicating vessel is proven by laws on pressure in liquids:
This is the case when the point in each of the three vessels (point 1, 2 and 3) is at the same vertical depth in comparison to the water level (picture 13)

- Let h1 h2 and h3 be the height difference between points 1, 2 and 3 and water level
- the pressure above the water surface is p_0
- the pressures in points 1, 2 and 3 are:

$$p_1 = p_0 + \rho g h_1 \qquad p_2 = p_0 + \rho g h_2 \qquad p_3 = p_0 + \rho g h_3$$

Since points 1, 2 and 3 are at the same horizontal level then:

$$p_1 = p_2 = p_3 \Rightarrow h_1 = h_2 = h_3$$



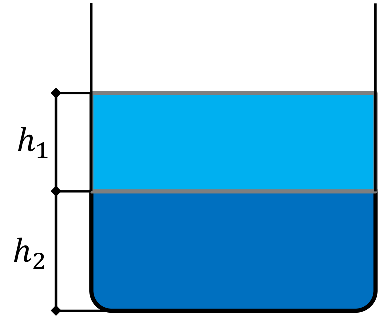
picture 13

PROBLEMS

1. a) Find the total pressure in sea water at a depth of 30 m.
   b) Calculate the force with which the water presses the outside window of submarine 5 cm high and 6 cm wide (at a depth of 30 m).

Assume that the density of water is $1000\ kg/m^3$, and $p_0 = 100\ kPa$.

2. a) A wide vessel is filled with water and oil. Find the hydrostatic pressure that act at the bottom of the vessel if the thickness of the oil layer is equal to $h_1 = 10\ cm$ and thickness of the water layer $h_2 = 12\ cm$
   b) Find the hydrostatic pressure that act at the bottom of the vessel, if the thickness of the water layer is equal to $h_2 = 12\ cm$ and mass of the oil is equal to the mass of the water.

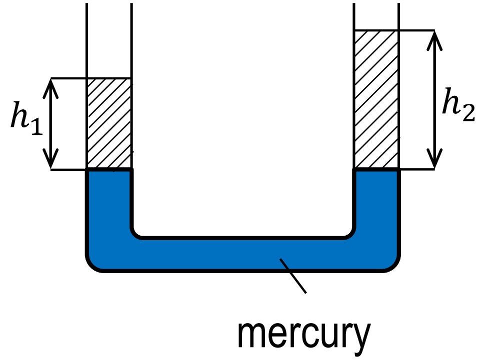


Density of the oil is equal to $800\ kg/m^3$.

3. In a swimming pool, whose base has a square shape (side a=10 m) thickness of the water layer is 2m. Find the force that exert water:
   a) on the bottom of the pool
   b) on the pool walls

The atmospheric pressure is negligible.

4. Water and oil are poured into the two limbs of a U-tube containing mercury. The interface of the mercury and liquid are at the same height in both limbs. Determinate the height of the water column h_1 if that of the oil $h_2 = 20cm$. The density of the oil is $800\ kg/m^3$.



5. In the fussed vessels under the light pistons there is water. The cross-section of one vessel is $100cm^2$, and another is $300cm^2$. If we put 0,5kg on a smaller piston and brick on another piston, the smaller piston is 6cm above the greater piston. Find the mass of the brick.