Fluids
Phases of Matter

Matter is anything that has mass and takes up space (volume). The three common phases of matter are solid, liquid, and gas.

A solid has a definite shape and size.
A liquid has a fixed volume but can be any shape.
A gas can be any shape and also can be easily compressed.

Liquids and gases both flow, and are called fluids.
Density and Specific Gravity

The density $\rho$ of an object is its mass per unit volume:

$$\rho = \frac{m}{V}$$

The SI unit for density is kg/m$^3$. Density is also sometimes given in g/cm$^3$; to convert g/cm$^3$ to kg/m$^3$, multiply by 1000.

Water at 4°C has a density of 1 g/cm$^3 = 1000$ kg/m$^3$.

The specific gravity of a substance is the ratio of its density to that of water.
Pressure in Fluids

Pressure is defined as the force per unit area.

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

Pressure is a scalar; the units of pressure in the SI system are Pascal: $1 \text{ Pa} = 1 \text{ N/m}^2$

Pressure is the same in every direction in a nonmoving fluid at a given depth.

The pressure at a depth $h$ below the surface of the liquid is due to the weight of the liquid above it. We can quickly calculate:

$$P = \frac{F}{A} = \frac{mg}{A} \quad m = \rho V \quad V = Ah$$

$$P = \frac{F}{A} = \rho Ahg \quad \rightarrow \quad p = \rho gh$$
The surface of the water in a storage tank is 30 m above a water faucet in the kitchen of a house. Calculate the difference in water pressure between the faucet and the surface of the water in the tank.
Atmospheric Pressure & Gauge Pressure

At sea level, the pressure of the atmosphere is defined as unit of pressure. This unit is called one atmosphere (atm).

\[ 1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2 = 101.3 \text{ kPa} \]

Another unit of pressure is the bar:

\[ 1 \text{ bar} = 1.00 \times 10^5 \text{ N/m}^2 \]

Standard atmospheric pressure is just over 1 bar.

This pressure does not crush us, as our cells maintain an internal pressure that balances it.

The absolute pressure is the sum of the atmospheric pressure and the gauge pressure.

\[ P = P_A + P_G \]

For example, if a tire gauge registers 220 kPa, the absolute pressure within the tire is 220 kPa + 101 kPa = 321 kPa, equivalent to about 3.2 atm (2.2 atm gauge pressure).
Measurement of Pressure

There are a number of different types of pressure gauges.

The simplest is the open-tube **manometer**. The pressure in the open end is atmospheric pressure; the pressure being measured will cause the fluid to rise until the pressures on both sides at the same height are equal.

\[ P = P_0 + \rho g \Delta h \]

Two more devices for measuring pressure:

- the aneroid gauge and
- the tire pressure gauge.
Measurement of Pressure

The mercury barometer, was developed by Torricelli to measure atmospheric pressure. The height of the column of mercury is such that the pressure in the tube at the surface level is 1 atm.

Therefore, pressure is often quoted in millimeters, centimeters, (or inches) of mercury.

The atmospheric pressure can support a column of mercury only about 76 cm high (exactly 76.0 cm at standard atmospheric pressure). That is, a column of mercury 76 cm high exerts the same pressure as the atmosphere

\[ P = \rho g \Delta h \]

\[ P = \left(13.6 \times 10^3 \frac{\text{kg}}{\text{m}^3}\right) \left(9.8 \frac{\text{m}}{\text{s}^2}\right) (0.760 \text{m}) = 1.013 \times 10^5 \frac{\text{N}}{\text{m}^2} = 1.00 \text{ atm} \]
Pascal’s Principle

Pascal's principle states that if an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

\[ P_{out} = P_{in} \]

This principle is used, for example, in hydraulic lifts and hydraulic brakes. When the driver presses the brake pedal, the pressure in the master cylinder increases. This pressure increase occurs throughout the brake fluid, thus pushing the brake pads against the disk attached to the car's wheel.
**Buoyancy and Archimedes’ Principle**

Objects submerged in a fluid appear to weigh less than they do when outside the fluid. When an object is submerged in a fluid, there is a net force on the object because the pressures at the top and bottom of it are different. The buoyant force is found to be the upward force on the same volume of water:

\[
F_B = F_2 - F_1 = P_2 A - P_1 A
\]

\[
F_B = \rho g h_2 A - \rho g h_1 A = \rho g \Delta h A = mg
\]

the magnitude of the buoyant force on an object immersed in a fluid is equal to the weight of the fluid displaced by that object.

\[
F_B = \rho_{\text{fluid}} V_{\text{disp}} g = mg
\]
Buoyancy and Archimedes’ Principle

The buoyant force on an object immersed in a fluid is equal to the weight of the fluid displaced by that object. The “fluid displaced” is the volume of fluid equal to the submerged volume of the object (or that part of the object that is submerged). If the object’s density is less than that of water, there will be an upward net force on it, and it will rise until it is partially out of the water.

For a floating object, the fraction that is submerged is given by the ratio of the object’s density to that of the fluid.

\[
\frac{V_{\text{displaced}}}{V_{\text{object}}} = \frac{\rho_{\text{object}}}{\rho_{\text{fluid}}} \quad \text{or} \quad \frac{V_{\text{displ}}}{V_o} = \frac{\rho_o}{\rho_F}
\]
Problem (2)

Estimate the volume of a person of mass 75-kg.
Problem (3)

Consider what happens when you push both a pin and the blunt end of a pen against your skin with the same force. What will determine whether your skin will be punctured?

a) the pressure on your skin
b) the net applied force on your skin
c) both pressure and net applied force are equivalent
d) neither pressure nor net applied force are relevant here
Problem (4)

Three containers are filled with water to the same height and have the same surface area at the base, but the total weight of water is different for each. Which container has the greatest total force acting on its base?

a) Container 1  
b) Container 2  
c) Container 3  
d) All three are equal
Problem (5)

An object floats in water with $\frac{3}{4}$ of its volume submerged. What is the ratio of the density of the object to that of water?

a) $\frac{1}{4}$  
b) $\frac{1}{3}$  
c) $\frac{4}{3}$  
d) $\frac{3}{4}$  
e) $\frac{2}{1}$
When a crown of mass 14.7 kg is submerged in water, an accurate scale reads only 13.4 kg. Is the crown made of gold?