MEDICAL UNIVERSITY – PLEVEN
FACULTY OF MEDICINE

DIVISION OF PHYSICS AND BIOPHYSICS

LECTURE 2

FLUID STATICS AND DYNAMICS

The states of matter. The definition of pressure. Pressure in liquids. Distribution of pressure in a static liquid. Transmission of pressure: Pascal's principle. Clinical applications of Pascal's principle. Buoyant force and Archimedes principle. Pressure in flowing fluids

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The general term *fluids* ("things which flow") includes both liquids and gases.

The solid state is characterized by internal order and fixed atomic positions. The solid keeps its shape.

In the liquid state, as in the solid state, the atoms or molecules have very strong cohesive forces which hold them together.

The molecules in liquids

- are free to move relative to one another;
- readily take the shape of any container;
- flow readily, but it takes a considerable force to separate the molecules.

Liquids are said to be "incompressible" and cannot be made to occupy a smaller volume without the exertion of enormous pressures.

In the gas phase, there are no longer appreciable attractive forces between molecules, and the only forces they exert upon each other are due to collisions.

THE DEFINITION OF PRESSURE

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

The penetrating ability of an object depends largely upon the pressure rather than just the force.

The hypodermic needle makes use of this fact to penetrate the skin with ease. Since the tip area is extremely small, a small force will result in a rather large penetrating pressure.

A sharper needle will require less force to produce the required penetrating pressure.

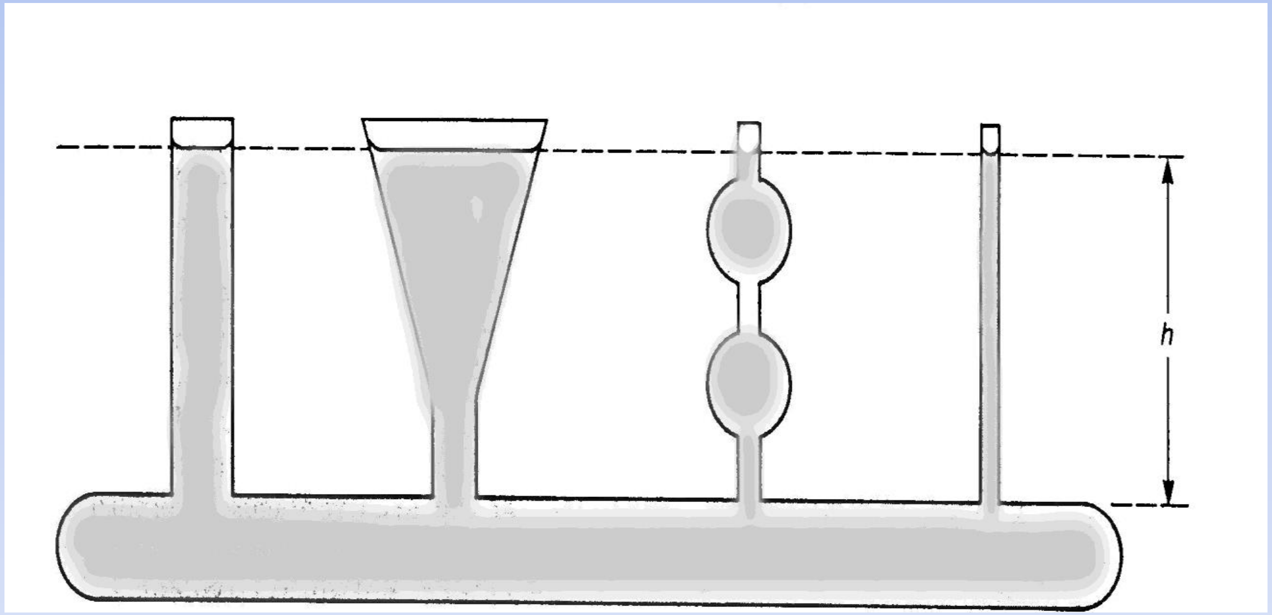
PRESSURE IN LIQUIDS

The pressure caused by a liquid which is at rest is proportional to the depth of the liquid and its density.

$$\boxed{P = \rho g h}$$

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

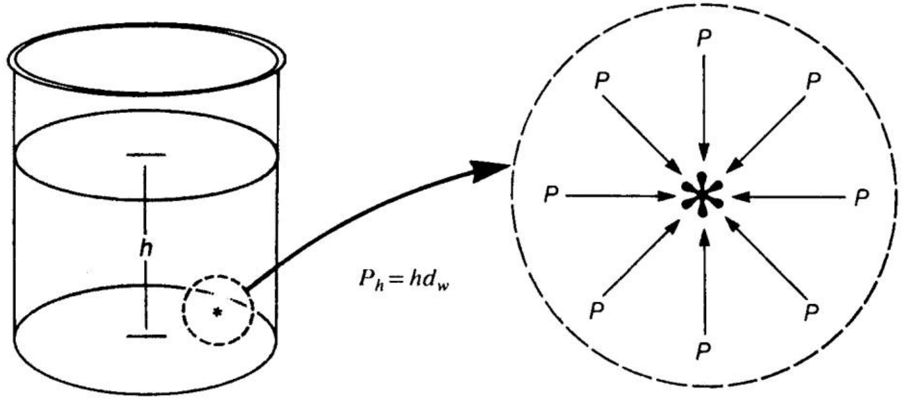
The pressure in a container of liquid is dependent upon the **depth** of the liquid only and not upon the shape of the container.

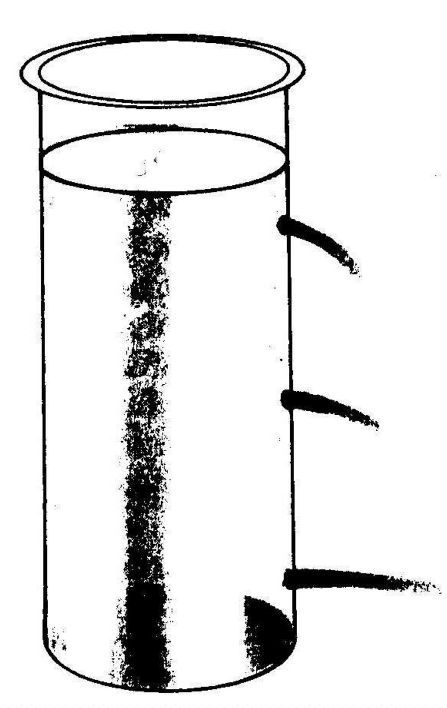


DISTRIBUTION OF PRESSURE IN A STATIC LIQUID

Pressure is exerted equally in all directions in a static liquid. If a tiny droplet of the liquid at a given depth could be examined, it would be found that the droplet is in equilibrium but it has forces exerted upon it from all directions.

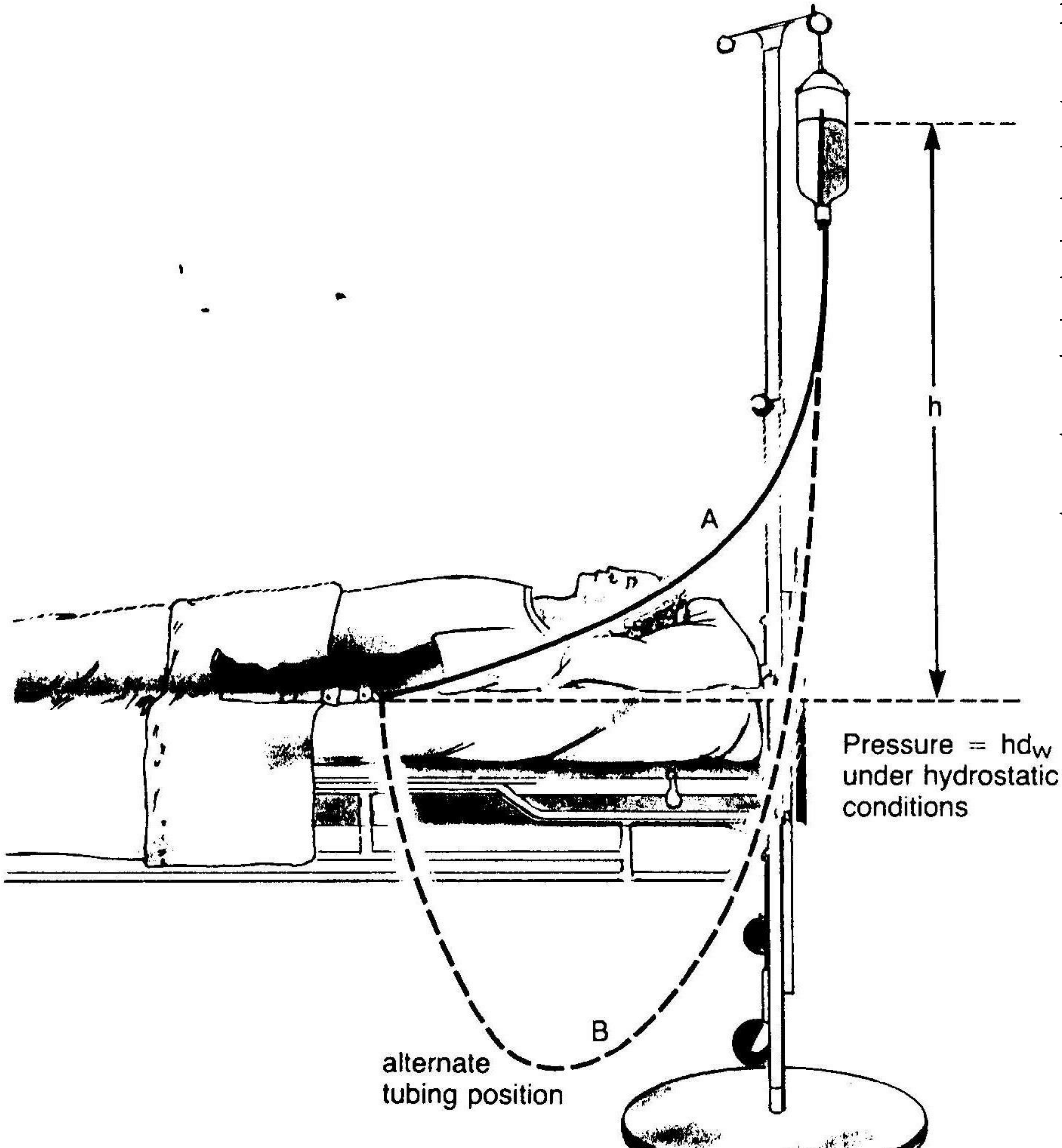
These forces must be exerted in pairs such that the net force is zero.





Since the pressure downward increases with depth, the horizontal pressure on the walls also increases.

If holes are punched in the side of a vessel, the increase in horizontal pressure with the increase in depth can be readily demonstrated.



In I.V. apparatus, the pressure is determined by the height of the liquid surface above the point of input to the patient. The pressure is transmitted through the tubing, even if it has turns or coils.

The pressure at the patient under static (no flow) conditions will be the same in configurations A and B of the tubing.

TRANSMISSION OF PRESSURE: PASCAL'S PRINCIPLE

Any change of pressure in an enclosed fluid is transmitted undiminished to all parts of the fluid.

CLINICAL APPLICATIONS OF PASCAL'S PRINCIPLE

- Chronically ill patients have a tendency to develop decubitus ulcers (bed sores) when confined on an ordinary mattress for a length of time. The use of an air or water mattress helps to prevent the formation of decubitus ulcers.

The ulcers tend to develop on the elbows and other locations which have the largest pressures exerted upon them by an ordinary mattress.

Since the air and water mattresses constitute closed fluid systems, the pressure is evenly distributed in them.

When the patient lies on the mattress, the same pressure is exerted against every part of the body which is in contact with the mattress.

- Pascal's law applies to the cerebrospinal fluid.

This fluid circulates around the spinal cord and up into the subarachnoid space around the lower part of the brain.

An increase in P at any point in the fluid will increase the pressure in all parts of the fluid. Thus, a brain tumor or any abnormal growth which protrudes into the space normally occupied by the fluid may cause a measurable increase in P in all parts of the fluid. A measurement of the pressure of the fluid at any convenient location can detect the increase in pressure.

- The unborn fetus is protected from external forces by the fluid in the amniotic sac surrounding it. This fluid tends to distribute the effect of a force exerted on the abdominal area.

Any pressure applied to the abdominal wall is transmitted to all parts of the fluid and will be exerted upon the fetus. The prenatal patient is usually cautioned against wearing tight clothing since there is a possibility that continuous pressure might produce fetal deformity.

- Since the eye contains an enclosed fluid, any blow to the front of the eye will transmit pressure to the back of the eye. The blood vessels, retina, and optic nerve are delicate structures and may be injured by excess pressure.

It is possible that a blow to the eye may not produce visible injury to the front of the eye but may damage the optic nerve because of the transmitted pressure.

- Pascal's law may be applied to explain the effects of collected fluid in the pericardial and pleural cavities.

Normally there is not enough fluid there to constitute a sizeable enclosed fluid. When fluid collects abnormally, then the pressures transmitted by these fluids may lead to abnormal pressures on the heart and lungs.

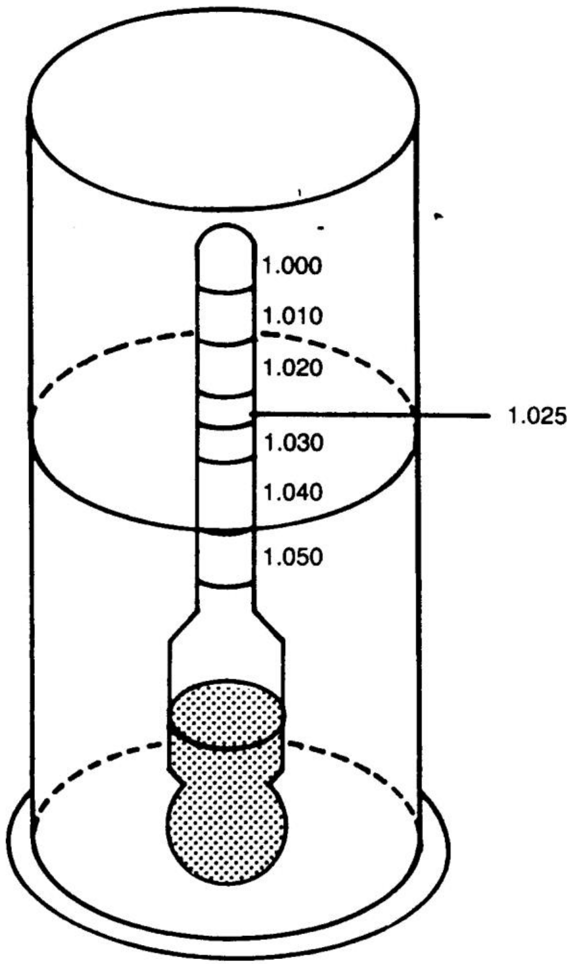
BUOYANT FORCE AND ARCHIMEDES' PRINCIPLE

When something is immersed in water or another fluid, it appears to weigh less than it does in air. This effect is called *buoyancy* and it provides the lifting force required to float a ship on water or a balloon in the air.

The buoyant force arises from the difference in liquid pressure above and below the object. The buoyant force on the submerged object is equal to the weight of the liquid displaced. The generalization of this idea is known as *Archimedes' principle.*

To measure the specific gravity of a liquid, a glass tube of standard specific gravity can be floated in the liquid. Such a device is called a hydrometer. If the specific gravity of the liquid is increased, the hydrometer will float higher.

A specialized hydrometer called a urinometer is used to measure the specific gravity of urine, which is an important physiological indicator.



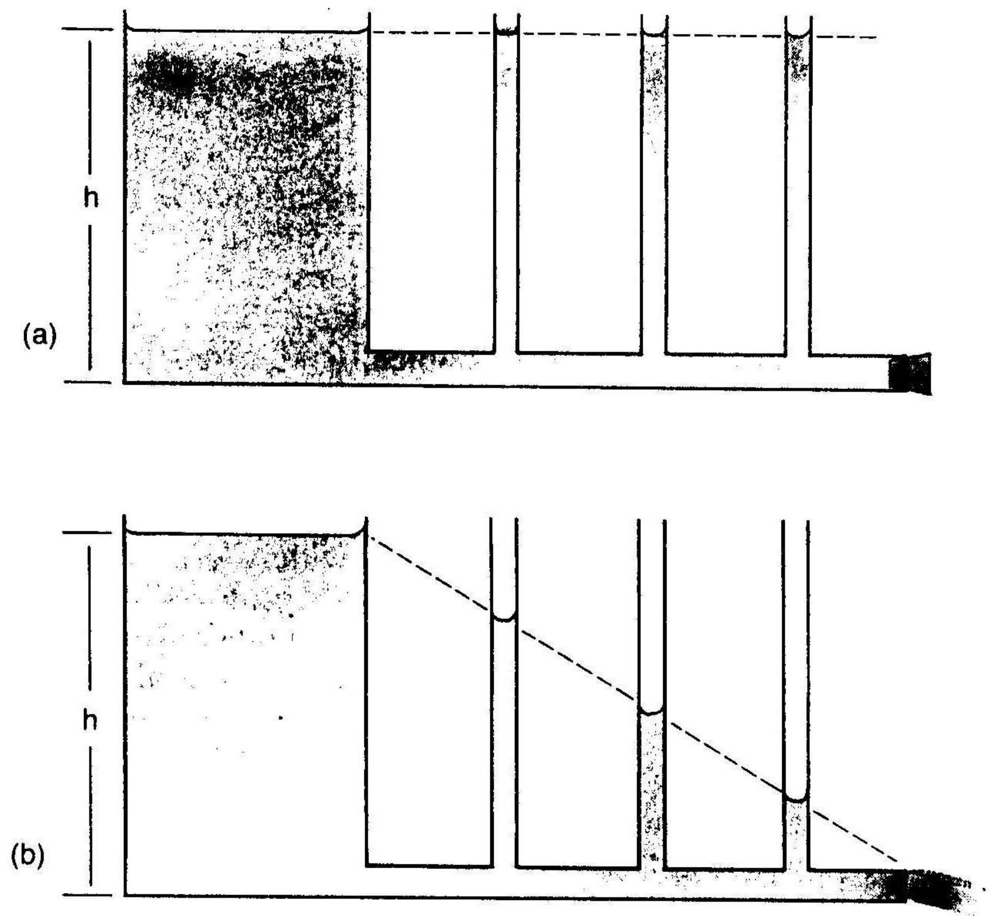
!!! Some diseases alter the composition of the urine and change its specific gravity.

Archimedes discovered that objects apparently weigh less when weighed under water, and he used this fact to measure densities.

The difference between the weight of an object in air and its weight when submerged in water is the buoyant force, which is equal to the weight of water displaced.

This actually provides an accurate method for the determination of the volume of an irregularly shaped object so that weight density can be calculated by dividing weight by volume.

PRESSURE IN FLOWING FLUIDS



The pressure is the same at all points along the horizontal tube when there is no flow.

A uniform pressure drop occurs when there is smooth flow through a uniform tube.

Several factors affect the rate of flow through a length of tubing. For the smooth flow of an ideal fluid, the factors can be summarized in the relationship:

$$F = \frac{P_1 - P_2}{R}$$

where P_1 and P_2 are the pressures at the upstream and downstream ends of the tube, F is the volume flow rate (volume flow rate = volume/time) and R is the effective resistance to flow. Drops in pressure during flow represent losses in energy.

!!! These losses are largely attributable to frictional effects.

In a straight tube with smooth walls, a fluid tends to flow in smooth layers. The layer nearest the wall will be essentially at rest. The speed gradually increases to a maximum on the central axis of the vessel.

The average flow speed is then about half the maximum speed found at the center. This type of flow is known as **laminar flow**, and it represents **the minimum energy loss.**

If the flow is speeded up past a certain critical speed, or if there is an obstruction in the flow path, eddies will start to form and the laminar flow may break down into **turbulent flow.**

The pressure gradient for a given flow rate will be lower if laminar flow can be maintained. The maintenance of laminar flow is important for efficient fluid circulation, whether it is in an intravenous fluid apparatus or the circulatory system of the body.

To prevent turbulent flow, it is important to make smooth transitions to different tubing sizes.

Deposits or constrictions in arteries or veins can generate a turbulent flow pattern. To maintain the normal flow rate, the pressure must then be raised, so an additional burden is placed on the heart.

A sudden change in the diameter of a blood vessel owing to weakening and dilation of the wall of the vessel will produce turbulent flow and have a similar effect.

Pure liquids such as water obey Poiseuille's law fairly well, but departures from the law may be substantial for suspensions and mixtures of liquids.

Blood is a rather **complicated fluid** and it does not precisely follow the behavior predicted by Poiseuille's relationship. The viscosity of water does not depend upon pressure, and if the pressure gradient in a tube of flowing water is doubled, the volume flow rate will very nearly double.

The viscosity of blood is found to decrease with increasing fluid pressure, implying that the flow rate would be more than doubled by doubling the pressure gradient.

This departure from Poiseuille's law is thought to be due to the increasing accumulation of red blood cells in the faster axial part of the flow, so that there are fewer red cells near the vessel walls to contribute to wall friction.

The viscosity is approximately a constant in the normal range of blood pressures. Anomalous decreases in viscosity with increased pressure have also been reported for the synovial fluid which helps in the lubrication of the human joints.

Since the pressure at the bottom of a column of liquid varies in direct proportion to the height of the column, it is often convenient to use the height of a liquid column as a pressure measuring instrument.

The simplest of such devices is the manometer, which consists of a single vertical tube of liquid, usually mercury or water.

If a pressure at the bottom of the tube is sufficient to push mercury into the tube to a height of 20 centimeters, then the pressure is said to be 20 cm Hg or 200 mm Hg. Likewise, a pressure sufficient to raise the level of water 20 cm in a manometer could be said to be a pressure of “20 cm of water” or “20 cm H_2O”.

Since the density of mercury is 13.6 times as great as that of water, it takes 13.6 times as much pressure to push a column of mercury as to push a column of water to the same height. The pressure required to push mercury 20 cm high would push a column of water 13.6 x 20 cm = 272 cm high.

Thus, as a *measure of pressure*,

20 cm Hg = 272 cm H_2O

or 1 cm Hg = 13.6 cm H_2O.

Such units of pressure prove to be convenient for the measurement of blood pressure, atmospheric pressure, the pressure of suction machines, and so forth.

- Which of the following factors affect the pressure at the bottom of an open liquid container: volume of liquid, total weight of liquid, weight density of liquid, depth of liquid, shape of container?

- State Archimedes' principle. What physical factor determines whether or not an object will float? How can Archimedes' principle be used to measure the specific gravity of a liquid sample?

- When intravenous fluids are administered to a patient, why is the bottle elevated? By what factor would the flow rate change if the height of the bottle above the patient is doubled, with other factors constant? (Assume that the back pressure from the vein is negligible.)

- Name the factors which affect the flow rate of a fluid through a tube. Which is the most important factor and why?

- Under what conditions does Poiseuille's law describe fluid flow accurately? Does it adequately describe the flow of blood? Explain.

- Assuming Poiseuille's law holds, what would be the effect on liquid volume flow rate through a tube if the following changes were made independently, with all other variables reset to their original values: double the length, halve the viscosity, quadruple the pressure, halve the radius?

PROBLEMS

1. At what depth in water will the liquid pressure and atmospheric pressure have equal influences?

2. The pressure required for the infusion of intravenous fluids into a vein is obtained by lifting the fluid bottle above the point of infusion. If the liquid level in a bottle is 47 cm above the point where the needle enters the vein and the liquid is assumed to have the same density as water, what is the liquid pressure at the needle?

3. An irregularly shaped pool has slanted walls so that the volume of water in it is difficult to determine. Its depth is measured to be 3 meters. How could you calculate the hydrostatic pressure at the bottom of the pool?

4. A person who weighs 801 N in air is weighed after exhaling and submerging in a tank of water. Under these conditions his apparent weight is 53.4 N. What is his body density?

5. Balance scales measure a mass of 90 kg for a person and an apparent mass of 3.7 kg when submerged in water. Find the density of the person.