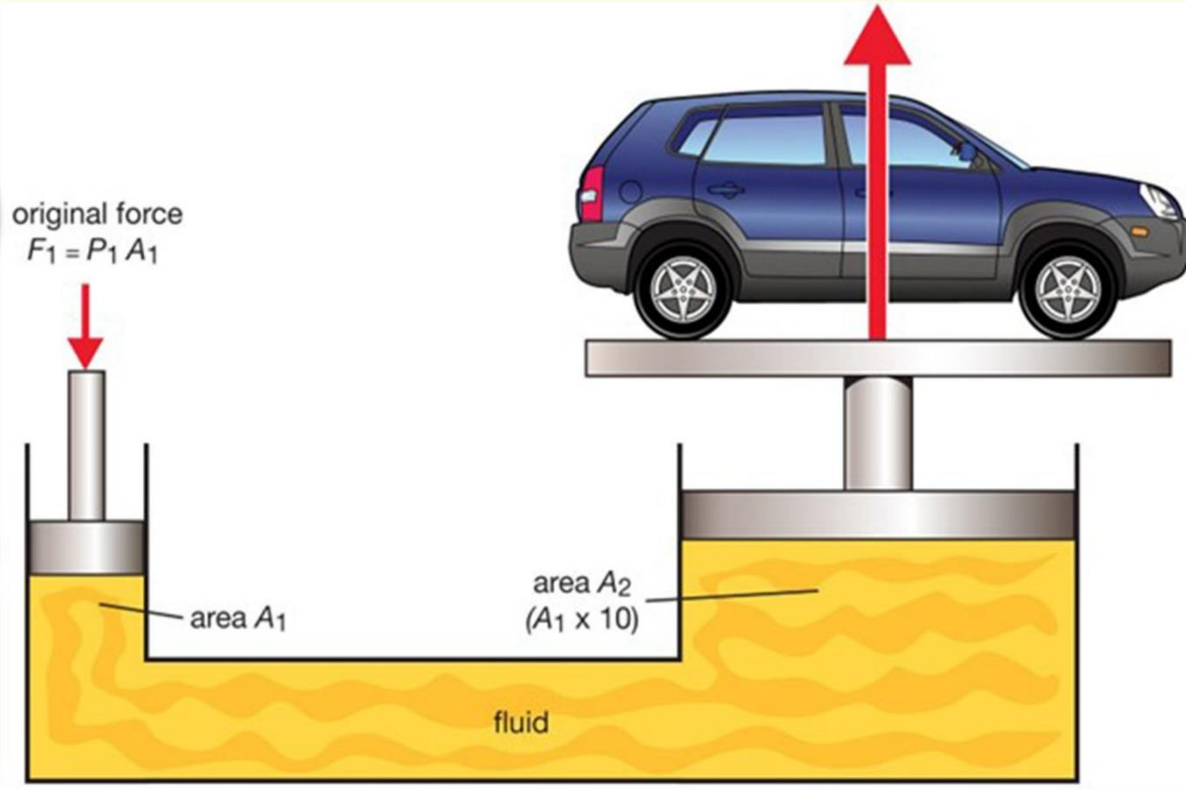
PHYSICS XI



FLUID STATICS

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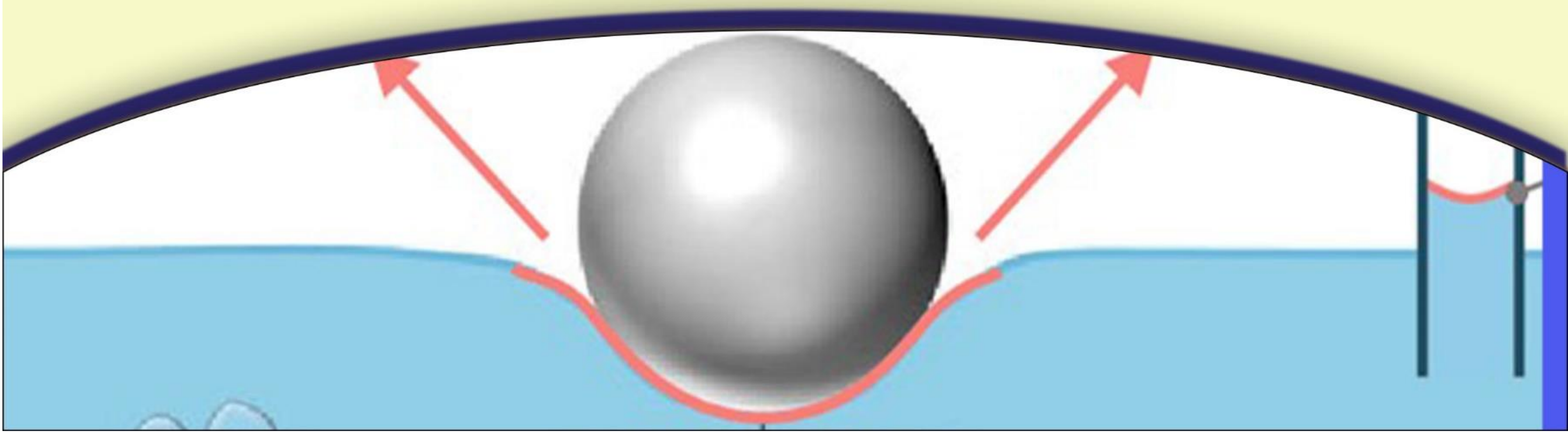


Fluid Statics

Fluid.

Fluids are those substances that can flow, such as gases and liquids.

Fluid Statics.

The branch of physics that studies the behavior of fluids at rest is known as fluid statics.

Applications of fluid statics.

Civil engineering, Naval architecture, Petroleum engineering, Aerospace engineering, and Biomedical engineering are the practical applications of fluid statics.

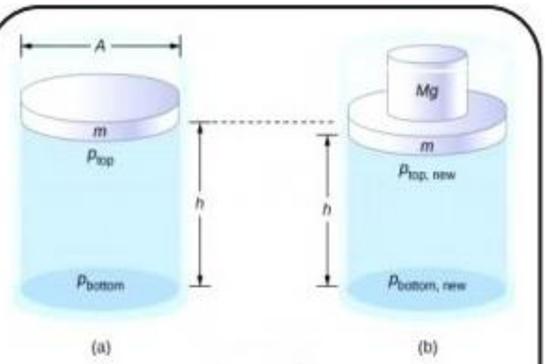
Properties of fluids.

Gases:
Gases have no specific shape, they conform to the shape of their container.
They have no specific volume, they conform to the volume of their container.
They are highly compressible.
They have low density as compared the liquids.
They have very low viscosity, no surface tension, and can flow freely.

Liquids:
Liquids don't have a specific shape, they conform to the shape of their container.
They have a definite volume.
They are slightly compressible.
They have a high density as compared to gases.
They have higher viscosity, and surface tension and can flow but not as freely as gases.

Pascal`s Law.

Statement:
When a change in pressure is applied at any point to any static fluid, it is transmitted perfectly to all portions of the fluid and the walls of the container.



Pressure in a fluid changes when the fluid is compressed.
(a) Pressure at top of fluid is different from pressure at bottom.
(b) The increase in pressure by adding weight over the piston, will be same everywhere.

EXPLANATION.

Consider a cylinder of height "h" and cross-sectional area "A" fitted with a movable piston of mass "m" and enclosed a liquid as shown in figure. Now adding the extra weight "Mg" on the top of piston, which also increase the pressure at the top of piston.
By the definition of pressure.

$$P = \frac{F}{A} - - - - - - (1)$$

Now, the change in pressure at the top of piston.

$$\Delta P_{top} = \frac{\Delta F}{A}$$

$$\Delta P_{top} = \frac{Mg}{A} - - - - - (2)$$

According to Pascal`s principle, the pressure across the water enclosed in a container changes by the same amount as $\frac{Mg}{A}$ .The pressure at the bottom of the container is equal to the sum of atmospheric pressure, the pressure due to the enclosed liquid, and the pressure supplied by the weight "Mg" placed at the top.
The change in pressure at the bottom of the container due to extra weight "Mg" is.

$$\Delta P_{bot} = \frac{Mg}{A} - - - - - (3)$$

By comparing equations (2) and (3).

$$\Delta P_{top} = \Delta P_{bot}$$

Therefore,

$$\Delta P = \Delta P_{top} = \Delta P_{bot} = \Delta P_{every\ where}$$

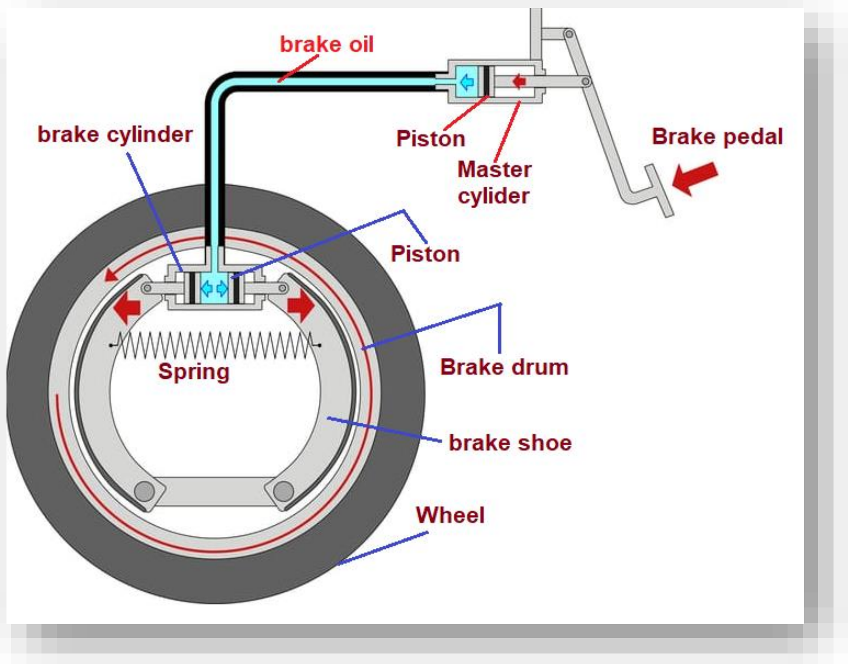
Thus, if an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount of applied pressure.

Applications of Pascal's Law:

Following are some applications of Pascal`s Law in different fields.

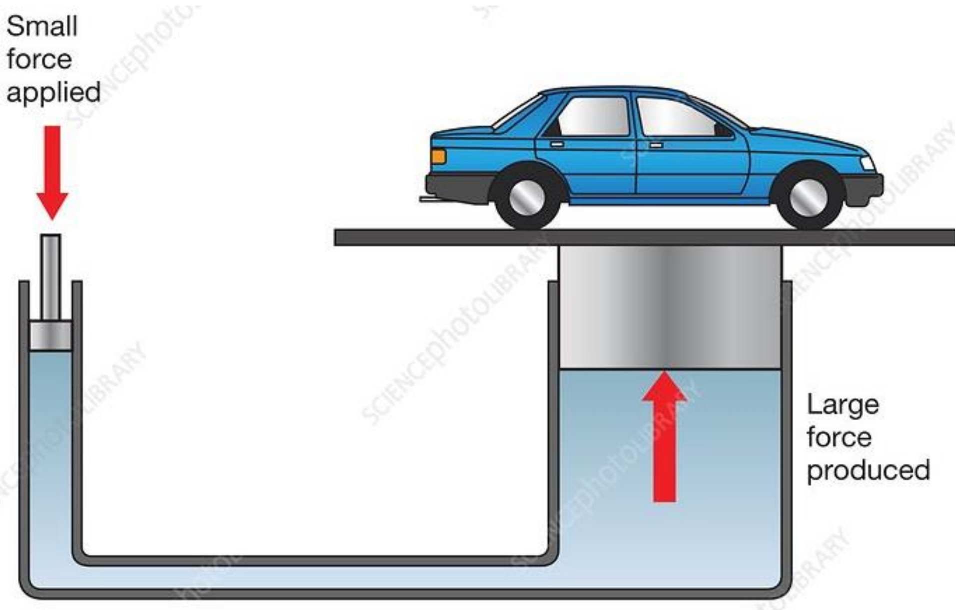
AUTOMOBILE HYDRAULIC BRAKE SYSTEM.

The rear wheel hydraulic brake system of a front-wheel-drive shown in the figure is an application of Pascal's principle. When the driver pushes the brake pedal, the pressure on the piston in the master cylinder is transmitted through the brake fluid to the two pistons in the brake cylinder. This transmitted pressure then forces the brake-cylinder pistons to push the brake shoes against the brake drum and stop the automobile. The brake pedal releases the pressure on the pistons in the brake cylinder. The spring pulls the brake shoes away from the brake drum, which allows the wheel to turn freely again.



1. **HYDRAULIC LIFT OR HYDRAULIC JACK.**

Hydraulic lift is able to raise up large weight up to relatively short distance.



The hydraulic lift or jack is applications of hydraulics being used as a simple machine to multiply force. It contains an incompressible fluid in a U-shaped tube which is narrower at start and becomes wider area at end which is fixed with a movable piston on each side. If a small force F_1 is applied to the small piston of the hydraulic lift as shown in figure, the pressure is transmitted with in all directions. The pressure on the large piston is the same as the pressure on the small piston; however, the force F_2 on the large piston is greater because of its large surface area which used to uplift the car.

the pressure on the small piston = the pressure on the small piston

$$P_1 = P_2$$

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

Or

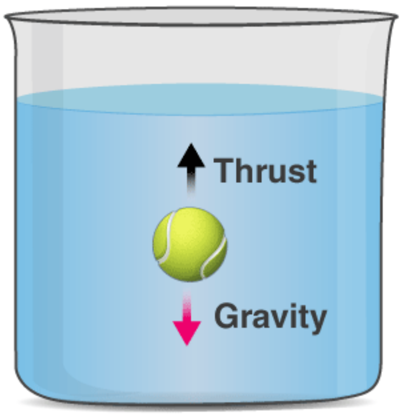
$$\frac{F_2}{F_1} = \frac{A_2}{A_1}$$

Where (F_2 / F_1) is known as mechanical advantage which is equal to the ratios of areas..

Archimedes' Principle:

STATEMENT:

"When an object is immersed into a liquid (fluid), it experiences upward thrust which is equal to the weight of the liquid displaced by that object."



FACTORS.

The magnitude of the upward force depends upon.

1. **Volume of the body, more fluid that is displaced the greater the upthrust.**
2. **Density of fluid- the greater the density, greater is upthrust.**

EXPLANATION.

If a sphere of material density "ρ" with radius " r " is fully immersed into a liquid of density "σ" shown in figure, the apparent weight of the sphere is given by.

Apparent Weight = Actual Weight - upthrust

Upthrust:

Definition.

"It is the force exerted upwards on an object submerged in a fluid, equal in magnitude to the weight of the fluid displaced by the object."

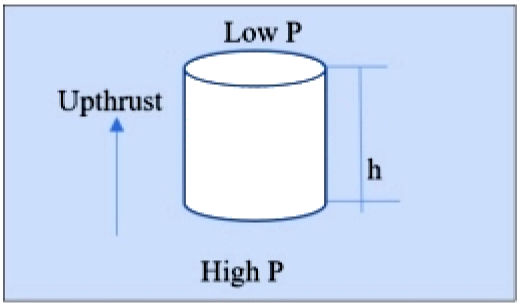
It is also known as buoyancy or buoyant force. Upthrust is significantly larger in liquids than in gasses because liquids are much denser.

Derivation.

Consider a cylinder of height "h" and area of cross-section "A" is immersed in a vessel containing a liquid of density " ρ". The upthrust as shown in the figure is acting on the cylinder from bottom to top.

As the cylinder dips deeper, pressure increases with depth. So the cylinder has low pressure at top and high pressure at bottom. this difference in pressure cause upthrust on cylinder.

By the definition of pressure.



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

$$F = \Delta P \times A$$

Or

$$F_{thrust} = \Delta P \times A - - - - - (1)$$

Now

$$\Delta P = \frac{\text{weight of cylinder}}{\text{cross sectional area of cylinder}}$$

$$\Delta P = \frac{mg}{A} - - - - - (2)$$

Where

$$\text{Density}, \rho = \frac{m}{V}$$

$$m = \rho V$$

$$m = \rho A (h_2 - h_1)$$

$$m = \rho A \Delta h$$

Subs in eq.(2)

$$\Delta P = \frac{\rho A \Delta hg}{A}$$

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

Subs in eq.(1)

$$F_{thrust} = \rho \Delta h g \times A$$

$$F_{thrust} = \rho g \Delta h A$$

Where.

$$\Delta h\, A = V$$

Therefore.

$$F_{thrust} = \rho\, g\, V$$

Where
F_{thrust} = upthrust
ρ = density of fluid
g = acceleration due to gravity
V = volume of fluid

BUOYANCY AND LAW OF FLOTATION:

Buoyancy and flotation are fundamental principles governing the behavior of objects in fluids. Understanding these principles is crucial in various fields, such as shipbuilding, engineering, swimming, and boating, allowing us to comprehend why objects float or sink and design stable structures and vessels in fluid environments.

BUOYANCY:

Definition.

Buoyancy is the upward force exerted by a fluid on an immersed object.

It is a result of the pressure difference between the top and bottom surfaces of the object due to the weight of the displaced fluid.
The magnitude of the buoyant force is equal to the weight of the fluid displaced by the object; this can be calculated using Archimedes' principle. The formula to calculate the buoyant force is.

Buoyant Force = Density of Fluid Volume of Displaced Fluid Acceleration due to Gravity

IN LIQUIDS.

If the weight of the submerged object is greater than buoyant force, the object sinks.
If the weight of object is equal to the buoyant force acting upwards on the submerged object, it remains at any level in fluid, like a fish.
If the buoyant force is greater than the weight of object which is completely submerged, it rises to the surface and floats.

IN GASES.

Balloons and other lighter than air objects are drifting above us. Air pressure acting upward against an object immersed in air is greater than the pressure above pushing down. The buoyancy is equal to the weight of fluid displaced. So, Archimedes' principle also implies to air which is stated as:
"An object surrounded by air is buoyed up by a force equal to the weight of the air displaced."

LAW OF FLOTATION:

Statement.

"A floating object displaces a weight of fluid equal to its own weight."

Floating of ships, boats, icebergs on the surface of water and balloons in air is based on the principle of floatation. The mean density of these bodies is less than the density of fluid.

SURFACE TENSION:

Definition.

"The force per unit length acting on either side of the imaginary line drawn on the liquid surface at rest. The direction of force is tangential to the surface and perpendicular to the line."

EXPLANATION.

Suppose an imaginary free surface of liquid as shown in figure. The molecules lying on the surface are behaving as tug of war i.e, one side molecules pull to their side while other side molecules to their side in order to decrease the surface area.

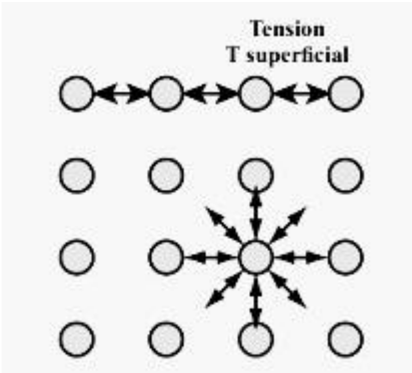
It is the ability of the surface of a liquid to act like a thin stretched membrane.

It is calculated as.

$$\text{Surface tension} = F / L$$

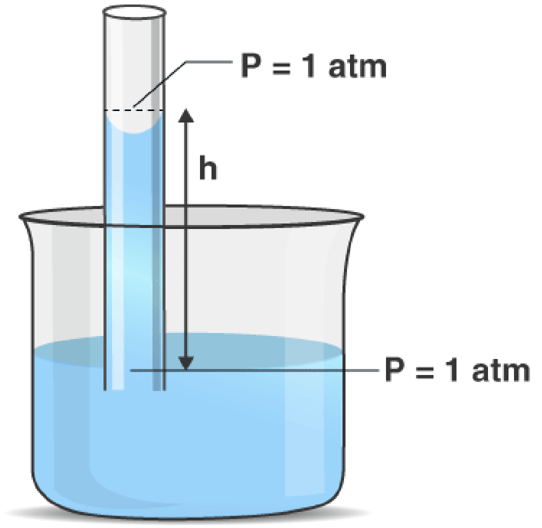
Its SI unit is N/m or $N\text{-}m^{-1}$

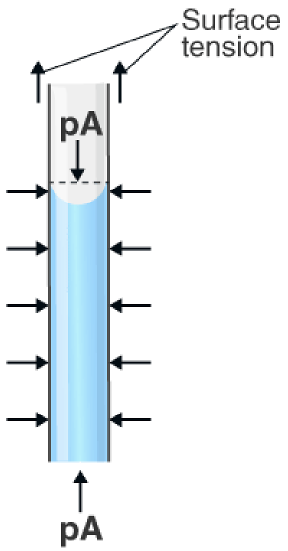
Examples:



1. When a pin is placed gently over the surface of water, it floats.
2. Some insects (with long legs) can walk over the water surface.
3. A drop of Olive oil is dropped through a pipette, gently inside a mixture of alcohol and water, which forms a perfectly spherical shape.
4. When mercury is dropped over glass surface, the globules are spherical in shape.
5. Capillarity;

A glass tube of the small bore is dipped into water; it rises the tube a few centimeters. As the tube becomes narrower, there is more rise up. The adhesion force between water and glass exceeds the cohesion force between water molecules, the meniscus causes up and surface tension.





This effect is called capillarity or capillary action.

THE HEIGHT OF THE COLUMN

In the vertical direction weight of the liquid column (mg) acts downward, and the force of surface tension acts in the upward direction, which acts along a circle of radius r.

Force by surface tension - weight of the liquid = 0

T (L) - mg = 0

T (2 π r) - m g = 0

T (2 π r) = m g ……….(i)

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

$$m = \rho\ V$$

$$m = \rho\ A\,h$$

$$m = \rho\ \pi\, r^2\, h$$

Substituting the expression for mass in equation (i), we get

$$T\,(2\,\pi\, r) = \rho\ \pi\, r^2\, h\, g$$

$$T\,(2\,) = \rho\ r\, h\, g$$

$$\frac{T\,(2\,)}{\rho\, r\, g} = h$$

$$h = \frac{2\,T}{\rho\, r\, g}$$

Where.

T = Surface tension.

r = Radius of tube

g = Acceleration due to gravity.

P = Density of liquid.

SELF-ASSESSMENT

Q1) How does Pascal`s law relate to the transmission of pressure in a confined fluid?

Transmission of pressure in a confined fluid was explained by Pascal. He stated that:

When a change in pressure is applied at any point to any confined fluid, it is transmitted perfectly and equally to all portions of the fluid and the walls of the container.

For example, as you squeeze your toothpaste tube at one end the same will be transmitted to the opening of the tube.

Q2) How does the principle of hydraulic systems rely on Pascal`s law?

Hydraulic systems based on the Pascal law, such as hydraulic lifts or presses, automobile brakes, and heavy machinery.

In the hydraulic system, a small force applied to the small piston can generate a much greater force on the larger piston due to the transmission of pressure through the confined fluid.

Q3) How is the weight of displaced fluid related to the upthrust acting on an immersed object?

According to Archimedes' principle when a body is submerged or immersed in a fluid, it displaces the fluid equal to its volume and experiences an upward force named upthrust or buoyancy.

The upthrust on the body by the fluid is given as.

$$F_{up} = \rho g v$$

Where

$$\rho = \text{Density of fluid} = \frac{m}{v}$$

$$F_{up} = \frac{m}{v} g v$$

$$F_{up} = mg$$

Where

$$mg = w$$

Then

$$F_{up} = w \text{ (wieght of the fluid)}$$

Q4) How do submarines and hot air balloons take advantage of the principles of Archimedes' theory in their design and operation?

According to Archimedes' principle, the upthrust (buoyant force) on a submerged or immersed body in a fluid is equal to the weight of the fluid displaced by the immersed body.

Submarine:

Submarines contain ballast tanks to control their mass and buoyancy.

When the tanks are empty, the submarine floats due to less mass, and when the tanks are filled then its mass increases and it sinks.

Hot air balloon:

Hot air balloons contain hot air inside the balloon, which is less dense as compared to surrounding air which exerts the upthrust (buoyant force) on the balloon, and the balloon floats.

The vertical movement of the balloon can be controlled by adjusting the amount of hot air inside the balloon.

Q5) Why does the steel ship, which is denser than water, float on the surface of the sea according to the principle of buoyancy and the law of floatation?

Answer.

A steel ship floats on the surface of the sea due to the principle of buoyancy which is described by Archimedes principle.

According to Archimedes' principle when an object is immersed into a liquid, it experiences an upward thrust which is equal to the weight of the liquid displaced by that object.

It is clear from the Archimedes principle that a floating body will displace its weight of fluid such that there is no vertical resultant force on the body. Which is also the law of floatation.

Steel ship is designed in such a manner that reduces their density (by increasing their volume) as compared to the density of water to experience the upthrust equal to its weight to float.

Q6) How does surface tension impact the behavior of liquid droplets, bubbles, and capillary action?

Surface tension significantly affects the behaviors of liquid droplets, bubbles, and capillary action.

Liquid droplets.

The spherical shape of liquid droplets is because of surface tension. Surface tension reduces the surface area for the given volume of liquid droplets. Liquid droplets can combine when they come into contact because surface tension pulls them together to reduce the total surface area.

Bubbles.

Surface tension creates a film (layer) of liquid that can trap air inside to stabilize the bubbles. The surface tension of bubble film minimizes the surface area and forms the spherical shape of bubbles.

Capillary action.

The rise or fall of liquid in narrow tubes because of surface tension and adhesive forces between the liquid and walls of the tube is known as capillary action.

Liquid with higher surface tension will rise higher in a capillary tube.

SHORT RESIONING QUESTIONS

1. State Pascal's principle. Describe its two applications

Ans:

Statement:

When a change in pressure is applied at any point to any static fluid, it is transmitted perfectly to all portions of the fluid and the walls of the container.

(See two applications from notes)

2 Why must a liquid and not a gas be used as the 'fluid' in a hydraulic machine?

Ans: A gas is not used in hydraulic machines as the fluid because gas is easily. compressible, so if a gas is used, the energy would mostly go into compressing it. therefore liquid is used in hydraulic machine systems because they are more difficult to compress than gases, so they are better at transmitting forces - when a pressure(force) is applied at one end of the system, it is easily transferred through the system.

3 On what other important properties of a liquid do hydraulic machines depend?

1. Viscosity - It is a measure of hydraulic fluids resistance to flow.
2. Compressibility - It is a measure of the amount of volume reduction due to pressure. Although hydraulic oils are incompressible.
3. Wear resistance - It is a hydraulic fluid ability to reduce the wear rate in frictional boundary contacts.
4. Oxidation stability - It is a hydraulic oil resistance to heat induced degradation caused by a chemical reaction with oxygen.
5. Thermal stability - It is the ability to resist breakdown at elevated temperatures.
6. The fundamental properties of fluid are temperature, density, and composition.
7. Density, Viscosity, and surface tension are physical properties of fluid.
8. Mass and volume are examples of extensive properties, the properties which depend on the amount of material

4 Why do you float higher in salt water than in freshwater?

Ans: Yes, we will float higher in saltwater than in freshwater. This phenomenon is due to the difference in density between saltwater and freshwater. Saltwater is denser than freshwater because of the dissolved salts in it. The increased density of saltwater provides more buoyant force to objects placed in it compared to freshwater.

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5 What is the difference between being immersed and being submerged in water?

Ans A submerged body is a body fully surrounded by water, meaning that the body is completely underwater. An immersed body, on the other hand, is a body that is partially submerged, with only parts of it in contact with the fluid in which it is immersed.

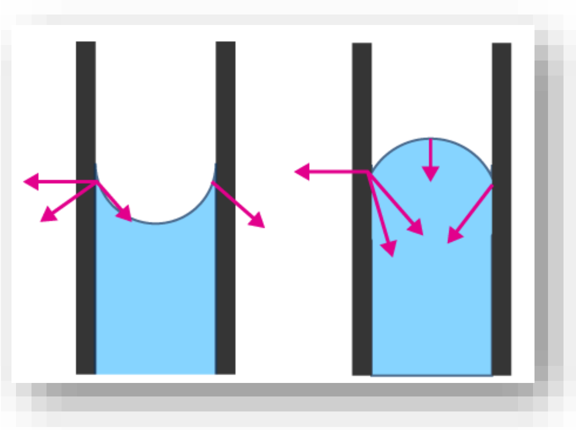
6 Define surface tension and give it any two applications

Ans **Definition.**

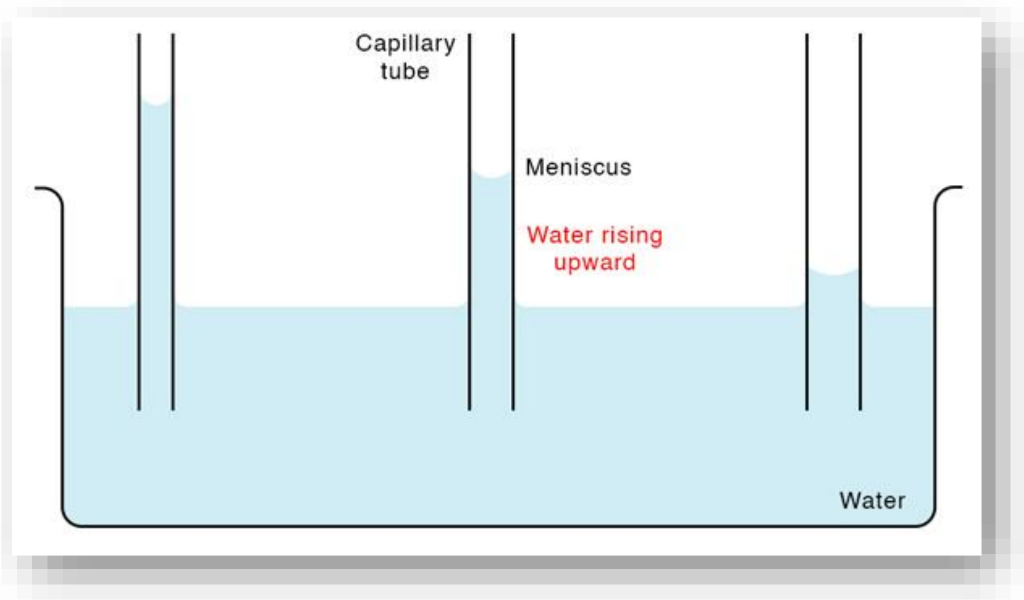
"The force per unit length acting on either side of the imaginary line drawn on the liquid surface at rest. The direction of force is tangential to the surface and perpendicular to the line."

APPLICATIONS

1 The liquid present on the top of a tube of mercury is always either convex or concave. This is caused due to surface tension between the cohesive forces and adhesive forces that are present between the walls of the tube. This way, a meniscus is formed. It is widely used to calculate contact angles as well as surface tension.



2 The liquid's ability to flow through the narrow spaces in opposition to gravity forces is known as capillary action. The attraction between glass and water is caused due to force known as adhesion. Due to surface tension, the inside of the glass contracts and starts to rise. This phenomenon can easily be noticed in the liquid molecules present between the hairs of a paintbrush



7 A swimmer dives off a raft in a pool. Does the raft rise or sink in the water? What happens to the water level in the pool? Give reasons for your answer

Ans: the raft was already floating in the water with the swimmer on it. Meaning the total mass is less than or equal to the upthrust due to atmospheric pressure. If the swimmer jumps off of the raft then there would be less force to act against the upthrust therefore the raft will rise.

the amount of water displaced is equal to the submerged volume of anything in the water. So for example, if the swimmer is completely underwater, the amount of water he's displacing is equal to his volume. The amount of water the raft is displacing is some fraction of the raft's total volume. This is useful because the more water is being displaced, the higher the water level.

8 Distinguish between flotation and upthrust.

In fundamental physics, the terms buoyancy and upthrust are sometimes used frequently. Even though some of us use them similarly, in spite of knowing they have different meanings. Buoyancy is the ability of an object to float in a fluid whereas upthrust is a force exerted on an object by a fluid within which the object is submerged. Simply, buoyancy is just the tendency of an object to rise in a given fluid when it is submerged. But upthrust is the buoyant force exerted on the object by the fluid.

9 Why don't ships made of iron sink?

ANS: The density of an iron nail is more than that of water, the nail sinks in water. But a huge ship made of iron floats. This is because of its shape. A ship is hollow in the middle. When the ship is in water the entire volume of the ship, including the hollow portion, displaces water to make space for itself. The volume of water displaced is much greater than the volume of the iron ship. Hence, according to Archimedes' principle, the upthrust is more than the weight of the ship. That is why the iron ship floats in water.