



Ratna Sagar

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PRIMUS

BYWORD

E-LIVE

Education, Our Mission



ICSE

Living Science

Physics

Class 10

**Chapter 6 Buoyancy and
Archimedes' Principle**



As per the latest ICSE syllabus

9



Living Science

PHYSICS



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LEARNING OBJECTIVES

Upthrust and Buoyancy

- ❖ Characteristic properties of upthrust

Archimedes' Principle

- ❖ Density and Relative Density

Principle of Floatation

- ❖ Law of floatation
- ❖ Characteristics of a floating body
- ❖ Verification of principle of floatation

Equilibrium of Floating Bodies

- ❖ Stable equilibrium
- ❖ Unstable equilibrium
- ❖ Neutral equilibrium

Applications of Law of Floatation

What is buoyant force or upthrust?

The upward force acting on an object when partly or wholly immersed in a fluid is called buoyant force or upthrust.

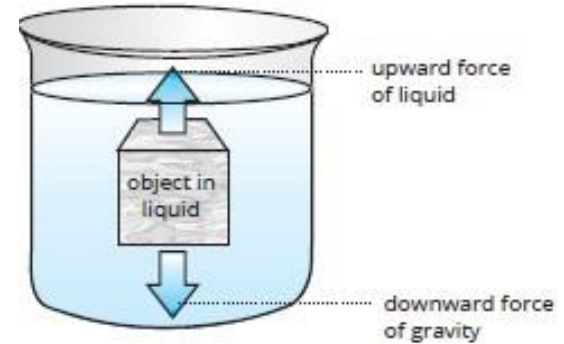
The tendency of a fluid to exert an upward force on an object placed in it is called buoyancy.



Upthrust and its Characteristic Properties

Upward thrust or upthrust is defined as the weight of the liquid displaced by the immersed part of the body.

Upward thrust = $V\rho g$, where V is the volume of liquid displaced, ρ is the density of liquid and g is the acceleration due to gravity.



Characteristic Properties

1. The upthrust is directly proportional to the volume of the body submerged in the fluid.
2. The upthrust is directly proportional to the density of the fluid in which the body is submerged.
3. The upthrust is directly proportional to the acceleration due to gravity.
4. The upthrust is inversely proportional to the temperature of the fluid.

Archimedes' principle

When a body is partially or wholly immersed in a fluid, it experiences an upthrust (or apparent loss in its weight), which is equal to the weight of the fluid displaced by the immersed part of the body. In other words,
Buoyant force acting on an object = Weight of the fluid displaced by that object



Density and Relative Density

Density of a substance is defined as its mass per unit volume, i.e.

$$\text{Density } (d) = \text{Mass } (m) / \text{Volume } (V)$$

Density of iron is more than that of cotton.

Its unit in CGS system is g/cm^3 and in SI system is kg/m^3 .

The relative density of a substance is defined as the ratio of the density of the substance to the density of water at 4°C . Thus,

$$\begin{aligned} \text{Relative density (R.D.)} &= \text{Density of the substance} / \text{Density of water at } 4^\circ \text{C} \\ &= \text{Mass of the substance} / \text{Mass of an equal volume of} \\ &\quad \text{water at } 4^\circ \text{C} \end{aligned}$$

Thus, relative density of a substance is the ratio of the mass of the substance to the mass of an equal volume of water at 4°C .

Relationship between density and relative density

$$\begin{aligned} \text{Density of a solid} &= \text{R.D. of the solid} \times \text{Density of water (in SI unit)} \\ &= \text{R.D. of the solid} \times 1000 \text{ kg/m}^3 \end{aligned}$$

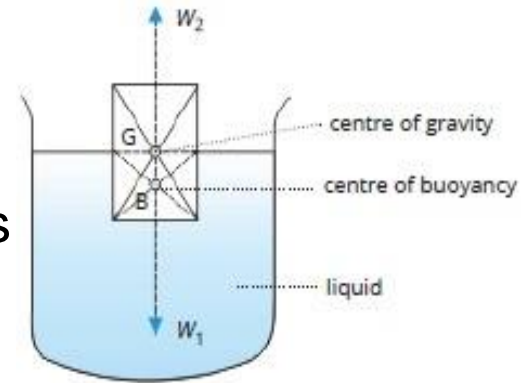
$$\begin{aligned} \text{Density of a solid} &= \text{R.D. of the solid} \times \text{Density of water (in CGS unit)} \\ &= \text{R.D. of the solid} \times 1 \text{ g/cm}^3 \end{aligned}$$



Principle of Floatation

When a body is immersed in a fluid, the following two forces act on the body:

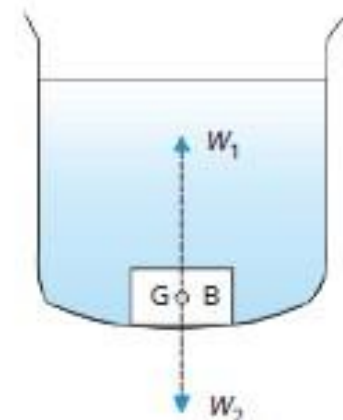
1. The weight of the body (W_1) acting vertically downwards through the centre of gravity of the body. This force has a tendency to sink the body (due to the force of gravity) in the fluid.



2. The upthrust (W_2) of the fluid acting vertically upwards through the centre of gravity of the displaced fluid called the centre of buoyancy. The upthrust (or buoyant force) is equal to the weight of the liquid displaced by the immersed part of the body. This force has a tendency to push the body out of the given fluid.

Case I: When the weight of the body is greater than the buoyant force, i.e. $W_1 > W_2$

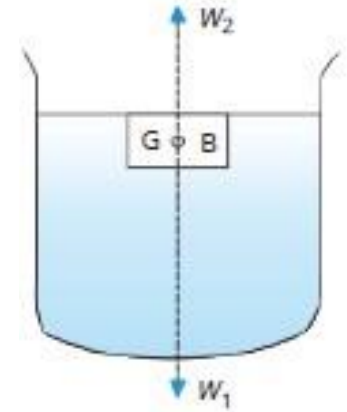
1. The body will sink in the fluid .
2. Its apparent weight (i.e. the weight inside the liquid) will be ($W_1 - W_2$) acting vertically downwards.





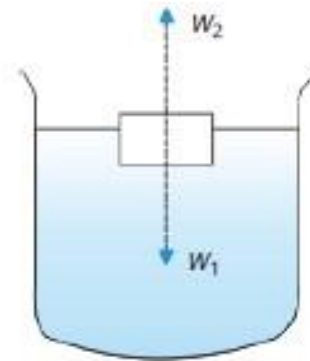
Case II: When the weight of the body is equal to the buoyant force, i.e. $W_1 = W_2$

1. The body will float just below the surface of the fluid .
2. Its apparent weight will be zero [$W_1 - W_2 = 0$], the body will be in a weightless condition.
3. The density of the solid is equal to the density of the fluid .
4. The centre of buoyancy and the centre of gravity will coincide with each other.
5. The apparent density of the body when immersed in fluid will be zero.



Case III: When the weight of a body is less than the buoyant force, i.e. $W_1 < W_2$

1. The body will float partially above the surface of the fluid.
2. The apparent weight of the body will be zero since only that much portion of the body will be immersed by which the weight of the fluid displaced balances the total weight of the body.
3. The density of such a body is less than the density of fluid, i.e. ($d_s < d_l$).
4. The apparent density of the solid in liquid is $d_s - d_l < 0$, i.e. the density is negative.





Law of Floatation

According to the principle of floatation, when a solid floats in a fluid, then the weight of the floating body is equal to the weight of the fluid displaced by the immersed part of the solid.

Characteristics of a floating body

1. The weight of the solid is equal to the weight of the liquid displaced by the immersed part of the solid.
2. The weight of the solid acts vertically downwards through the centre of gravity whereas buoyant force acts vertically upwards through the centre of buoyancy.
3. The centre of gravity and the centre of buoyancy of the body will coincide with each other or lie on the same vertical line.
4. In the floating position, the apparent weight of the body will be zero and the body will be in a weightless condition.
5. In the floating position, the apparent density of the body is zero.

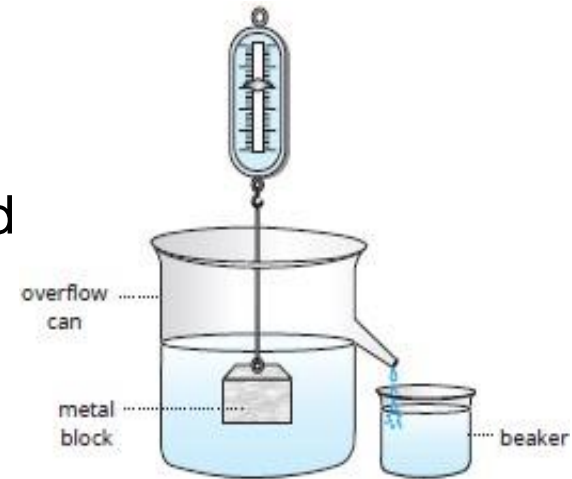
Verification of principle of floatation

According to the principle of floatation, the weight of a floating body is equal to the weight of the liquid displaced.



The above result can be verified with the help of a simple experiment.

Pour water into an overflow can to the level of spout. Place a beaker under the spout. Take a metal block and weigh it. Let it be W_1 . Now, immerse the metal block in the overflow can. It displaces water which overflows through the spout and gets collected in the empty beaker. Weigh the displaced water. Let it be W_2 .



Result

The weight of the displaced water (W_2) is equal to the weight of the floating body in air (W_1).

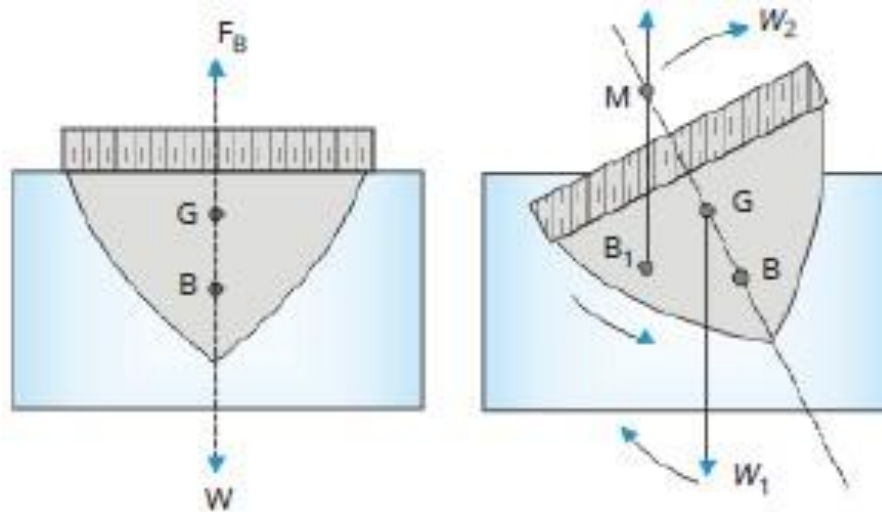
Equilibrium of floating bodies

A floating body must satisfy the following two conditions to be in equilibrium while floating:

1. The weight of the floating body (W_1) must be equal to the weight of the liquid displaced (i.e. buoyant force or upthrust), W_2 by the immersed part of the body.
2. The centre of gravity (G) of the body and the centre of buoyancy (B) of the liquid displaced must either coincide with each other or lie on the same vertical line.



If the floating body is slightly displaced from its equilibrium position by applying an external force, it gets slightly tilted. Now, the centre of gravity (G) and the centre of buoyancy (B) do not fall on the same vertical line. Actually, the vertical line passing through the new centre of buoyancy (B_1) intersects the former vertical line joining the centre of gravity (G) and the original centre of buoyancy (B) at some point. This point is called **metacentre**. So, metacentre is the point where the vertical line passing through new centre of buoyancy intersects the original line passing through the centre of gravity and original centre of buoyancy. It is denoted by the letter M .

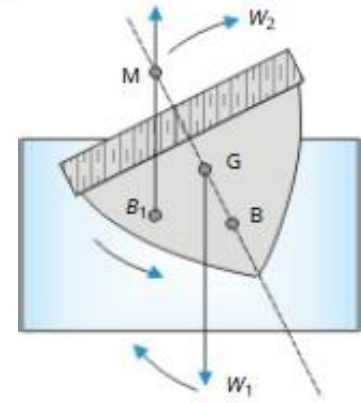


Depending upon the position of the metacenter with respect to the centre of gravity, the floating body can have the following three types of equilibrium:



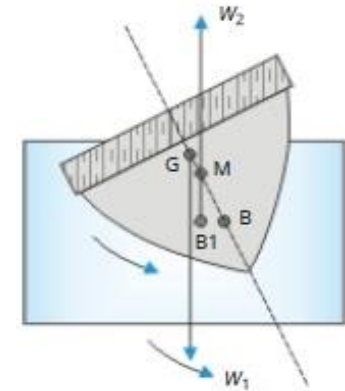
1. Stable equilibrium

If the centre of gravity G of the body lies below the metacentre M , the body will be in stable equilibrium. This is possible only when the body is heavily loaded at its bottom. If the body gets tilted the body has a tendency to get back to its original untilted position.



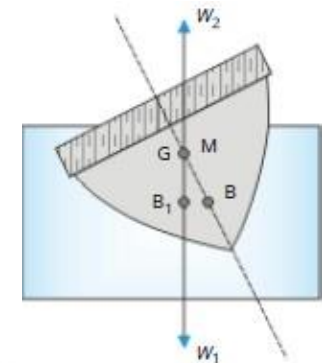
2. Unstable equilibrium

If the centre of gravity G of the body lies above the metacentre M , the body is in unstable equilibrium. This is possible when the body is heavily loaded at its top and the base is lighter. The body has the tendency to tilt further in the direction in which it was initially tilted. The body will not be able to regain its position and will overturn.



3. Neutral equilibrium

If the metacentre M coincides with the centre of gravity G of the body, the weight of the body $W1$ and the upthrust $W2$ will be in the same vertical line even in the tilted position. So, they balance each other.

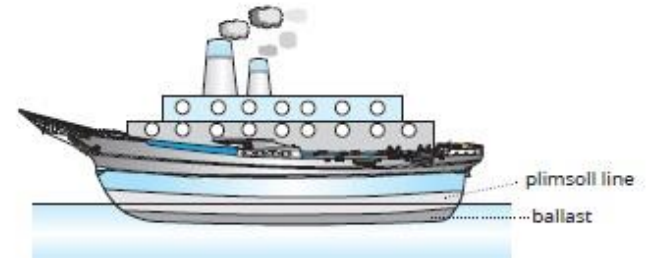




Applications of law of floatation

Floatation of iron ships

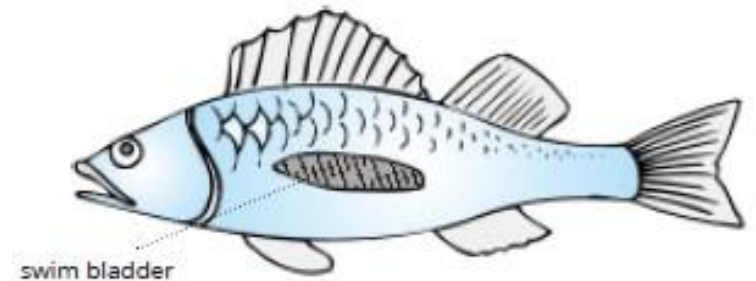
An iron nail sinks in water while a ship made of iron does not sink and keeps on floating. Since the density of iron is greater than that of water, therefore if we place an iron nail on the surface of water, the weight of the nail is greater than the weight of water displaced by it, so it sinks.



On the other hand, an iron ship does not sink because a ship is made hollow from inside which reduces the average density of ship than that of water. So, a ship floats on water. Therefore, even when a small part of a ship is submerged, the weight of the water displaced becomes equal to the weight of the entire ship. So, the iron ship keeps on floating.

Floatation of fish

Many species of fish have compressible organ called **swim-bladder**. It enables the fish to change the volume of its body and hence its average density.

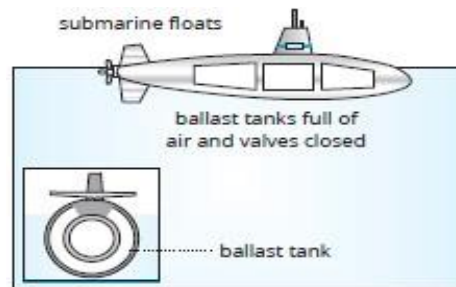




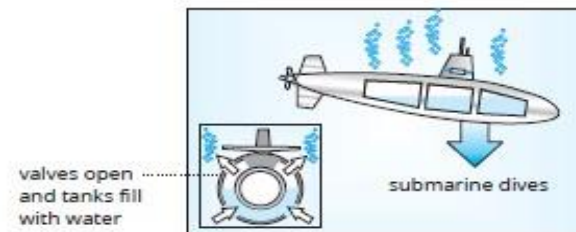
1. In order to rise up, the gases diffuse from the fish's body fluids into the bladder. As a result, the volume of the fish increases and so the upthrust increases and the fish rises up as its average density becomes less than that of sea water.
2. In order to come down, the gases diffuse from the bladder and the fish thus empties its bladder. As a result, volume of the fish decreases and so the upthrust decreases, and hence the fish comes down.

Floatation of submarine

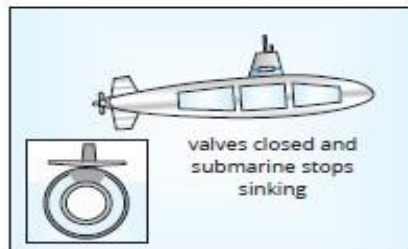
A submarine is a fish-shaped ship, which can travel under water. It has ballast tanks.



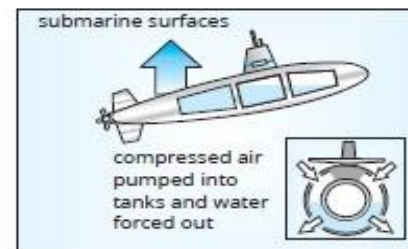
a.



b.



c.



d.



Floatation of man

1. The average density of human body with empty lungs is 1.07 g/cm^3 while with lungs filled with air is 1.00 g/cm^3 . A good swimmer can lie in water like a floating object, with his lungs filled with air and his head just above the water surface. The weight of the water displaced by him is nearly equal to his own weight. Because of this, he can swim with very little effort.
2. In the Dead Sea, the density of water is 1.16 g/cm^3 . Therefore, it offers a greater buoyant force. Therefore, the chances of drowning in the Dead Sea are very less. A man can easily swim with his shoulders above the water all the time.

Floatation of icebergs

The density of ice (0.917 g/cm^3) is less than the density of water (1 g/cm^3). Therefore, huge masses of ice known as icebergs are able to float on water. It has been found that an iceberg floats in sea water with $11/12$ part of its volume below the water surface and $1/12$ part of its volume above sea water. Icebergs are extremely dangerous for ships as the ships may hit the underwater icebergs due to their non-visibility and could sink into the sea.



SUMMARY...

1. Buoyant Force: The upward force acting on an object when partly or wholly immersed in a fluid.

2. Factors on which Buoyant Force Depends:

a. Volume of the body submerged in the fluid **b.** Density of the fluid in which the body is submerged **c.** Acceleration due to gravity **d.** Temperature of the fluid.

3. Archimedes' Principle: When a body is partially or wholly immersed in a fluid, it experiences an upthrust which is equal to the weight of the fluid displaced by the immersed part of the body.

4. Relative Density: The relative density of a substance is defined as the ratio of the density of the substance to the density of water at 4 °C. It has no units.

5. Law of Floatation: When a body is floating in a fluid, then the weight of the floating body is equal to the weight of fluid displaced by the immersed part of the body.

6. Types of Equilibrium: **a.** Stable equilibrium **b.** Unstable equilibrium **c.** Neutral equilibrium.

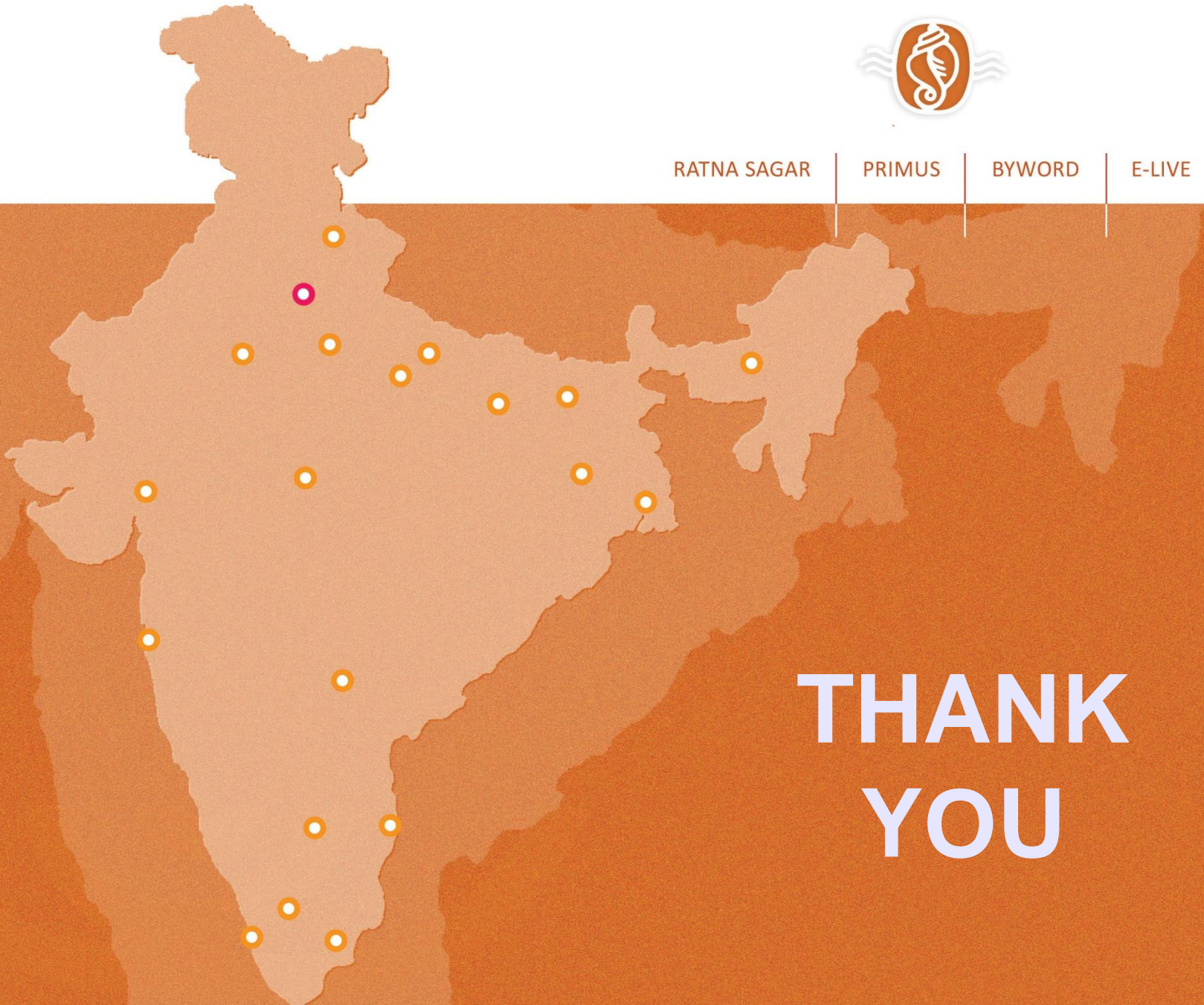


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