ARCHIMEDES' PRINCIPLE: DETERMINATION OF DENSITY OF UNKNOWN LIQUIDS

Gagan Gupta, Rajat Sardana and Ajit Singh Jhala

Department of Education in Science and Mathematics
NCERT, New Delhi

This simple activity demonstrates the buoyancy in classrooms and determines the density of an unknown solution using Archimedes' Principle by preparing a calibration chart using the solutions of known densities.

Introduction and Experimental Setup

Archimedes' Principle states that, "Any object completely or partially submerged in a fluid (gas or liquid) at rest is acted upon by an upward (or buoyant) force, the magnitude of which is equal to the weight of the fluid displaced by the body." Thus, the apparent loss in the weight of a submerged object is equal to the weight of the fluid displaced by it. The activity presented here shows the principle in action, which can easily be performed in classroom situations anywhere. It indeed does not require any rigorous instrumentation. We have used a lever of first kind (Fig.1), similar to a beam balance often used by street vendors to sell vegetables, etc.

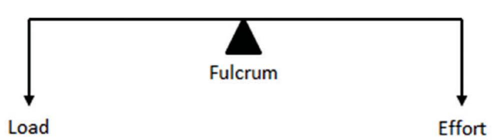

Fig. 1: Lever of First Kind

Let us consider a case where the beam is balanced in the horizontal plane. We have chosen a particular situation in which the load and effort are equidistant from the fulcrum. In this case, it is obvious to say that the masses (and thereby weights), of the two objects being used as load (A) and effort (B), respectively, are equal. Now, if one of them (B) is immersed in a fluid (say, water) (Assumption: Object B is non-porous and rigid), what would happen? Object B would appear lighter because the fluid applies an upward force, buoyant force, on the object. As a result, the beam of the balance would tend to lower down towards the mass that is not submerged in any fluid that is object A (mass mA). This lowering down of the beam would be in proportion to the weight (or mass) of the fluid displaced by the submerged object B (mass mB). This change in the alignment of the beam may experimentally be observed in terms of its deflection from the horizontal level, that is, angle θ, as shown in Fig. 2. This angle, therefore, obviously depends on the fluid density.

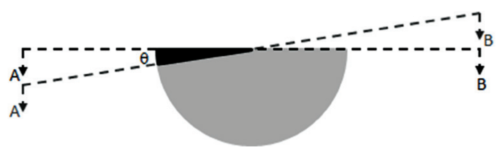

Fig. 2: The Tilting of Balance Beam by Angle (θ)

This idea can be used to determine the density of any fluid. What we can do for it is that we observe the deflection (or angle θ) for different liquids of known densities. This data leads to the plotting of a calibration curve between the density of a liquid and the tilt θ. This calibration curve can be used to determine the density of an unknown liquid.

Figure 3 gives the experimental setup. It comprises two objects, A and B, of equal masses, representing Load and Effort, respectively (see Fig.1). The balancing beam

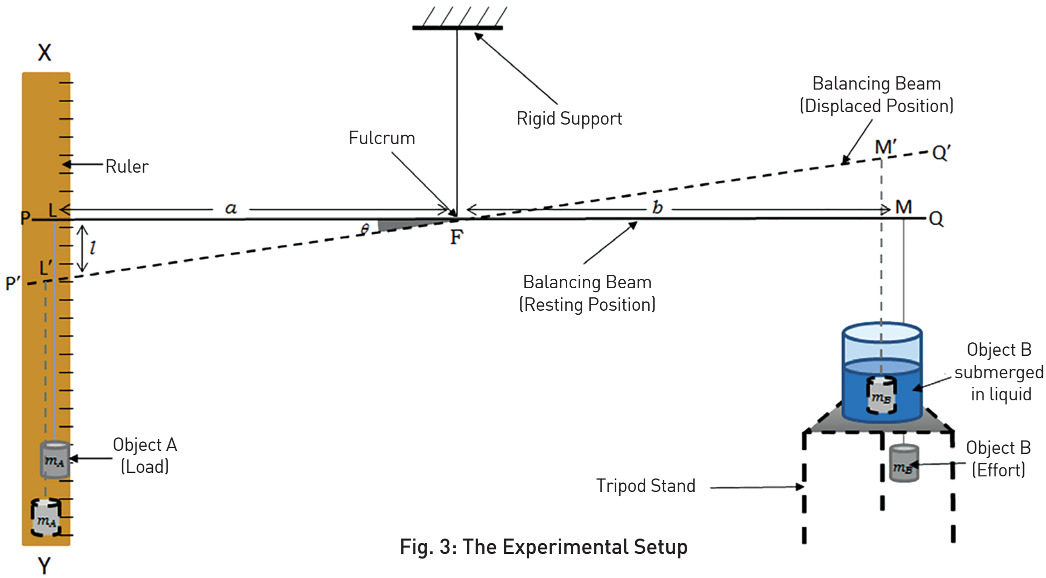

Fig. 3: The Experimental Setup

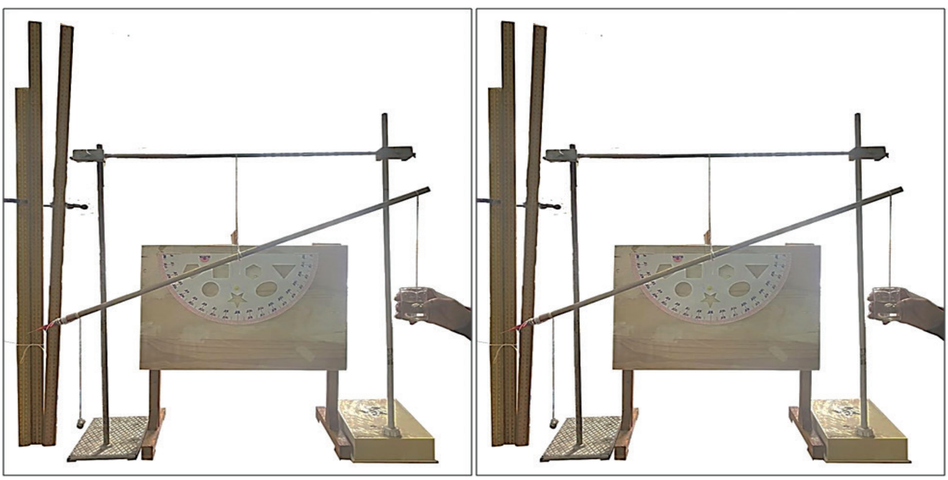

Fig. 4: The Actual Experimental Setup

(PQ) through which the masses are hanging freely at its ends is also shown. The beam is supported at Fulcrum (F) from a rigid support.

It is ensured first that the two masses A and B are suspended through the beam PQ such that it remains horizontal. That is

$$mA \times b = mB \times a$$

Here the distances a and b are explained in Fig. 3. We intend to submerge the mass B in different liquids, and we are using a vertical scale XY to see the deflection in beam PQ towards object A. The experimental setup is placed in a room away from air currents (i.e., not directly in front of a fan or window), which may affect the observations. Object B is a non-porous and rigid solid. For preparing the calibration curve, we have taken liquids as shown in Table 1.

Calibration Curve

We observe that the beam gets tilted in the direction of the object suspended in air (mass A), as object B is submerged in liquid. This implies that mass B has suffered an apparent loss in weight due to buoyant force exerted by the liquid. This verifies Archimedes' Principle.

This deflection in the beam could also be measured using the protractor placed in line with the beam (initially) behind the setup, as shown in Fig. 4. We, however, avoided this method to minimise the random errors in taking observations that might have arisen due to the finite thickness of the beam. Instead, we have observed the lowering of end P of the beam in the vertical plane (l) using the ruler XY. Using trigonometric relations, we have determined the angle θ.

$$\theta=\tan^{-1}\frac{1}{a}$$

Object B is successively submerged in different liquids of known densities, as given in Table 1. The corresponding tilts (θ) are given in Table 2. Fig. 5 plots the calibration curve. For the setup, a = b = 38 cm.

Table 1

S. No.	Liquid	Density (kg/m^3)
1.	Petroleum Ether	649
2.	Diethyl Ether	713
3.	Acetone	784.5
4.	Ethyl Acetate	902
5.	Deionised Water	1000
6.	Glycerine	1260

Table 2

S. No.	Material	Label as shown in Fig. 5	l (cm)	Density (kg/m^3)	θ (°)
1.	Petroleum Ether	A	9.3	649	13.70
2.	Diethyl Ether	B	10.4	713	15.24
3.	Acetone	C	11.1	784.5	16.24

4.	Ethyl Acetate	D	12.3	902	17.88
5.	Deionised Water	E	13.7	1000	19.85
6.	Glycerine	F	15.9	1260	22.76

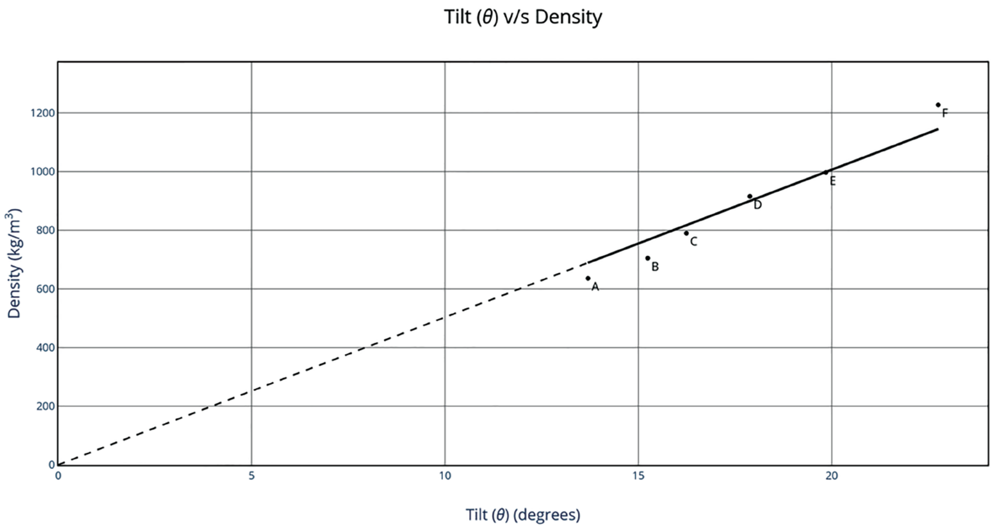

Fig. 5: Calibration Curve

Now, in turn, the density is plotted against the deflection recorded (Fig. 5).

Three samples containing different concentrations of salt (NaCl) were prepared. The same procedure was followed to determine their deflection. Their density was measured by weighing a given volume of the sample, as D.

Conclusion

Corresponding to the deflection, the density of the solution was determined using the calibration curve. This density is then compared with the density obtained by conventional means. Hence, the deviation between two values is calculated (in percentage).

We can see that the experimental results are very close to the correct values. Therefore, the given method can indeed rudimentarily be used in our school laboratories:

1. to demonstrate the Archimedes' Principle and
2. to determine the density of an unknown solution.

Solution	l (cm)	θ (°)	Density (from Graph) (kg/m^3)	Density (kg/m^3)	Percentage Error
Salt Solution I	14.4	20.77	1042.47	1014.82	1.53
Salt Solution II	14.6	21.07	1057.02	1055.69	0.13
Salt Solution III	15.2	21.77	1093.29	1086.59	0.62