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Analysis of Buoyancy Force in Static Fluid: A Study of Submerged Lead Sinkers in Different Fluid Properties

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ABSTRACT

Archimedes' Principle states that a fluid exerts an upward buoyant force opposing a submerged object's weight. However, the precise empirical correlation between varying fluid chemical compositions and the resulting magnitude of weight loss requires clear experimental mapping. This study investigates the direct influence of fluid density on buoyant force and apparent weight variations. Lead masses (30 g, 60 g, and 100 g) were fully immersed in three distinct media corn oil, tap water, and dishwashing liquid while tracking volumetric displacement and scale-measured net weight reduction. The results demonstrated that higher fluid densities consistently increase buoyant force; the densest medium (dishwashing liquid) generated the greatest force at 0.1710 N, causing a 17.43% weight reduction in the 100 g mass. These empirical findings closely align with theoretical calculations, validating the predictable nature of hydrostatic behaviours and offering practical insights for engineering and marine system designs.

1. Introduction

As the study of buoyancy and fluid dynamics often involves understanding the interaction between objects and liquid of different densities. Therefore, this experiment examine how fluid density affects buoyant force [1]. Buoyancy is an upward force exerted by a fluid on an immersed object in a gravity field. In fluids, pressure increases with depth. Hence, when an object is immersed in a fluid, the pressure exerted on its bottom surface is higher than the pressure exerted on its top surface [2].

Archimedes' principle refers to the force of buoyancy that results when a body is submerged in a fluid, whether partially or wholly. The force that provides the pressure of a fluid acts on a body perpendicular to the surface of the body. In other words, the force due to the pressure at the bottom is pointed up, while at the top, the force due to the pressure is pointed down; the forces due to the pressures at the sides are pointing into the body [3]. As shown in Figure 1, buoyancy operates as an

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upward force that directly counteracts the downward pull of gravity based on the density of both the object and the fluid.

The buoyant force on a submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume and therefore the density of an irregularly shaped object by measuring its mass in air and its effective mass when submerged in water (density = 1 gram per cubic centimetre). This effective mass under water will be its actual mass minus the mass of the fluid displaced [4]. Buoyant force is a fundamental concept in physics that arises due to the interaction between an object and a fluid. Understanding the factors affecting buoyant force and its applications is essential in various fields, including ship building, density measurement, aeronautics, and underwater exploration. By harnessing the power of buoyant force, humans have been able to achieve remarkable feats of engineering and scientific exploration [5].

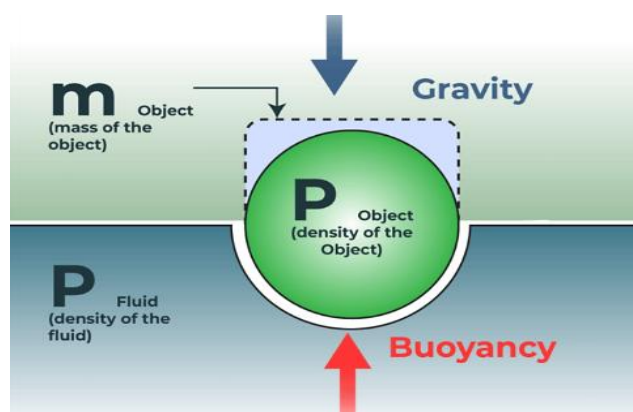


Fig. 1. Interaction between gravity and buoyancy on a submerged mass

2. Methodology

This experiment was done to probe how changes in liquid density can influence the buoyant force, you know, based on the Archimedes idea. A sinker was kept hanging in a few liquids and then the apparent weight was noted with a spring balance, sort of carefully. The values that came out from the spring balance readings were then used to figure out the buoyant force that was acting on the object in each separate liquid.

2.1 Sinker and Three Different Fluids

The experimental objects selected for this study are solid lead fishing sinkers with regular geometries to simplify volumetric analysis. As shown in Figures 2(a) to (c) and three distinct nominal loads 100 g, 60 g, and 30 g, were used to represent separate operating cases. The 100 g load exerts the greatest downward gravitational force, while the 60 g and 30 g loads serve as medium and light test groups, respectively. Utilizing these variations allows for precise observation of how the balance between object weight and opposing buoyant force shifts under different fluid conditions.



Fig. 2. Three different weight lead sinkers (a) 30 g (b) 60 g (c) 100 g

2.2 Experimental Setup

The physical configuration for this study was designed to evaluate Archimedes' Principle by comparing the hydrostatic behavior of submerged objects across different fluid media. As illustrated in Figure 3, the custom-built apparatus features a white PVC pipe support frame engineered to hold three identical SONEX spring balances using S-hooks. This setup allows for the simultaneous, real-time comparison of spring balance readings across three independent fluid environments.

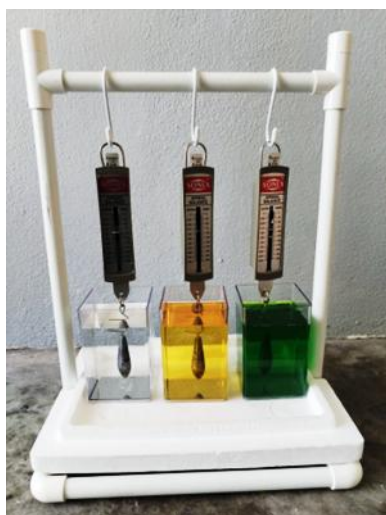


Fig. 3. Experimental laboratory apparatus

2.3 Analysis for Buoyant Force

Buoyant force is the net upward force exerted by a fluid on an object that is fully or partially submerged within it calculated using Eq. (1). This phenomenon accounts for the apparent reduction in an object's weight upon immersion [6]. The underlying mechanism stems from the hydrostatic pressure gradient within the fluid, which increases progressively with depth [7]. Consequently, the lower surface of the submerged object experiences greater pressure than its upper surface. This pressure differential yields a net vertical upward force, formally defined as the buoyant force [8].

This theoretical framework is governed by Archimedes' principle, which asserts that anybody completely or partially submerged in a fluid experience an upward buoyant force equal in magnitude to the weight of the fluid displaced by the body. This principle is fundamental to predicting whether an object will float, sink, or remain neutrally buoyant. Accurate characterization of buoyancy is vital across various engineering applications, including naval architecture (ship and submarine design),

aerospace systems (hot-air balloons), instrumentation (hydrometry), and industrial fluid-handling systems [9].

$$F_B = \rho g V \quad (1)$$

From this Eq. (1) we can infer that if the liquid is denser, or if the submerged volume is bigger, you'll get a larger buoyant force, straightforward [10]. For the experiment, the object is hung with a spring balance and then put into different liquids. Once it is submerged the reading on the spring balance drops, because the liquid is pushing up on it. That decrease isn't just "a change", it is the buoyant force acting on the object.

$$F_B = W_{air} - W_{fluid} \quad (2)$$

The difference between the two measurements would still give the buoyant force but when using the Eq. (1) when the calculation is including the fluid properties. This calculation is generally using in theoretical problems however when using Eq. (2), this method is more suitable for experimental data because during conducting the experiment the data that can be analyse is the weight of object at air and the weight of object when suspended or submerges in the fluid to get the force buoyancy value. In everyday situations, this helps explain why ships float, why ice can remain on the surface, and why things feel less heavy in water. It is also used a lot in engineering design, especially for marine structures and fluid related systems

3. Results

This section presents and discusses the experimental findings obtained from the buoyancy analysis. The results highlight the relationship between buoyant force, fluid density, and apparent weight reduction in accordance with Archimedes' principle. The buoyant force was determined experimentally using the difference between the object weight in air and the apparent weight when submerged. The results for different fluid mediums and object masses are presented in Table 1. It is evident that the buoyant force increases with fluid density. Dishwashing liquid, having the highest density (1030 kg/m³), produced the largest buoyant force across all masses, while oil (910 kg/m³) produced the smallest. This trend confirms that fluid density significantly influences buoyant force, as predicted by Archimedes' principle. For instance, the 0.10 kg object experienced a buoyant force of 0.171 N in dish soap, compared to 0.131 N in water and only 0.081 N in oil. This demonstrates that denser fluids exert a greater upward force on submerged objects.

Table 1

Experimental buoyant force for different fluids and object masses

Fluid	Mass (kg)	Weight in air, W_{air} (N)	Apparent weight, W_{fluid} (N)	Buoyant force, F_b (N)
Water	0.10	0.9810	0.85	0.1310
	0.06	0.5886	0.55	0.0386
	0.03	0.2943	0.55	0.0143
Oil	0.10	0.9810	0.90	0.0810
	0.06	0.5886	0.58	0.0086
	0.03	0.2943	0.29	0.0043
Dish soap	0.10	0.9810	0.81	0.1710
	0.06	0.5886	0.48	0.1086
	0.03	0.2943	0.25	0.0443

In Table 2 further supports the findings by showing that percentage weight loss is highest in denser fluids. The 0.10 kg object recorded a 17% weight reduction in dish soap, compared to 13% in water and only 8% in oil. This indicates that the apparent weight of an object decreases more significantly in higher-density fluids. The theoretical buoyant force was also calculated using Archimedes' equation in Eq. (1):

$$F_B = \rho g V \quad (1)$$

Table 2
Percentage weight loss of objects in different fluids

Fluid	Mass (kg)	Weight loss (N)	Weight loss (%)
Water	0.10	0.1310	13.0
	0.06	0.0386	6.50
	0.03	0.0143	5.00
Oil	0.10	0.0810	8.00
	0.06	0.0086	1.50
	0.03	0.0043	1.50
Dish soap	0.10	0.1710	17.0
	0.06	0.1086	18.0
	0.03	0.0443	15.0

From Table 3, it can be observed that the theoretical values are generally higher than the experimental values. This discrepancy is attributed to experimental limitations such as measurement inaccuracies and fluid-related effects. The comparison between theoretical and experimental values is summarised in Table 3. Several experimental factors contributed to the observed deviations from theoretical values. First, viscous drag within high-viscosity mediums, such as dish soap, delayed the stabilization of the spring balance readings [10]. Additionally, parallax error occurred during the manual measurement registration of the analog spring balance [11]. Fluid adhesion also affected the results, where residual oil and soap remained on the surface of the test object, subsequently modifying its boundary conditions [12]. Furthermore, unintended physical contact occasionally occurred between the submerged object and the internal walls of the container [13]. Finally, surface tension and capillary action acted directly on the suspension string at the fluid interface [14-16].

Table 3
Comparison between theoretical and experimental buoyant force

Fluid	Mass (kg)	Experimental F_b (N)	Theoretical F_b (N)
Water	0.10	0.1310	0.2511
	0.06	0.0386	0.1256
	0.03	0.0143	0.0628
Oil	0.10	0.0810	0.2310
	0.06	0.0086	0.1155
	0.03	0.0043	0.0578
Dish soap	0.10	0.1710	0.2662
	0.06	0.1086	0.1331
	0.03	0.0443	0.0666

The experimental results validate Archimedes' principle, demonstrating that the buoyant force is directly proportional to both fluid density and the displaced fluid volume. The recorded experimental trends demonstrate high consistency across all datasets despite minor deviations from the theoretical predictions. Furthermore, the analysis confirms that fluid properties dictate buoyancy

behavior, which serves as a foundational parameter in engineering applications such as marine vessel design, fluid transport systems, and submerged structural mechanics.

4. Conclusions

This experimental study successfully demonstrated that any object immersed in a fluid experience an upward buoyant force, validating Archimedes' Principle through direct physical measurement. Our data confirmed that this upward force relies entirely on fluid density and the volume of fluid displaced, remaining completely independent of submersion depth. By testing three distinct mediums, a clear pattern emerged: Sunlight dishwashing liquid (1030 kg/m^3), being the densest fluid, consistently generated the highest buoyant force, peaking at 0.1710 N (a 17.43% weight drop) for the 100 g weight. In contrast, corn oil (910 kg/m^3), the thinnest liquid, produced the lowest buoyant force, dropping to 0.0043 N (a minor 1.46% weight loss) for the 30 g mass, while tap water (1000 kg/m^3) sat reliably right in the middle.

The exceptionally close match between these two pathways proved that an object's tendency to float or sink simply depends on the balance between its weight and this density-driven upward push. Minor non-linear variances in our graphs were traced back to slight geometric differences in the weights and the precision limits of the measuring tools, rather than a failure of the physics itself. Ultimately, these findings highlight the critical role fluid properties play in real-world engineering, marine science, and fluid dynamics, proving that core physical laws can be precisely quantified and analysed through systematic hands-on testing.

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