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Analysis of the Physical Quantites Relationship of a Floating Object in Liquid.

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Abstract. *A concept relationship analysis of physical quantities for Buoyant Force* $\vec{F}_A$, *, Weight Force in the air* $\vec{w}_B$*, and Weight Force in the liquid* $\vec{w}'_B$ *on floating objects has been undertaken. It is found that in a static equilibrium state, there was no effect on the object's weight in the liquid* w'_B *or* $w'_B = 0$ *with the equation* $F_A = w'_B$. *Meanwhile, in a dynamic state, there is any effect on object's weight in the liquid* w'_B *with the equation* $F_A = w_B + w'_B$.

Keywords: , Floating Object, Buoyant Force, Weight Force.

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I. INTRODUCTION

One of the events or phenomena studied in physics by physicists is the object's condition of sinking, drifting, and floating when it is immersed in the fluids. Archimedes (287-212 BC), a physicist from Syracuse, Greece, examined this event, suggesting that an object immersed in a fluid experiences an upward buoyant force F_A equal to the weight of the fluid displaced w'_f or $F_A = w'_f$ which is known as Archimedes' law.

Based on Archimedes' law, if we examine an object immersed in a liquid, it is found that the upward buoyant force F_A exerted on an object submerged in the fluid, either partially or completely submerged, is equal to the weight of the fluid displaced w'_f by the object and works upwards towards the center of mass of the fluid being displaced which is called Archimedes' law which is formulated by $F_A = w'_f = \rho_f . V'_f . g$ with ρ_f as the density of the liquid and V'_f as the volume of the fluid displaced. (Tipler, 2011; Halliday and Resnick, 2006; Giancoli; 2001).

The application of Archimedes' principle by physicists can explain the floating, drifting and sinking of an object in a liquid. In studying the events of solids, hereinafter referred to as objects that sink and float in liquids, there are still differences in the studies carried out by several physicists in some of their research results (Abdullah, 1996)

In the event that objects sink in liquid by Lima et al. (2014) they state that Archimedes' principle does not apply to the objects that sink in liquid at the bottom of a container that does not touch the liquid at the bottom. However, Mohazzab, (2017) from the results of his research found that Archimedes' principle still applies to objects sinking in liquid at the bottom of the container by using a balance.

In the same year, Nergaard et al. (2017) found that the Archimedes' principle always applies to the relationship between the magnitude of the buoyant force F_A equal to the weight of the liquid displaced w'_f or $F_A = w'_f$. While the study of the relationship between the magnitude of the buoyant force F_A and the magnitude of the object's gravity in the air w_b by Fakhruddin (2019) found that objects floating in a liquid can occur if the magnitude of the buoyant force F_A is greater or equal to the magnitude of the object's weight w_B or the relationship applies $F_A \geq w_B$ which can occur in a static equilibrium state if $F_A = w_B$ and in a dynamic state if $F_A > w_B$.

In the same year, Cavazzini (2019) stated that the floating of solids on the surface of liquids in a static equilibrium is only caused by two gravity forces, namely the gravity of the solid in the air in an immersed state w_{BU} which points downward and the gravity of the immersed solid inside the liquid w'_{Bf} pointing up. In this case, Cavazzini (2019) does not examine floating objects in a dynamic state and does not compare the total weight of the solid in air before being immersed w_B and the total gravity of the solid while in the liquid w'_B.

II. METHODS

The method in this study uses a systematic literature review by examining some relevant literature from book or journals to find solutions to research problems. The systematic literature review procedure begins with developing a research problem formulation, then designing a conceptual framework to find alternative solution, then building selection criteria and developing a literature search strategy by means of studies using selection criteria, coding studies, and assessing the quality of the synthesized studies, after that on the final stage is to report the findings on the analysis or synthesis results.

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III. RESULTS AND DISCUSSION

1. The relationship between the concept of Buoyant Force $\vec{F}_A$, the weight of an object in the air $\vec{w}_B$, and the weight of an object in a liquid $\vec{w}'_B$ on an object sinking in a liquid

An irregularly shaped object whose weight in the air is w_B with a density of ρ_B hanging from a rope that has a magnitude of the tension in the rope T equal to the weight of the object in air w_B or T=w_B. Then it is put it in a container filled with liquid with a density of ρ_B at a height H which has a cross-sectional area A as shown in Figure 1a.

After being immersed in the liquid, the water surface will experience an increase in height by ΔH with the magnitude of the tension in the rope T' when the object in the liquid is equal to the weight of the object in the liquid w'_B which is usually called the apparent weight of the object (Mohazzabi, 2017) as in Figure 1b.

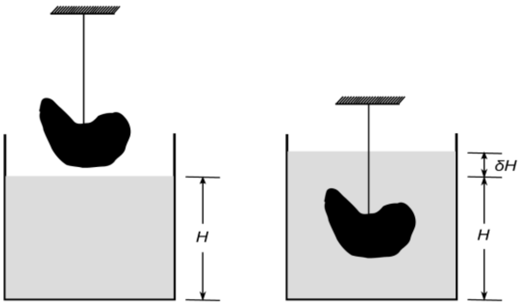

Figure 1. (a). Objects before being immersed in liquid, (b) Objects after being immersed in liquid (Source: Mohazzabi and James 2017)

The volume change of the displaced liquid is $V'_f = A.\Delta H$ whose mass is m'_f so that the weight of the displaced fluid w'_f is:

$$w'_f = m'_f.g = \rho_f.V'_f.g \qquad (2)$$

The weight of the displaced fluid 〖w'_f is the same as the additional weight of the object in the liquid $\vec{w}'_B$ downwards (Mozzabi and James 2017). However, this was revised by Mozzabi (2017) by conducting an experiment by placing a balance at the bottom of the container as shown in Figure 2a.

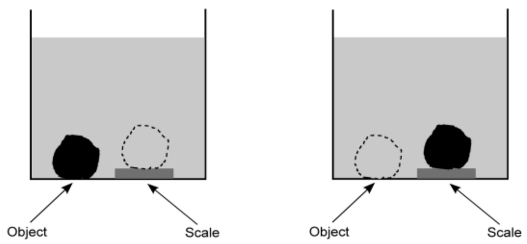

Figure 2. (a) Objects sink to the bottom of the container and there is a balance, (b) objects are placed on the balance

(source: Mohazzabi, 2017)

If an object sinks to the bottom of a container in a liquid with the weighs w'_B, then the magnitude is equal to the magnitude of the weight designation on the balance in Figure 1.b. The weight of the object in liquid w'_B is equal to the difference in the weight of the object in air w_B and the weight of the fluid displaced w'_f using the equation (Mozzabi (2017)

$$w'_B = w_B - w'_f = w_B - F_A$$
$$= m'_B \cdot g - r_f g\, V'_f \quad (3)$$

Therefore, the weight of an object in a liquid or the apparent weight of an object $\vec{w}'_B$ in a static submerged state has the direction of the upward gravitational force in the same direction as the buoyant force $\vec{F}_A$.
The cause of the buoyancy force $\vec{F}_A$ is obtained as follows.

$$\vec{F}_A = \vec{\boldsymbol{w}}_{\boldsymbol{B}} - \vec{\boldsymbol{w}}'_{\boldsymbol{B}} \quad (4)$$

The result of equation (4) describes that the buoyant force of a liquid $\vec{F}_A$ in a system of sinking objects in a liquid at rest is caused by a reduction in the weight of the object in air w_B with the weight of the object in liquid w'_B.

2. The relationship between the concept of buoyancy $\vec{F}_A$, the weight of an object in the air $\vec{w}_B$, and the weight of an object in a liquid $\vec{w}'_B$ on an object floating in a liquid

According to Fakhruddin (2019), the event of floating objects in liquid can be studied in two states, namely floating objects in a state of static equilibrium (at rest) if $F_A = w_B$ and objects in a dynamic state (moving) if $F_A > w_B$. In general, it is found that objects floating in liquids apply the equation $F_A \geq w_B$.

2.1 A floating object in a liquid in a dynamic state.

For example, if a floating object in a liquid has a mass of m_B, a density of ρ_B and a weight ofw_B in the air as shown in Figure 3.a, it is placed in a non-viscous liquid with a density of ρ_f with $\rho_f > \rho_B$ to a container as shown in Figure 3.b. The object is then released so that the object moves upward as shown in Figure 3.c.

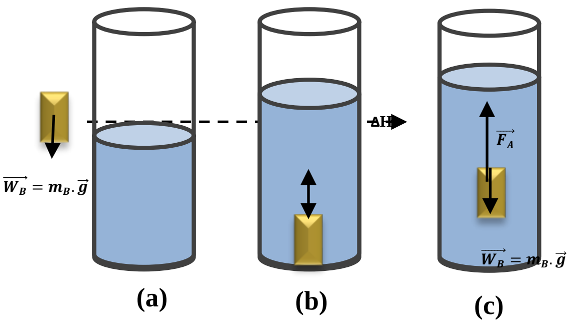

Figure 3. (a) a floating object in the air with a weight $\vec{w}_B$, (b) a floating object is placed in a liquid at the bottom of the vessel with a change in the height of the liquid ΔH, (c) The floating object moves upward due to the buoyant force $\vec{F}_A$ and object's gravity $\vec{w}_B$

Based on Newton's 2nd law, if there is no external force acting on the object, then the object can move upwards with a deceleration $-\vec{a}$ whose downward direction is caused by the resultant force $\sum \vec{F}$ then the equation is obtained:

$$-\vec{a} = \frac{\sum \vec{F}}{m'_B} \quad (5)$$

with m'_B as the mass of the object in the liquid or the apparent mass of the object in the liquid.

The magnitude of the resultant force $\sum \vec{F}$ exerted is caused by the difference in the magnitude of the buoyant force $\vec{F}_A$ by the liquid with the weight of the object in the air $\vec{w}_B$ or the equation is obtained as follows.

$$\sum \vec{F} = \vec{F}_A - \vec{w}_B . \quad (6)$$

if equation (6) is substituted to equation (5), it can be obtained as follows.

$$-\vec{a} = \overrightarrow{(F_A} - \vec{w}_B)/m'_B$$

or

$$m'_B\ (-\vec{a}) = \vec{F}_A - \vec{w}_B \qquad (7)$$

The magnitude of the object's deceleration upward a is equal to the acceleration of gravity g because there is no external force exerted on the object, hence equation (5) can be written

$$-m'_B\ .\vec{g} = \vec{F}_A - \vec{w}_B \qquad (7.\text{a})$$

the object's weight $-m'_B\ .\vec{g}$ is the object's weight in liquid $\vec{w}'_B$ so that the object's weight in liquid w'_B is directed downward in the direction of the object's weight in air $\vec{w}_B$ which can be formulated:

$$w'_B = m'_B\ .g \qquad (8)$$

thus, the equation (7.a) can be written as:

$$-\vec{w}'_B = \vec{F}_A - \vec{w}_B \qquad (7.\text{b})$$

the weight direction a floating object in a liquid in a dynamic state (moving) $\vec{w}'_B$ points downward in the opposite direction to the buoyant force $\vec{F}$. Thus, the magnitude of the object's weight in the liquid w'_B is $w'_B = F_A - w_B$.

According to Archimedes' law, the magnitude of the buoyant force F_A is equal to the weight of the displaced liquid w'_f or $F_A = w'_f = m'_f.g = \rho_f.V'_f.g$, thus equation (9) can be written as follows.
$w'_B = F_A - w_B = w'_f - w_B = \rho_f.V'_f.g - w_B$ (10)

The result of equation (10) is identical to equation (3) obtained by Mozzabi (2017) for an object immersed in a liquid in a static state where the direction of the gravitational force (object's weight) of the object in the liquid $\vec{w}'_B$ is directed upward in the direction of the buoyant force $\vec{F}_A$.
The cause of the buoyant force $\vec{F}_A$ is obtained based on Newton's 3rd law

$$-\vec{F}_A = \vec{w}_B + \vec{w}'_B \qquad (11)$$

the magnitude of the buoyant force $\vec{F}_A$ as the reaction force in the opposite direction to the gravity $\vec{w}_B + \vec{w}'_B$ as the action is obtained as follwos.

$$F_A = w_B + w'_B \qquad (12)$$

The result of equation (12) describes that the buoyant force of a liquid $\vec{F}_A$ on a floating body system in a liquid in a moving state is caused by an "addition of the object's weight" from the weight of the object in air w_B and the weight of the object in liquid w'_B.

2.2 The Floating Object in liquids in a state of static equilibrium (at rest)
Cavazzini (2019) examines the floating objects in liquids in a state of static equilibrium (at rest) as shown in Figure 4.

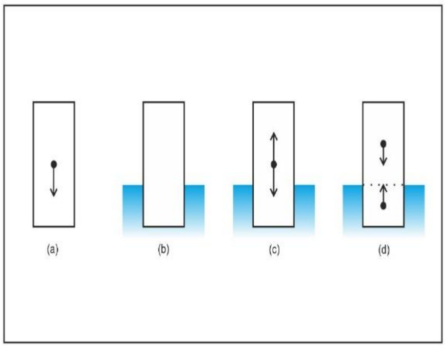

Figure 4. (a) objects in air, (b) objects floating in liquid, (c) first mechanical interpretation when floating objects are in equilibrium, (d) second mechanical interpretation when floating objects are in equilibrium

Cavazzini (2019) suggests that there are two hypotheses that can occur for objects floating in liquid in a state of static equilibrium, namely the magnitude of the gravitational force between objects with mass m_B and the planetary mass M does not change wherever the object is immersed in liquid as shown in Figure 4.c which results in the weight of the object in the air w_B being equal to the buoyant force of Archimedes F_A . In this case the equation applies:

$$w_B = F_A \qquad (12)$$

The second hypothesis is that when an object is immersed in a liquid, it "loses weight" as shown in Figure 4.d. In this case, the static equilibrium occurs from the interaction of the weight of the object that is not immersed in the liquid w_{BU} which is directed downwards with the weight of the object immersed in the liquid w'_{Bf} which is directed upwards. In this case the equation applies:

$$w_{BU} = w'_{Bf} \qquad (13)$$

This second hypothesis or equation (13) is proven by Cavazzini (2019) by examining an object whose volume is V_B and densityρ_B floating in a liquid whose density is ρ_B with the volume part of the object immersed in water V'_B. The volume of an object that is not immersed V'_{BU} is $V'_{BU} = V_B - V'_B$.

The weight of the object that is not immersed in the liquid $w_{BU} = m_{BU}.g = (\rho_B - \rho_U).V'_{BU}.g$ which is downward. While the weight of the object immersed in the liquid $w'_{Bf} = m_{Bf}.g = (\rho_f - \rho_B).V'_{BU}.g$ which is directed upwards is not the weight of the object whose volume is V_B in liquid w'_B.

Because the magnitude of $w_{BU} = w'_{Bf}$ and $V'_{BU} = V_B - V'_B$, thus equation (13) can be written as follows.

$(\rho_B - \rho_U).V'_{BU}.g = (\rho_f - \rho_B).V'_B.g$ (14)

Or

$(\rho_B - \rho_U).(V_B - V'_B).g = (\rho_f - \rho_B).V'_B.g$ (15)

The magnitude of $r_B - r_u \approx r_B$ because $r_B >> r_u$ and $V'_B = V'_f$ thus equation (15) can be written

$$\rho_B.V_B.g = \rho_f.V'_f.g \qquad (16)$$

The magnitude of $\rho_B.V_B$ is the mass of solid m_B and $\rho_B.V'_f$ with the mass of displaced liquid m'_f hence equation (16) can be written:

$$m_B.g = m'_f.g \qquad (17)$$

Since the magnitude of $m_B.g$ is the object's weight w_B and $m'_f.g$ is the weight of displaced liquid w'_f or the the magnitude of buoyant force F_A, hence equation (17) can be obtained as follows.

$$w_B = w'_f = F_A \qquad (18)$$

By examining equations (12) and (18), it can be seen that although they are physically different, they have the same result in explaining the validity of Archimedes' principle. However, the study conducted by Cavazzini (2019) in studying floating objects in liquids in a state of static equilibrium has not been able to explain whether there is weight in liquid w'_B as in equation (8).

Another form of study can be carried out in analyzing floating objects in liquids in a state of static equilibrium by using Newton's laws of motion. Based on Figure 4.c which describes a floating object in a liquid in a state of static equilibrium, Newton's 1st law applies, i.e.

$$\sum \vec{F} = \vec{0} \qquad (19)$$

because a floating object is in a static equilibrium (at rest) is immersed in a liquid, then there are only two forces acting, namely the object's weight in the air $\vec{w}_B$ and the buoyant force $\vec{F}_A$ so that the resultant force acting is

$$\sum \vec{F} = \vec{F}_A - \vec{w}_B = \vec{0} \qquad (20)$$

The magnitude of buoyant force F_A is equal to the magnitude of the liquid's weight displaced w'_f hence equation (20) can be written:

$$F_A = w'_f = w_B \qquad (21)$$

Equation (21) is identical to equation (18), but equation (21) explains that for an object floating in a liquid in static equilibrium (at rest) there is no weight of the object in the liquid w'_B or $w'_B = 0$ so ``that no 'change in weight of an object' when it is in a liquid.

IV. CONCLUSION

Based on the analysis result of the relationship between the physical quantities of the buoyant force $\vec{F}_A$, the weight of an object in air $\vec{w}_B$, and the force of gravity of an object in a liquid $\vec{w}'_B$ on an object floating in a liquid, it is found that:

1. In floating objects in a liquid in a dynamic state (moving), there is an "addition of the object's weight" from the weight of the object in air w_B and the weight of the object in liquid w'_B caused by the resultant force between the buoyant force $\vec{F}_A$ and the weight of the object in air $\vec{w}'_B$ resulting in the presence of the object's gravity in the liquid $\vec{w}'_B$ which is downward in the opposite direction to the buoyant force $\vec{F}_A$ which has the magnitude $w'_B = F_A$ - w_B. The magnitude of the buoyant force $\vec{F}_A$ is obtained by $F_A = w_B + w'_B$ which means it happens.
2. In a floating object in a liquid in a state of static equilibrium (at rest), there is no change in the weight of the object in the liquid caused by the magnitude of the buoyant force F_A which is equal to the weight of the object in air w_B with the equation $F_A = w_B$, so there is no weight of the object in liquid w'_B or $w'_B = 0$.

REFERENCES

[1]. Lima, F. M. S., Venceslau, G. M., & Brasil, G. T. (2014). *A downward buoyant force experiment*. www.sbfisica.org.br
[2]. Mohazzab, P. (2017). Archimedes' Principle Revisited. *Journal of Applied Mathematics and Physics*, *05*(04), 836–843. https://doi.org/10.4236/jamp.2017.54073
[3]. Nergaard, A., Architect, N., & Engineer, P. (2017). The Magic of Buoyancy and Hydrostatics –Buoyancy and Effective Forces. *Modern Applied Science*, *11*(12), 77. https://doi.org/10.5539/mas.v11n12p77
[4]. Fakhruddin (2019). Influence Analysis of Physical Quantity of Weight, Buoyant Force, and the Density of Floating Object in the Fluid. International Journal of Science and Research (IJSR). Volume 8 Issue 9, 50-53
[5]. Cavazzini, G. (2019). Archimedes' Principle and the Concept of Gravitation. Applied Physics Research; Vol. 11, No. 6,11-18
[6]. Tipler Paul A. (2001). Physics for scientists and engineers (third edition). Worth Publisher, Inc. New York.
[7]. Halliday & Resnick. (2006) Physics (6rd Edition). John Wiley & Sons, Inc., New York.
[8]. Giancoli. Douglas C.(2001). .Physics (seventh edition). Prantice Hall Inc, New Jesley..
[9]. Abdullah, M. (2016) . *Fisika Dasar 1*, Bandung: ITB.