Archimedes Principle & The Floating Pennies

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Archimedes Principle: *"The buoyant force on an object is equal to the weight of the fluid the object displaces."*

Objectives: Calculate the buoyant force on an object.
Compare the buoyant force on an object with its weight.

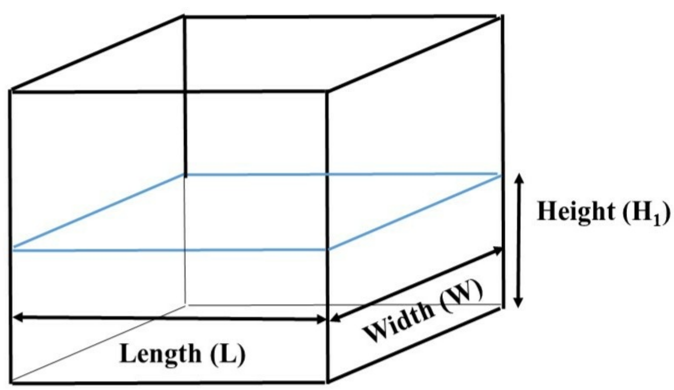
Materials:

Triple-beam balance
Transparent or translucent plastic tub (16 cm x 16 cm inside dimensions, 17.5 cm high)); a 16-cup capacity food storage container available from Walmart retail stores or www.walmart.com is an ideal size with a volume of 4,000 cm^3.
Clear plastic beverage cup (9 ounce); holds 256 cm^3 of water.
Two metric rulers
100 pennies (1 penny = 2.5 grams)
Water

Procedure:

1. Fill the tub ½ full of water. In the attached data table, record in centimeters the length, L (16 cm) and width, W (16 cm) of the tub. Measure the initial height of the water, $\mathbf{H_1}$, by placing the ruler into the water. See FIGURE. Record this value in the DATA TABLE.

2. Use the equation given in the table to calculate and record the **initial volume** of water in the tub



Trial 1

3a. Place the plastic cup in the tub of water, and add about 50 pennies of mass until the cup sinks to about 3/4 of its height. Place a metric ruler in the center of the cup and gently push it down until the cup is just about to sink, but still remains floating. Measure the new height, $\mathbf{H_2}$, of the water in the tub by placing the ruler into the water. Record this value, called **"New Height"**, on **row 3a** in the DATA TABLE.

3b. Use the new height to calculate the new **total volume** of water in the tub. Record the result on **row 3b** in the DATA TABLE.

Remove and dry off the outside of the cup containing the pennies. Use the triple-beam balance to determine their total mass in grams and record this value, $\mathbf{m_2}$, on **row 7** in the DATA TABLE.

Convert the mass (g) to weight in Newtons (N) and record it on **row 8** under **Trial 1** in the DATA TABLE. Grams/100 = Newtons.

4. Calculate the volume of the water that the cup and pennies displaced. Record the result on **row 4** in the DATA TABLE. This displaced volume, $\Delta\mathbf{V}$, is equal to the new total volume minus the initial volume.

5. Calculate the mass of the displaced water, $\mathbf{m_1}$, by multiplying the displaced volume by its density (water density = 1 g/cm^3). Record this value on **row 5** in the DATA TABLE.

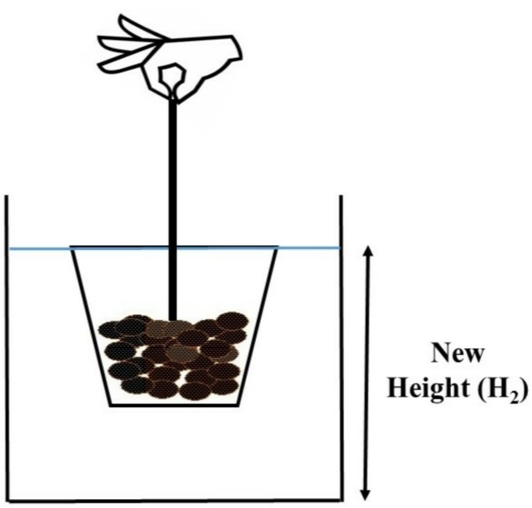
6. Divide the mass by 100. The resulting value is the weight of displaced water in Newtons (N) , which is equal to the **buoyant force**. Record the weight of the displaced water on **row 6** in the DATA TABLE.

7. Compare the value in **row 6** with the one on **row 8**.

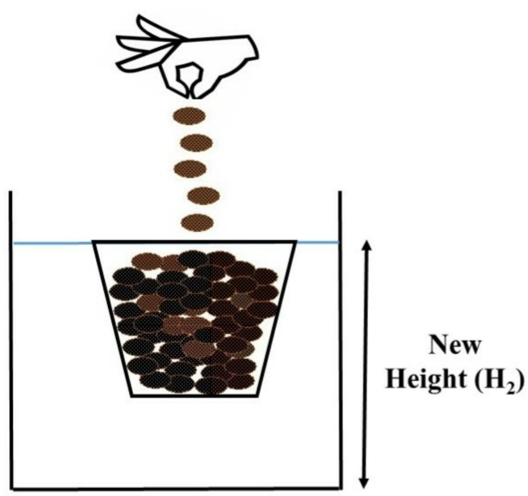
Trial 2

Repeat steps 3a - 7. This time add more pennies one at a time until the cup is just about to sink, but still remains floating..

Trial 1



Trial 2



DATA TABLE: Floating Pennies

Step	Measurement	Trial 1		Trial 2	
		Calculation	Data/Results	Calculation	Data/Results
1 a	Length = L in centimeters				
1 b	Width = W in centimeters				
1 c	Initial Height = H_1 in centimeters				
2	Initial Volume = V_1 in cm^3 $V_1 = L \times W \times H_1$				
3 a	New Height = H_2 in centimeters				
3 b	New Total Volume = V_2 in cm^3 $V_2 = L \times W \times H_2$				
4	Displaced Volume of Water $\triangle V = V_2 - V_1$				
5	Mass of Displaced Water in grams $m_1 = \triangle V \times 1 g/cm^3$				
6	Weight of Displaced Water in Newtons $m_1/100$ = Buoyant Force				
7	Mass of Cup + Pennies, m_2 in grams				
8	Weight of Cup + Pennies $m_2/100$ = Newtons				

QUESTIONS:

1. In trial 1, the weight of the displaced water (buoyant force) is: (circle one)

   a. More than the weight of the cup and pennies.
   b. Less than the weight of the cup and pennies.
   c. Approximately Equal to the weight of the cup and pennies.

2. In trial 2,the weight of the displaced water (buoyant force) is: (circle one)

   a. More than the weight of the cup and pennies.
   b. Less than the weight of the cup and pennies.
   c. Approximately Equal to the weight of the cup and pennies.

3. If even more mass is added in trial 2, then I predict that the cup will (circle one):

   a. Float
   b. Sink

4. An object floats when its ______________equals the____________________exerted by the surrounding fluid.

5. If a boat's shape has more_________underwater, then the boat can float more mass because the ***force*** of gravity per square unit decreases as the ***pressure*** is spread across more__________as a result of P = F/A.

6. An object that is more dense than the surrounding fluid__________, and an object that is less dense than the surrounding fluid _________.

7. The________ of the displaced water equals the________________________of the displaced water in Newtons.

8. The buoyant force is equal to the________of gravity, or_________of the displaced water.

TEACHER NOTES, DATA TABLE EXAMPLE & ANSWER KEY

In order for the students to get meaningful results, the size of the plastic tub should not be too large, otherwise students will have difficulty in obtaining a significant difference between H_1 and H_2. The square container recommended in the material list works quite well, but any plastic box of a similar size can be used. Because of the tapered nature of these containers, there are inevitable measurement errors, so the buoyant force measured in Trial 1 and Trial 2 will sometimes differ as shown in the example below.

A 9-ounce, clear plastic beverage cup has a total volume of about 250 cubic centimeters and a mass of about 10 grams. When completely submerged in water up to its lip, the weight of the water displaced by the cup will therefore be approximately 260 grams. This equates to a buoyant force of 2.6 Newtons. Thus, in Trial 2, the weight of the floating cup and pennies should be less than or approximately equal to the buoyant force as shown in the example below.

DATA TABLE: Floating Pennies
EXAMPLE

Step	Measurement	Trial 1		Trial 2	
		Calculation	Data/Results	Calculation	Data/Results
1 a	Length = L in centimeters		16 cm		16 cm
1 b	Width = W in centimeters		16 cm		16 cm
1 c	Initial Height = H_1 in centimeters		10 cm		10 cm
2	Initial Volume = V_1 in cm^3 $V_1 = L \times W \times H_1$	16 x 16 x 10 =	2,560 cm^3	16 x 16 x 10 =	2,560 cm^3
3 a	New Height = H_2 in centimeters		10.8 cm		11 cm
3 b	New Total Volume = V_2 in cm^3 $V_2 = L \times W \times H_2$	16 x 16 x 10.8 =	2,765 cm^3	16 x 16 x 11 =	2,816 cm^3
4	Displaced Volume of Water $\triangle V = V_2 - V_1$	2,765-2,560 =	205 cm^3	2,816-2,560 =	256 cm^3
5	Mass of Displaced Water in grams $m_1 = \triangle V \times 1 g/cm^3$	205 x 1 =	205 g	256 x 1 =	256 g
6	Weight of Displaced Water in Newtons $m_1/100$ = Buoyant Force	205 / 100 =	**2.05 N**	256 / 100 =	**2.56 N**
7	Mass of Cup + Pennies, m_2 in grams		138.4 g		249.0 g
8	Weight of Cup + Pennies $m_2/100$ = Newtons	138.4 / 100 =	**1.38 N**	249 / 100 =	**2.49 N**

Compare steps 6 and 8 - Buoyant Force is greater than mass of pennies, enabling the cups with pennies to float

ANSWER KEY:

1. **a, MORE THAN**

2. **a, MORE THAN**

3. **b, SINK**

4. An object floats when its _**WEIGHT**_____equals the_**BUOYANT FORCE**_exerted by the surrounding fluid.

5. If a boat's shape has more **AREA** underwater, then the boat can float more mass because the ***force*** of gravity per square unit decreases as the ***pressure*** is spread across more__**MASS**______as a result of P = F/A.

6. An object that is more dense than the surrounding fluid__**SINKS**______, and an object that is less dense than the surrounding fluid __**FLOATS**___.

7. The_**WEIGHT**_of the displaced water equals the_**BUOYANT FORCE**_of the displaced water in Newtons.

8. The buoyant force is equal to the__**FORCE**___of gravity, or_**WEIGHT**__of the displaced water.