Archimedes Principle

Introduction

Many of the substances we encounter in our every day lives do not have rigid structure or form. Such substances are called fluids and can be divided into two categories: liquids and gases. The forces between atoms and molecules in these substances are not strong enough to keep them in fixed place (as it happens in solids) and molecules move freely about. In liquids, these internal forces are strong enough to hold the substance loosely together. In gases, the forces are so weak that molecules are nearly independent of each other. Because these forces are so weak, a gas expands to fill any volume in which it is contained. In this laboratory we introduce one of the most important physical quantities used in the description of fluids: mass density, and the concept of buoyancy.

Biological Systems

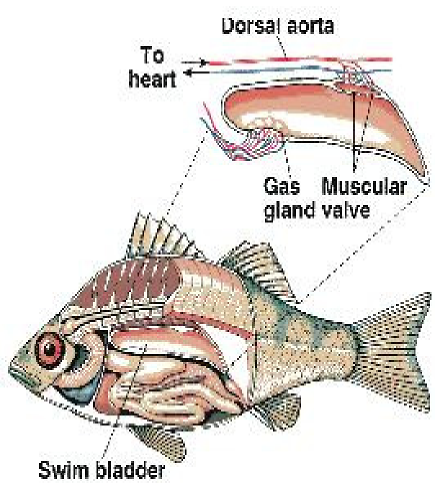

Fig. 1: Swim bladder (*Review of the Universe*)

An object submerged in a fluid experiences a force called the buoyant force. Fish effectively use the buoyant force and a special buoyancy organ, swim bladder, to maintain their position in water, descend or ascend by controlling their buoyancy. Swim bladder is a gas-filled sac located in the dorsal portion of the fish. Walls of the swim bladder are flexible and impermeable to gasses. As a fish starts to descend, the increasing water pressure leads to the compression of the gas inside the swim bladder, increasing the density of the fish. As the fish becomes denser than water it continues to sink. On the other hand, as a fish starts to ascend, the water pressure decreases and the gas inside the swim bladder expands, decreasing the density of the fish. As the fish becomes denser than water it continues to sink. On the other hand, as a fish starts to ascend, the water pressure decreases and the gas inside the swim bladder expands, decreasing the density of the fish. Since the fish now is less dense than the surrounding water, it starts to float upward. To maintain a constant volume of the swim bladder and thus to preserve neutral buoyancy over a wide range of depths and pressures, many fish have mechanisms that allow them to either add or remove gases from the bladder.

Experiment

Let us first define the physical quantity which is of prime importance in discussion of liquids: the mass density. The mass density of an object (not necessarily fluid, the definition works for any kind of substance) is given by:

$$\rho = m/V \tag{1}$$

where
ρ is the mass density of an object,
m is the mass of the object, and
V is the volume of the object.

One of the objectives of our lab is to measure the mass densities of three unknown objects by using the method that is attributed to the greatest scientist of ancient Greece Archimedes (c.287 BC- c. 212 BC).

Fig. 2: Archimedes (*Wikipedia*)

As seen from the definition of mass density, to find the density of an object we need to measure two quantities: the mass of the object and its volume. Mass of an object can usually be found easily with a scale, but measuring volume is more complicated, especially for objects that do not have regular, symmetric shapes. Archimedes realized that the difficult task of finding a volume of an irregularly shaped object can be done by simply measuring the volume of the displaced liquid once the object is submerged into it.

Another important principle discovered by Archimedes is one of buoyancy (or Archimedes Principle) which explains why some objects, such as wood or plastic, float in water when others, such as metals, sink.

Archimedes realized that an object immersed in fluid will be lighter by an amount equal to the weight of the fluid it displaces. This upward force exerted on the object by the fluid is known as the buoyant force:

$$F_B = g\,\rho_F\,V \qquad (2)$$

where
F_B is the buoyant force on the object,
g is the acceleration due to gravity,
ρ_F is the density of the fluid, and
V is the volume of the object immersed in a fluid.

Experiment 1.

It is possible to use Archimedes principle to determine the density of an object without ever determining its volume. According to Archimedes principle

$$F_B = w_A - w_F \qquad (3)$$

where

F_B is again the buoyant force on the object,

w_A is the normal weight of the object measured in air ($w_A = m\,g$), and

w_F is the weight taken while the object is immersed in a fluid of density ρ_F.

Comparison between equations (2) and (3) allows us to write

$$g\,\rho_F\,V = w_A - w_F \qquad (4)$$

Solving this equation for the volume of the object

$$V = (w_A - w_F)/(g\,\rho_F) \qquad (5)$$

and substituting it into the definition of density (1) we arrive (after some simplification) to

$$\rho = [w_A/(w_A - w_F)]\,\rho_F \qquad (6)$$

Experiment 2.

In this experiment we will use Archimedes principle to measure the density of an unknown fluid. Using equation (5) to solve for the density of fluid we arrive to

$$\rho_F = (w_A - w_F)/(g\,V) \tag{7}$$

Procedure

1. Secure the necessary equipment (triple-beam balance, beaker, graduated cylinder, three objects made of different materials, string, and overflow can).

2. Using the triple-beam balance weigh the objects in air and submerged in water. Record your data in the tables provided below.

3. Fill the beaker with the unknown fluid and submerge one of the objects into it. Weigh your object while submerged. Take the object out of liquid and weigh it in air. Using the overflow can and graduated cylinder measure the volume of the displaced liquid. Record your data. Repeat experiment using two more objects.

Fig. 3: Overflow can (*Pasco*)

Data analysis

Experiment 1.

Calculate density of the three objects by using Formula (6). Calculate percent discrepancy for the densities.

Experiment 2.

Calculate density of the unknown fluid by using formula (7). Average the results of three trials. Compare the experimental result to the accepted value by calculating percent discrepancy.

Name:

Partners:

Experiment 1.

	m_A (g)	m_F (g)
Object 1		
Object 2		
Object 3		

Density of the object 1 = ___________________

Accepted density of the object = ____________

Percent discrepancy = _____________________

Density of the object 2 = ___________________

Accepted density of the object = ____________

Percent discrepancy = _____________________

Density of the object 3 = ___________________

Accepted density of the object = ____________

Percent discrepancy = _____________________

Experiment 2

	m_A (g)	m_F (g)	V (cm^3)
Object 1			
Object 2			
Object 3			

Density of the fluid trial 1 = ________________

Density of the fluid trial 2 = ________________

Density of the fluid trial 3 = ________________

Average density of the fluid= _______________

Accepted density of the fluid = ______________

Percent discrepancy = ____________________

1. Assess the accuracy of your experiment

2. What are the sources of random error in your experiment?

3. What are some of the systematic errors in this experimental set-up?