Module 12
Mechanical Properties of Matter

What this module is about

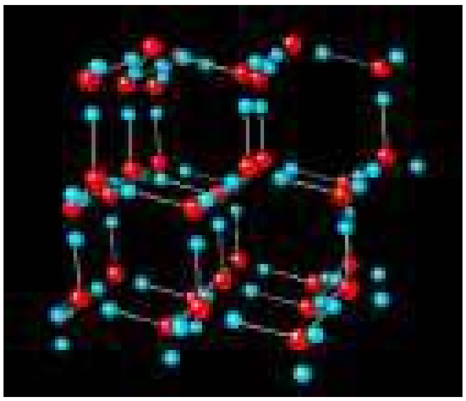


Fig 1. Crystalline Structure of Ice

Matter is usually described as anything that occupies space and has mass. It is made up of molecules. There are basically four (4) states or phases of matter namely solid, liquid, gas and plasma. Molecules that make up a solid material usually have a specific crystalline structure like the one shown in figure 1. This is the crystalline structure of ice. Liquids, gases and plasma have different molecular arrangements. Nonetheless, these molecules that make up matter exert intermolecular forces on one another.

In this module you will learn many things about Physics particularly about the forces on matter. This module includes the following lessons:

- **Lesson 1 - Elasticity: A Property of Solids**
- **Lesson 2 - Fluids**
- **Lesson 3 - Pressure in Fluids**
- **Lesson 4 - Archimedes' Principle**

Read, enjoy, and discover the secrets of Physics!

What you are expected to learn

At the end of the chapter, you should be able to:

1. describe completely the mechanical properties related to solids, liquids and gases;
2. solve problems in hydrostatics; and
3. explain how the concepts of stress and strain, pressure and the Archimedes' principle apply to air/or sea transport.

How to learn from this module

Here's a simple guide for you in going about the module.

1. Read and follow the instructions very carefully.
2. Take the pretest. It is a simple multiple-choice test provided at the start to determine how much you know about the content of this module.
3. Check your answers against the answer key provided at the last page of the module.
4. Be very honest in taking the test so you know how much knowledge you already have about the topic.
5. Read the different lessons about the earth, sun and moon.
6. Perform all the activities to help you have a better understanding of the topic.
7. Take the self-tests at the end of each lesson to determine how much you remember about the lesson.
8. Finally, take the post-test at the end of this module.

Good luck and have fun!

What to do before (Pretest)

A. Direction: Choose the letter of the best answer. Write your answer on a separate sheet of paper.

1. Density is described as
   a. length divided by time.
   b. mass times acceleration
   c. length divided by volume
   d. mass divided by volume

2. Which has more density, a lake full of water or a cup full of lake water?
   a. the cup
   b. the Lake
   c. Both have the same density
   d. Cannot be determined

3. Which has more density, a loaf of bread just after it comes out of the oven or the same loaf of bread that has been squeezed into a small volume?
   a. the fresh loaf
   b. the squeezed loaf
   c. They both have the same density.

4. Which of the following is made of an inelastic material?
   a. a bow
   b. a spring
   c. a tennis ball
   d. a piece of cookie dough

5. What is the reason why an I-beam is nearly as strong as a solid bar?
   a. The I-beam weighs less.
   b. An “I” is a really strong shape.
   c. Objects are placed on top of the beam.
   d. The stress is predominantly at the top and the bottom parts.

6. Pressure in a liquid depends on the ____________
   a. density of the liquid.
   b. volume of the liquid.
   c. mass of the liquid.
   d. amount of the liquid.

7. Archimedes’ principle states that an object is buoyed up by a force that is equal to ____________.
   a. the mass of the object.
   b. the mass of the fluid displaced.
   c. the weight of the fluid displaced.
   d. the volume of the fluid displaced.

8. Suppose a stone weighs 3 N in the air, but in water it weighs only 2 N. What is the buoyant force acting on the stone?
   a. 5 N
   b. 3 N
   c. 2 N
   d. 1 N

9. If an object has a density greater than the density of water, it will ____________
   a. float
   b. sink
   c. neither float nor sink, but stay anywhere it is put.
   d. need more information to say.

10. Pascal’s principle says that changes in pressure at many points in an enclosed fluid __________.
    a. are transmitted to all points in the fluid.
    b. quickly diminish from point to point in the fluid.
    c. remain only at the point.
    d. are transmitted only to points below it.

11. The main difference between gases and liquids is that in a gas ____________
    a. molecules move faster.
    b. forces between molecules are larger.
    c. distances between molecules are larger.
    d. All of the above.

12. Which of the following is the proper unit for pressure?
    a. joule
    b. newton
    c. pascal
    d. watt

13. Atmospheric pressure at sea level is about ___________.
    a. 100 kP
    b. 20 kP
    c. 100 P
    d. 10 P

14. At the top of a barometer there is a space that is filled with ____________
    a. air
    b. helium
    c. water vapor
    d. dense mercury

15. An aneroid barometer is an instrument used to measure _____________.
    a. liquid pressure
    b. well pressure
    c. atmospheric pressure
    d. none of the above.

B. Direction: Write "True" if the statement is true and "False" if the statement is false. Write your answers on a separate sheet of paper.

1. The density of an object is its mass divided by its volume.
2. Elasticity is the property of an object that allows it to return to its original shape when deformed.
3. The stretch of a spring is inversely proportional to the applied force.
4. Pressure in a liquid depends on the direction the pressure gauge is pointing.
5. The buoyant force on a submerged rock is equal to its weight in the water.
6. An object will sink in water if its density is greater than the density of water.
7. The weight of fluid a floating object displaces is equal to the weight of the object.
8. Pressure in a fluid is inversely proportional to the depth at which the pressure measurement is taken.
9. A fish moves up or down in water by changing its density.
10. The buoyant force on a submerged rock depends on the weight of the rock.

Key to answers on page 28

Lesson 1 Elasticity: A Property of Solids

Fig 1.1 Elastic and Inelastic materials

Did you know that elasticity is one of the properties of a solid? It determines whether a material will return to its original size and shape after the force exerted on the object is removed. Spring, bow, rubber band and steel are some examples of highly elastic materials. In reality, all materials are elastic. However, these materials differ in the degree of elasticity. A wooden stick easily breaks when a large force is exerted on it. On the other hand, steel usually bends when a large force is exerted on it. This means that steel is more elastic than wood. Those materials that tend to break or be distorted permanently when subjected to a force are known as inelastic materials. Examples of such materials are putty, clay and dough.

What you will do

Activity 1.1 Force vs. Elongation

Objective: To be able to relate restoring force and displacement.

Materials: Ruler, 20 pieces of P1.00 coin, plastic cup, spring

Procedure:

1. Hang the spring on a nail placed on the wall of your house.
2. Hang the plastic cup at the bottom of the spring.
3. Determine the original length (L_o) of the spring using the ruler.
4. Place 5 pieces of P1 coins on the plastic cup.

Determine the new length of the spring. Record the result on the table provided.

5. Place another 5 pieces of P1 coins on the plastic cup. Determine the new length of the spring. Record the result on the table provided.
6. Repeat step 5 until all the 20-pieces P1 coins are inside the cup.

Data and Results

L_o = _______________

Number of Coins	New Length L (cm)	Elongation ΔL (cm)
5		
10		
15		
20		

Guide Questions

1. What happens to the length of the spring as more P1.00 coins are placed on the cup?
2. What quantity is represented by the weight of the P1.00 coins?
3. How would you relate this quantity to the change in length of the spring?

Key to answers on page 28

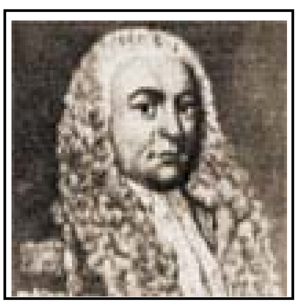


Fig.1.3 Robert Hooke

Robert Hooke, a British physicist did come up with the same relationship between force and elongation as you did. As the force or the load on the spring is increased, the elongation is also increased. Further, he stated that since the weight of the load (F) corresponds to the restoring force of the spring, then the restoring force (F_r) is directly proportional to the elongation (x), which is popularly known as Hooke's law. In symbols,

$$F = -F_r$$
$$F_r \sim x$$

If we determine the ratio of F_r and x, then

$$-F_r/x = k$$

$$F_r = -kx \qquad \text{(Hooke's Law)}$$

or $$\mathbf{F_r = -kx}$$

Hooke's law states, "The amount of stretch or compression, x, is directly proportional to the applied force F. If an elastic material is stretched or compressed beyond a certain amount, it will not return to its original state. Instead, it will remain distorted. The distance beyond which permanent distortion occurs is called **elastic limit.** Hooke's law holds true as long as the force does not stretch or compress the material beyond its elastic limit.

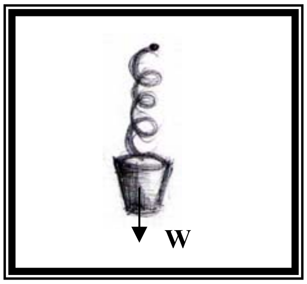


Fig. 1.4. A load on a spring

Take a look at figure 1.4. The weight of the load represents the force exerted on a unit area of the spring. The ratio of the force and the unit area is known as **stress**. In equation,

Tensile Stress = Stretching Force/Area

If the spring is being compressed then the stress is specifically called compressive stress,

Compressive Stress= Compressive Force/Area

In both cases, stress caused by the elongation or compression on the spring is collectively called **change in length** of the spring. The ratio of the change in length of the spring and its original length is known as **strain**. In equation,

$$Strain = \Delta L/L_o$$

where: ΔL = change in length or elongation
L_o = original length

The ratio of stress and strain is a constant for every material known as Young's modulus of elasticity. In equation,

Y (Young's Modulus of Elasticity) = Stress/Strain

The Young's modulus of elasticity is a constant for every material. It determines if the material is highly elastic or not. Large values of Y means that the material is highly elastic and is capable of withstanding greater load as compared to materials of small Y.

What you will do
Self-Test 1.1

Bridges are usually made up of cement, rocks and iron or steel. Why do engineers prefer to use iron or steel with concrete in building bridges rather than pure concrete alone?

Key to answers on page 28

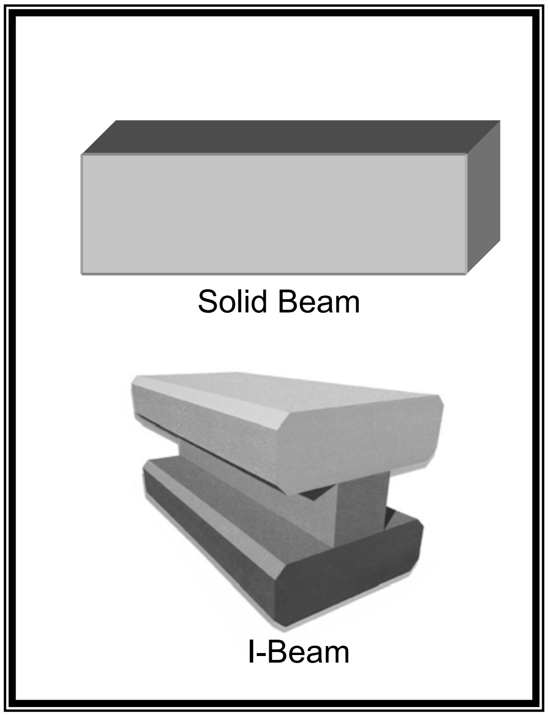


Fig. 1.5. Elastic and Inelastic Materials

If you were an engineer, which would you prefer to use in building bridges and other buildings: a **solid beam** or an **I-beam** of the same dimensions and size?

Take a look at a load placed on top of a solid beam on which the two ends of the beam is supported as shown in figure 1.5. As you can see the solid beam is compressed at the top while it is being stretched at the bottom. You will notice that the middle portion of the beam is a neutral layer. This means that the middle portion can be of smaller dimension as compared to the top and the bottom parts of the beam. This, in turn, makes an I-beam. Most of the materials in these I-beams are concentrated in the top and bottom parts or flanges. The piece joining the bars, called the web, is of thinner solid beams because of the fact that stress is predominantly in the top and the bottom flanges when the beam is used horizontally in construction. One flange tends to be stretched while the other tends to be compressed. The web between the top and the bottom flanges is a stress-free region that acts principally to connect the top bottom flanges together. This is the neutral layer, where comparatively little material is needed. An I-beam is nearly as strong as if it were a solid bar, and its weight is considerably less.

Lesson 2 Fluids

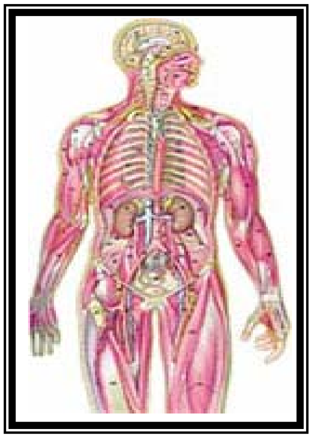


Fig. 2.1. The Human Body

Our body is filled with a lot of **fluids**. A fluid is any substance that cannot maintain its own shape; in other words, they have the ability to flow. **Liquids** and **gases** have the ability to flow thus, they are called fluids. In our bodies, blood and water are examples of fluids. Blood is a liquid tissue consisting of two parts: the plasma, which is the intercellular fluid, and the cells, which are suspended in the plasma. Plasma is about 90% water, 9% protein and 0.9% salts, sugar and traces of other materials. They are usually responsible in transporting nutrients to the different parts of the body.

Fluids, like solids, have different properties. Density is one of the most familiar properties of fluids. How would you know if a material or another fluid like oil could float in water or not? One possible property of fluid that we can use to answer our question is density. **Density** is usually thought of as the "lightness" or 'heaviness" of materials having the same volume. Quantitatively, it is described as the ratio of the mass and the volume of a material. In symbols;

$$\rho = \frac{m}{v}$$

where:
(rho) ρ = density
m = mass
v = volume

The mass is either expressed in grams or kilograms while volume is expressed in cubic centimeters (cm^3) or cubic meters (m^3). Thus, density of a material is expressed in g/cm^3 or kg/m^3. Saline solution used in the hospital has about 1.06 g/cm^3 density which is greater than the density of water (1.00 g/cm^3).

What you will do

Activity 2.1 Density and Flotation

Objective: To relate the density of the material with water and its ability to float in water.

Materials: glass jars (3), 0.5 L water, 0.5 L cooking oil, ice, and small piece of iron.

Procedure:

1. Place the ice cubes in the glass of water. Observe what happens. Tick on the appropriate box on the given table.
2. Place a small piece of iron in the glass of water. Observe what happens. Tick on the appropriate box on the given table.
3. Pour the cooking oil into the glass of water. Observe what happens. Tick on the appropriate box on the given table.

Data and Results

Density of water = 1.0 g/cm^3

Material/Substance	Density	Floats on Water	Sinks on Water
Ice cubes	0.92 g/cm^3		
Small piece of iron	7.80 g/cm^3		
Cooking oil	0.90 g/cm^3		

Guide Questions:

1. Does the ice cube float or sink in water?
2. Compare the density of ice and the density of water.
3. Does the piece of iron float or sink in water?
4. Compare the density of iron and the density of water.
5. Does the cooking oil float or sink in water?
6. Compare the density of cooking oil and the density of water.
7. How would the density of the given material or substance be used in determining whether the substance or the material could float or sink in water?

Key to answers on page 28

Objects with **greater density** than the density of water tend to **sink**. Mercury has 13.6 g/cm^3 thus, mercury sinks in water. Objects with **lesser density** than water tends to **float** e.g. oil, with a density of about 0.9 g/cm^3. Materials with density equal to the density of water tend to be submerged. Submarine is one example of a material with the same density as that of water.

Here are the densities of some materials

Materials	ρ (g/cm^3)	ρ (kg/m^3)
Liquids		
Mercury	13.6	13,600
Glycerin	1.26	1,260
Seawater	1.03	1,025
Water at 4^{o}C	1.00	1,000
Benzene	0.9	899
Ethyl Alcohol	0.81	806
Solids		
Osmium	22.5	22,480
Platinum	21.5	21,450
Gold	19.3	19,320
Uranium	19.0	19,050
Lead	11.3	11,344
Silver	10.5	10,500
Copper	8.9	8,920
Brass	8.6	8,560
Iron	7.8	7,800
Tin	7.3	7,280
Aluminum	2.7	2,702
Ice	0.92	917
Gases (atmospheric pressure at sea level)		
Dry air		
0^{o}C	0.00129	1.29
10^{o}C	0.00125	1.25
20^{o}C	0.00121	1.21
30^{o}C	0.00116	1.16

A quantity known as weight density is also commonly used. It is the ratio of the weight of the object and its volume. In symbols;

$$\rho_{weight} = \frac{w}{v}$$

where:

ρ_{weight} = weight density
w = weight = mg = (mass x 9.8 m/s^2)
v = volume

Specific gravity of a substance is related to the concept of density. It is defined as the ratio of the density of the substance to the density of water at 4^{o}C. In symbols;

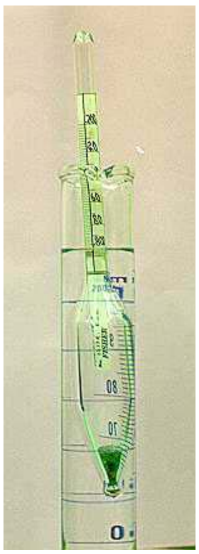


Fig. 2.2. Hydrometer

$$s.g = \frac{\rho_{material}}{\rho_{water}}$$

where:

sg = specific gravity
$\rho_{material}$ = density of a material
ρ_{water} = density of water at 4^{o}C

Specific gravity is a pure number. This means that there are no units for specific gravity. In other sources, specific gravity is termed as relative density. The specific gravity of water is 1. If the specific gravity of the substance is greater than 1, the substance will sink. If the specific gravity of the substance is less than 1, the substance will float. If the specific gravity of the substance is equal to 1 then the object is submerged.

Hydrometer is an instrument that measures density of liquid. It is a sealed tube with a narrow part at one end and some very dense material such as lead at the other end. If made correctly, such a tube floats "vertically" so that the narrow part sticks out of the liquid while the heavy end sinks. The narrow part is calibrated for density. The hydrometer floats higher in liquids of higher density and lower in liquids of lower density.

What you will do
Self-Test 2.1

Oops! Before you go on, try this one!

1. Which of the following statements is **not** correct?
    a. Matter is composed of tiny particles called molecules.
    b. These molecules are in constant motion.
    c. All molecules have the same size and mass.
    d. The differences between the solid, liquid, and gaseous states can be attributed to the relative freedom of motion of their respective molecules.

2. In order for an object to sink when placed in water, its specific gravity must be ________.
    a. less than 1
    b. equal to 1
    c. more than 1
    d. any of the above, depending on the shape.

3. The density of fresh water is 1.00 g/cm^3 and that of seawater is 1.03 g/cm^3. A ship will float __________.
    a. higher in fresh water than in seawater
    b. at the same level in fresh water and in sea water
    c. lower in fresh water than in sea water
    d. any of the above, depending on the shape of the hull

4. Which of the following materials will tend to float in oil?
    a. Water
    b. Iron
    c. Mercury
    d. Ethel Alcohol

5. Which of the following will sink in Mercury?
    a. Brass
    b. Gold
    c. Ice
    d. Iron

Key to answers on page 29

Lesson 3 Pressure in a Fluid

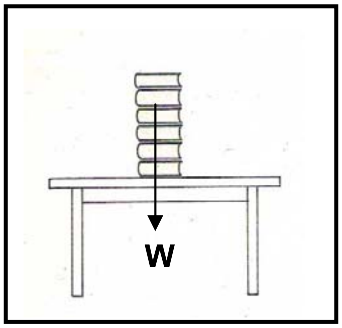


Fig 3.1. Book on top of the table

Take a look at the book lying on top of the table. The book exerts a force on the table equal to its weight. This force is exerted perpendicular to the surface area on which the book lies. The ratio of this perpendicular force and the surface area is called **pressure**. In symbols;

$$P = \frac{F}{A}$$

where:

P = pressure exerted by the book on the table
F = force exerted by the book
A = surface area

Since force is expressed in newton (N) and surface area is expressed in square meters (m^2), pressure is then expressed as N/m^2. **One N/m^2 is equivalent to 1 pascal (Pa)**. This is in honor of Blaise Pascal who discovered the Pascal's Principle. Pressure can also be expressed in other units such as torr, mm of Hg, atm or millibars. Atmospheric pressure is usually expressed in millibars.

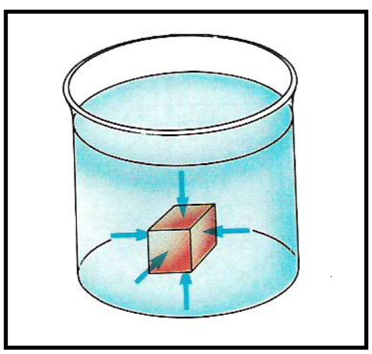


Fig 3.2. Cylindrical container with liquid

Now, take a close look at the cylindrical container filled with liquid. The weight of the liquid itself exerts a force on the bottom of the cylinder. This force results to a pressure on the bottom of the cylinder. Since pressure is defined as the ratio of the force and the surface area, thus;

$$P = \frac{F}{A}$$

Since the force applied on the bottom of the cylinder is equal to the weight of the liquid, then

$$P = \frac{W}{A}$$

but

$$W = mg$$

thus

$$P = \frac{mg}{A}$$

but

$$\rho = \frac{m}{v}$$

$$m = \rho v$$

thus

$$P = \frac{\rho V g}{A}$$

but

$$v = A \times h$$

$$P = \frac{\rho A h g}{A}$$

$$\mathbf{P = \rho g h}$$

where:

P = pressure
ρ = density of fluid
$g = 9.8\ m/s^2$
h = altitude/depth

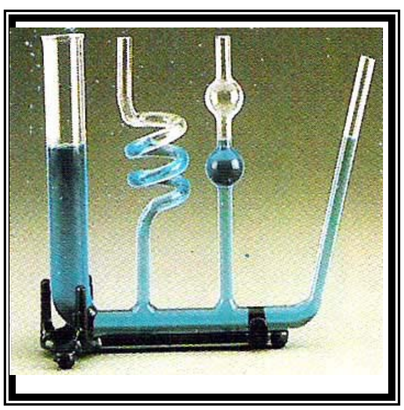


Fig 3.3 Containers of different cross-section

This means that pressure exerted by fluids only depends on the **density of the fluid**, **acceleration due to gravity of the place** and **altitude** (for gasses) or depth (for liquid). Pressure in fluids is independent of the amount of fluid. Thus, separate containers of different sizes, holding identical liquids of uniform density, have equal pressure at equal depths. Even cross-sectional area doesn't account for the pressure exerted by the fluid. Thin containers experience the same pressure at the bottom as wide containers as long as they contain the same liquid of the same depth. Thus, when liquid is poured into a transparent tube, liquid on both sides would always be of the same depth to attain equal pressures. That's why carpenters tend to say, "***Water seeks its own level***". When measuring depths carpenters often use this concept of pressure.

What you will do

Activity 3.1 Fluid Pressure

Objective: To be able to relate the depth of the liquid and fluid pressure.

Materials: used plastic cup, nail, candle, match, water, ruler

Procedure:

1. Heat the pointed part of the nail in the candle flame.
2. Use the heated pointed part of the nail to make tiny holes on one side of the plastic cup.
3. Label the holes as 1, 2, and 3 starting from the bottom of the plastic cup.
4. Determine the depth of each hole using a ruler.
   (Depth is the length from the rim of the cup to the hole)
5. Place an amount of water up until the rim of the plastic cup. Observe how the water flows out of the holes.

Data and Results

Hole #	Depth (cm)	Observation
1		
2		
3		

Guide Questions

1. On which hole did you observe the fastest flow of water?
2. On which hole did you observe the slowest flow of water?
3. Which hole experiences the greatest fluid pressure?
4. How would you relate fluid pressure and the depth of the fluid?

Key to answers on page 29

Sample Problem

A nurse administers medication in a glucose solution to a patient by infusion into a vein in the patient's arm. The density of the solution is 1.0 x 10^3 kg/m^3. The gauge pressure inside the vein is 2.4 x 10^3 Pa. How high above the insertion point must the container be hung so that there is sufficient pressure to force the fluid into the patient?

Solution:

Given: ρ = 1 x 10^3 kg/m3
P = 2.4 x 10^3 Pa
g = 9.8 m/s^2
Required: h = ?
Solution:

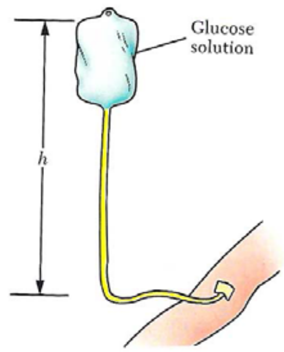
P = ρgh

$$h = \frac{P}{pg}$$

$$h = \frac{2.4\ x10^3\, Pa}{(1x10^3\, kg/m^3)(9.8m/s^2)}$$

h = 0.24 m

h = 24 cm



What you will do

Self-Test 3.1

Oops! Before you go on, try this one!

1. How does pressure differ from force?
2. What is the relationship between liquid pressure and depth of the liquid?
3. If a diver swims twice as deep in the water, how much more water pressure is exerted on her/his ears?
4. If a diver swims in salt water, will the pressure at the same depth be greater than in freshwater?

Key to answers on page 29

Pascal's Principle

Fig 3.5 Blaise Pascal

Did you know that Blaise Pascal, a French mathematician, discovered the Pascal's principle during his time (1623-1662)? He said, "**Changes in pressure at any point in an enclosed container at rest is transmitted undiminished to all points in the fluid and act in all directions.** Due to his discovery, the SI unit of pressure was named after him. For example, if the pressure of city water is increased at the pumping station by 5 units of pressure, the pressure everywhere in the pipes of the connected system will be increased by 5 units of pressure provided that the water is at rest.

Fig 3.6 Hydraulic jack

Usually, a device known as hydraulic jack employs the Pascal's principle. It works just like a U-tube shown in the figure. The left side of the tube has a smaller area than the right side of the tube. In the figure, the piston on the left has an area of one square centimeter and the piston on the right has an area fifty times as great, in this case, 50 square centimeters.

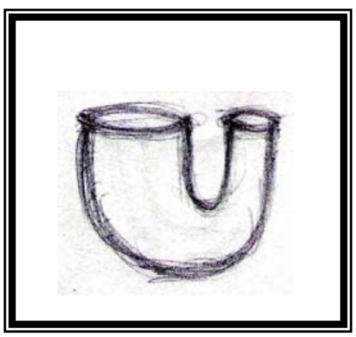


Figure 3.7 U-tube

If there is one newton (1 N) load on the left piston then an additional pressure of one newton (! N) per square centimeter (N/cm^2) is transmitted throughout the liquid and up against the larger piston. This means that 1 N/cm^2 is exerted against every square centimeter. Since there are 50 square centimeters, the total extra force exerted on the larger piston is 50 N. Thus, the larger piston will support a 50-Newton load. This is fifty times the load on the smaller piston! This means that we can multiply the force with such a devise.

Blood Pressure

Every time you go to a clinic for medical check-up, one of the nurses measures your blood pressure. A cuff is wrapped around your arm, and then the cuff is inflated until it is tight. Then, the nurse listens through a stethoscope held to your arm while letting the cuff slowly deflate.

The two very significant pressures in the heart's action are the **systolic pressure**, when the beat is contracted, and the **diastolic pressure**, when the heart is relaxed between beats. Normal heart action causes arterial blood pressure to oscillate between these two valves.

The most direct way of measuring blood pressure is to insert a fluid-filled tube into the artery and connect it to the pressure gauge. This is sometimes done but it is neither comfortable nor convenient. The commonly used indirect method involves a device called **sphygmomanometer.** A non-elastic cuff that has an inflatable bag within it is placed around the upper arm, at the same level as the heart so as to measure the same pressure. When the cuff is inflated, the tissue in the arm is compressed; if sufficient pressure is applied, the flow of arterial blood in the arm stops. If the cuff is long enough and if it is applied smugly, the pressure in the tissues in the arm is the same as the pressure in the artery. In effect, Pascal's principle holds for the system composed of the cuff, arm and artery.

After the blood flow has been cut off, the pressure in the cuff is reduced by releasing some of the air. At some point, the maximum arterial pressure slightly exceeds the pressure in the surrounding tissue and cuff, allowing the blood to resume flowing. The acceleration of the blood through the arteries gives rise to a characteristic sound, which can be identified by means of a stethoscope. When this sound occurs, the manometer indicates the maximum, or systolic pressure. As the pressure in the cuff falls further, a second change in the sound is heard which is characteristics of the drop below diastolic pressure. The two pressures are reported such as 100 over 75, which corresponds to the blood pressure of a healthy person.

Lesson 4 Archimedes Principle


Fig 4.1 Fat Man

Can you carry the person in the figure while standing? Can you carry him while in a swimming pool? Usually we tend to carry a load easier in water than in air. This apparent loss of weight if submerged is known as buoyancy.

The liquid tends to exert an upward force for objects submerged or objects located underwater. This upward force exerted by the liquid on the submerged object is called **buoyant force**, which is a consequence of increasing pressure with depths.

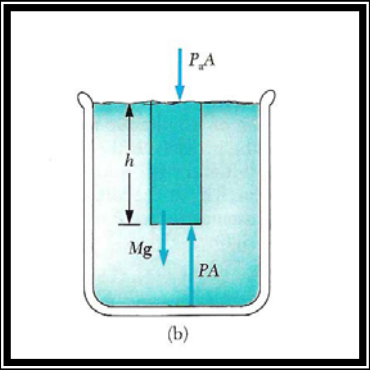


Fig 4.2 Submerged load

Take a look at the load submerged in water. At greater depth, there exists a large pressure of the liquid on the load. This results to a large upward force.

$$P = \frac{F}{A}$$

At the top of the load, lesser pressure is exerted by the liquid on the load resulting to lesser downward force.

$$P = \frac{F}{A}$$

Thus, there exists an unbalanced upward and downward force, which results to a net upward force by the liquid on the load. This net upward force is called **buoyant Force**. If the weight of the submerged object is greater than the buoyant force, the object sinks. If the object's weight is equal to the buoyant force, the object remains at any level. If the buoyant force, on the other hand, is greater than the weight of the object then the object floats on the liquid.

Read this:

Archimedes, one of the greatest scientists (287-212 BC) was given the task of determining whether a crown made for King Heiron II was of pure gold or whether it was made of some cheaper metals. Archimedes then knew the concept of density and if he could compute for the density of the old crown, he could determine whether the crown was made of pure gold or not But the crown was an irregularly shaped object, thus, he had difficulty determining its volume.

One day, his friends asked him to join them to have their bath at the public bath tubs. At first, he was hesitant since he still had not found how to determine the volume of the crown. But his friends insisted thus he went with them. When he immersed his naked body to the water in the tub, he realized that he could do the same to the crown. Thus, story has it that he immediately rushed naked through the streets shouting "Eureka, Eureka" (I have found it, I have found it)

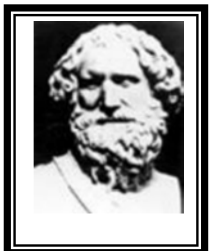


Fig 4.3 Archimedes

What Archimedes had discovered was a simple and accurate way of finding the volume of an irregular object – **the water displacement method**. When an object is immersed in water, water is displaced by the immersed object. **The volume of the displaced water is equal to the volume of the immersed object**. Thus, Archimedes made use of the displacement method to determine the volume of the crown and calculate its density.

Archimedes further studied on the concept of buoyancy. Later, he came up with the relationship between buoyancy and displaced liquid. This is now known as the **Archimedes' Principle, which states that an immersed body is buoyed up by a force equal to the weight of the fluid it displaces.** This principle holds true of all fluids, both liquids and gases.

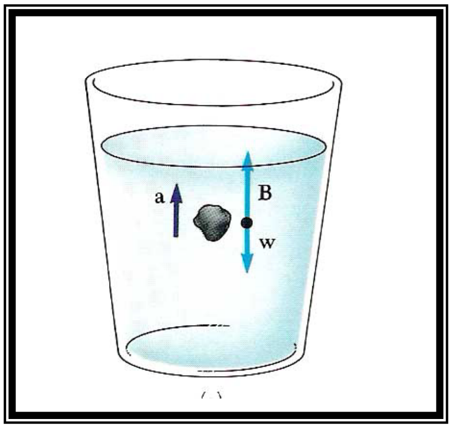


Fig 4.4 Object submerged

$$B.F. = W_{air} - W_{water}$$

Take a look at the figure. The resultant force along the y-axis;

$$\Sigma Fy = F_1 - F_2 - W$$

Since the liquid is in equilibrium,

$$\Sigma Fy = 0$$

But

$$0 = F_1 - F_2 - W$$

$$F_1 - F_2 = W$$

But

$$B.F. = F_1 - F_2$$

Thus

$$B.F. = W$$

But

$$W = mg$$
$$m = \rho v$$

Thus

$$B.F. = \rho vg$$

where:

B.F. = buoyant force
ρ = density of the fluid
v = volume of object/volume of displaced liquid
g = acceleration due to gravity

For example, if we immerse a sealed 1-liter container halfway into the water, it will displace a half-liter of water. If we immerse it all the way (submerge it), it will be buoyed up by the **weight of a full liter of water (9.8 N**). Unless we compress the completely submerged container, the buoyant force will equal the weight of one liter of water at any depth due to the fact that at any depth, the container will displace the same volume of water. **The weight of the displaced liquid is the buoyant force exerted by the water.**

Another way of determining the **buoyant force** applied by the water is to take the **difference between the weight of the object in air and its weight in water**. If a 300-gram block weighs about 3 N in air while its weight in water is about 1 N, then the buoyant force is 3 N minus 1 N. This means that the buoyant force is about 2 N. This also means that the block displaces an amount of water, which weighs about 2 N.

What you will do

Activity 4.1

Objectives: To verify Archimedes' principle.

Materials: 2 pieces of cardboard, ten 5-peso coins, basin, water

Procedure:

1. Crumple the first piece of cardboard.
2. Make a container of 5-peso coin using the second piece of cardboard. (Note: make sure that you can make something that holds as many 5-peso coins as possible).
3. Place the crumpled cardboard and the container made of cardboard on a basin of water. Observe what happens.
4. Place the 5-peso coins one at a time on the container made of cardboard until before the container starts to sink. Observe.

Guide Questions:

1. Which among the two cardboards was able to float for a longer time in water?
2. Why do you think that the cardboard you have specified in question #1 was able to float for a longer time in water?
3. Relate your answers to how ships made of metals and iron are made.

Key to answers on page 29

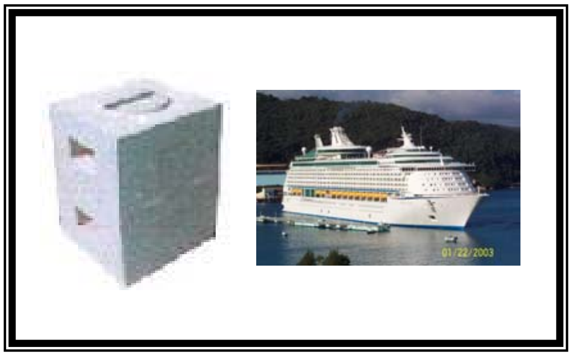


Fig. 4.6 Block of iron and a ship

Hundreds of years ago, if you had said that you were going to build a ship made of iron, everyone would have laughed at you because everybody knew that since iron was denser than water, it would sink. Now we know that if we are going to re-shape the iron to have a large volume (like a bowl) then most probably that piece of iron will float.

If the weight of the displaced water equals the weight of the bowl then the bowl floats. This is because the buoyant force is now equal to the weight of the bowl. This is known as the **principle of flotation**: **A floating object displaces a weight of fluid equal to its own weight.**

Every ship must be designed to displace a weight of water equal to its own weight. Thus, a 10 000-ton ship must be built wide enough to displace 10 000 tons of water before it sinks too deep below the surface.

What you will do

Self-Test 4.1

Oops! Before you go on, try this one!

A.

1. A 1-L container, which is completely filled with mercury, has a mass of 13.6 kg and weighs about 133.3 N. If it is submerged in water, what is the buoyant force acting on it?
2. We know that if a sea creature such as a fish makes itself more dense (denser than water) it will sink while if it makes itself less dense (less dense than water) it will float or it will rise. In terms of buoyant force, why is this so?

B. Complete the following statements.

1. The volume of a submerged object is equal to the _________ of the liquid displaced.
2. The weight of a floating object is equal to the _________ of the liquid displaced.

Key to answers on page 29

Let's summarize!

1. Elasticity is one of the properties of a solid.

2. Elastic materials return to their original shape when a deforming force is applied and removed, as long as they are not deformed beyond their elastic limit.

3. Hooke's law states that the amount of stretch or compression is proportional to the applied force (within the elastic limit)

4. Inelastic materials remain distorted after the force is removed.

5. Density is the ratio of mass and volume

$$\rho = \frac{m}{v}$$

6. Weight density is the ratio of the weight and volume

$$\rho_{weight} = \frac{w}{v}$$

7. Specific gravity is the ratio of the density of a material to the density of water.

8. Pressure is the ratio of a force perpendicular to the surface area. It is expressed in units such as Pa, atm, torr, mm of Hg, bar.

9. Fluid pressure depends on the density of the fluid, acceleration due to gravity and depth.

$$P = \rho gh$$

10. Pascal's principle: The pressure applied at one point in an enclosed fluid is transmitted undiminished to every point of the fluid and to the walls of the container.

11. Archimedes' principle: A body, whether completely or partially submerged in a fluid, is buoyed up by a force that is equal to the weight of the displaced liquid.

    a. The principle of flotation: A floating object displaces a weight of fluid equal to its own weight.

Posttest

A. Choose the letter of the best answer. Write the chosen letter on a separate sheet.

1. When a solid block of material is cut in half, its density is ____________.
    a. halved
    b. unchanged
    c. doubled

2. Which has greater density, a lake full of water or a cup full of lake water?
    a. The cup
    b. The lake
    c. Both have the same density

3. Compared to the density of a kilogram of feathers, the density of a kilogram of lead is __________.
    a. less
    b. more
    c. the same

4. Water pressure on a submerged object is greatest against the ____________.
    a. top of the object
    b. bottom of the objects
    c. sides of the object
    d. Water pressure is the same against all surfaces of the object

5. The buoyant force on an object is least when the object is _____________.
    a. partly submerged
    b. submerged near the surface
    c. submerged near the bottom
    d. None of the above.

6. What is the most probable reason why a life jacket helps you float in water?
    a. The jacket makes you weigh less.
    b. The jacket has the same density as an average human.
    c. The jacket repels water.
    d. You and the jacket together have density less than your density alone.

7. Lobsters live in the bottom of the ocean. The density of a lobster is _________.
    a. greater than the density of the seawater
    b. equal to the density of seawater
    c. less than the density of seawater

8. The density of a submerged submarine is about the same as the density of __________.
    a. a crab
    b. iron
    c. a floating submarine
    d. water

9. An egg is placed at the bottom of a bowl filled with water. Salt is slowly added to the water until the egg rises and floats. From this experiment, one can conclude that ____________.
    a. calcium in the eggshell is repelled by sodium chloride
    b. the density of salt water exceeds the density of the egg
    c. buoyant force do not always act upward
    d. salt sinks to the bottom

10. Compared to an empty ship, the same ship loaded with Styrofoam will float _________
    a. higher in water
    b. lower in water
    c. at the same level
    d. Need more information to say

11. When a boat sails from freshwater to seawater, the boat will float ___________.
    a. lower in the seawater
    b. higher in the seawater
    c. at the same level

12. If the part of an iceberg that extends above the water were removed, the __________.
    a. iceberg would sink
    b. buoyant force on the iceberg would decrease
    c. density of the iceberg would change
    d. pressure on the bottom of the iceberg would increase

13. When an ice cube in a glass of water melts, the water level ____________.
    a. rises
    b. falls
    c. remains the same
    d. Increase and then decrease

14. A floating ice cube in a glass of water contains a small piece of iron. After the ice cube melts, the water level will ___________.
    a. rise
    b. fall
    c. remain unchanged
    d. increase then decrease

15. An ice cube floating in a glass of water contains many air bubbles. When the ice melts, the water level will ___________.
    a. rise
    b. fall
    c. remain unchanged
    d. increase and then decrease

B. Write A if the statement is true and write B if the statement is false.

1. A barometer is used to measure water pressure.
2. Density of liquids is determined using hydrometer.
3. A fluid can either be a gas or a liquid.
4. Pascal principle states that changes in pressure at any point in an enclosed container which may be at rest or moving is transmitted undiminished to all points in the fluid and acts in all directions.
5. Archimedes' principle states that a body, whether completely or partially submerged in a fluid, is buoyed up by a force that is equal to the weight of the displaced liquid

Key to answers on page 30

Key to Answers

Pretest

A.

1. d
2. c
3. c
4. d
5. d
6. a
7. c
8. d
9. b
10. a
11. d
12. c
13. a
14. a
15. c

B.

1. True
2. True
3. False
4. False
5. False
6. True
7. True
8. False
9. True
10. False

Lesson 1

Activity 1.1

1. The spring increases in length.
2. Force on the spring
3. The greater the force on the spring, the larger the elongation

Self-Test 1.1

1. Pure concrete alone has smaller modulus of elasticity than a bridge constructed with iron or steel. Since bridges with iron or steel have large modulus of elasticity they are capable of withstanding greater load before permanent deformation takes place.

Lesson 2

Activity 2.1

1. The ice cube floats in water.
2. The density of ice cube is less than the density of water.
3. Iron sinks in water.
4. The density of iron is greater than the density of water.
5. Cooking oil floats in water.
6. The density of the cooking oil is less than the density of water.

7. When the density of a substance is greater than the density of water, the substance/material sinks. When the density of the substance or material is less than the density of water, the substance or material floats.

Self-Test 2.1

1. c
2. c
3. c
4. d
5. b

Lesson 3

Activity 3.1

1. The last/bottom hole. (hole 1)
2. The first/topmost hole. (hole 3)
3. The last/bottom hole (hole 1)
4. As the depth of the liquid increases, the fluid pressure increases.

Self-Test 3.1

1. Force is a push or a pull while pressure is a force exerted per unit area.
2. As the depth of the liquid increases, pressure exerted by the liquid increases.
3. Twice.
4. Yes. This is because the density of salt water is greater than that of the freshwater.

Lesson 4

Activity 4.1

1. The crumpled one
2. The smaller the volume, the larger the density than the density of water.
3. Metals of small volume have densities larger than the water thus they tend to sink.

Self-Test 4.1

A.

1. 9.8 N

Given:

Volume of container = 1 L = $1000\ cm^3$ = $1 \times 10^3\ cm^3$

since 1 m = 100 cm

then $1\ m^3 = 1{,}000{,}000\ cm^3 = 1 \times 10^6\ cm^3$

thus $1\ L = 1 \times 10^{-3}\ m^3$

density of water = $1 \times 10^3\ kg/m^3$

Solution:

Volume of container = volume of water displaced = $1 \times 10^{-6}\ m^3$

Weight of water displaced (W_w) = volume of water displaced (V_w) x density of water (ρ_w)

$$W_w = V_w\rho_w$$
$$= 1 \times 10^{-3}\ m^3 \times 1 \times 10^3\ kg/m^3$$
$$= 1\ kg$$
$$\text{but } 1\ kg = 9.8\ N$$
$$\text{therefore } W_w = 9.8\ N$$

2. When the fish increases its density by decreasing its volume, it displaced less water, so the buoyant force decreases. When the fish decreases its density by expanding, it displaced a greater volume of water and the buoyant force increases.

B.

1. volume
2. weight

Post Test

A.

1. b
2. c
3. b
4. b
5. a
6. d
7. a
8. d
9. b
10. b
11. b
12. b
13. b
14. b
15. b

B.

1. B
2. A
3. A
4. B
5. A

-End of Module-

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