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2nd Edition

Biophysics in Nursing

As per the Syllabus of Post Basic BSc Nursing

Suresh K Sharma

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CHAPTER

3

Gravity

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Chapter Outline

- Specific Gravity
- Center of Gravity
- Principles of Gravity
- Mass and Weight
- Effects of Gravitational Forces on Human Body and Applications of Principles of Gravity in Nursing

INTRODUCTION

Gravity is defined as the accelerating tendency of the bodies toward the center of the earth or towards the center of the other heavenly bodies, such as the moon. Gravity is very important to us. We could not live on Earth without it. The sun's gravity keeps Earth in orbit around it, keeping us at a comfortable distance to enjoy the sun's light and warmth. It holds down our atmosphere and the air we need to breathe. Gravity is what holds our world together. Gravitation is the force with which all bodies in the universe attract one another. According to Newton's law of universal gravitation, the gravitational force between any two bodies in the universe is proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F = \frac{G M_1 M_2}{d^2}$$

Where,

F = gravitational force
M_1 and M_2 = any two masses in the universe
d = distance between two masses
G = universal gravitational constant = 6.67×10^{-11} Nm^2/Kg^2

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SPECIFIC GRAVITY

Specific gravity is the ratio of the density of any substance to that of water at a specified temperature. It is also known as relative density and clinically expressed as specific gravity. Specific gravity actually signifies how many times lighter or heavier a substance is than an equal volume of water.

$$\text{Specific density} = \frac{\text{Density of the object}}{\text{Density of the water}}$$

It is common to use the density of water at 4 °C as a reference point, as water at this point has the highest density of 1000 kg/m^3. The specific gravity of a substance is expressed numerically by the values of its density in grams per cubic centimeter (gm/cm^3), but with the unit omitted. For example, the specific gravity of a substance 'A' with a density of 5 gm/cm^3 will be 5. It means the substance is five times heavier than water under the same circumstances.

It is clear that specific gravity depends on the density of the substance; for example, if urine is concentrated and has more salts dissolved, will likely have higher specific gravity and if urine is less concentrated then specific gravity will be likely to be lower (Normal specific gravity of urine is 1.010–1.030). Similarly, the specific gravity of blood ranges between 1.055 and 1.066; blood with higher plasma proportion in comparison to blood cells will have lower specific gravity.

As we have learned that specific gravity is the ratio of the density of any substance to that of water. So to determine the specific gravity of a solid substance when weight the substance in air and then water **(Table 3.1)**. The difference between the two weights gives the

Table 3.1: Specific gravity of some substances.

Substance	*Density (kg/m^2)*	*Relative density/Specific gravity*
Pure water	1000	1.00
Alcohol	790	0.79
Whole blood	1060	1.06
Blood plasma	1030	1.03
Aluminum	2700	2.70
Platinum	21400	21.40
Lead	11400	11.40
Gold	19300	19.30
Iron	7950	7.90
Mercury	13550	11.55

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apparent loss of weight in water. The apparent loss of weight is equal to the weight of water displaced. Therefore, in physical properties, specific gravity can also be estimated by the following formula.

$$\text{Specific gravity} = \frac{\text{Weight of the object in air}}{\text{Weight of equal volume of water}}$$

CENTER OF GRAVITY

The center of gravity is considered to be the point at which all external forces are applied to an object. If an object is suspended from this point, it will remain in balance without turning whatever its position is.

In general, the center of gravity or center of mass of a body is the point at which all the mass is considered to be centered.

When a person is standing, her/his center of gravity is located in the pelvic cavity. A line drawn perpendicularly downwards from the center of gravity of a person passes through the area bounded by her/his feet **(Fig. 3.1)**. It is for this reason that while carrying a heavy object, balance is obtained easily if the feet are placed farther apart.

In nursing practice, it is often necessary for a nurse to carry heavy objects close to the body, so that the center of gravity does not deviate and does not put extra strain on the body. For example, carrying a large water basin in hands away from the body will put extra strain on back muscles since a heavy object in the hands adds weight to



Fig. 3.1: Center of gravity in a person standing.

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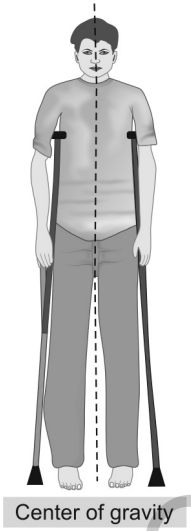

Fig. 3.2: Center of gravity in a person using crutches.

the front of the body, the center of gravity shifts forward; in order to keep the normal position and maintain equilibrium, muscles of the back exert a backward pull. To minimize this strain, one should keep the object in hand as close to the body as possible, i.e. as close to the center of gravity as possible.

For Example

- In folding a blanket, the arms should be held relaxed at the side of the body and forearms should be flexed because outstretched extremities increase the distance through which the force act on the center of rotation at the shoulder.
- During the use of crutches, the area bounded by the crutches and the uninjured foot becomes the base through which the vertical line through its center of mass must pass. These supports must be kept far enough apart so that the vertical line always passes through the base area, otherwise, the patient may fall **(Fig. 3.2)**.

MASS AND WEIGHT

Although commonly we use the terms mass and weight in the same sense, the two terms have different meanings in physics. In physics

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concepts of mass and weight are different. The mass of a body is the quantity of matter contained in it. Everything we see around us has mass. For example, a table, a chair, your bed, a football, a glass, and even air has mass. That being said, all objects are light or heavy because of their mass.

The SI unit of mass is the kilogram (kg). The formula of mass can be written as:

$$\text{Mass} = \text{Density} \times \text{Volume}$$

On the other hand, weight is defined as the gravitational force with which a body is pulled towards the center of the earth.

Mathematically, we write

$$W = mg$$

where 'W' denotes the weight of the body, 'm' is its mass and 'g' is the acceleration due to gravity.

Since the value of the acceleration due to gravity varies with the distance of an object from the center of the earth, the weight of the object changes with its position on the earth. For example, an object at sea level weighs more than it does on a high mountain because the value of the acceleration due to the gravity of the earth on the object is greater at sea level. The mass, however, remains the same everywhere.

The mass of an object is measured by a physical balance, whereas its weight is measured by a spring balance.

Mass is a scalar quantity while weight is a vector quantity because it is directed toward the center of the earth.

The mass of a person is the same on the earth as well as on the moon, but the weight of the person is different in these two places because their pulls on the person are different. A person weighs six times more on earth than on the moon.

Whereas mass and weight have the same numerical value, it is important in solving problems to indicate the unit specifically, as one of force (weight) or as one of mass.

One gram (gm) is a unit of mass.

One gram weight is unit of weight.

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Mass	*Weight*	
Definition	Mass is defined as the amount of matter in a substance	Weight is defined as the amount of force acting on the mass of an object because of acceleration due to gravity.
Denotation	Mass is represented by "M."	Weight is represented by "W."
Formula	◆ Mass is always constant for a body. ◆ One way to calculate mass: Mass = density × volume.	◆ Weight is the measure of the gravitational force acting on a mass. ◆ Formula of weight: Weight = mass × acceleration due to gravity
Unit of measurement	The SI unit of mass is "kilogram".	The SI unit of weight is Newton (N).
Quantity type	◆ Mass is a base quantity. ◆ Mass only has magnitude and hence, it is a scalar quantity	◆ Weight is a derived quantity. ◆ Weight has both magnitude and direction (toward the center of gravity) and hence, it is a vector quantity.
Measuring instrument	Mass can be easily measured using any ordinary balance. For example, beam balance, lever balance, pan balance, etc.	Weight can be measured by a spring balance or by using its formula given above.

PRINCIPLES OF GRAVITY

The most important principle of gravity is Archimedes' Principle. Archimedes, a Greek mathematician gave Archimedes' Principle.

It is a common experience for all of us that while standing in water, we feel as if we are being pushed upwards by force acting from below. Similarly, balloons filled with a gas, say hydrogen, rise in the atmosphere on their own. In fact, all bodies experience an upward force when held inside a fluid.

The force of thrust is opposite to the force of gravity. When pressure is put on any fluid, the body is submerged in it, and this force is thrust. The force reduces as it goes down because of gravity and thus the body feels light. Swimming is an example of this concept.

Thrust = Pressure × Area

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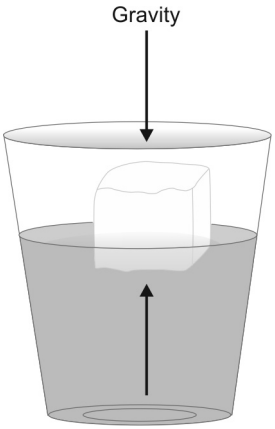

Fig. 3.3: Buoyant force.

"The tendency of a fluid to exert an upward force on an object immersed in it is called buoyancy. The upward force acting on the object is known as the buoyancy force."

The upthrust due to buoyancy results in an apparent loss in the weight of the body **(Fig. 3.3)**.

You can see its manifestation if you draw water from a well using a bucket-rope arrangement. As soon as the bucket comes out of the water, it suddenly feels heavier.

We know that when a body is immersed in a fluid, it displaces some amount of fluid. If we imagine that the space occupied by the body is replaced by the fluid, then the center of gravity of this fluid is called the center of buoyancy. The upthrust on a body acts through the center of buoyancy. If a body of uniform density is submerged fully in a fluid, then its center of gravity coincides with the center of buoyancy. The quantitative measure of buoyant force is given by Archimedes' principle.

Archimedes' principle may be stated as follows:

"When a body is wholly or partially immersed in a fluid, it experiences an upward thrust, which is equal to the weight of the fluid displaced."

This principle can also be stated as follows:

- When a body is wholly or partially immersed in a fluid, it experiences an apparent loss in its weight (due to upward thrust), which is equal to the weight of the fluid displaced by it **(Fig. 3.4)**.

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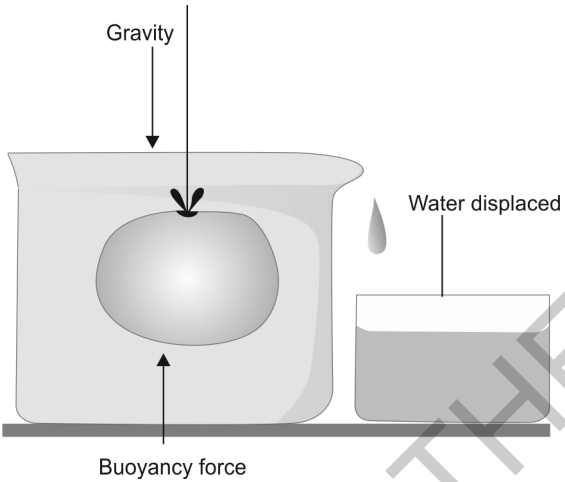

Fig. 3.4: Archimedes' Principle.

❖ Sometimes this principle is also known as the principle of buoyancy. Archimedes' principle can be used to determine the specific gravity of a solid substance.

APPLICATIONS OF ARCHIMEDES' PRINCIPLE

❖ Submarine – Ballast tank inside the submarine makes the weight of the submarine greater than the buoyant force.
❖ Hot air balloon – The buoyant force of a balloon is less than the surrounding air by varying the quantity of hot air in the balloon
- A hydrometer, used for measuring the specific gravity of liquids operates on this principle.
- Urinometer also works on the same principle.
- Underwater exercises, where patients with joint or muscular problems can be facilitated for exercise, where they feel easy to perform exercises in water due to buoyancy forces **(Fig. 3.5)**.

EFFECTS OF GRAVITATIONAL FORCES ON THE HUMAN BODY AND APPLICATION OF PRINCIPLES OF GRAVITY IN NURSING

Diagnosis using principles of gravity

❖ The erythrocyte sedimentation (ESR) is based on gravity only. In this test, the sedimentation rate is measured by the depth of surface between the clear plasma and the cells in a test tube for over an hour. The faster this happens, the higher the ESR and there may be more inflammation in the body because during inflammation there

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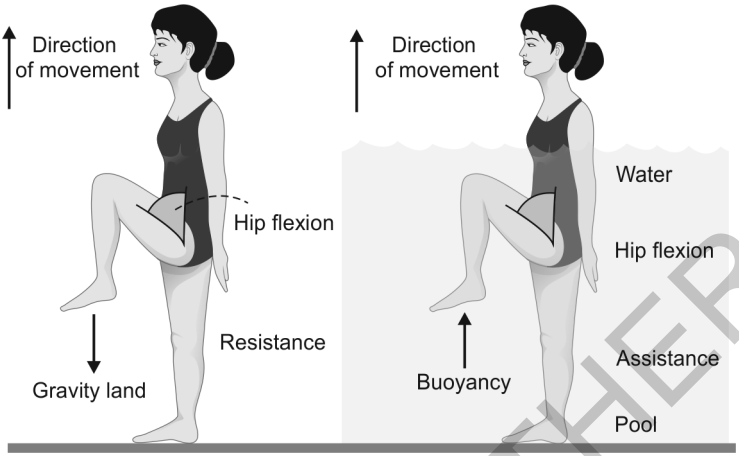

Fig. 3.5: Exercise in and out of water.

may be more protein in RBCs or they may clump together due to surface proteins and become heavier as a result more gravitational force is applied to make them settle fast.

- Haemoglobin screening is done during blood donation using an appropriately standardized $CuSO_4$ solution having a specific gravity of 1.053 based on gravitation force. If the drop of blood float on the surface it is assumed the person is having Hb level below 12 g/dl so he or she is not fit for blood donation. This is very useful during blood donation camps.
- A urine-specific gravity test compares the density of urine to the density of water by using principles of gravity. This quick test can help determine how well kidneys are diluting or concentrate the urine.

Position of the patient according to principles of gravity

- Brain surgery is frequently done with the patient in a sitting or semi-sitting position to lessen the danger of haemorrhage.
- After a rib resection, the patient is kept in a semi-sitting position to increase drainage from the thorax through the drainage tube by gravity.
- When a patient who is under the effect of anesthesia or an unconscious patient, his or her head is placed on one side, then tongue and oral secretions drop down due to gravity that makes a larger passageway for air to enter and respiration will improve.
- A dependent position with legs dragged on one side of beds, for a patient with congestive cardiac failure, it accumulate excess fluid in legs and facilitate breathing (also achieved through gravity).

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- Oscillating beds are used to change the positions to facilitate the circulation of blood and lymph is achieved with gravity.
- Post radical mastectomy affected sidearm is kept in a high position, so that with gravity lymph can be drained effectively and swelling on the arm can be prevented.

Fluid movement due to gravity

- Infusion of intravenous fluid, blood transfusion, nasogastric tube feeding, irrigation of body cavities, urinary drainage, or drainages from other body cavities cannot be imagined without principles of gravity.
- Without gravity, there would be no pressure in the liquid. So we cannot give intravenous infusion or blood transfusion in the absence of gravity **(Fig. 3.6)**.
- Blood circulation in the body mainly depends on gravity. Changes in body position alter the pressure of blood in different parts of the body. If a person faints, his head should be lowered. This helps the blood to return to the head (by gravity).
- A person standing for a long period of time may have edema of the legs **(Fig. 3.7)**. Gravity exercises are sometimes prescribed for patients with circulatory disorders of the lower extremities.
- During thoracentesis, Paracentesis, the peritoneal dialysis fluid is drained with principles of gravity.
- Postural drainage after the chest physiotherapy is also based on gravity only.



Fig. 3.6: IV fluid administration with gravity.

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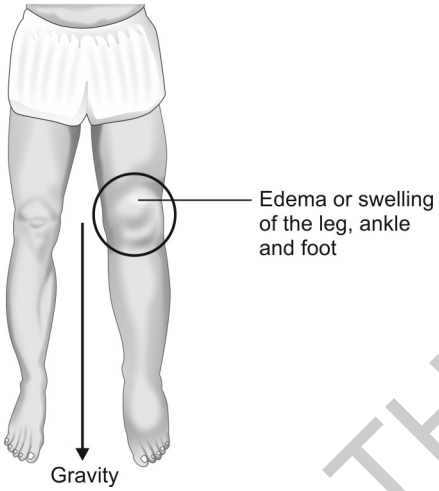

Fig. 3.7: Edema due to gravity.

Stability and gravity

Body alignment is achieved by placing one body part in line with another body part in a vertical or horizontal line. Correct alignment contributes to body balance and decreases strain on muscle-skeletal structures. Without this balance, the risk of falls and injuries increases. In the language of body mechanics, the **center of gravity** is the center of the weight of an object or person. A lower center of gravity increases stability. This can be achieved by bending the knees and bringing the center of gravity closer to the base of support, keeping the back straight. A wide base of support is the foundation for stability. A wide **base of support** is achieved by placing feet a comfortable, shoulder-width distance apart. When a vertical line falls from the center of gravity through the wide base of support, **body balance** is achieved. If the vertical line moves outside the base of support, the body will lose balance.

- Persons with obesity may have a greater risk of falling while walking or running because some timeline of gravity may fall out base of support, so we should be careful while moving the obese patient.
- Chronic low back pain may be due to having the center of gravity located excessively towards the back caused by decreased low back strength and decreased amount of normal low back curve. If center of gravity is too far, a black person might have strength and balance challenges to overcome in order to re-establish postural control. So the right posture should be maintained during the working and shifting of patients.

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Patient handling and gravity

Principles of body mechanics should be applied properly during all patient-handling activities.

- Assess the weight of the load before lifting and determine if assistance is required. Plan the move; gather all supplies and clear the area of obstacles. Avoid stretching, reaching, and twisting, which may place the line of gravity outside the base of support.
- Tighten abdominal, gluteal, and leg muscles in anticipation of the move.
- Stand up straight to protect the back and provide balance.
- Place the weight of the object being moved close to your center of gravity for balance. Equilibrium is maintained as long as the line of gravity passes through its base of support.
- Facing the direction prevents abnormal twisting of the spine. Turning, rolling, pivoting, and leveraging requires less work than lifting.
- Do not lift if possible; use mechanical lifts as required.
- Encourage the patient to help as much as possible.
- Keep all work at waist level to avoid stooping. Do not bend at the waist.
- Reduce friction between surfaces so that less force is required to move the patient. Bending the knees maintain your center of gravity and let the strong muscles of your legs do the lifting.
- It is easier to push an object than to pull it.
- Less energy is required to keep an object moving than it is to stop and start it.
- Use assistive devices (gait belt, slider boards, mechanical lifts) as required to position patients and transfer them from one surface to another.
- The person with the heaviest load should coordinate all the effort of the others involved in the handling technique.

A new horizon of gravity used in medical treatment:

Neural plasticity, the ability of the brain to learn from experience and to adapt to new environments is recognized to be profound and exposure to altered gravity has an effect on communication sites between the sensory cells and the nerve fibers ending on them. This could lead to the assumption that similar exposure to a force greater than 1G on a centrifuge on earth might one day prove useful in restoring a sense of balance to disabled people who have lost it. There are cases of children with medical disorders, such as autism, attention deficit disorders, fragile X etc.

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Biophysics in Nursing

Biophysics in Nursing is precisely written as per the Indian Nursing Council syllabus for the Post Basic BSc Nursing students. It may also serve as an introductory text for other healthcare professionals. The book is an excellent attempt towards introducing students to the various biophysical methodologies adopted in the field of nursing.

Salient Features

- **Comprehensive and complete:** This textbook presents complete required content very comprehensively to meet all the needs of Post Basic BSc Nursing students related to biophysics.
- **Simple and lucid content:** This edition provides clear and concise content about concepts and principles of biophysics in a simple and lucid manner incorporating their applications to healthcare and nursing sciences.
- **East-to-follow:** This is an applied, user-friendly, and self-explanatory textbook with simple language and illustrative presentation.
- **An example-oriented book:** This is an example-oriented book, where numerous examples are cited throughout the textbook for enriching understanding about the applicability of biophysics principles in nursing.
- **Illustrative presentation:** Presentation of content has been supplemented with illustrations to facilitate quick review and recall of important concepts.

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