Medical Physics, Terminology, Modeling

Terminology

What about the forces of the body during various activities, how much the body can do useful work, the relationship of an electrocardiogram to the heart's electrical activity, how a medical X-ray works, or how much radiation you receive from an X-ray? These questions and many others like them involve applications of physics to medicine and are answered in this subject.

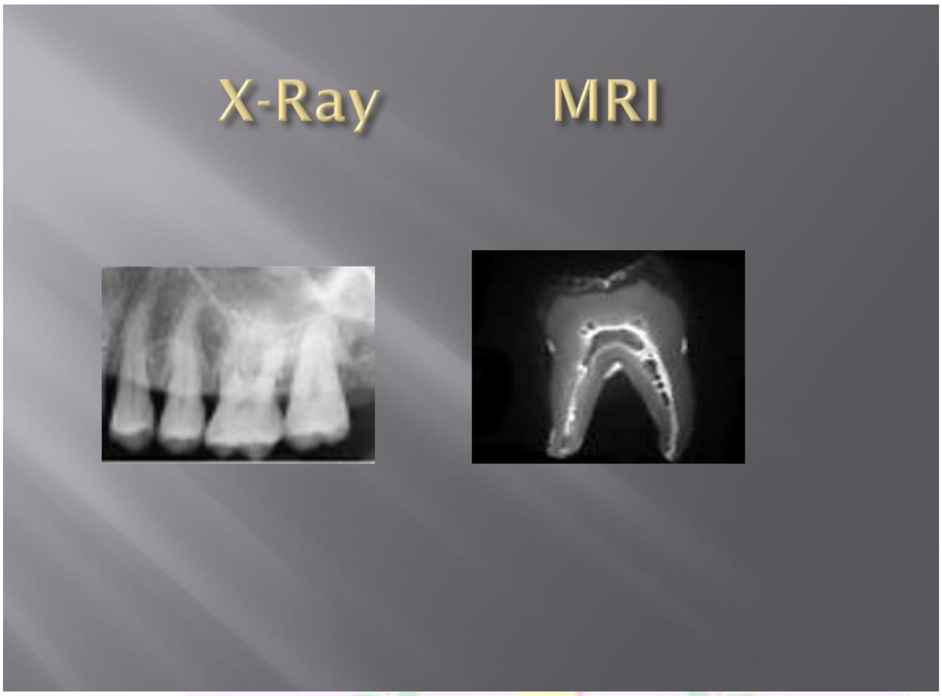
While the roles of chemistry and biology in medicine are well accepted, the role of physics is usually not as obvious. Even though all medical and paramedical students take the principles of physics, they often see little or no relationship between physics and medicine. This communication gap is primarily because their studies did not include sufficient coverage of physics applied to medicine.

The term medical physics refers to **two** major areas: -

I. The applications of physics to the function of the human body in health and disease.

II. The applications of physics in the practice of medicine.

The first of these could be called the physics of physiology or the physics of the various organ systems such as the eyes, ears, lungs, and the heart and circulatory system.; **the second** includes such things as the physics of the stethoscope, the tapping of the chest (percussion), and the medical applications of lasers, ultrasound, radiation, mechanics, heat, light, sound, electricity, and magnetism to medicine.



The word **physical** appears in several medical contexts. Only a generation ago in England a professor of physics was actually a professor of medicine. The words physicist and physician have a common root in the Greek word Physics (science of nature). Today the first thing a physician does after taking a medical history of a patient is to give him a physical examination. During this examination he uses the stethoscope, taps the chest, measures the pulse rate, and in other ways applies physics.

The branch of medicine referred to as **physical medicine** deals with the diagnosis and treatment of disease and injury using physical agents such as manipulation, massage, exercise, heat, and water.

Physical therapy is the treatment of disease or bodily weakness by physical means such as massage and gymnastics rather than by drugs.

Biophysics includes medical physics as a narrower sub-discipline. Biophysics is a relatively broad specific field that is not limited to medicine. It is mainly involved in the physics of various organisms, including microorganisms such as viruses, etc., although it approaches and overlaps with medical physics in many areas such as the transport of substances across cell membranes.

The field of medical physics has several subdivisions: -

1. Most medical physicists work in the field of ***radiological physics***. This involves the applications of physics to radiological problems and includes the use of radiation in the diagnosis and treatment of disease as well as the use of radionuclides in medicine (nuclear medicine).
2. Another major subdivision of medical physics involves ***radiation protection*** of patients, workers, and the general public. In the United States, this field is often called ***health physics***. Health physics also includes radiation protection outside of the hospital such as around nuclear power plants and in industry.
3. Very often an applied field of physics is called ***engineering***. Thus, medical physics could be called ***medical engineering***.

4. In some areas, such as the applications of ultrasound in medicine and the use of computers in medicine, you are likely to find medical physicists and medical engineers in nearly equal numbers. (The word ***medical*** is sometimes replaced with the word ***clinical*** if the job is closely connected with patient problems in hospitals, i.e., clinical engineering or clinical physics).

Modeling

Even though physicists believe that the physical world obeys the laws of physics, they are also aware that the mathematical descriptions of some physical situations are too complex to permit solutions.

If you tore a small corner off this page and let it fall to the floor, it would go through various gyrations. Its path would be determined by the laws of physics, but it would be almost impossible to write the equation describing this path. Physicists would agree that the force of gravity would cause it to go in the general direction of the floor if some other force did not interfere. Air currents and static electricity would affect its path. In trying to understand the physical aspects of the body, we often resort to analogies. Physicists often teach and think by analogy. Keep in mind that analogies are never perfect.

For example:

In many ways the eye is analogous to a camera; however, the analogy is poor when the film, which must be developed and replaced, is compared to the retina, a light detector of the eye. So, analogies are often used to help explain some aspect of the physics of the body. All explanations are incomplete to some degree although the success of this method. The real situation is always more complex than the one we describe.

Some models involve physical phenomena that appear to be completely unrelated to the subject being studied, For example:

A model in which the flow of blood is represented by the flow of electricity is often used in the study of the body's circulatory system. This electrical model can simulate very well many phenomena of the cardiovascular system. Of course, if you do not understand electrical phenomena the model does not help much. Also, as mentioned before, all analogies have their limitations. Blood is made up of red blood cells and plasma, and the percentage of the blood occupied by the red blood cells (the hematocrit) changes as the blood flows toward the extremities. This phenomenon is difficult to simulate with the electrical model.

Other models are mathematical; equations are mathematical models that can be used to describe and predict the physical behavior of some systems. In the everyday world of physics, we have many such equations.

While the laws of physics are involved in all aspects of body function, each situation is so complex that it is almost impossible to predict the exact behavior from our knowledge of physics. Nevertheless, a knowledge of the laws of physics will help our understanding of physiology in health and disease. Some are of such general use that they are referred to as laws. For example, the relationship between force F, mass m, and acceleration a, usually written as $F = ma$, is known as Newton's second law. Other mathematical expressions of this law may look quite different to a layperson but are recognized by a physicist as other ways of saying the same thing. Newton's second law can be expressed in the form $F = \Delta mv/\Delta t$, where v is the velocity, t is the time, and Δ indicates a small change in the quantity. The quantity is the momentum, and the part of the equation $\Delta/\Delta t$ means the rate of change (of momentum) with time.

Many functions of the body are controlled by homeostasis, which is analogous to feedback control in engineering. An engineer who wants to control some quantity that changes with time, will take a sample of what is being produced and use this sample as a signal to control the production to some desired level. So, the production will increase or decrease according to the level of this sample. The process is described as a negative feedback that produces a stable control.

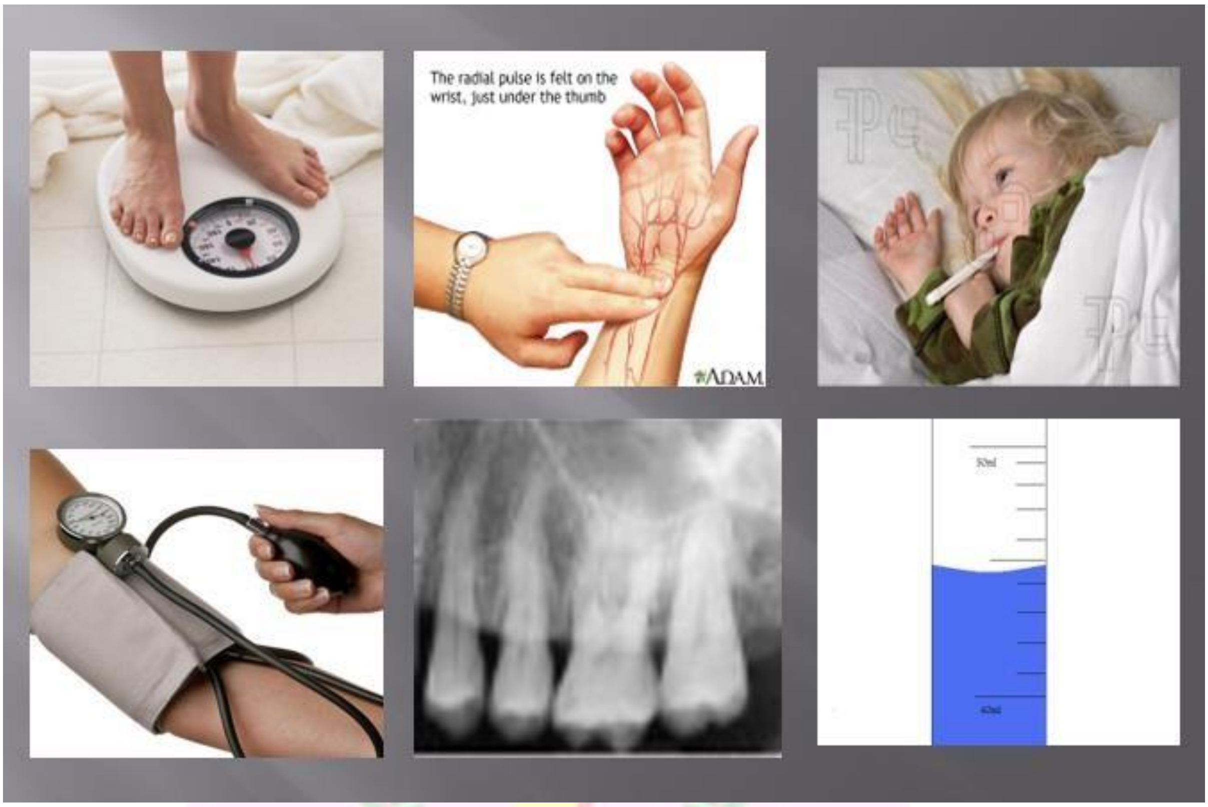
Negative feedback control is common in the body. For example, one important function of the body is to control the level of calcium in the blood. If the level drops too low, the body releases some calcium from the bones to increase the level in the blood. If too much calcium is released, the body lowers the level in the blood by removing some via the kidneys. While many of the control mechanisms of the body are not yet understood, various diseases are directly related to the failure of these mechanisms. For example, as the body grows, its cells keep increasing in number until it reaches adult size, and then the body remains almost constant in size under some type of feedback control. Occasionally some cells do not respond to this control and become tumors.

□ Measurement

One of the main characteristics of science is its ability to reproducibly measure quantities of interest. The growth of science is closely related to the growth of the ability to measure. In the practice of medicine, early efforts to measure quantities of clinical interest were often scorned as detracting from the skill of the physician. Even though body temperature and pulse rate could be measured during the seventeenth century, these measurements were not routinely made until the nineteenth century.

In this century there has been a steady growth of science in medicine as the number and accuracy of quantitative measurements used in clinical practice have increased.

The following figure illustrates a few of the common measurements used in the practice of medicine. Some of these measurements are more reproducible than others.



For Example: -

An X-ray gives only qualitative information about the inside of the body; a repeat X-ray taken with a different machine may look quite different to the ordinary observer. There are many other physical measurements involving the body and time. We can divide them into two groups: -

1. Measurements of repetitive processes, such as the pulse.

2. Measurements of nonrepetitive processes, such as how long it takes the kidneys to remove a foreign substance from the blood.

Measurements of the repetitive processes usually involve the number of repetitions per second, minute, hour, and so forth.

For Example: -

The pulse rate is about 70/min

The breathing rate is about 15/min.

Nonrepetitive time processes in the body range from the action potential of a nerve cell (1 msec) to the lifespan of an individual.

In science accuracy and precision have different meanings: -

- **Accuracy**

Refers to how close a given measurement is to an accepted standard.

For Example: -

A person's height measured as 1.765m may be accurate to 0.003m (3mm) compared to the standard meter.

Precision

Refers to the reproducibility of a measurement and is not necessarily related to the accuracy of the measurement.

For Example: -

An ill person measured her temperature ten times in a row and got the following values in degrees Celsius: 36.1, 36.0, 36.1, 36.2, 36.4, 36.0, 36.3, 36.3, 36.4, and 36.2. The precision was fairly good, with a variation of 0.2°C from the average value of 36.2°C. It is an accepted fact in science that the process of measurement may significantly alter the quantity being measured. This is especially true in medicine.

The process of measuring blood pressure may introduce errors (uncertainties). Although the data are scarce, it is generally believed that when an attractive woman is performing the measurement, the blood pressure of a young man will increase. Similarly, a handsome man may affect the blood pressure measurement of a female patient.

When the physician decides if the patient is ill or not?

After he or she has reviewed a patient's: -

1. Medical history.

2. The findings of the physical examination.

3. The results of clinical laboratory measurements.

It is not surprising that sometimes wrong decisions are made. These wrong decisions are of two types: -

1. False Positives.

2.False Negatives.

A **false positive** error occurs when a patient is diagnosed to have a particular disease when he or she does not have it.

A **false negative** error occurs when a patient is diagnosed to be free of a particular disease when he or she does have it.

<u>Note:</u> **-** In some situations, a diagnostic error can have a great impact on a patient's life.

For Example:

A young woman was thought to have a rheumatic heart condition and spent several years in complete bed rest before it was discovered that a false positive diagnosis had been made of arthritis.

In the early stages of many types of cancer, it is easy to make a false negative diagnostic error because the tumor is small. Since the probability of cure depends on early detection of the cancer, a false negative diagnosis can greatly reduce the patient's chance of survival.

Diagnostic errors (false positives and false negatives) can be reduced by: -

1. Research into the causes of misleading laboratory test values.
2. Development of new clinical tests and better instrumentation.

Errors or uncertainties from measurements can be reduced by: -

1. Using care in taking the measurement.
2. Repeating measurements.
3. Using reliable instruments.
4. Properly calibrating the instruments.

In summary: -

1. All measurements are uncertain and inaccurate.

2. With special effort we can reduce the error and the uncertainty.

3. In many cases there is no need to improve the measurement because the quantity being measured is variable.

Types of Forces

Forces could be divided into two parts

1- Forces in the body	**2- Forces on the body**
A: Gravitational force	A: fractional force
B: Electrical force	B: Static force
C: Nuclear force	C: Dynamic force

Forces In the Body

A: Gravitational force

F = mg.

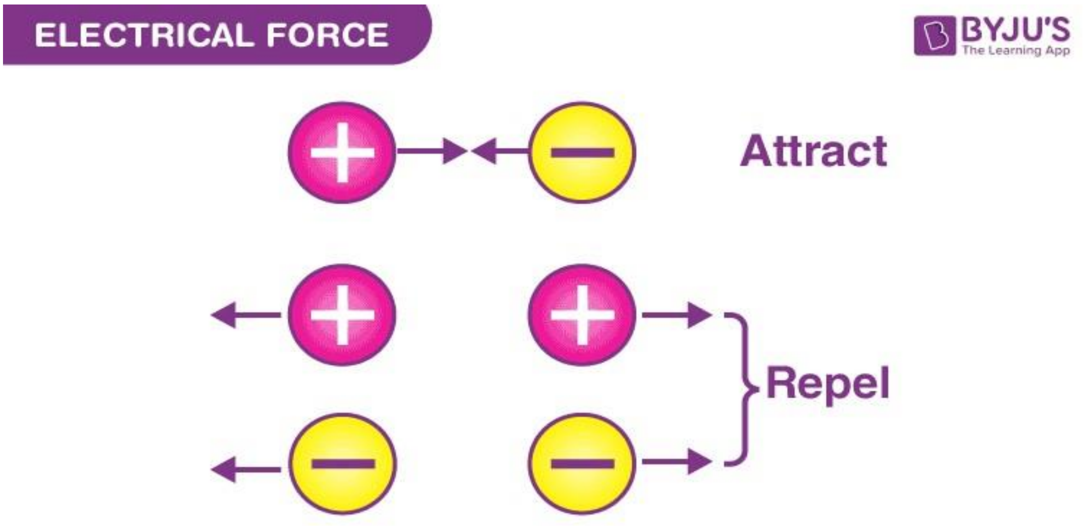
Where F is the attraction force, m is the mass (Kg,g), g is the acceleration due to gravity (cm/sec^2) or (m/sec^2)

Our weight is due to the attraction between the earth and our bodies. The medical effect of **Gravitational force** is the formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart. Varicose veins are veins that have become enlarged and twisted. When veins become varicose, the leaflets of the valves no longer meet properly (Fig-1), and the valves do not work. This allows blood to flow backwards and they enlarge even more. Varicose veins are most common in the superficial veins of the legs, which are subject to high pressure when standing. Besides being a cosmetics problem, varicose veins can be painful, especially when standing. When a person becomes weightless, such as

1- in an orbiting satellite, he or she loses some bone mineral. This may be a serious problem on very long space journeys.
2- Long-term bed rest is similar in that it removes much of the force of body weight from the bones which can lead to serious bone loss.

B: Electrical force

It is the repulsive or attractive interaction between any two charged bodies.

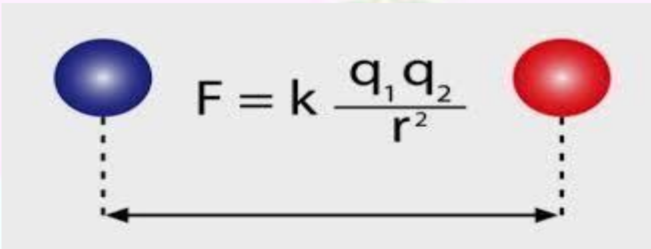


What Is Coulomb's Law?

The value of the electrostatic force of interaction between two point charges is directly proportional to the scalar multiplication of the charges and inversely proportional to the square of the distance among them.

What Is the Formula of Electric Force?

The electric force formula can be obtained from Coulomb's law as follows:



When,

- K is the constant of proportionality.
- q_1 and q_2 are the amounts of charge on each body.
- r is the distance between the charged bodies.
- F is the electrical force directed between two charged bodies

Electrical forces are immense compared to gravitational force. For example, the electrical force between an electron and a proton in a hydrogen atom is about 10^{39} times greater than the gravitational force between them.

Our bodies are electrical machines. These forces produced by the muscles are caused by electrical charges attracting or repelling other electrical charges. Control of the muscles is primarily electrical. Each of the billions of living cells in the body has an electrical potential difference across the cell membrane because of the differences in charge between the inside and outside of the cell. This amounts to less 3 than 0.1V, but because of the very thin cell wall, it may produce a field as large as 10^5 V/cm.

C-Nuclear forces:

The nuclear force keeps the positive charges "proton" together inside the nucleus. We have two types of nuclear forces:

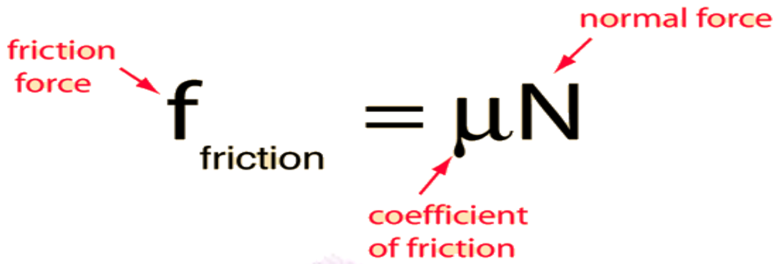
1- Strong nuclear force: it is much larger than the other type. It acts as "glue" to hold the nucleus against the repulsive forces that are produced by the protons on each other

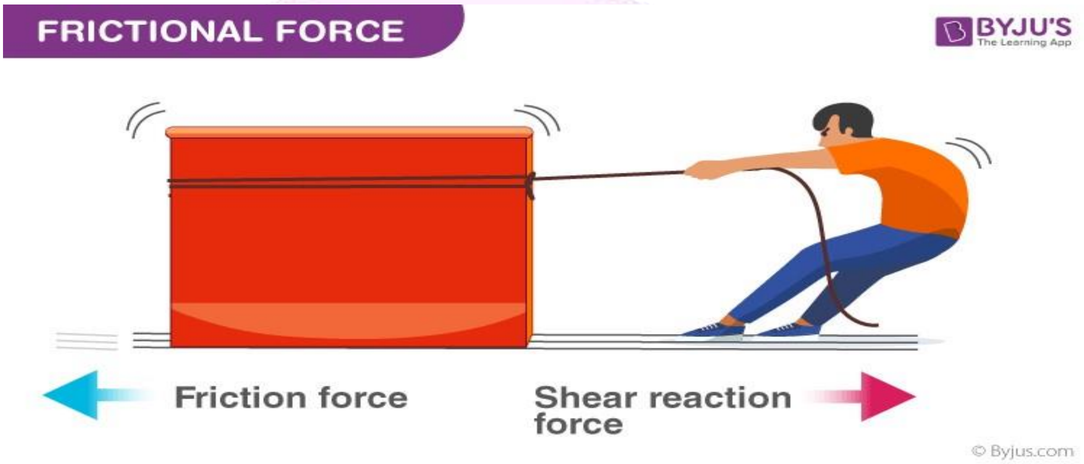
2-Weaker nuclear force: it is involved with electron decay from the nucleus. It may be related to the electrical force.

Forces on the body

A- Frictional Forces

Frictional force refers to the **force generated by two surfaces that contact and slide against each other.**





A few factors affecting the frictional force:

- These forces are mainly affected by the surface texture and the amount of force impelling them together.
- The angle and position of the object affect the amount of frictional force.
- If an object is placed flat against an object, then the frictional force will be equal to the weight of the object.
- If an object is pushed against the surface, then the frictional force will be increased and become more than the weight of the object.

Types of Frictional Forces

The friction that takes place between solid surfaces is classified as **Static, Kinetic, Rolling,** and **Sliding Friction**. The friction that takes place between fluids and gases is termed fluid friction. Hence, friction is broadly classified as:

- Dry Friction
- Static Friction
- Kinetic Friction
- Rolling Friction
- Sliding Friction
- Fluid Friction

Dry friction

Dry **friction describes the reaction between two solid bodies in contact when they are in motion (kinetic friction)** and when **they are not (static friction).** Both static and kinetic friction are proportional to the normal force exerted between the solid bodies. The interaction of different substances is modeled with different coefficients of friction. By this, we mean that certain substances have a higher resistance to movement than others for the same normal force between them. Each of these values is experimentally determined.

Fluid Friction

Is the force that obstructs the flow of fluid? It is a situation where the fluid provides resistance between the two surfaces. If both the surfaces offer high resistance then it is known as high viscous and, generally, we call them greasy. For example, to avoid creaking sounds from doors, we lubricate the door hinges which leads to the smooth functioning of door hinges.

Q/ A large block of ice is being pulled across a frozen lake. The block of ice has a mass of 300 kg. The coefficient of friction between two ice surfaces is small: $\mu_k = 0.05$. What is the force of friction that is acting on the block of ice?

$F_f = \mu * N$

Where **N** is a normal force and μ is the coefficient of friction between the two surfaces.

N = m*g. Where m is the mass, g=9, 8 m/s²

$F_f = \mu * N$

$F_f = \mu * m * g$

$F_f = 0.05 \times 300\ kg \times 9.8\ m/s^2$

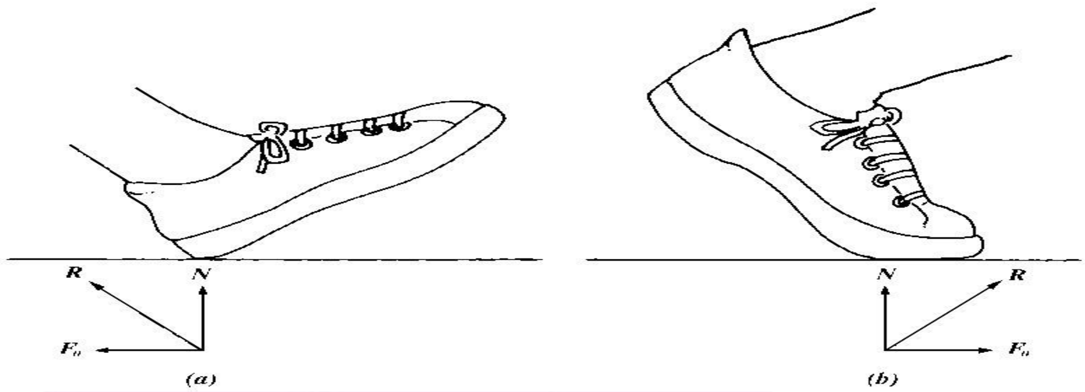
$= 147\ kg.m/s^2$ or $147\ N$.

The force of friction acting in the opposite direction as the block of ice is pulled across the lake is 147 N.

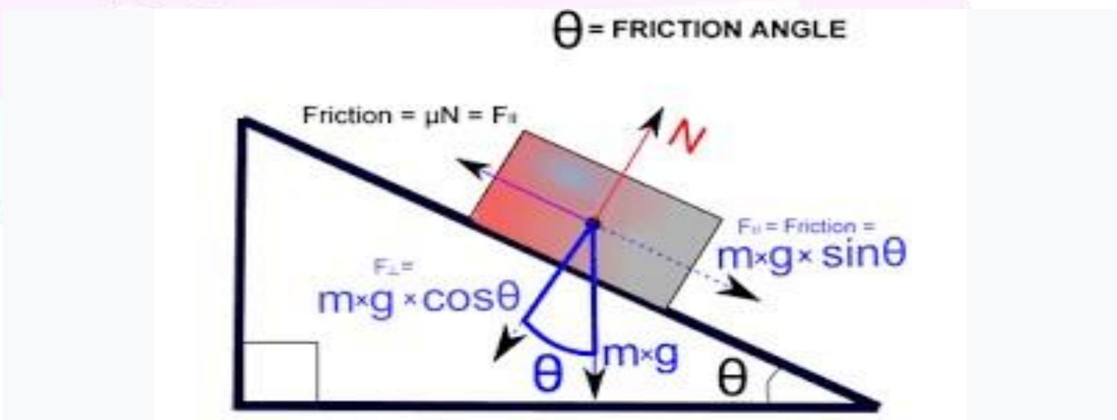
Some diseases of the body, such as **arthritis**, increase the friction in bone joints. Friction plays an important role when a person is walking. A force is transmitted from the foot to the ground as the heel touches the ground. This force can be resolved into vertical and horizontal components. The vertical reaction force, supplied by the surface, is labeled N (a force perpendicular to the surface). The horizontal reaction component, $\mathbf{F_H}$, must be supplied by frictional forces. The maximum force of friction $\mathbf{F_f}$ is usually described by:

The value of ***f depends upon the two materials in contact***, and it is essentially **independent** of the surface area.

This is how large the frictional force must be to prevent the heel from slipping. If we let **N~W**, we can apply a frictional force as large as $f =$ **W**.



Normal walking. (a) Both a horizontal frictional component of force, F_H, and a vertical component of force N with resultant R exist on the heel as it strikes the ground, decelerating the foot and body. **The friction between the heel and surface prevents the foot from slipping forward. At (b)** when the foot leaves the ground, the frictional component of force, **F_H, prevents the foot from slipping backward and provides the force to accelerate the body forward. a person slips on an icy, wet, or oily surface where (f) is less than 0.15.** This is not only embarrassing; it may result in broken bones. **Slipping can be minimized by taking very small steps.**



N = mg cos θ

When μ_s (coefficient of static friction) = 0.6

μ_k(coefficient of Kinetic friction) = 0.3

If $\theta = 30^o$

$F = N\mu$

If the body does not move then **If there is little push to the body then**

$F = N\ \mu_s = mg \cos 30^o\ \mu_s$

Fnet = FAid - Fopposing

$F\ net = mg \sin\theta - mg \cos\theta\ \mu_s$ $Fnet = mg \sin\theta - mg \cos 30^o\ \mu k$

If $mg \cos\theta\ \mu s > mg \sin\theta$ If $mg \cos 30^o\ \mu k < mg \sin 30^o$

بالقسمه على mg

$\mu_s > \sin\theta / \cos\theta > \tan\theta$ $\mu k < \sin\theta / \cos\theta < \tan\theta$

0.6 > 0.57 NO **move static case** 0.3 < 0.57 **friction force less than Pushing force**

لحساب التعجيل للجسم المتحرك

$a = F_{net} / m$

$= mg \sin 30^o - mg \cos 30^o\ \mu k / m$

بلقسمه على Divided to m

$= g (\sin 30^o - \cos 30^o)\ \mu k$

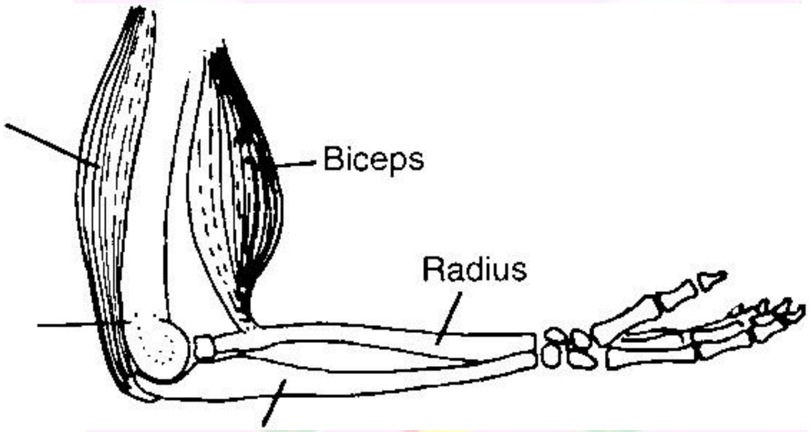
$= g (\sin 30^o - \cos 30^o)\ 0.3$

B-Statics Force:

When objects are stationary (static) they are in a state of equilibrium. The sum of the forces in any direction is equal to zero, and the sum of the torques about any axis is also zero

4- Forces, Muscles, and joints

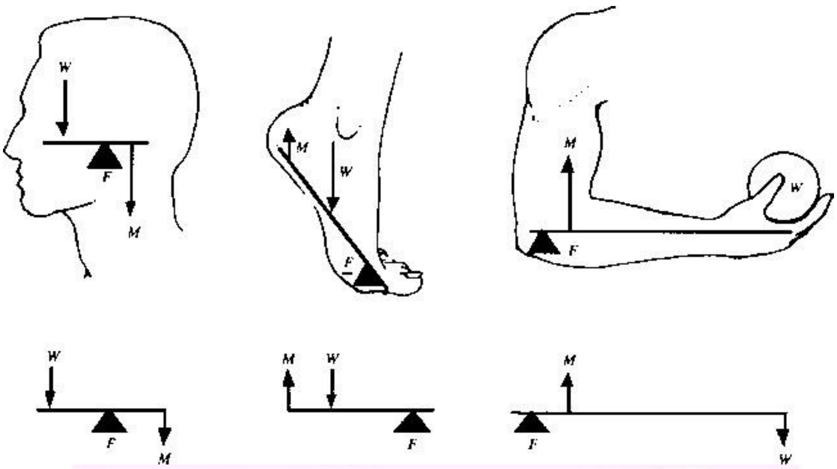
Skeletal muscles have small fibers with alternating dark and light bands, called *striations*—hence the name *striated muscle.* The fibers are smaller in diameter than human hair and can be several centimeters long. The other muscle form, which does not exhibit striations, is called ***smooth muscle.*** The fibers in the striated muscles connect to tendons and form bundles.



4.1-Muscle Forces Involving Levers

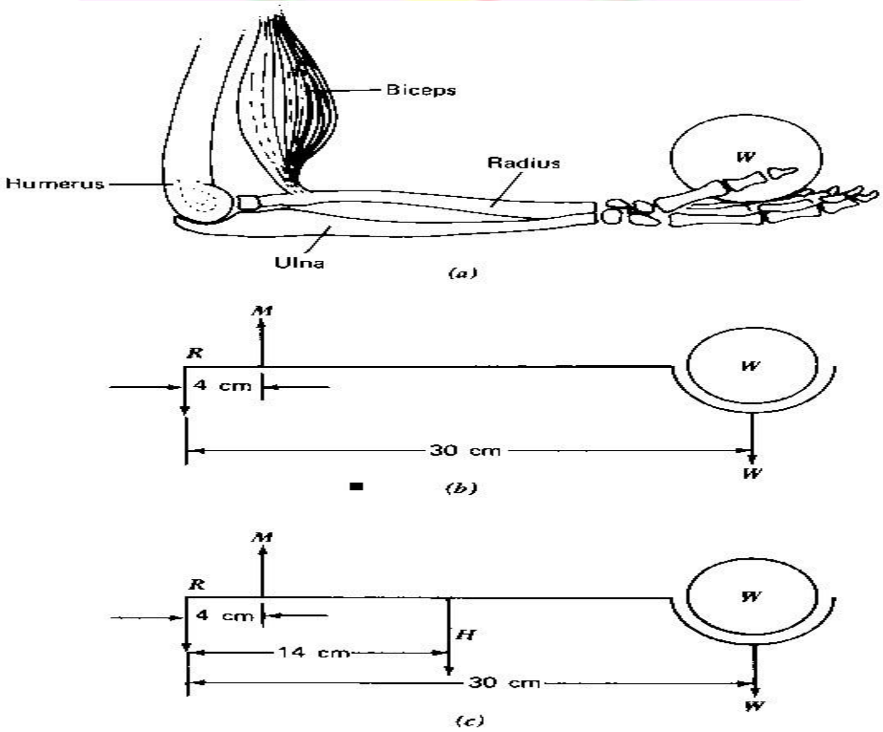
For the body to be at rest and in equilibrium (static), the sum of the forces acting on it in any direction and the sum of the torques about any axis must both equal **zero.**

Many of the muscle and bone systems of the body act as levers. Levers are classified as first-, second-, and third-class systems. ***Third-class levers are most common in the body, while first-class levers are least common***.



first-class Second - class Third - Class

W is a force that is usually **the weight**, **F** is the force at the **fulcrum point**, and **M** is the **muscular force.**



Example: If $w = 10N$, $H = 20N$ the effort exerted by the biceps muscle (M), and the reaction due to the upper arm (R), calculate M and R.

$$M \times 4 = H \times 15 + W \times 30 = 20 \times 15 + 10 \times 30 = 280 + 300 = 580 \text{ N}$$

$M = 580 / 4 = 145N$ *the Effort*

Resolving vertically gives

$R + 20 + 10 = 145 \rightarrow R = 114N$ *Reaction due to upper arm*

Notes

- The ***mechanical advantage*** of a system is defined by

$$MA = \frac{load}{effort}$$

In the example above the effort has to be bigger than the load, **because it acts closer to the fulcrum than the load does**. Although this makes the mechanical advantage **less than one,** it means that **large movements of the arm are produced by only small contractions of the muscles**.

- Most of the joints in the body are **third–class levers**. Since all third–class levers have a mechanical advantage which is less than one, it follows that **most joints are designed for speed of movement rather than for lifting heavy loads.**

Static equilibrium *is a state where bodies are at rest*; dynamic equilibrium is a *state where bodies are moving at a constant velocity (rectilinear motion).* In both cases, the sum of the forces acting on them is zero.

If only two forces (the weight of the body acts downward, and the reaction force of the ground acts upward) act on a body in the state of either static or dynamic equilibrium, they have equal magnitude but opposite directions.

C: Dynamics Force

Forces on the body where acceleration, Newton's second law, force equals mass times acceleration. $F = ma$

The force equals the change of momentum Δ (mv) over a short interval of time Δt or

$F = (\Delta (mv))/\Delta t$

Example: **a** :(60 kg) person walking at (1 m/sec) bumps into a wall and stops at a distance of (2.5 cm) in about (0.05sec) What is the force developed on impact?

$\Delta(mv) = (4\ kg)\ (1 m/sec) – (4\ kg)\ (0\ m/sec) = 4\ kg\ m/sec$

$F = (\Delta (mv))/\Delta t = \frac{4kgm/sec}{0.01sec} = 400\ kgm/sec^2 = 400N$

b- If the steel beam has (2cm) of padding and Δt is increased to (0.04 sec), what is the force developed?

$F = (\Delta (mv))/\Delta t = \frac{4kgm/sec}{0.04sec} = 100\ kgm/sec^2 = 100N$

Accelerations can produce several effects such as

1-An apparent increase or decrease in body weight

2-Changes in internal hydrostatic pressure

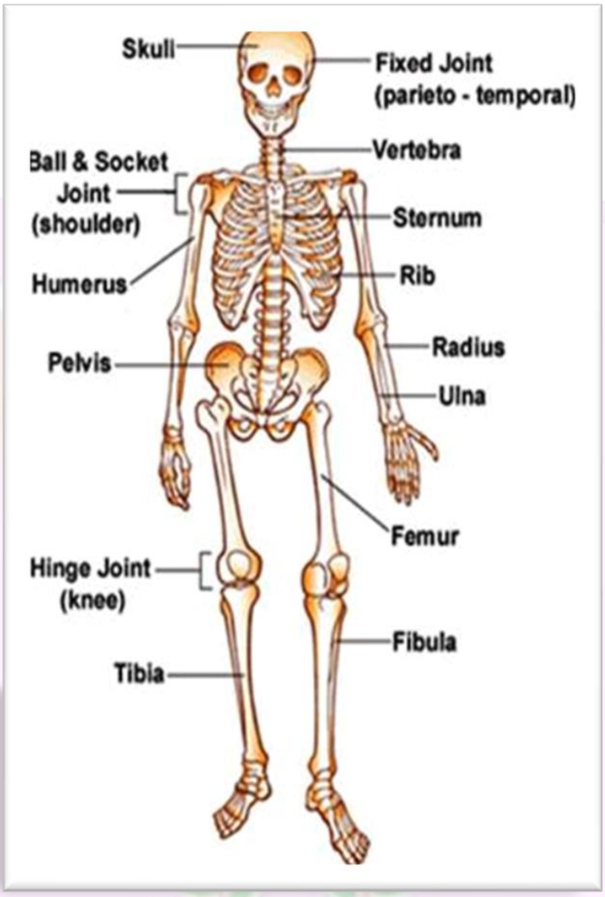
3-Distortion of the elastic tissues of the body

4-the tendency of the solids with different densities suspended in a liquid to separate.

A- If the acceleration becomes large and may pool in various regions of the body, the location of the pooling depends upon the direction of acceleration. If a person is accelerated head first the lack of blood flow to the brain can cause a blackout.

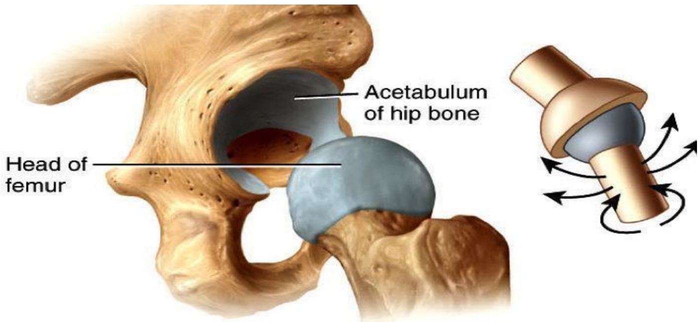
B -Tissue can be distorted by acceleration, if the forces are large, tearing or rupture can take place.

The Humen Skelton System



Bones and Joints:

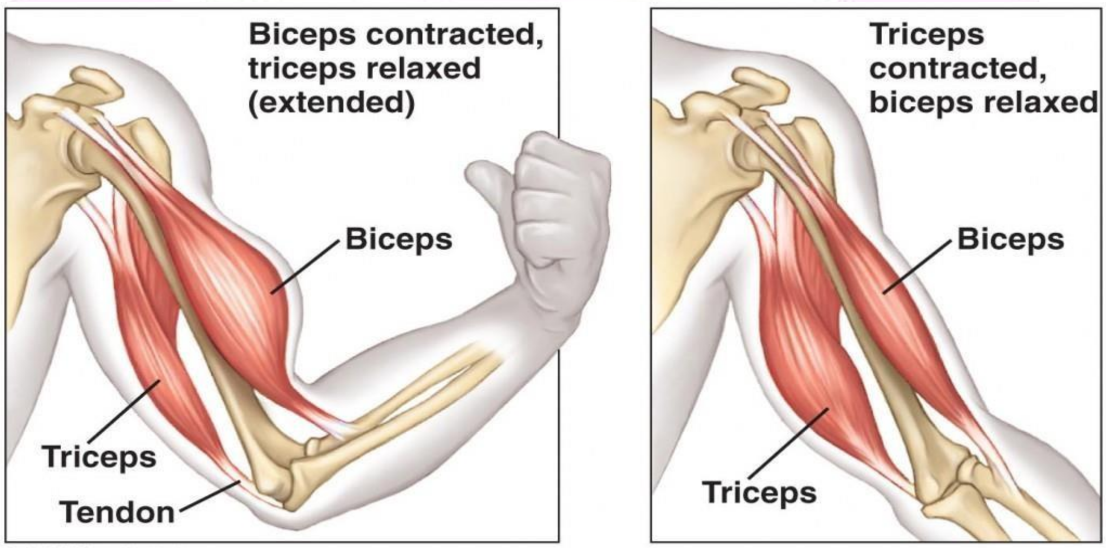
The human skeleton consists of about **206 bones**. Junctions between neighboring bones are called **Joints**. Although some joints like those in the skull allow little or no movement, the majority enable bones to move freely. These are known as **Synovial joints,** and different types allow different types of movement. The **elbow**, for example, is a **simple hinge,** whereas the **shoulder and the hip**, which have a greater range of movement, are ball-and-socket joints.



The bones on either side of a synovial joint are held together by **ligaments**. The parts of the bones that form the joint are covered with **cartilage** tough, slightly elastic material that protects the bones from damage. Friction between the layers of cartilage
is minimized by the presence of a **lubricant known as synovial fluid**.

Muscles:

Bones are moved by **muscles** which are attached to them by **tendons**. When a muscle contracts (under the action of nerve impulses from the brain) it pulls on the bones on each side of it and causes one of them to move. **Muscles cannot push** and therefore to return the bone to its original position, the first muscle relaxes, and a second muscle, acting in opposition to the first, contract Figure below. The two muscles are known as an **antagonistic pair.**



Q/ What is bone made of?

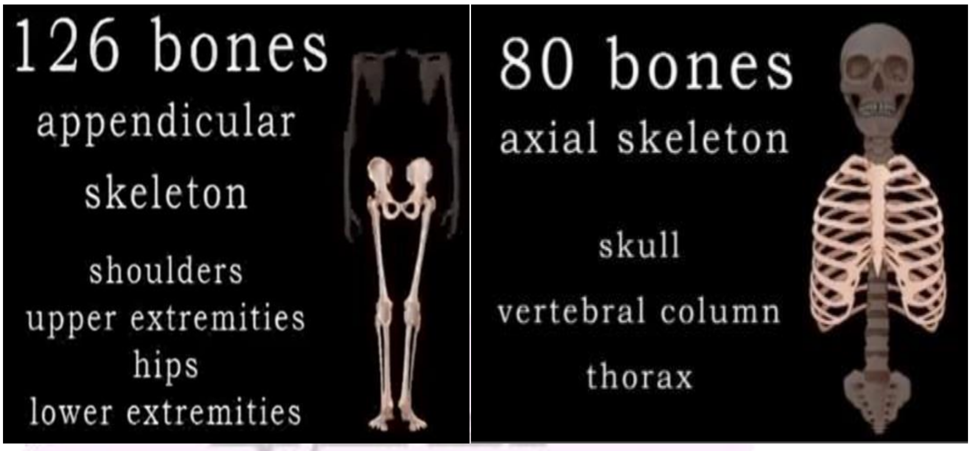
- The outer surface of bone is called the periosteum. It's a thin, dense membrane that contains nerves and blood vessels that nourish the bone.
- The next layer is made up of compact bone. This part is smooth and very hard. It's the part you see when you look at a skeleton.
- Within the compact bone are many layers of cancellous (spongy) bone, which looks a bit like a sponge. Cancellous bone is not quite as hard as compact bone, but it is still very strong.
- In many bones, the cancellous bone protects the innermost part of the bone, the bone marrow. Bone marrow is sort of like a thick jelly, and its job is to make blood cells.

There are two kinds of bones Compact bone & cancellous (spongy) bone

What is the advantage of a sponge over compact bones?

1- Sponge bone under compressive forces gives the strength necessary with less material than compact.

2- Sponge bones are relatively flexible and can absorb more energy when large forces are involved such as walking, raining, and jumping.



All bones could be divided into two parts axial & appendicular Skelton

Bone remolding: A continuous process of destroying old bone and building new ones. There are two types of cells in bone remolding.

- Osteoblasts are mononucleate bone-forming cells. They are located on the surface of osteoid seams and make a protein mixture known as osteoid, which mineralizes to become bone.

- Osteoclasts are the cells responsible for bone resorption, thus they break down bone. New bone is then formed by the osteoblasts. Bone is constantly remodeled by the resorption of osteoclasts and created by osteoblasts. Bones have about (1000g of Ca). Each day the osteoclast destroys bones containing 0.5 g of Ca, while the osteoblast builds new bone using the same amount of Ca. So, we have a new Skelton about every seven years.

Osteoporosis

Osteoporosis is a disease of bone where there is reduced bone mineral density, increasing the likelihood of fractures. Osteoporosis is most common in women, especially in the spine and hip. Osteoporosis usually has no symptoms until a fracture occurs. Up to 35 – 40 years old the activity of the osteoblast is greater than osteoclast. Over that age, the process is reversed causing a gradual decrease in bone mass that continues until death.

Osteoporosis treatment includes advice to

1- stop smoking,

2- decrease alcohol consumption,

2- exercise regularly,

3- and have a healthy diet.

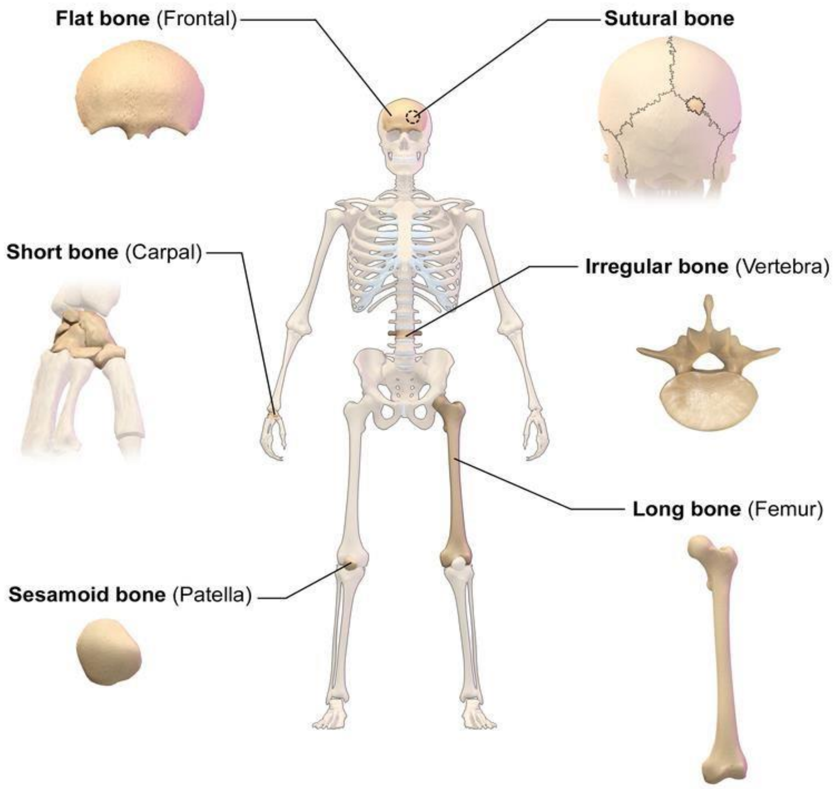
5- Calcium supplements may also be advised, as May Vitamin D.

Here are five types of bones in the human body: long, short, flat, irregular, and sesamoid.

Types of Bones

- Long bones are characterized by a shaft, the diaphysis that is much longer than its width; and by an epiphysis, a rounded head at each end of the shaft. They are made up mostly of compact bone, with lesser amounts of marrow, located within the medullary cavity, and spongy, cancellous bone. Most bones of the limbs, including those of the fingers and toes, are long bones femur, and tibia.
- Short bones are roughly cube-shaped and have only a thin layer of compact bone surrounding a spongy interior. The bones of the wrist and ankle are short.
- Flat bones are thin and generally curved, with two parallel layers of compact bones sandwiching a layer of spongy bone. Most of the bones of the skull are flat bones, as is the sternum.
- Sesamoid bones are bones embedded in tendons. Since they act to hold the tendon further away from the joint, the angle of the tendon is increased and thus the leverage of the muscle is increased. Examples of sesamoid bones are the patella and the pisiform.
- Irregular bones do not fit into the above categories. They consist of thin layers of compact bone surrounding a spongy interior. As implied by

the name, their shapes are irregular and complicated. Often this irregular shape is due to their many centers of ossification or because they contain bony sinuses. The bones of the spine, pelvis, and some bones of the skull are irregular. Examples include the ethmoid and sphenoid bones.



Classification of Bones by Shape

Q/ What could determine the bone function?

1- The bone shape.

2- The interval construction of bone.

3- The type of material to be formed.

Bones have many functions, including the following:

Shape

Bone structure gives shape to the body. This shape changes as you grow, and your skeletal system determines your height, width, and other factors, such as the size of your hands and feet. Body shape or type is genetically inherited. There are three main body shapes: ectomorphs (tall and thin), mesomorphs (shorter and muscular), and endomorphs (apple or pear-shaped).

Support

The skeleton provides support to the body and keeps your internal organs in their proper place. The vertebral column allows you to stand erect, while cavities hollow spaces in the skeleton are designed to hold your organs. For example, the skull holds the brain; the chest cavity holds your lungs and heart and the abdominal cavity holds your gastrointestinal organs. Additionally, the pelvis and leg bones are strong and thick to support the weight of the entire skeleton.

Movement

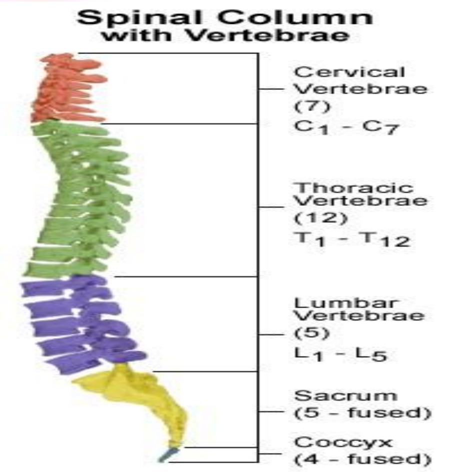
The skeletal bones are held together by ligaments. Tendons attach your muscles to the bones of your skeleton. The muscular and skeletal systems work together to carry out bodily movement, and together they are called the musculoskeletal system. When muscles contract, the skeleton moves. The shape of the skeletal system also impacts movement. The small bones of the foot allow for adaptation to all sorts of terrain, while the small bones in the hands allow for precise and detailed movement.

Protection

His skeleton protects vital organs from damage, encasing them within hard bones. The cranium bone --skull -- houses the brain, while the vertebral, or spinal, column protects the delicate spinal cord, which controls all bodily functions through communication with your brain. The bony thorax, comprised of the ribs and sternum, protects your heart and lungs.

Blood Cell Production and Storage

The spongy tissue inside long bones, such as the femur, or thigh bone, has two types of marrow responsible for blood cell production. On average, 2.6 million red blood cells are produced each second by the bone marrow. Red bone marrow gives rise to blood cells while yellow bone marrow stores fat, which turns into red bone marrow in case of severe red blood cell depletion or anemia. Skeletal bones also function as a storage bank for minerals, such as calcium and phosphorus. These minerals are necessary for vital body functions, such as nerve transmission and metabolism. The vertebral column (Spine)



The spine consists of (33 vertebrae) and provides the main support for the body. Nine of the vertebrae at the base of the spine are fused, five to form the sacrum and four to form the coccyx. The top 24 are covered with cartilage and are separated from each other by tough fibrous known as discs. The discs allow the spine to bend and twist.

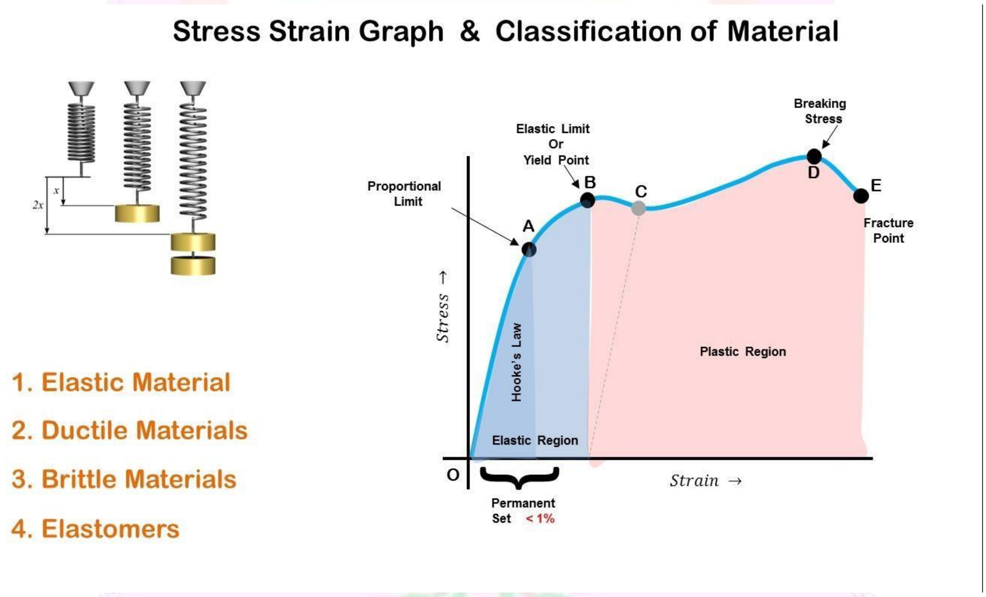
They also protect the vertebrae from wear and cushion them from shock.

Note: R force on lumbosacral disc, is over times body weight and nearly six times the force on it when standing upright. Lifting heavy weight with the back in this position puts even greater stress on the disc and might even cause it to rupture.

Damage is much less likely to occur if heavy objects are lifted with the knees bent and the back vertical

Stress-strain curve

The stress-strain curve is a behavior of material when it is subjected to load. In this diagram, stresses are plotted along the vertical axis, and as a result of these stresses, corresponding strains are plotted along the horizontal axis.



From the diagram, one can see the different mark points on the curve. This is because, when a ductile material like mild steel is subjected to a tensile test, then it passes various stages before fracture. These stages are;

1. Proportional Limit
2. Elastic Limit
3. Yield Point
4. Ultimate Stress Point
5. Breaking Point

1- Proportional Limit

The proportional limit **is a point on the curve up to which the value of stress and strain remains proportional**. From the diagram, point **A** is called the **proportional limit point** or it can also be known as the limit of proportionality. The stress Up to this point can be also known as **proportional limit stress.**

Hook's law of proportionality from the diagram can be defined between point **OA**. It is so because **OA** is a straight line which shows that Hook's law of stress-strain is followed up to point **A**.

2- Elastic Limit

Elastic limit is the limiting value of stress up to which the material is perfectly elastic. From the curve, point B is the elastic limit point. The material will return to its original position if it is unloaded before the crossing of point B. This is so because the material is perfectly elastic up to point B.

3- Yield Stress Point

Yield stress is defined as the stress after which material extension takes place more quickly with no or little increase in load. Point B is the yield point on the graph and stress associated with this point is known as yield stress.

4- Ultimate Stress Point

The ultimate stress point is the maximum strength that the material has to bear stress before breaking. It can also be defined as the ultimate stress corresponding to the peak point on the stress-strain graph. On the graph point D is the ultimate stress point. After point D material has very minute or zero strength to face further stress.

5- Breaking Stress (Point of Rupture)

The breaking point or breaking stress is the point where the strength of the material breaks. The stress associated with this point is known as breaking strength or rupture strength. On the stress-strain curve, point E is the breaking stress point.

Consider a bar of cross-sectional area (A) being subjected to equal and opposite forces (F) pulling at the ends so the bar is under tension. The material is experiencing stress defined to be the ratio of the force to the cross-sectional area of the bar:

Stress = $\frac{F}{A}$ N/m^2 = Pa

Now consider a force that is applied tangentially to an object. The ratio of the shearing force to the area A is called the shear stress. Or the ratio between changing in length ($\Delta \boldsymbol{l}$) to the original length (l).

Strain = $\frac{\Delta l}{l}$

Finally, the shear modulus Y of a material is defined as the ratio of shear stress to shear strain at any point in an object made of that material. The shear modulus is also known as the torsion modulus.

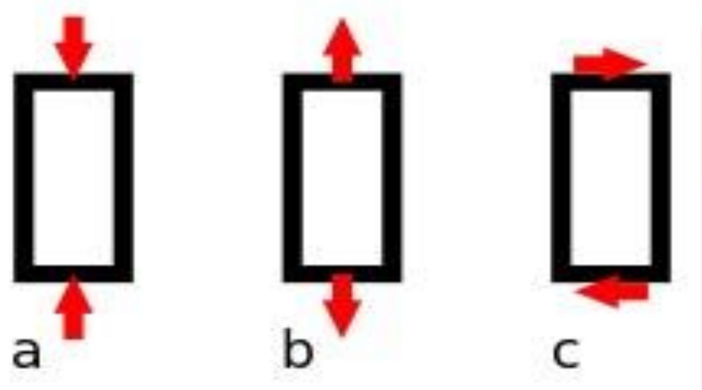
Y = $\frac{Stress}{Strain} = \frac{F*l}{A*\Delta l}$ Pa

6- Strength of material = its ability of a material to withstand an applied load without failure or plastic deformation.

1- Compressive stress = is the stress state caused by an applied load that acts to reduce the length of the material along the axis of the applied load, for example pushing forces. (a)

2- Tensile stress is the stress state caused by an applied load that tends to elongate the material along the axis of the applied load, for example by pulling the material. (b)

3- **Shear stress is the stress state caused by the combined energy of a pair of opposing forces acting along parallel lines of action through the material**, for example, stress is caused by the faces of the material **sliding** relative to one another. (**c**)



Elasticity is the ability of a material to return to its previous shape after stress is released.

Plasticity or plastic deformation is the opposite of elastic deformation and is defined as unrecoverable strain.

Heat and cold in medicine

. Physical basis of heat and temperature

. The ways to measure the temperature (thermometry)

. Mapping of the surface temperature of the body (thermography) as a diagnosis tool

. Heat therapy

. Uses of cold in medicine (cryogenics and cryosurgery)

Physical basis of heat and temperature

We should try to understand the temperature from the molecular scale. Molecules are in motion in a gas and liquid, even in a solid the molecules have some motion about their sites.

The fact that the molecules move means that they have kinetic energy, and this kinetic energy is related to the temperature. The average kinetic energy of the molecules of an ideal gas can be shown to be directly proportional to the temperature; liquids and solids show similar temperature dependence.

Temperature scales and Thermometry

Temperature scales: There are 3 temperature scales:

Anders Celsius (1701-1744) -Celsius (C)

Gabriel Fahrenheit(1686 -1736)-Fahrenheit (F)

Lord Kelvin (1824-1907) -Kelvin (K)

Differ by (a) the basic unit size or degree

(b) zero temperature

All measures are defined by the freezing point and the boiling point of water.

(at standard atmospheric pressure):

Freezing point of water: 0C or 32F Boiling point of water: 100C or 212F.

Range-freezing to the boiling point of water:

Celsius, 100 degrees Fahrenheit, 180 degrees

Normal body temperature is about 37°C, 98.6 F

Kelvin Temperature Scale:

Kelvin (K) scale is the absolute scale: it is directly proportional to the average kinetic energy in an ideal gas. It fixes the absolute lower limit of zero at 0 K which is a unique temperature equal to

273° C; it is called absolute zero. Theoretically, the ultimate in cold is "absolute zero" which is experimentally unattainable.

Kelvin Temperature Scale has the same basic unit size as Celsius.

The freezing point of water: 273 K

The boiling point of water: 373 K

Converting Temperatures from

Celsius to Fahrenheit:

$$T_F = 9/5\ T_C + 32$$

Fahrenheit to Celsius:

$$T_C = 5/9\ [T_F - 32]$$

Celsius and Fahrenheit scales allow for negative temperature

Celsius to kelvin

$$T_K = T_C + 273$$

Applications

- In the oral environment temperature is not constant because of hot and cold food and drink.

- Dental pulp is sensitive, and may be damaged if its temperature increases >5^{o}C). So the dental drilling rise in temperature of pulp during drilling should be less than 5^{o}C.

Exercise

Body temperature can increase from 98.60F to 107.0F during extreme physical exercise or viral infections. Convert these temperatures to Celsius and Kelvin and calculate the difference in each case.

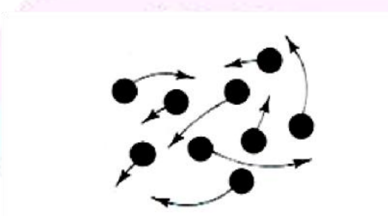
Thermal expansion

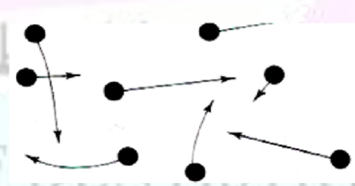
Most materials

•expand when temperature is increased

•contract when temperature is decreased

This is called thermal expansion and contraction





Low-Temperature High Temperature

When the average kinetic energy (or speed) of atoms is increased, they experience stronger collisions, increasing the separation between atoms

Assume no change in phase thermal expansion depends on:

•Material

•Size

•Temperature change

Linear Thermal Expansion

Important, for example, for metals in buildings, bridges dental filling materials, etc., the Bar of initial length changes by an amount

ΔL when its temperature changes by a mount ΔT.

The coefficient of linear expansion for the material is defined as:

α is the fractional change in length over the fractional change in temperature

$$\propto = \frac{\Delta L/L}{\Delta T} \qquad \Delta L = (L)\,(\alpha)(\Delta T)$$

ΔL = change in length L=original length ΔT = change in temperature α = coefficient of linear expansion

units ($°C^{-1}$ or K^{-1}) α depends on the type of material.

In restorations, decayed dentine was removed and replaced by filling. The coefficient of thermal expansion of the restorative material should be similar to that of the tooth thermal expansion/contraction due to hot and cold foods should not cause separation at the tooth filling interface. A large mismatch in expansion coefficients causes fluid leakage between the filling and the surrounding tooth.

Exercise

Amalgam 8 mm wide, oral temperature decreases by 10°C.
Compare the contraction of amalgam with that of enamel.

Coefficient of Thermal linear expansion				
Enamel	Dentine	Amalgam	Composite filling material ("white")	Gold
$11.4 \times 10^{-6} K^{-1}$	$8.3 \times 10^{-6} K^{-1}$	$25 \times 10^{-6} K^{-1}$	$\approx 30 \times 10^{-6} K^{-1}$	$14.5 \times 10^{-6} K^{-1}$

Area and volume thermal expansion Similarly:

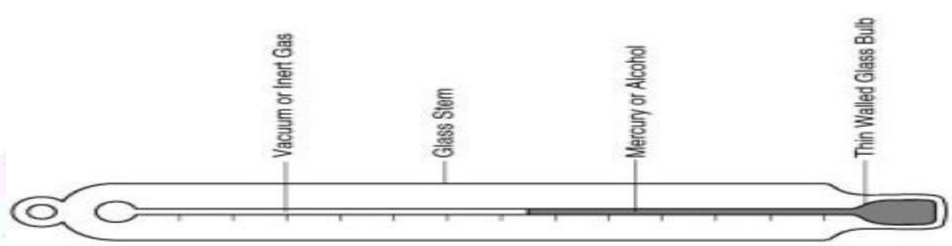
$\Delta A = A (2\alpha) \Delta T$

the coefficient of area expansion equals to 2α

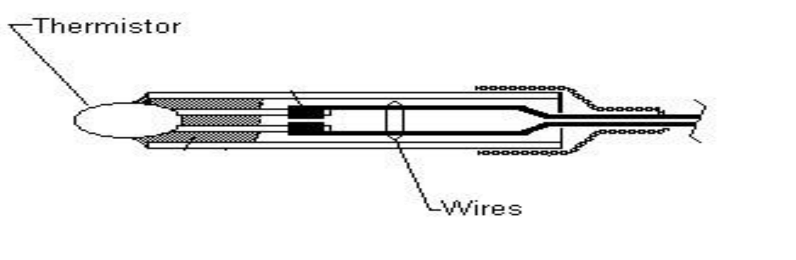
$\Delta V = V(3\alpha)\Delta T$ the coefficient of volume expansion equals to 3α

Thermometry:

Glass-liquid thermometer: The most common way to measure temperature is with a glass fever thermometer containing mercury or alcohol. The principle behind this thermometer is that an increase in the temperature of different materials usually causes them to expand in different amounts. In a fever thermometer, a temperature increase causes the alcohol or mercury to expand more than the glass and thus produces an increase in the level of the liquid.



Thermistor: A thermistor is a special resistor that changes its resistance rapidly with temperature. Initially, a temperature change causes the thermistor resistance to change. Thermistors are used quite often in medicine because of their sensitivity; with a thermistor, it is easy to measure temperature changes of O.O1° C.



Thermocouple: A thermocouple consists of two junctions of two different metals. If the two junctions are at different temperatures, a voltage is produced that depends on the temperature difference. Usually, one of the junctions is kept at a reference temperature. It can be used to measure temperatures from -190 to 300°C.

Thermography- mapping the body's temperature

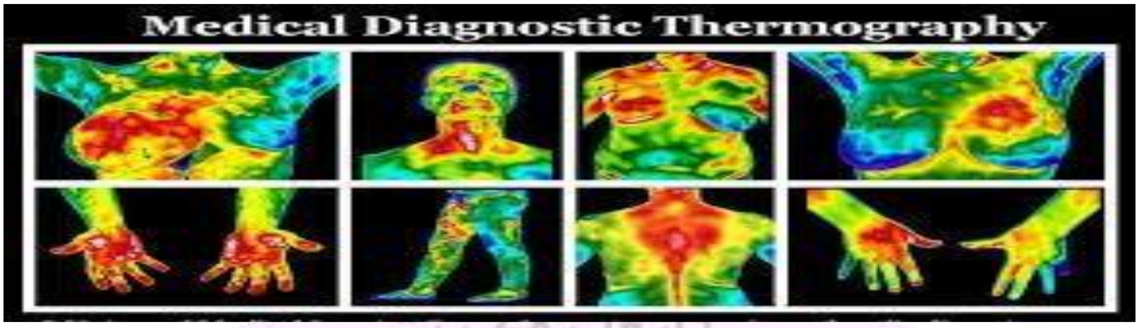
Measurements of body surface temperature indicate that the surface temperature varies from point to point depending upon:

I- External physical factors

II- Internal metabolic processes

III- Circulatory processes near the skin.

Blood flow near the skin is the dominant factor. Since variations in these internal processes may be symptomatic of abnormal conditions, many researchers have attempted to accurately measure the surface temperature of the body and relate it to pathologic conditions. One very appealing method of obtaining a thermogram is to measure the radiation emitted from the body. All objects regardless of their temperature emit radiation. At body temperature, the emitted radiation is in the far infrared (IR) region at wavelengths much longer than those observable by the human eye. The IR transparent filter removes visible light, and the detector converts the IR (or body heat) radiation to an electrical signal that is proportional to the temperature of the surface from which the radiation originated. The cathode ray tube CRT displays the different body temperatures as different shades of gray or colors.



Stefan-Boltzmann law for the total radiative power per surface area W is used. It is:

$$W = \sigma T^4$$

Where T is the absolute temperature; σ (the Stefan-Boltzmann constant) is 5.7×10^{-12} W/cm^2K^4. Thus, if we measure W, we can find the temperature T. The power radiated per square centimeter is small, as shown in Example:

Example

a. What is the power radiated per square centimeter from skin at a temperature of 306°K (~33°C)?

$$W = \sigma T^4 = (5.7 \times 10^{-12})(306)^4 \approx 0.05\ W/cm^2$$

b. What is the power radiated from a nude body 1.75 m^2 (1.75×10^4 cm^2) in area?

$$W = (0.05)(1.75 \times 10^4\ cm^2) = 875\ W$$

The radiative power received from the surrounding walls at 293°K (~20°C) would be about 735 W, for a net loss of 140 W. Since normally most of the body is clothed, the loss is considerably smaller than 140 W, but it is still significant.

Heat therapy

The primary therapeutic effects take place in the heated area:

1- There is an increase in the metabolism resulting in a relaxation of the capillary system.

2-There is an increase in the blood flow, as blood moves in to cool the heated area.

The physical methods of producing heat in the body

1-<u>The conductive method:</u>

The conductive method is based on the physical fact that if two objects at different temperatures are placed in contact, heat will transfer by conduction from the warmer object to the cooler one.

Heating pads and hot paraffin are applied to the skin to heat the body by conduction, which leads to local surface heating. This method is used to treat arthritis, neuritis, and back pain.

2- Radiant methods (diathermy):

Diathermy is the use of high-frequency electric current to produce heat. The heat from diathermy penetrates deeper into the body than conductive heat, so it is useful for internal heating and has been used (for example) in the treatment of inflammation of the Skelton.

A. Infrared heat:

It is used for surface heating; the waves penetrate the skin about (3mm) and increase the surface temperature. Excessive exposure causes reddening and sometimes swelling. This method is more effective because the heat penetrates deeper.

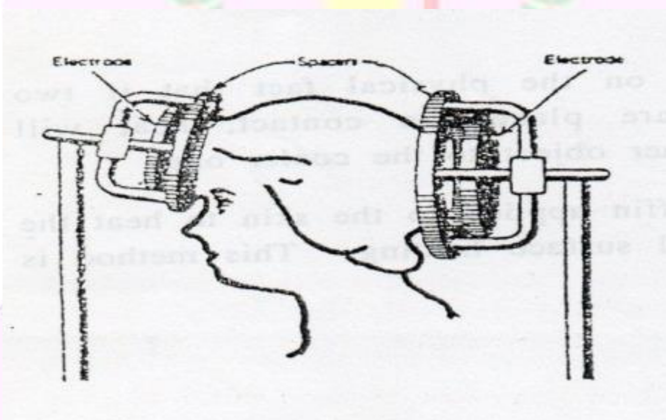
B. Shortwave diathermy:

short wave diathermy utilizes electromagnetic waves in radio range (wavelength ~10 m).

Two different methods are used for transferring the electromagnetic energy into the body in short wave diathermy:

1. **<u>By using capacitor plates:</u>**

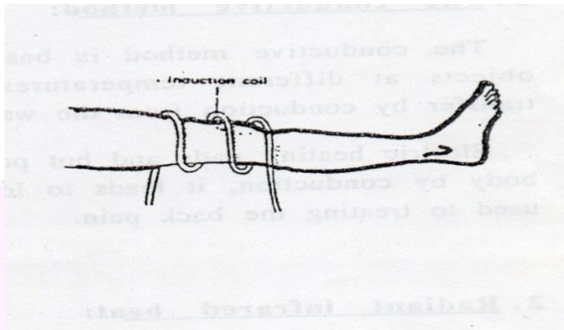
The part of the body to be treated is placed between two metal plates. Like electrodes which are energized by high-frequency voltage. The body tissue between the plates acts like an electrolytic solution, the charged particles are attracted to one plate and then the other depending upon the sign of the alternating voltage on the plates, which produces resistive heating.



2. **<u>Magnetic induction method:</u>**

The magnetic induction method is the second method to transfer short-wave energy into the body. In induction diathermy, a coil is placed around the body region to be treated. The alternating current in the coil produces an alternating magnetic field in the tissues;

consequently alternating (eddy) currents are induced, producing joule heating.



C. <u>**Microwave diathermy:**</u>

Microwave diathermy uses electromagnetic waves in the radar range (wavelength ~12 cm). Microwave diathermy is another form of electromagnetic energy. These waves are produced in a special tube called a magnetron and then emitted from the applicator (antenna) which is placed several inches from the region to be treated. These waves penetrate deep into the tissues causing a temperature rise and deep heating. Microwave diathermy is used in the treatment of fractures and strains.

D. **Ultrasonic wave:**

Ultrasonic waves are completely different from electromagnetic; they produce mechanical motion like audible sound waves. As the ultrasonic waves move through the body the particles in the tissues move back and forth producing heating in the tissues. This method is useful for depositing heat in bones because they absorb ultrasound energy more effectively than doe's soft tissues.

Use of cold in medicine

Low temperatures are referred to as the cryogenic region (from the ancient Greek word kryos, which means icy cold).

Cryogenics is the science and technology of producing and using very low temperatures. Liquid nitrogen (-196^o C) and liquid helium (-269^o C) are used.

How are cryogenic methods used in medicine? Low temperatures have been used for the long-term preservation of blood, sperm, bone marrow, and tissues. Blood can be stored for a much longer time if it is rapidly frozen.

Banks are formed for skin, bone, muscle, and organs. These substances are harder to preserve than simple cells such as red blood cells for several reasons: (1) the large physical dimensions limit the cooling rate and (2) adding and removing protective agents is difficult.

Cryosurgery: Cryogenic methods are also used to destroy cells; this application is called cryosurgery. Cryosurgery has several advantages:

(1) There is little bleeding in the destroyed area

(2) The volume of tissue destroyed can be controlled by the temperature of the cryosurgical probe

(3) There is little pain sensation because low temperatures tend to desensitize the nerves.

Safety with cryogenics: Many laboratories and hospitals that use cryogenic fluids have cylindrical containers of gases that are stored at high pressure. Such a cylinder can be dangerous if its valve is accidentally broken off, so these containers should be handled with care and chained in position. Caution should be exercised when cryogenic liquids or cold gases are used because any contact between these materials and the eyes or the skin results in "freeze burns."

If liquid oxygen spills on clothing, the clothing should be removed and allowed to air out for 30 min since clothing is highly flammable and easily ignited when it contains concentrated oxygen.

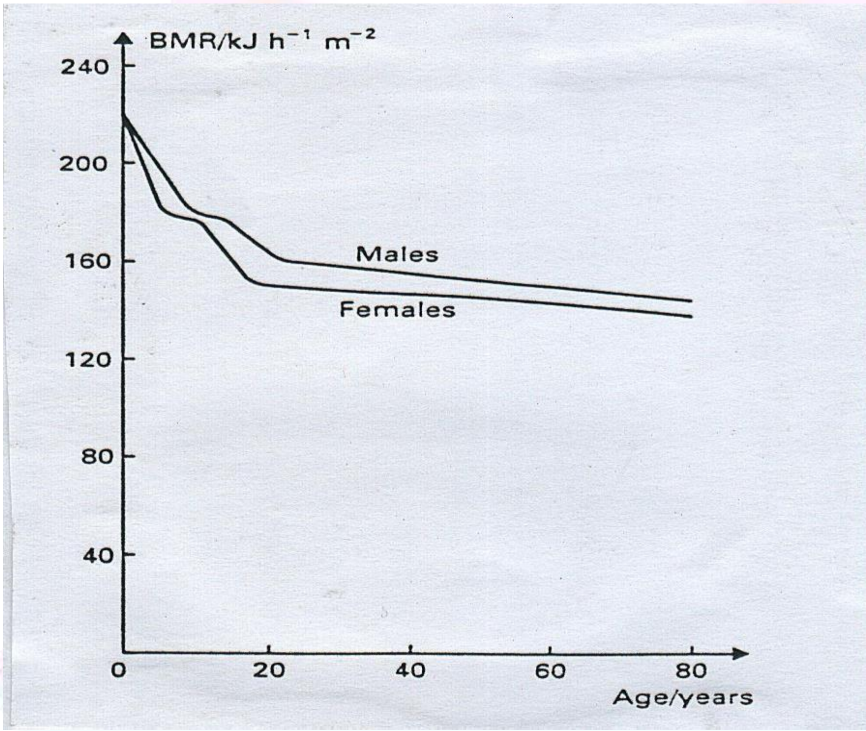
Energy expenditure

1.1 Basal Metabolic Rate

The body requires a regular intake of energy, from **carbohydrates, fats,** and **proteins,** to perform its normal functions.

Metabolic rate: The rate at which the body uses energy.

Basal metabolic rate: The rate at which the body uses energy when it is completely at rest. (BMR). Kj h^{-1} m^{-2}.



From the fig. above we can note that:

1- Children have high values of BMR **because of the energy required for growing.**

2- Men have slightly higher values than women **because men have less body fat and therefore use more energy in maintaining body temperature.**

Ex-If a man is found to consuming energy at 82.1 W, and a surface area of 1.92 m^2. What is his BMR expressed in KJ h^{-1} m^{-2}?

$W = J / S \rightarrow KJ/h \rightarrow 10^{-3} /1/3600 = 3.6$ KJ/h

Power = 82.1 x 3.6 KJ h^{-1} =295.56 KJh^{-1}

BMR = 295.56 / 1.92 = 153.93 KJ h^{-1} m^{-2}

2. Daily Energy Requirement

We have to expend energy in order to maintain normal body temperature, both to **keep warm when we are cold and to keep cool when we are hot.** The daily energy requirement of an individual depends on:

1- ***BMR***
2- ***The ambient temperature.***
3- ***The amount of clothing worn.***
4- ***The surface area of the body.***
5- ***The amount of exercise undertaken.***

*The daily energy requirement of an adult is usually in the range (1 – 1.6) MJ. The rates at which the average person consumes energy whilst performing various activities are shown in the table.

Activity	**The typical rate of consumption of energy / w**
Resting	80
Walking slowly	200
Walking quickly	350
Swimming	450
Playing football	600
Sprinting	1000

* The rate at which the body **produces** energy depends largely on **tissue volume**, whereas the rate at which energy is **lost** depends on **body surface area.**

The smaller the body, the greater the ratio of surface area to volume S/V. So babies are more at risk of hypothermia than adults. Small people need to eat more per kilogram of body mass than large people.

Metabolism: *can refer to all chemical reactions that occur in living organisms, including digestion and the transport of substances into and between different cells, in which case* ***the set of reactions within the cells*** *is called* an ***intermediary.***

BMR formula: The Harris-Benedict Equation has for a long time been the standard formula and is widely used for estimating BMR. Use the calculations below to calculate BMR, where: Wt = weight in kg, Ht = height in cm, and A = age in years.

Men: *kcal/day* = ***(13.8 x Wt) + (5 x Ht) - (6.8 x Age) + 66*** ***women***: *kcal/day* = ***(9. 6 x Wt.) + (1.8 x Ht) - (4.7 x Age) + 655***

Work ***can be defined as a transfer of energy***. In physics, we say that work is done on an object when you transfer energy to that object. If one object transfers (gives) energy to a second object, then the first object does work on the second object.

Work is the application of a force over a distance. Lifting a weight from the ground and putting it on a shelf is a good example of work. The force is equal to the weight of the object, and the distance is equal to the height of the shelf (**W= F*d**).

Work-Energy Principle: The change in the ***kinetic energy*** of an object is equal to the net work done on the object.

Energy ***can be defined as the ability to do work.*** The simplest case of mechanical work is when an object is standing still and we force it to move. The energy of a moving object is called ***kinetic energy***. For an object of mass m, moving with a velocity of magnitude v, this energy can be calculated from the formula $E = 1/2\, mv^2$.

Types of Energy

Kinetic Energy = Energy of Motion = $\mathbf{1/2\, mv^2}$

Potential Energy = Stored Energy = $\mathbf{m*g*h}$

Forms of Energy

Solar Radiation -- Infrared Heat, Radio Waves, Gamma Rays, Microwaves, Ultraviolet Light

Atomic/Nuclear Energy: energy released in nuclear reactions. When a neutron splits an atom's nucleus into smaller pieces it is called **fission**. When two nuclei are joined together with fewer than millions of degrees of heat it is called **fusion**.

Electrical Energy: The generation or use of electric power over a period expressed in kilowatt-hours (kWh), megawatt-hours (MWh), or gigawatt-hours (GWh).

Chemical Energy: Chemical energy is a form of potential energy related to the breaking and forming of chemical bonds. It is stored in food, fuels, and batteries, and is released as other forms of energy during chemical reactions.

Mechanical Energy: Energy of the moving parts of a machine. Also refers to movements in humans.

Heat Energy: a form of energy that is transferred by a difference in temperature.

What is Power?

Power is the work done in a unit of time. In other words, power is a measure of how quickly work can be done. The unit of power is the Watt = 1 Joule/ 1 second.

One common unit of energy is the kilowatt-hour (kWh). If we are using one kW of power, a kWh of energy will last one hour.

Calculating Work, Energy, and Power

WORK = **W**= F * d

Because energy is the ability to do work, we measure energy and work in the same units (N m or joules).

POWER (P) is **the rate of work done over time p = Fxd / t**

Power's SI unit of measurement is the **Watt**, representing the **generation or absorption of energy at the rate of 1 Joule/sec**. Power's unit of measurement in the English system is the **horsepower**, which is equivalent to **735.7** Watts.

How does the energy work with muscles during any physical work or exercise? Does the body lose energy or gain energy by doing work and how?

The muscle uses **chemical energy**. How this works in detail is not physics but a biology question. **The chemical reaction will create heat and cause your muscles to contract.** Consequently, your body loses chemical energy, that's why you have to eat, drink and breathe, to keep these reactions going. In return your body loses heat energy to its environment, as well as kinetic energy, which will be the actual movement of your arm.

If you do exercises, long-term speaking, **your body will not gain or lose any energy**; it will become more **efficient and capable** of converting chemical energy to kinetic energy, potential energy, etc.

2.4 Estimation of the Power-Provided Muscles

This can be achieved by **carrying out simple experiments designed to measure the power output of a specific of muscles**. The power of the leg muscles, for example, can be obtained by **timing a person running up a flight of stairs or by determining the number of times he can raise his leg in a given time with a weight attached to his ankle**.

Example 2:

A man of mass 75 kg runs up a flight of 50 steps in 15 seconds. Calculate the power output of his leg muscles given that the vertical height of each step is 0.2 m.

Work done = PE

$= m*g*h = 75 \times 10 \times (50 \times 0.2) = 7500$ J

Power = work done / time taken

$= 7500 / 15 = 500$W

TDEE = Total number of calories your body burns in each day,

Resting energy expenditure (REE) = energy burned when you are not physically active or digesting food. **(60 - 75%)**

Thermic effect of food (TEF) = energy required to digest food. **(10%)**

Basal metabolic rate = Resting energy expenditure + thermic effect of food.

Activity energy expenditure (AEE) = energy burned during physical activity. **(15 – 35%)**

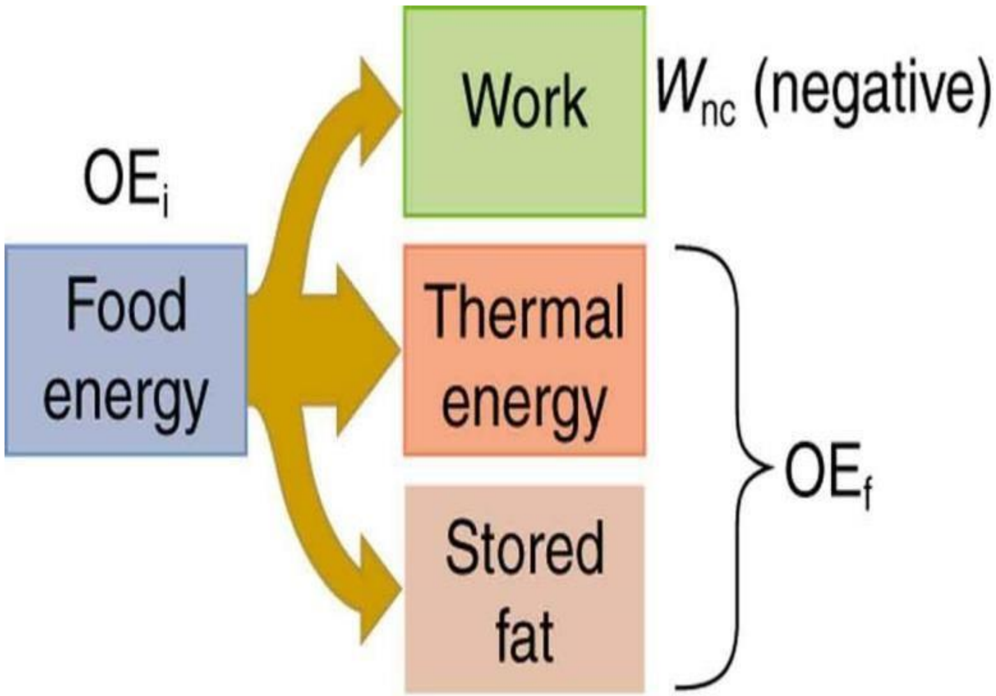
Metabolism = the total of all the chemical reactions in the human body.

TDEE = REE + TEF + AEE = 100%

It is kind of the **balance** between **building things** up or storing inside the body and **breaking things down** usually for energy needs.

Energy Conversion in Humans

Our bodies, like all living organisms, are **energy-conversion machines**. Conservation of energy implies that the **chemical energy stored in food is converted into work, thermal energy, and/or stored as chemical energy in fatty tissue. (See Figure.)** The fraction going into each form **depends** both on **how much we eat** and on **our level of physical activity**. **If we eat more than is needed to do work and stay warm, the remainder goes into body fat.**



$$OE_i + W_{nc} = OE_f$$

Energy consumed by humans is converted to work, thermal energy, and stored fat. By far the **largest fraction goes to thermal energy,** although the fraction varies depending on **the type of physical activity**.

Power Consumed at Rest

The rate at which the body uses food energy to sustain life and to do different activities is called the **metabolic rate**. The total energy conversion rate of a person at rest is called the **basal metabolic rate** (**BMR**) and is divided among various systems in the body, as shown in Table. ***The largest fraction goes to the liver and spleen, with the brain coming next.*** Of course, ***during vigorous exercise***, the energy consumption of the skeletal muscles and heart increases markedly. ***About 75% of the calories burned in a day*** go into these basic functions. ***The BMR is a function of age, gender, total body weight, and amount of muscle mass*** (**which burns more calories than body fat**). Athletes have a greater BMR due to this last factor.

Energy consumption is directly proportional to oxygen consumption **because the digestive process is one of oxidizing food**.

Calculating Weight Loss from Exercising

If a person who normally requires an average of 13,000 kJ (3000 kcal) of food energy per day consumes 12,000 kJ per day, he will steadily gain weight. How much bicycling per day is required to work off this extra 1000 kJ? Assuming the energy content of fat to be 39 kJ/g.

Solution

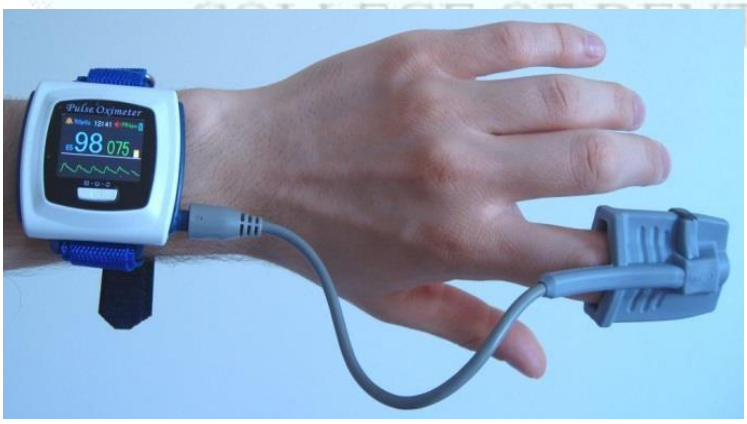
About (400 W) is used when cycling at a moderate speed. The time required to work off 1000 kJ at this rate is then

Time=energy/ (energy/time) =1000 kJ /400 W=10^{6}x10^{-2}/4 2500 s = 42 min.

Discussion

If this person uses more energy than he or she consumes, the person's body will obtain the needed energy by metabolizing body fat. If the person uses 13,000 kJ but consumes only 12,000 kJ, then the amount of fat loss will be

$$\text{Fat loss} = (1000\ \text{kJ})\ \left(\frac{1g\ fat}{39\ kJ}\right) = 26g$$



A pulse **oximeter** is an apparatus that **measures the amount of oxygen in blood. Oximeters can be used to determine a person's metabolic rate**, which is the rate at which food energy is converted to another form. Such measurements can indicate the level of athletic conditioning as well as certain medical problems.

All bodily functions, from thinking to lifting weights, require energy The many small muscle actions accompanying all quiet activity, from sleeping to head-scratching, ultimately become thermal energy, as do less visible muscle actions by the heart,

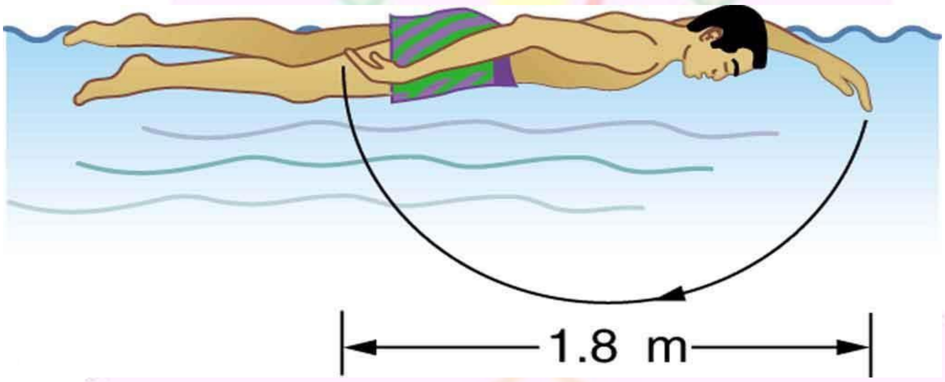
Lungs and digestive tract. Shivering is an involuntary response to low body temperature that pits muscles against one another to produce thermal energy in the body (and does not work). **The kidneys and liver consume a surprising amount of energy, but the biggest surprise of all is that a full 25% of all energy consumed by the body is used to maintain electrical potentials in all living cells.** (Nerve cells use this electrical potential in nerve impulses.) This bioelectrical energy ultimately becomes mostly thermal energy, but some is utilized to power chemical processes such as in the kidneys and liver and fat production.

Summary

- The human body converts energy stored in food into work, thermal energy, and/or chemical energy that is stored in fatty tissue.
- The *rate* at which the body uses food energy to sustain life and to do different activities is called the ***metabolic rate***, and the corresponding rate when at rest is called ***the basal metabolic rate (BMR)***

- The energy included in the basal metabolic rate is divided among various systems in the body, with the ***largest fraction going to the liver and spleen, and the brain coming next***.
- About 75% of food calories are used to sustain basic body functions included in the basal metabolic rate.
- The energy consumption of people during various activities can be determined by measuring their oxygen use because the digestive process is one of oxidizing food.

Example: The swimmer shown in Fig exerts an average horizontal backward force of 80N with his arm during each 1.8 m long. (a) What is his work in each stroke? (b) Calculate the power output of his arms if he does 120 strokes per minute.



(a) Work = Force x distance = 80 x 1.8 = 144 J

(b) Power = J / S = 144 / 60 = 2.4 W

2.4 x 120 = 288 W

3 Temperature Regulation

Body temperature: It is the temperature of various organs of the body of about (37ºC) which is kept fairly constant by a complicated control mechanism.

* The temperature of the skin is influenced by the ambient temperature, it is typically about (4°C) below body temperature.

* The effects of (hypothermia) ***lowering*** *of body temperature* and (hyperthermia) ***rising*** *of body temperature* are summarized in the table below.

Temperature	Condition
Above 43 °C	Death
41 °C	Damage to the central nervous system. Convulsions.
39 °C	Dilation of peripheral blood vessels increases blood flow to the skin and so increases the rate of loss of heat. Reduced blood flow to the brain and possible loss of consciousness.
37 °C	Normal.
35 °C	Shivering. Constriction of peripheral blood vessels reduces blood flow to the skin and so reduces the rate of loss of heat.
32 °C	Shivering ceases. Temperature regulation fails.
30 °C	Loss of consciousness.
Below 28 °C	Death.

1- A body temperature of over 39 ° C is classed as ***hyperthermia*** and less than 35 ° C is classed as ***hypothermia.***

2- An estimate of body temperature can be made simply by placing a mercury – glass ***(clinical thermometer)*** in the mouth and leaving it there for a couple of minutes to come into thermal equilibrium.

The body controls its temperature by maintaining a ***balance between the rate at which it produces heat and the rate at which it loses it.*** The body generates heat by oxidizing food, and it loses heat by conduction, convection, radiation, evaporation, and respiration.

The various heat loss mechanisms depend on:

1- The type of activity being undertaken.

2- The environmental conditions.

3- The extent to which the body is covered by clothing.

Q: How could the body maintain the balance between heat loss and heat production?

The body can do this by various means such as:

1- It may alter the metabolic rate.

2- Blood loses heat as it flows through the capillaries near the surface of the skin. The capillaries widen (vasodilatation) in warm conditions, thereby increasing the rate at which blood flows through them and so increasing the rate of loss of heat

The opposite effect (vasoconstriction) occurs in cold condition

.

3- Muscular activity generates heat. Most of the energy consumed by our muscles produces heat rather than useful work. The body makes use of this when we are cold by causing rapid contractions of the muscles (shivering).

4- The sweat glands become more when we are hot.

There is a limit to what the body can do for itself and we can do many things to keep our body warm such as:

1- By wearing clothing suited.

2- By exercising.

3- By taking hot drinks.

Q: How can clothes give our body warm?

We need to wear clothes that trap air between the different layers of clothing. The volume of the trapped air is too small to allow convection currents to circulate and therefore since air is a poor conductor of heat, the trapped air insulates as from the surrounding.

Q: Are too tight clothes protected from cold?

No: Because in too-tight clothes there is no trapped air and therefore little insulation.

Q: Do too loose clothes keep as warm?

No: Because the volume of air between adjacent layers is large enough for convection currents to circulate.

Q: Do wet clothes make as warm or not?

No: Because when clothes become wet provide very little insulation because the trapped air is replaced by water which is a much better conductor of heat than air.

The first law of thermodynamics

Biological energy is expressed using the energy unit Calorie with a capital C (i.e. kilocalorie),

Calorie: ***the energy needed to increase the temperature of 1 kilogram of water by 1 °C (about 4.18 kJ).***

Energy balance can be measured with the following equation:

Energy intake (food) = Energy expended (heat + work) + Energy stored.

The first law of thermodynamics ***states that energy can be neither created nor destroyed. But energy can be converted from one form of energy to another.*** So when a calorie of food eaten enters a body, ultimately ***100% of that calorie will be converted to heat***, resulting in three particular short-term effects: a portion of that calorie is either ***stored as fat***, or ***transferred to the body's cells as chemical energy***.

Suppose the system changes from an initial state (i) to a

final state (f). During this change energy transfer by heat (Q) to the system occurs, and work (W) is done by the system.

$\triangle E_{int} = \triangle Q - \triangle W$

Q = positive when the energy enters the system.

Q= Negative when the energy leaves the system.

W= Positive when the system does work on the surroundings.

W= Negative when work is done on the system.

1- ***If the system is isolated*** (does not interact with its surroundings).

$Q = W = 0$

$\triangle E_{int} = 0$

2- ***If the value of the work done by the system (w) during some process is zero***

$\triangle E_{int} = Q$

When Q is (+) the energy enters the system leading to an increase the internal energy because of ***increasing the kinetic energy of molecules***.

3- ***If no energy transfer occurs during some process but work is done by the system.***

$\triangle E_{int} = \ -W$

If gas is compressed by a moving position in an insulated cylinder no energy is transferred by heat and the work done by the gas is negative, thus the internal energy is transferred from the moving piston to the gas molecules.