# *Energy expenditure*

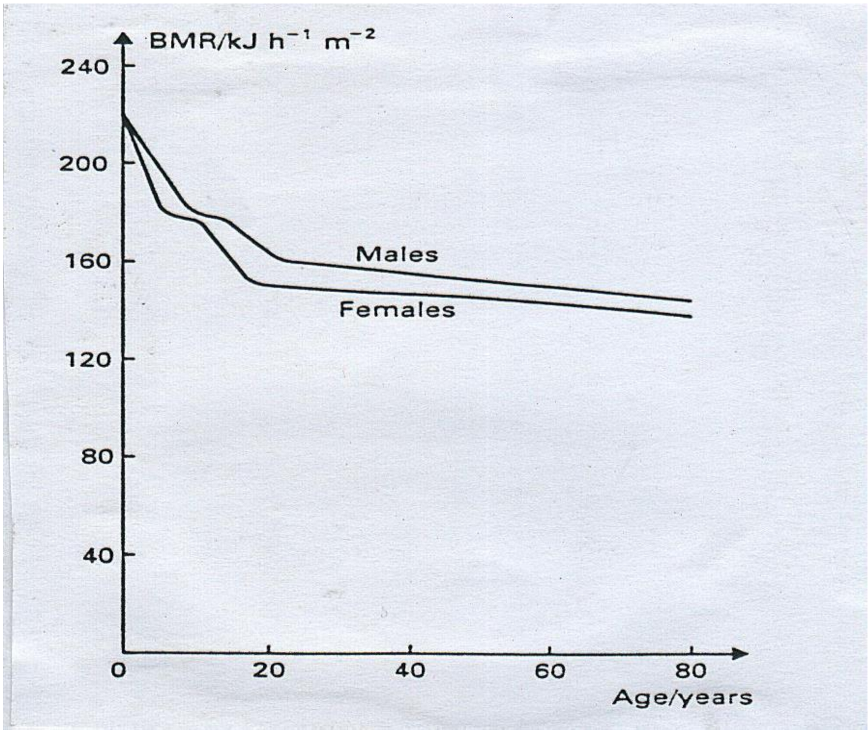
**Lech 2** ***Dr. Jaafar M. Moosa***

## 2.1 *Basal Metabolic Rate*

The body requires a regular intake of energy, from ***carbohydrates, fats*** and ***proteins,*** in order 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 notes 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 found to consuming energy at 82.1 W, and surface area of 1.92 m$^2$. What is his BMR expressed in KJ h$^{-1}$ m$^{-2}$ ?

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

$Power = 82.1 \times 3.6\ KJ\ h^{-1} = 295.56\ KJh^{-1}$

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

## 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 table.

| Activity | 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 ***<u>tissue volume</u>***, whereas the rate at which energy is ***lost*** depends on ***<u>body surface area.</u>***

***The smaller the body, the <u>greater</u> the ratio of surface area to volume S/V. So babies are more at risk of hypothermia than***

***adults.*** The 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* ***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, 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 transfer of energy***. In physics we say that work is done on an object when you transfer energy to that object. If one objects 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= Fxd**).

***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 for doing 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 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 = **mgh**

## *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 fewer than millions of degrees of heat it is called ***fusion*.**

***Electrical Energy***: The generation or use of electric power over a period of time 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 X 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 body loses energy or gains energy by doing work and how?***

**T**he muscle actually uses **chemical energy**. How this works in detail is not physics but a biology question. ***The chemical reaction will create heat and cause your muscle 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.

**I**f 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

**T**his 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 or 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**

= mgh

= 75 x 10 x (50 x 0.2)

= 7500 J

**Power = work done / time taken**

= 7500 / 15 = 500W

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

***Resting energy expenditure (REE)*** = energy burned when you are not physical 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 sum total of all the chemical reaction is the human body.

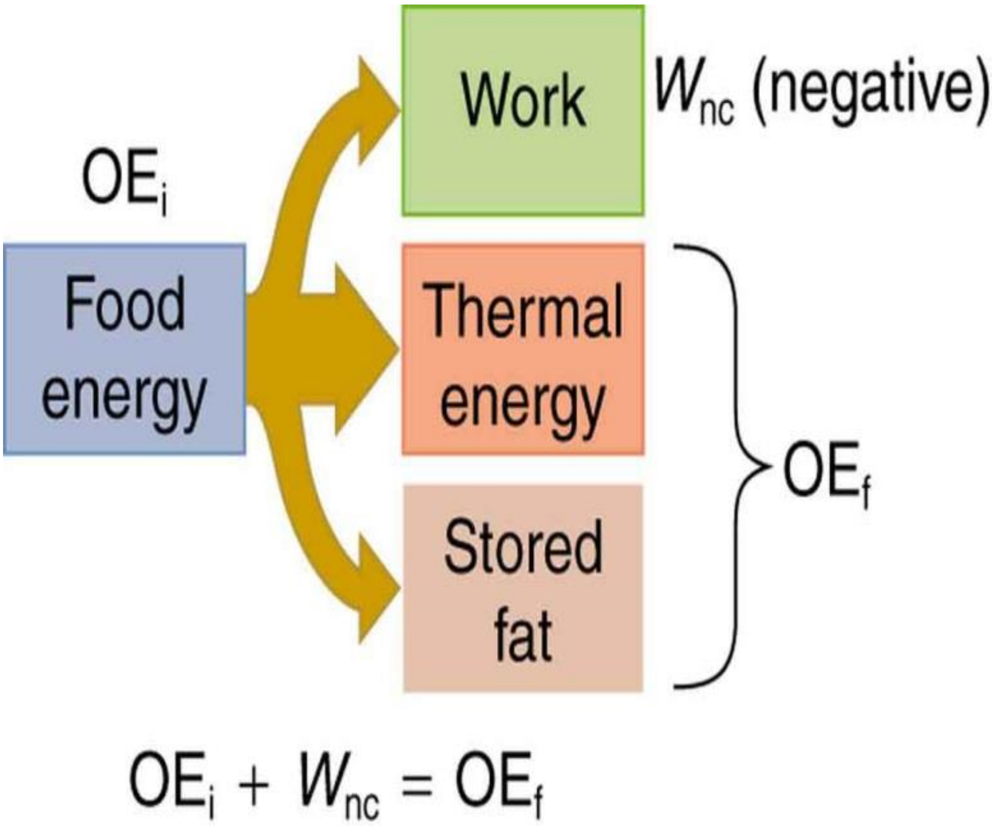
***TDEE = REE + TEF + AEE = 100%***

It is kind of the ***balance*** between ***building things*** up or storing inside body and ***breaking***

***things down*** usually for energy needs.

# *Energy Conversion in Humans*

Our own 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.***



***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 increase 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 basically 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) are used when cycling at a moderate speed. The time required to work off 1000 kJ at this rate is then

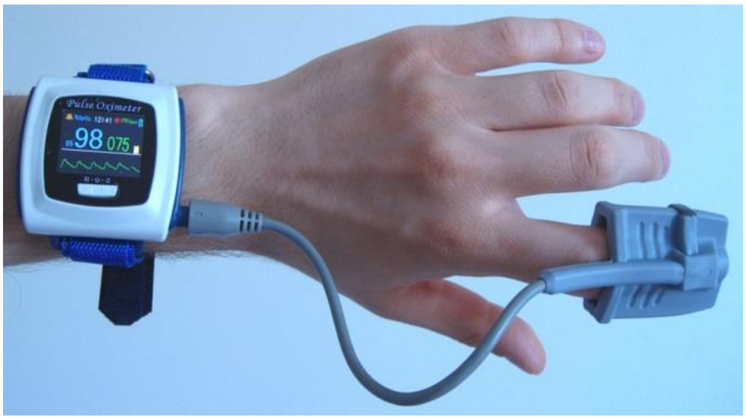
$$\text{Time}=\text{energy}/\ (\text{energy/time})=1000\ \text{kJ}\ /400\ \text{W}=10^{6}\text{x}10^{-2}/4$$

$$2500\ \text{s} = 42\ \text{min.}$$

### 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

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



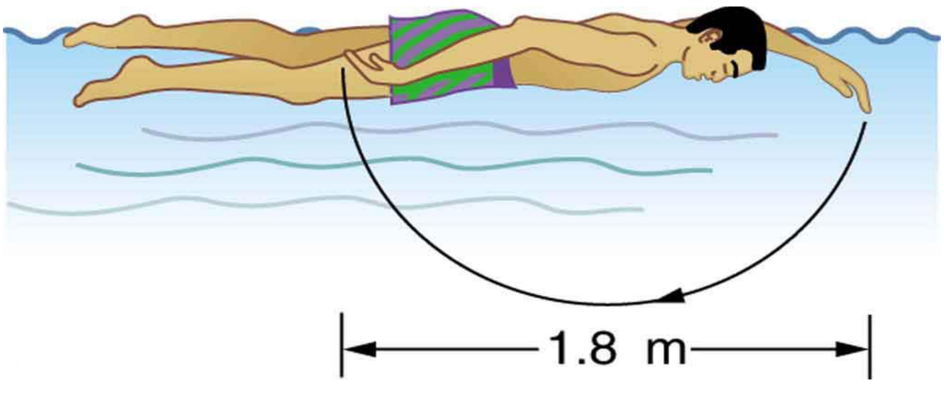
A pulse ***oxymeter*** is an apparatus that ***measures the amount of oxygen in blood. Oxymeters can be used to determine a person’s metabolic rate***, which is the rate at which food energy is converted to another form. Such measurements can indicate the level of athletic conditioning as well as certain 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, in fact, is an involuntary response to low body temperature that pits muscles against one another to produce thermal energy in the body (and do no work). ***The kidneys and liver consume a surprising amount of energy, but the biggest surprise of all it 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 in 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 basically one of oxidizing food.

**EX: 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

## 2.3 Temperature Regulation

**Body temperature:** It is a temperature of various organs of the body of about (37$^{o}$C) which keep at a fairly constant by a complicated control mechanism.

* The temperature of the skin is influenced by the ambient temperature, it is typically about (4$^{o}$C) below body temperature.

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

| Temperature | Condition |
|---|---|
| Above 43 $^{o}$C | Death |
| 41 $^{o}$C | Damage to central nervous system. Convulsions. |
| 39 $^{o}$C | Dilation of peripheral blood vessels increases blood flow to skin and so increases rate of loos of heat.<br>Reduced blood flow to brain and possible loss of consciousness. |
| 37 $^{o}$C | Normal. |
| 35 $^{o}$C | Shivering. Constriction of peripheral blood vessels reduces blood flow to skin and so reduces rate of loss of heat. |
| 32 $^{o}$C | Shivering ceases. Temperature regulation fails. |
| 30 $^{o}$C | Loss of consciousness. |
| Below 28 $^{o}$C | Death. |

1- A body temperature of over 39 $^{o}$ C is classed as ***hyperthermia*** and less than 35 $^{o}$ C is classed as ***hypothermia.***

2- An estimate of body temperature can be made simply by placing a mercurying – 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 maintains 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 condition , 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 thinks to keep our body warm such as:***

**1-** By wearing clothing suited.

**2-** By exercising.

**3-** By taking hot drinks.

***Q: How could 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: Is too tight clothes protect as from cold?***

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

***Q: Is too loose clothes keep as warm?***

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

***Q: Does a wet clothes give 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.

### *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***, ***transferred to the body's cells as chemical energy***.

Suppose the system undergoes a change 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 surrounding.

W= Negative when work done on the system.

***1- If the system is isolated*** (dose not interact with its surrounding).

$Q = W = 0$

$\triangle E_{int} = 0$

**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 lead to 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.

# Types of Forces

Dr.Jaafar M.Moosa

## 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 |

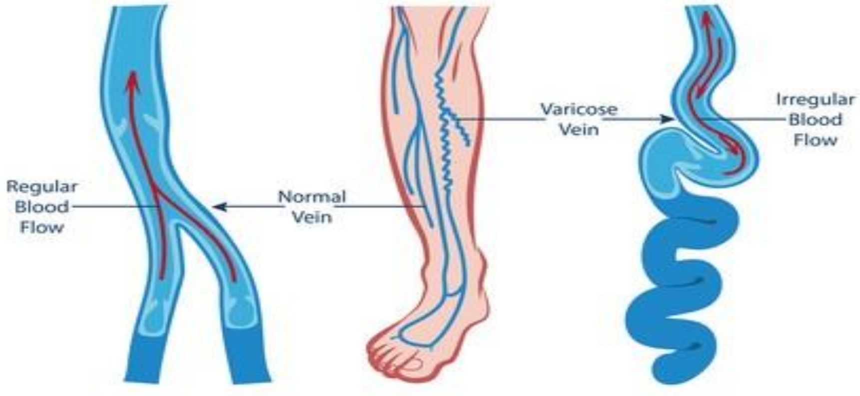
## FORCES IN THE BODY

### A: Gravitational force

**$F = mg$.**

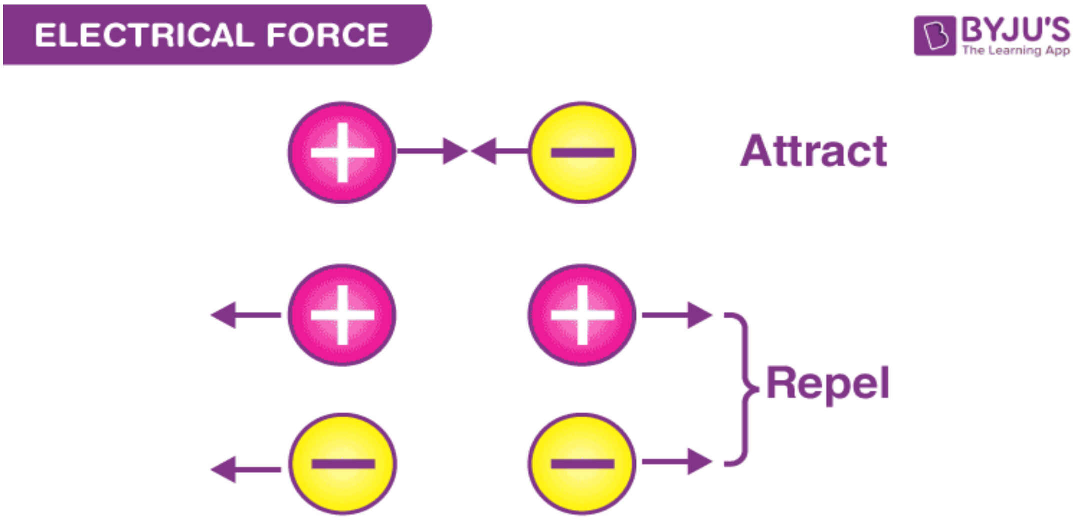
**Where F is the attraction force, m is the mass (Kg,g), g is acceleration due to gravity ($cm/sec^2$) or ($m/sec^2$)**

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 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.

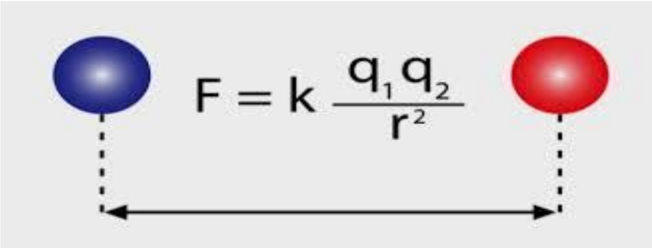


### What Is Coulomb’s Law?

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?

Electric force formula can be obtained from Coulomb’s law as follows:



Where,

- 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 basically electrical machines. This forces produced by the muscles are caused by electrical charges attracting or repelling other electrical charges. Control of the muscles is primary electrical .Each of the billions of living cells in the body has in electrical potential difference across the cell membrane because of the differences in charge between the inside and outside of the cell. This amount 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:

Nuclear force keep the positive charges "proton" together inside the nucleus .we have two types of nuclear forces:

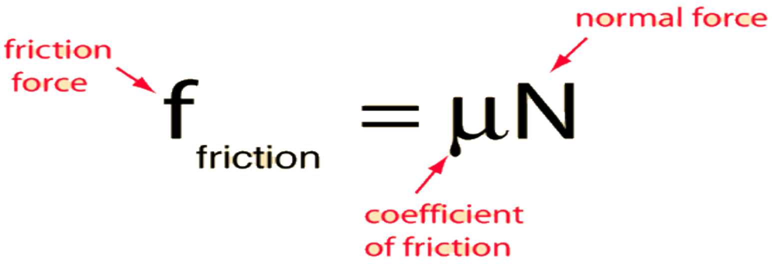
**1- *Strong nuclear force***: it is very larger than the other type. it is act as "glue" to hold the nucleus against the repulsive forces that produce by the protons on each other

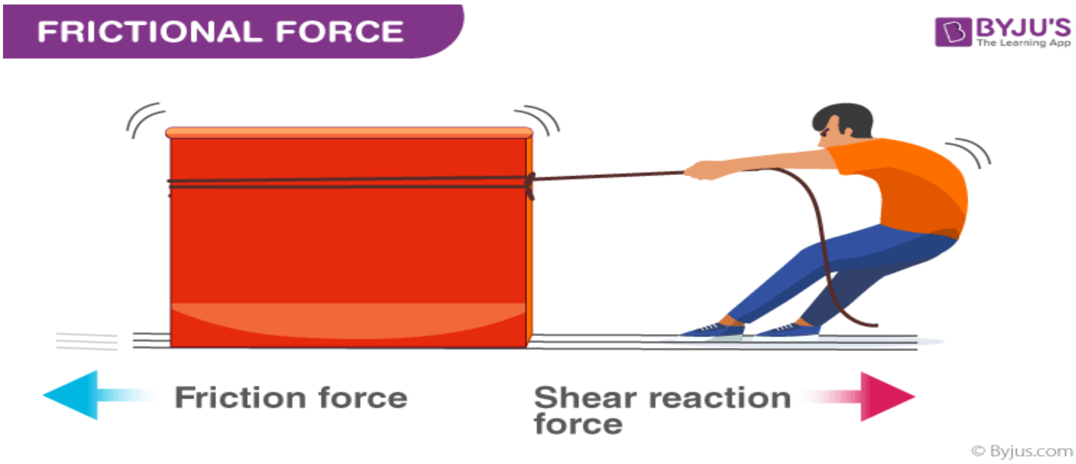
**2-*Weaker nuclear force***: it is involved with electron decay from the nucleus. It may be related to the electrical force.

## Forces on the body

### A- Frictional Forces

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





A few factors affecting the frictional force:

- These forces are mainly affected by the surface texture and 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 becomes 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 are termed as 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 is 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 are 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 $\mu$ is the coefficient of friction between the two surfaces.

**$N = mg$. Where m is the mass, g=9, 8 $m/s^2$**

$F_f = \mu N$

$F_f = \mu mg$

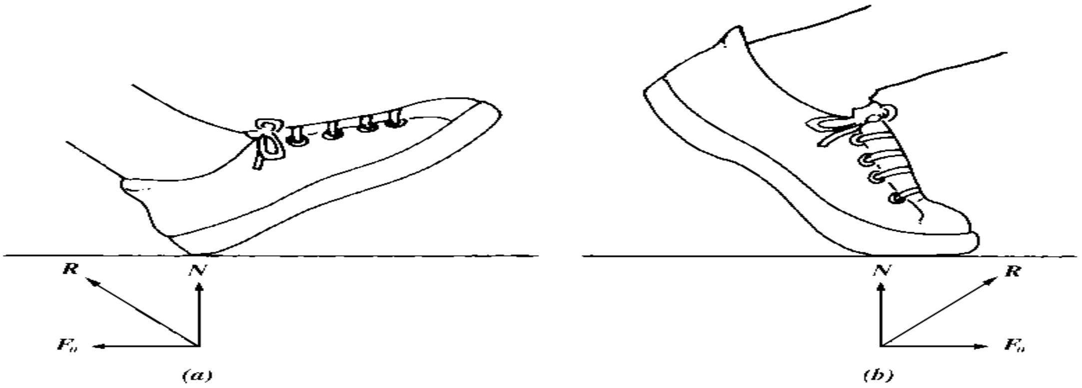
$F_f = 0.05 \times 300\ kg \times 9.8\ m/s^2$

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

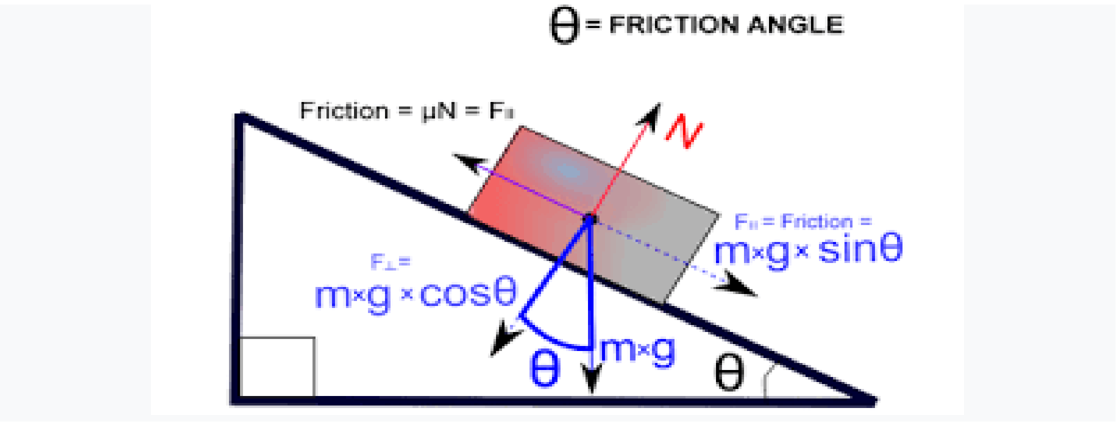
The force of friction acting in the opposite direction as the block of ice is pulled across the lake is 147 N.

**S**ome 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 in order 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.***



**$N = mg \cos \theta$**

When $\mu_s$ (coefficient of static friction) = 0.6
$\mu_k$(coefficient of Kinetic friction) = 0.3
If $\theta = 30^{o}$
$F = N\mu$

**If the body does not move then**

$F = N\ \mu_s = mg \cos 30^{o}\ \mu_s$
Fnet = FAid - Fopposing
$Fnet = mg \sin \theta - mg \cos \theta\ \mu_s$
If $mg \cos \theta\ \mu s > mg \sin \theta$
بالقسمه على mg
$\mu_s > \sin \theta / \cos \theta > \tan \theta$
$0.6 > 0.57$ NO **move static case**

**If there is little push to the body then**

$Fnet = mg \sin \theta - mg \cos 30^{o}\ \mu k$
If $mg \cos 30^{o}\ \mu k < mg \sin 30^{o}$
$\mu k < \sin \theta / \cos \theta < \tan \theta$
$0.3 < 0.57$ **friction force less than Pushing force**

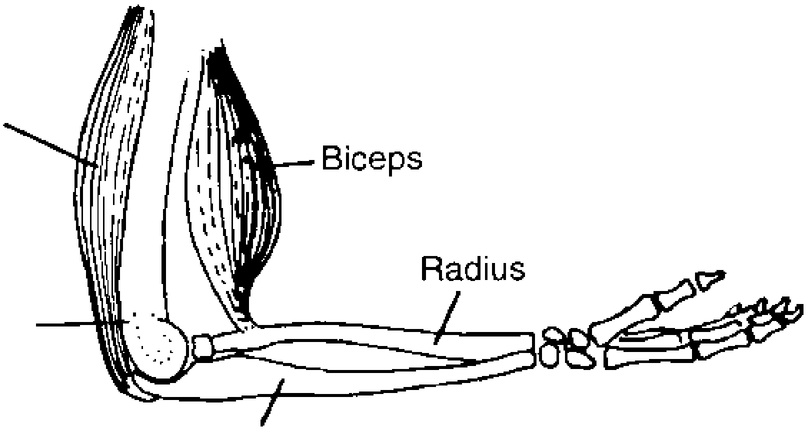
لحساب التعجيل للجسم المتحرك
$a = F_{net} / m$
$= mg \sin 30^{o} - mg \cos 30^{o}\ \mu k / m$
بلقسمه على m
$= g (\sin 30^{o} - \cos 30^{o})\ \mu k$
$= g (\sin 30^{o} - \cos 30^{o})\ 0.3$

## 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 also zero

## 4- Forces, Muscles, and joints

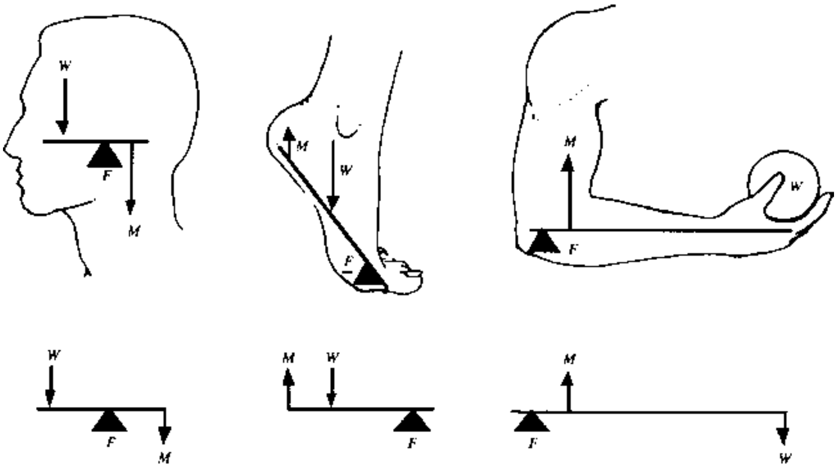
**Skeletal muscles** have small fibers with alternating dark and light bands, called *striations*—hence the name *striated muscle*. The fibers are smaller in diameter than a human hair and can be several centimeters long. The other muscle form, which does not exhibit striations, is called ***smooth muscle.***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



### 4.1-Muscle Forces Involving Levers

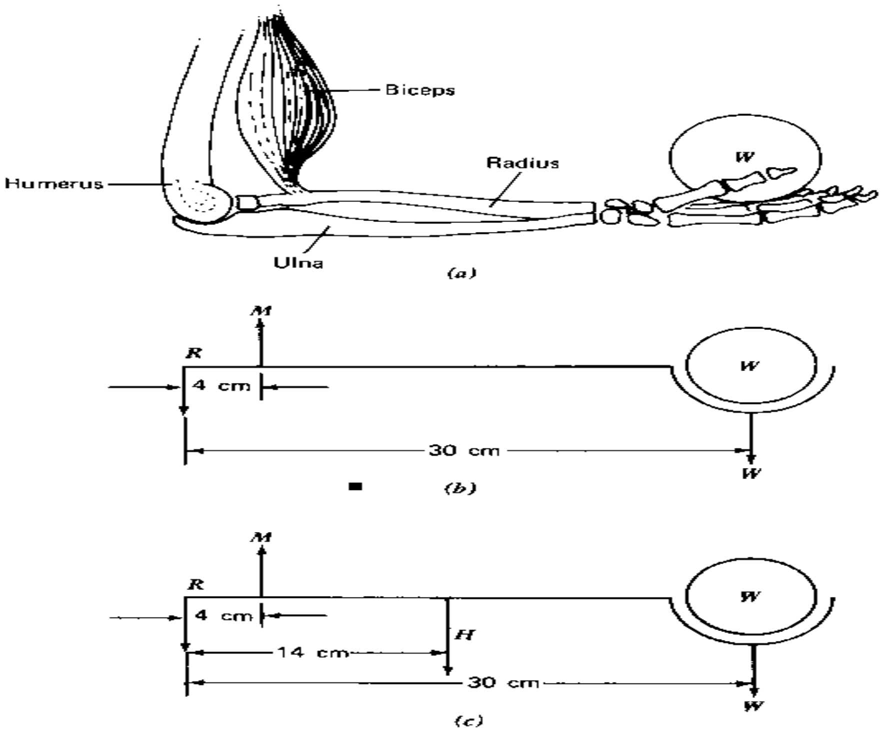
For the body to be at rest and in equilibrium (static), the sum of the forces acting on it in any direction and the sum of the torques about any axis must both equal **zero.**

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 x 4 = H x 15 + W x 30 = 20 x 15 + 10 x 30 = 280 + 300 = 580 N

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

Resolving vertically gives

R + 20 + 10 = 145 →R = 114N *Reaction due to upper arm*

***Notes***

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

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

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 joint in body are ***third – class levers***. Since all third – class levers have a mechanical advantage which is less than one, it follows that

***most of 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 body acts downward, and 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 direction**.

## C: DYNAMICS FORCE

Forces on the body where acceleration, the Newton's second low, force equals mass times acceleration.

$F = ma$

The force equals the change of momentum Δ (mv) over a short internal 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 in a distance of( 2.5 cm )in a about( 0.05sec) .what is the force developed on impact ?

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

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

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

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

**Accelerations can produce a number of 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 become large 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 blackout.

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

# 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 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 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 boiling point of water:
Celsius, 100 degrees Fahrenheit, 180 degrees
Normal body temperature is about $37^oC$, 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 unique temperature equals to -$273^o$ C; it is called absolute zero. Theoretically, the ultimate in cold is "absolute zero" that is experimentally unattainable.

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

*Freezing point of water : 273 K*
*Boiling point of water: 373 K*

**Converting Temperatures**

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

## Exercise

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

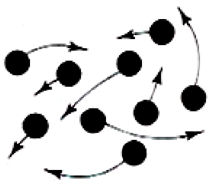
## Thermal expansion

Most materials

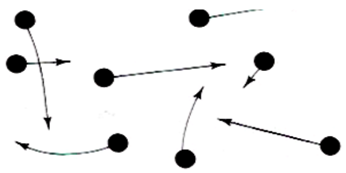
•expand when temperature is increased

•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

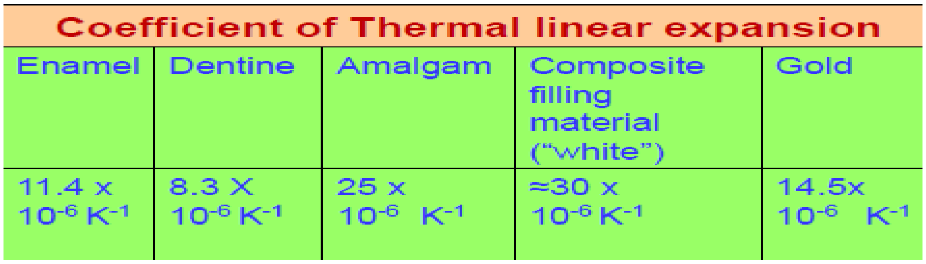
Important, for example, for metals in buildings, bridges and dental filling materials etc., Bar of initial length changes by an amount ΔL when its temperature changes by a mount ΔT.
Coefficient of linear expansion for the material is defined as:
**α** is fractional change in length over fractional change in temperature

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

$\Delta L$ = change in length
$L$ = original length
$\Delta T$ = change in temperature
$\alpha$ = coefficient of linear expansion
units ($°C^{-1}$ or $K^{-1}$)
α depends on the type of material.

In restorations, decayed dentine removed and replaced by filling. 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. Large mismatch in expansion coefficients causes fluids leakage between filling and surrounding tooth.

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

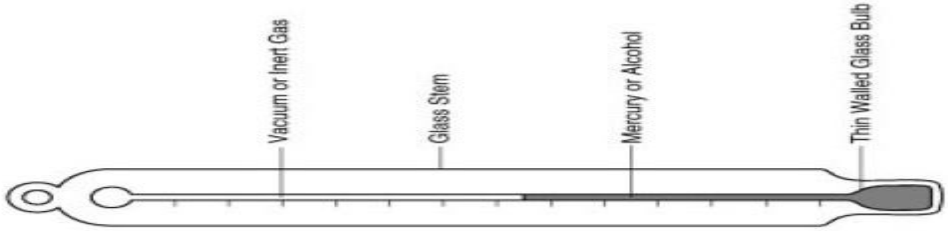


| Coefficient of Thermal linear expansion | | | | |
|---|---|---|---|---|
| Enamel | Dentine | Amalgam | Composite filling material ("white") | Gold |
| 11.4 x $10^{-6}$ $K^{-1}$ | 8.3 X $10^{-6}$ $K^{-1}$ | 25 x $10^{-6}$ $K^{-1}$ | ≈30 x $10^{-6}$ $K^{-1}$ | 14.5x $10^{-6}$ $K^{-1}$ |

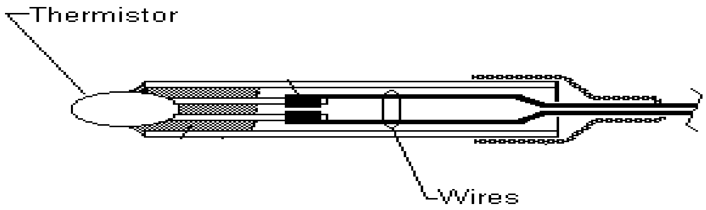
Area and volume thermal expansion
Similarly:
$\Delta A = A (2\alpha) \Delta T$
the coefficient of area expansion equals to $2\alpha$
$\Delta V = V (3\alpha) \Delta T$
the coefficient of volume expansion equals to $3\alpha$

## 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 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$^{o}$ C.



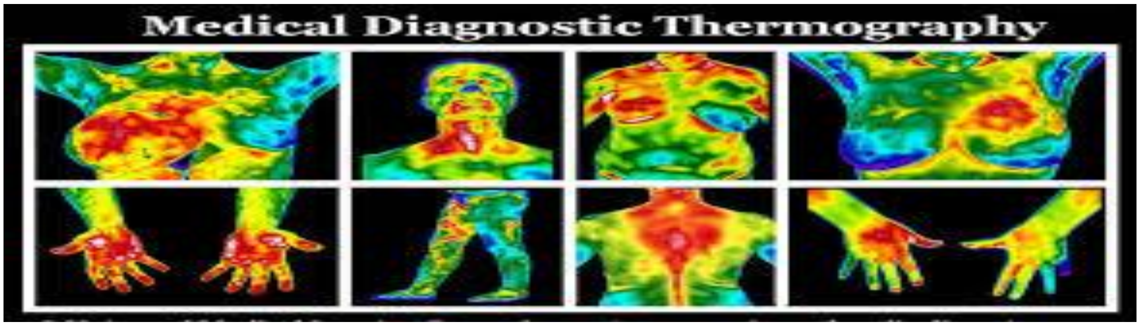
**Thermocouple:** A thermocouple consists of two junctions of two different metals. If the two junctions are at different temperatures, a voltage is produced that depends on the temperature difference. Usually one of the junctions is kept at a reference temperature. It can be used to measure temperatures from -190 to 300$^o$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 thermosgram 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 x $l0^{-12}$ $W/cm^2K^4$. 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)?

$$W = \sigma T^4 = (5.7 \text{ x } l0^{-12})(306)^4 \approx 0.05 \text{ W/cm}^2$$

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

$$W = (0.05)(1.75 \text{ x } 10^4 \text{ cm}^2) = 875 \text{ W}$$

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 applied to the skin to heat the body by conduction, it leads to local surface heating. This method is used to treating arthritis, neuritis and back pain.

### 2- Radiant methods (diathermy):

Diathermy is the use of high frequency electric current to produce heat. 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.

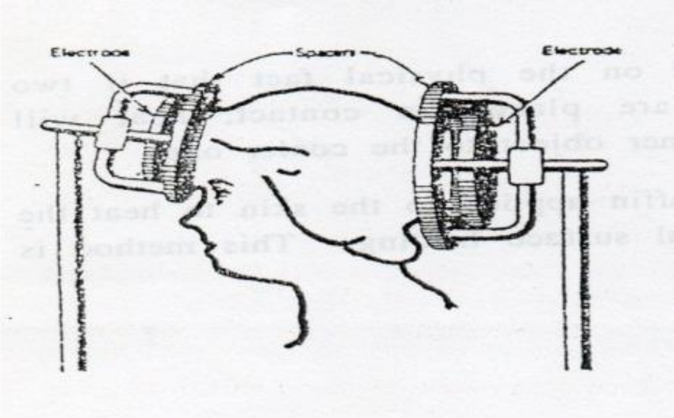
#### B. Shortwave diathermy:

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:

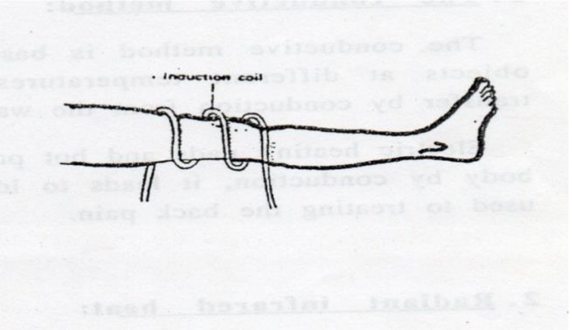
1. **By using capacitor plates:**

The part of the body to be treated is placed between two metal plates. Like electrodes which energized by the 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 produce resistive heating.



2. **Magnetic induction method:**

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. Microwave diathermy:

Microwave diathermy uses electromagnetic waves in 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 at 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 the 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 produce 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° C) and liquid helium (-269° C) are used.

How are cryogenic methods used in medicine? Low temperatures have been used for 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 a number of 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.

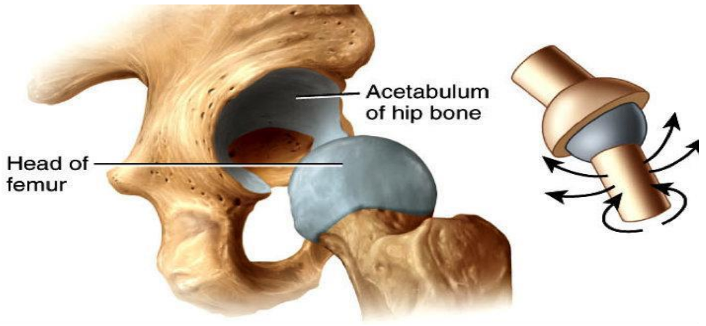
*Jaafar M. Moosa*

*Dental college*

# THE HUMAN SKELETAL SYSTEM

## *Bones and Joints:*

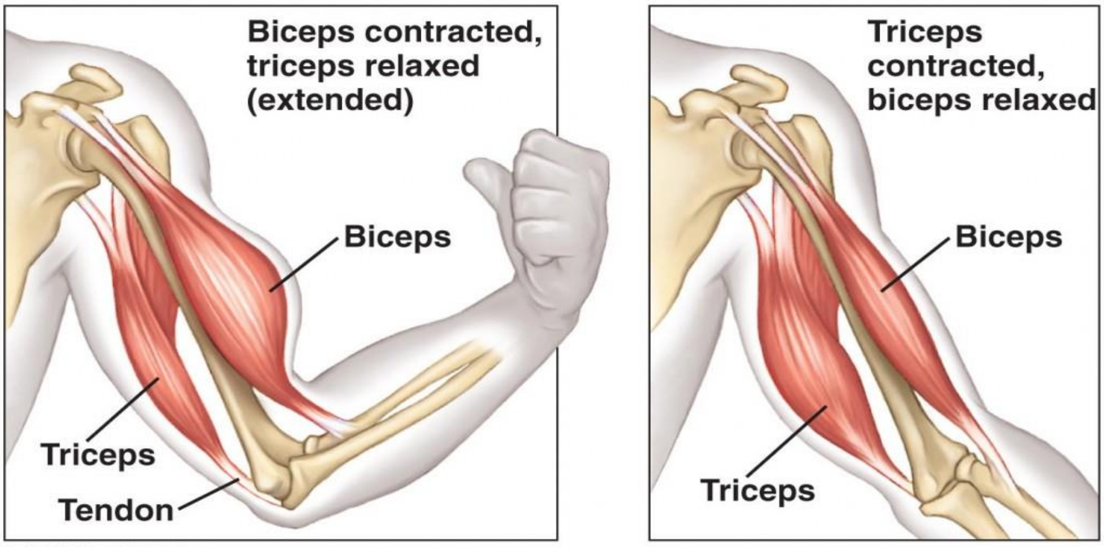
The human skeleton consists of about ***206 bones***. Junctions between neighboring bones are called ***Joints***. Although some joints like those in the skull allow little or no movement, the majority enable for bones to move freely. These are known as ***Synovial joints,*** and different types allow 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 joint.



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***-*a 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 contract (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***.



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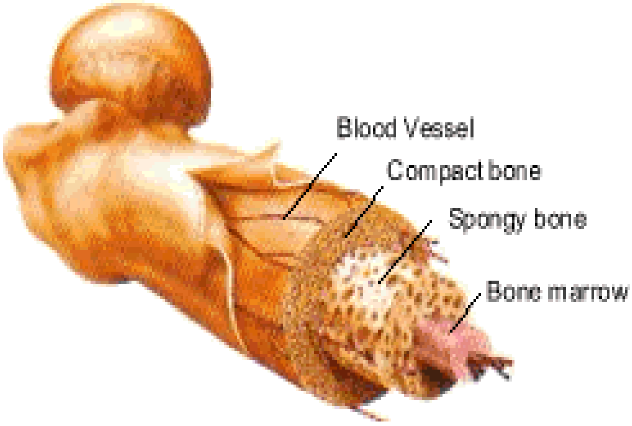
## *Q/What is bone made of?*

- 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**. <u>Bone marrow</u> ***is sort of like a thick jelly, and its job is to make blood cells.***

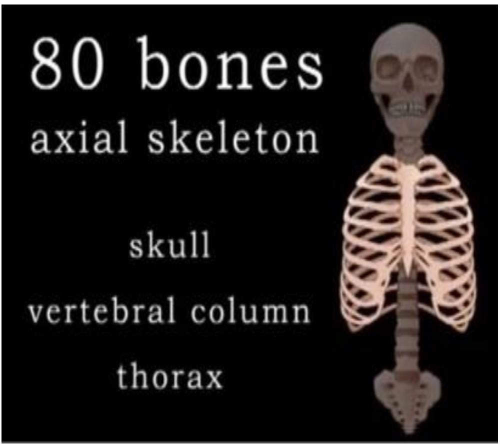
There are two kinds of bones ***Compact bone & cancellous (sponge) bone***



***What is the advantage of 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.



The all bones could be divided into two parts ***axial & appendicular Skelton***

***Bone remolding***: A continues process of destroying old bone and building new one. There are two types of cell 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 has about (1000g of Ca). Each day the osteoclast destroying bones containing 0.5 g of Ca, while 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 spine and hip***. Osteoporosis usually has ***no symptoms*** until a fracture occur. ***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.

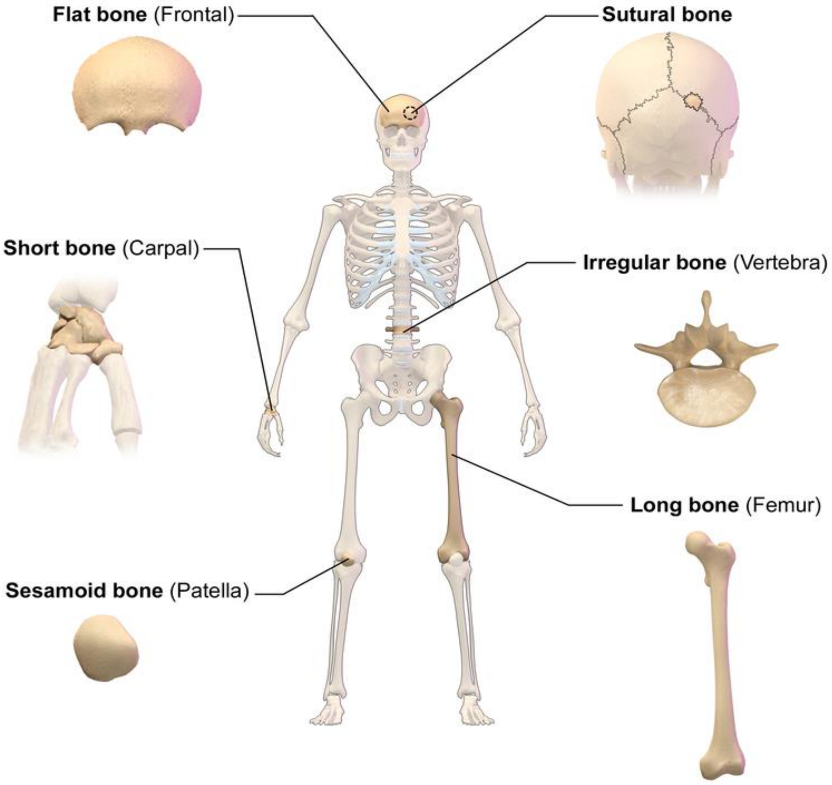
***Osteoporosis treatment*** includes advice to**1-** ***stop smoking***, **2-** ***decrease alcohol consumption***, **3-** ***exercise regularly***, **4-** and ***have a healthy diet***. **5-** ***Calcium supplements may also be advised, as May Vitamin D.***

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***, ***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 bones.
- ***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 bones. 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*** while 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***.

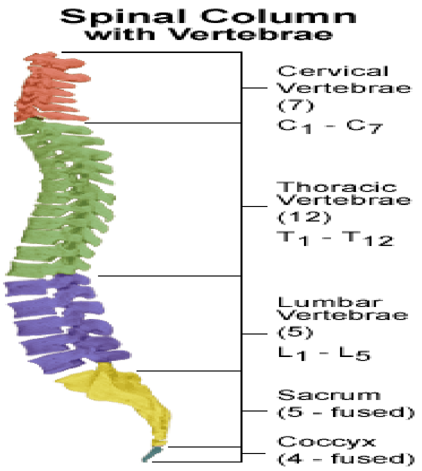
## *Protection*

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.

## ***Vertebral column (Spine)***

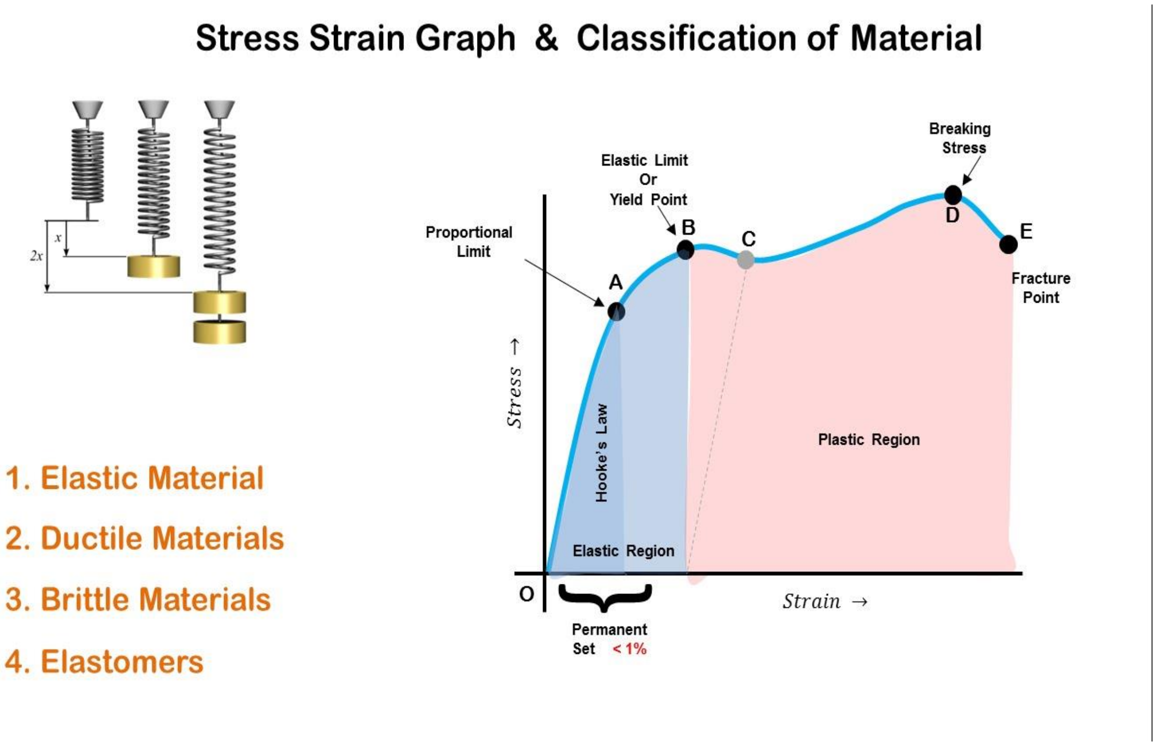


The spine consists of ***(33 vertebrae)*** and provides the main support for the body. Nine of the vertebrae at the base of the spin are fused, five to form the sacrum and four to form the coccyx. The top 24 are covered with ***cartilage*** and are separated from each other by tough fibrous known as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

***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. It is because, when a ductile material like mild steel is subjected to 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

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

Hook's law of proportionality from 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. Material will return back to its original position, if it is unloaded before the crossing of point **B**. This is so, because 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

**Ultimate stress point** is ***the maximum strength that 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 have very minute or zero strength to face further stress.

## **5-** BREAKING STRESS (POINT OF RUPTURE)

**Breaking point** or breaking stress ***is point where strength of material breaks.*** The stress associates with this point 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 a 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 (***$\Delta l$***) 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.

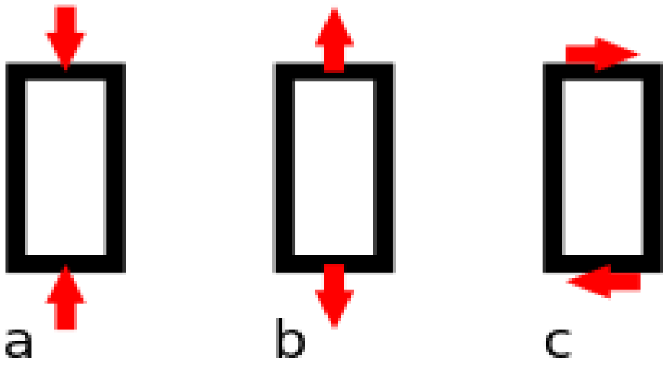
$$Y = \frac{Stress}{Strain} = \frac{F*l}{A*\Delta l} \quad \text{Pa}$$

**6-** Strength of material = ***its ability of 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,*** 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,*** 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*** , example tress caused by 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***.

# Interactions of X-rays with matter and Image Quality

Dr. Amal Yousif Al-Yasiri

College of Dentistry- University of Baghdad

## Introduction

Ionizing radiation includes

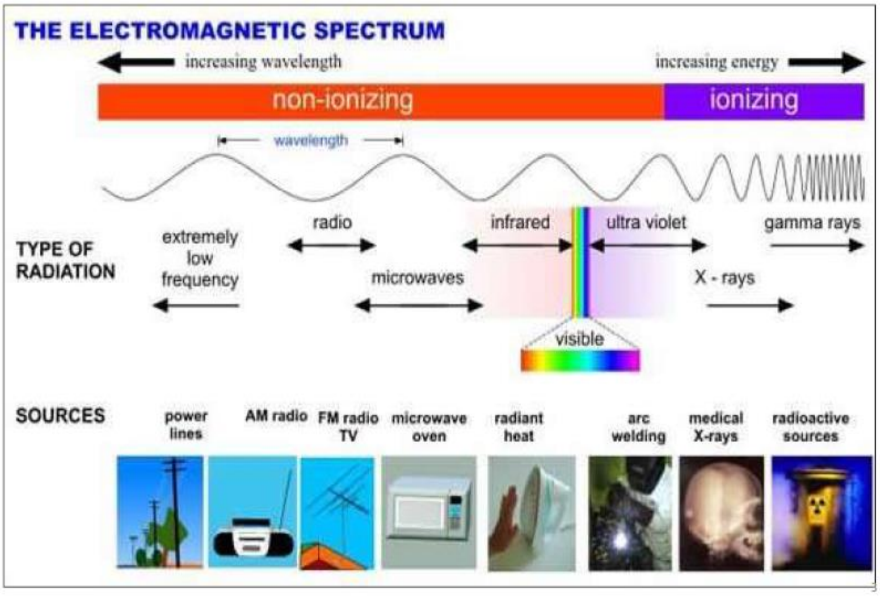
1. Charged particles (such as alpha and beta particles, and electrons)
2. Uncharged particles include :-

A. Electromagnetic radiation or photons (such as X-rays and Gamma-rays)

B. Neutrons

Note: Lower frequencies of electromagnetic radiation, consisting of ultraviolet (UV), Visible light, infrared (IR), microwave (MW), Radio Frequency (RF) are types of non-ionizing radiation because of their low energy which is not enough to produce an ion pair.

- Ultraviolet (UV) radiation is a form of non-ionizing radiation that is emitted by the sun and artificial sources, such as tanning beds. While it has some benefits for people, including the creation of Vitamin D, it also can cause health risks.



In this lecture, we will be talking only about the interaction of an ionizing electromagnetic radiation with matter, specifically about the interaction of X-Rays with the matter

Note: Gamma rays interact with the matter by the same way that X-rays interact with matter. In this lecture, we just focused on X-rays to complete our previous lecture about the production of X-rays

## X-Rays Interactions

When X-ray photon enters a layer of matter such as human body, it is possible that it will penetrate through without any interaction, or it may interact and transfer energy to the matter in one or two of the interactions. There are four major types of interactions of x-ray photons with matter, the first three of which play a role in diagnostic radiology

1- **Rayleigh (Coherent) scattering**

2- **Photoelectric effect**

3- **Compton effect**

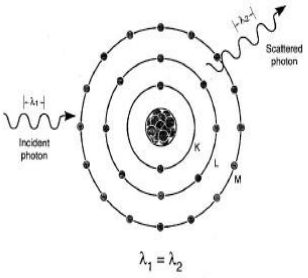
4- **Pair production (Annihilation radiation)**

## X-Rays Interactions

### 1- Rayleigh (Coherent) Scattering

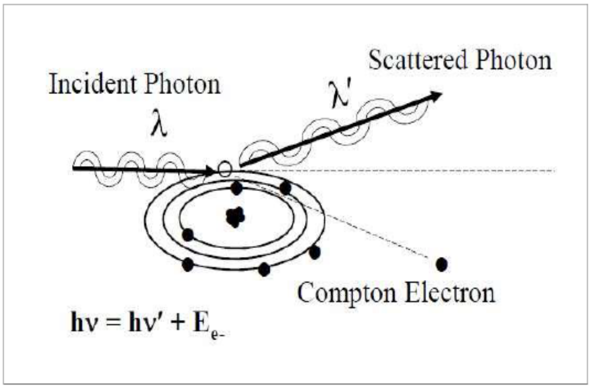
### (elastic scattering )

- During the Rayleigh scattering event, the electric field of the incident photon's electromagnetic wave expends energy, causing all of the electrons in the scattering atom to oscillate in at the same frequency.
- The x-ray photon is scattered through small angle without change of x-ray energy or loss of energy to the medium. (i.e. the scattered photon has the same energy as the incident photon):
- This interaction occurs mainly with very low energy x-rays, (15 to 30 keY).
- In this interaction, electrons are not ejected, and thus ionization does not occur.



# X-Rays Interactions

**2- Compton Scattering (inelastic scattering)**



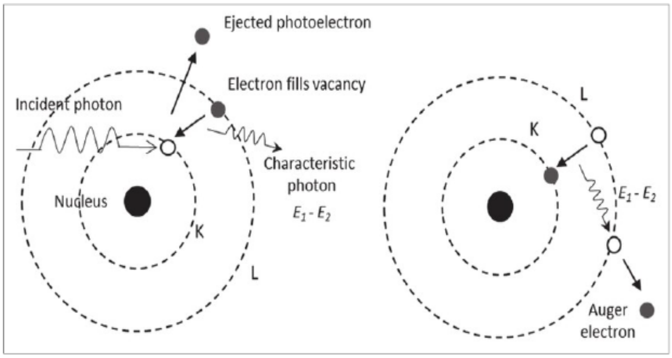
# X-Rays Interactions

**2- Compton Scattering (inelastic scattering)**

- Compton scattering is the predominant interaction of x-ray with soft tissue in the energy range approximately from **30 KeV to 24 MeV.**
- This interaction is most likely to occur between photons and outer ("valence") shell electrons. The electron is ejected from the atom, and the photon is scattered with some reduction in its energy.
- The energy of the incident photon (Eo) is equal to the sum of the energy of the scattered photon (Ese) and the kinetic energy of the ejected electron (Ee-)
- The binding energy of the electron that was ejected is very small and can be ignored.

# X-Rays Interactions

3- **Photoelectric Effect**



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# X-Rays Interactions

3- **Photoelectric Effect**

- In the photoelectric effect, all of the incident photon energy is transferred to an electron which is ejected from the atom.
- After ejection of the electron, the neutral atom becomes a positively charged ion with a vacancy in an inner shell that must be filled with a nearby less tightly bound electron.
- The kinetic energy of the ejected photoelectron (Ee) is equal to the incident photon energy ($E_o$) minus the binding energy of the orbital electron ($E_b$).

$$E_e = E_o - E_b$$

- In order for photoelectric absorption to occur, the incident photon energy must be greater than or equal to the binding energy of the electron that is ejected.

# X-Rays Interactions

3- **Photoelectric Effect**

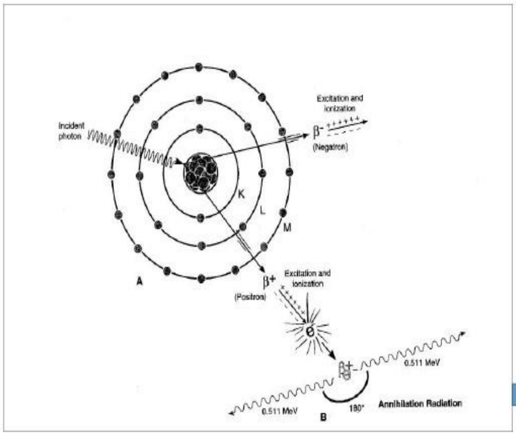
- The probability of photoelectric absorption per unit mass is approximately proportional to **Z*3/E*3**, where Z is the atomic number and E is the energy of the incident photon.
- The photoelectric effect predominates when lower energy photons interact with high Z materials
- The benefit of photoelectric absorption in x-ray transmission imaging is that there are no additional secondary photons to degrade the image.

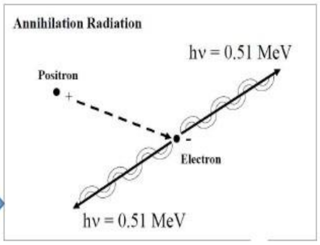
# X-Rays Interactions

4- **Pair production (Annihilation radiation)**

- Pair production **can only occur** when the energies of x-rays exceed 1.02 MeV (i.e. if the energy of the X-ray photon is less than 1.02 MeV, this interaction cannot happen).
- In pair production, an x-ray photon interacts with the electric field of the nucleus of an atom. The photon's energy is completely converted into an electron-positron pair.
- The rest mass energy equivalent of each electron is 0.511 MeV, and this is why the energy threshold for this reaction is 1.02 MeV.
- Photon energy in excess of 1.02 MeV appears as kinetic energy, which may be distributed in any proportion between the electron and the positron.

# X-Rays Interactions





# X-Rays Interactions

4- **Pair production (Annihilation radiation)**

- The electron and positron lose their kinetic energy via excitation and ionization. when the positron comes to rest, it interacts with an electron. Then both particles undergo mutual annihilation, with the appearance of two annihilation photons each with an energy of 0.511 MeV traveling in opposite directions.
- Pair production becomes more likely with **increasing atomic number** and **increasing photon energy**.
- Pair production has NO importance in diagnostic x-ray imaging because of the extremely high energies required for this interaction to occur.

# X-Rays Interactions

Photon interactions probabilities

1-Photoelectric effect

- Directly proportional to Z*3
- Inversely proportional to E*3

2-Compton scattering

- Directly proportional to the electron density
- Independent of Z

3- Pair production

- Directly proportional to Z*2
- Directly proportional to E

# Relative importance of photon interactions

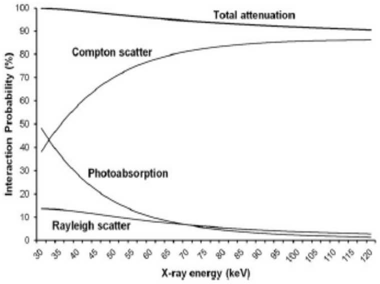
For soft tissues (Z = 7)

- Photoelectric effect is the predominant interaction for beams below about 30 keV.
- Compton is predominant interaction for beams above 30 keV and below 24 MeV
- Pair production becomes the predominant interaction Above 24 MeV

# Interactions of X rays: total attenuation

- Through a combination of these three interactions, an X ray beam is attenuated (i.e. reduces in intensity) when traversing a patient
- In medical radiography, only a small fraction (<10%) of the X rays reaches the detector

Interaction probability for 30-120 keV X rays traversing 14 cm. Only a small fraction of (mainly high-energy) X rays are not attenuated and reach the receptor



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# Image Quality

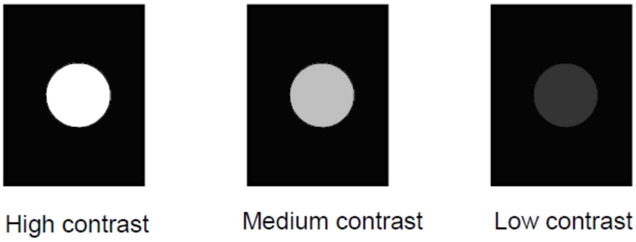
Description of the Medical Image (Basic concepts)

1- Contrast
2- Noise
3- Spatial resolution

## Basic Concepts

- **Contrast**

*the difference in brightness or darkness in the image between an area of interest and its surrounding background*



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## Noise

All imaging systems have noise ( it degrades the image quality)

1- Quantum Noise: Quantum noise is the main and the most significant source of noise in radiography. It is a random process due to fluctuations in the number of photons reaching the detector from point to point.

2- Electronic Noise: Electronic noise can be caused by vibrations of any hardware components, especially power fluctuations.

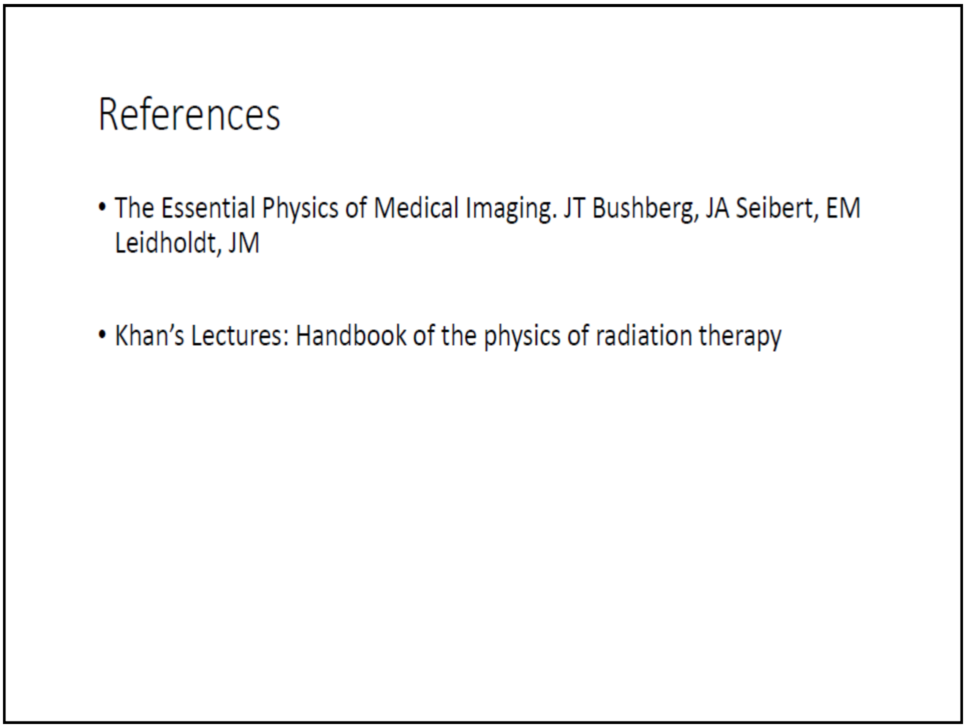
3- Other random influences:

# Spatial resolution

- Spatial resolution in radiology refers to the ability of an imaging system to differentiate between two nearby objects. i.e. Spatial resolution describes the ability to observe two objects as they become smaller and closer together
- High spatial resolution improves the visibility of small details

# Contrast media in radiography

- Contrast media are a group of medical drugs used to improve the visibility of internal organs and structures in X-ray based imaging techniques such as radiography and computed tomography (CT).
- Iodine and barium are the most common types of contrast agents

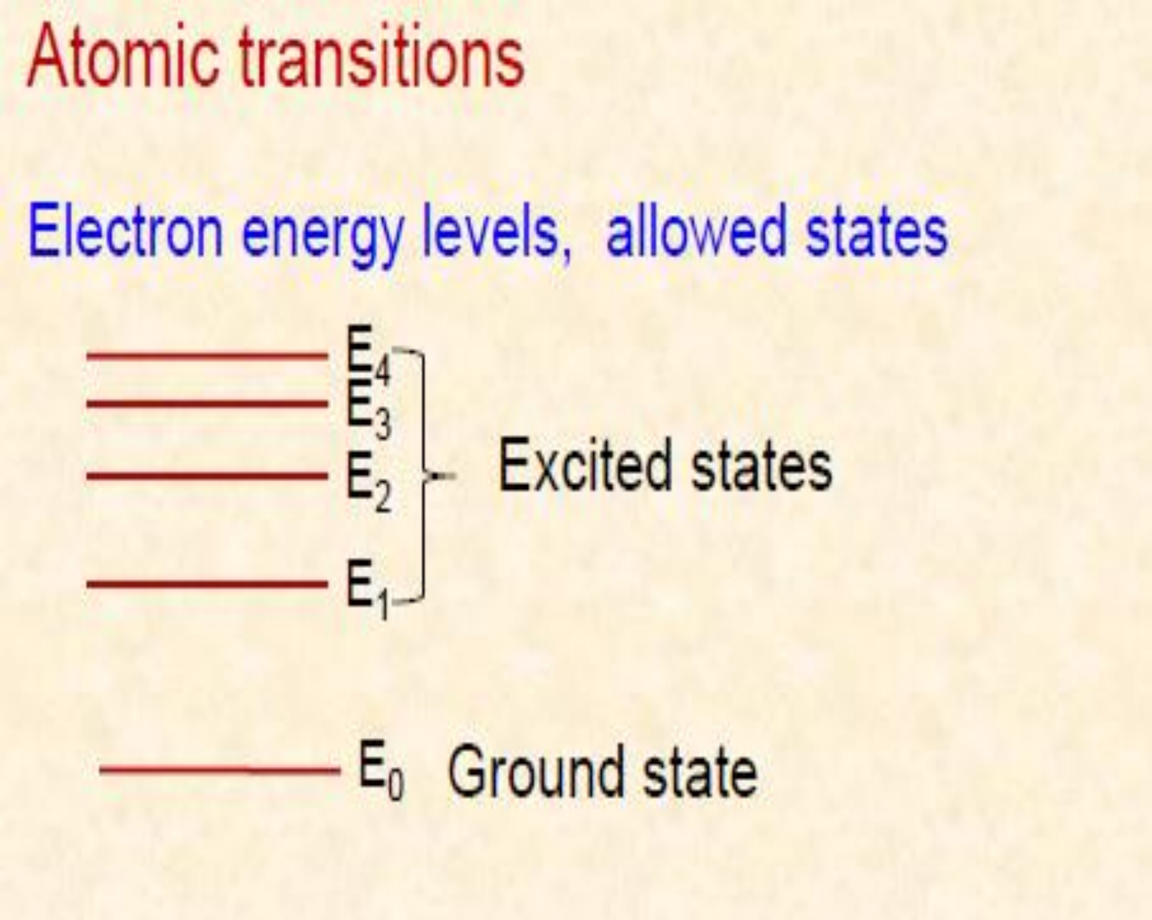


## References

- The Essential Physics of Medical Imaging. JT Bushberg, JA Seibert, EM Leidholdt, JM

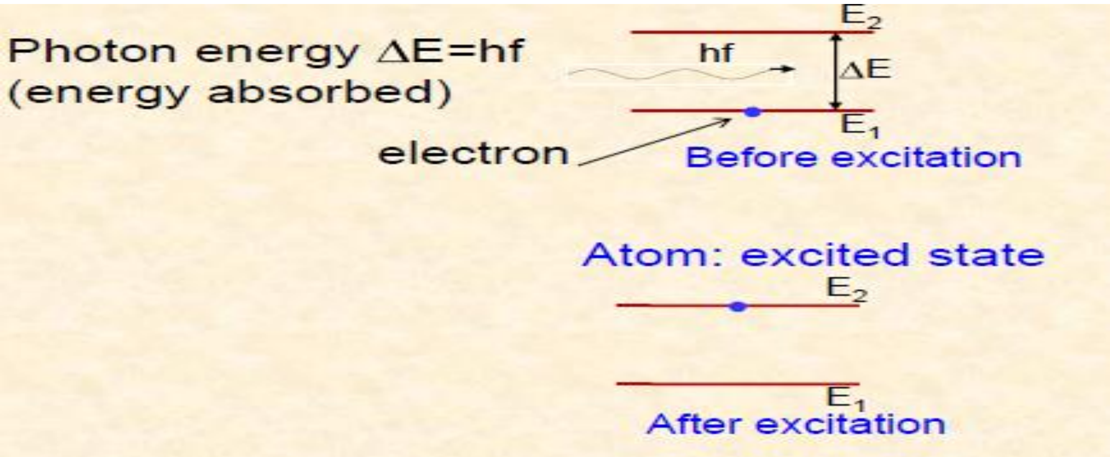
- Khan's Lectures: Handbook of the physics of radiation therapy

# Principles of Laser



Atomic transitions

Electron energy levels, allowed states

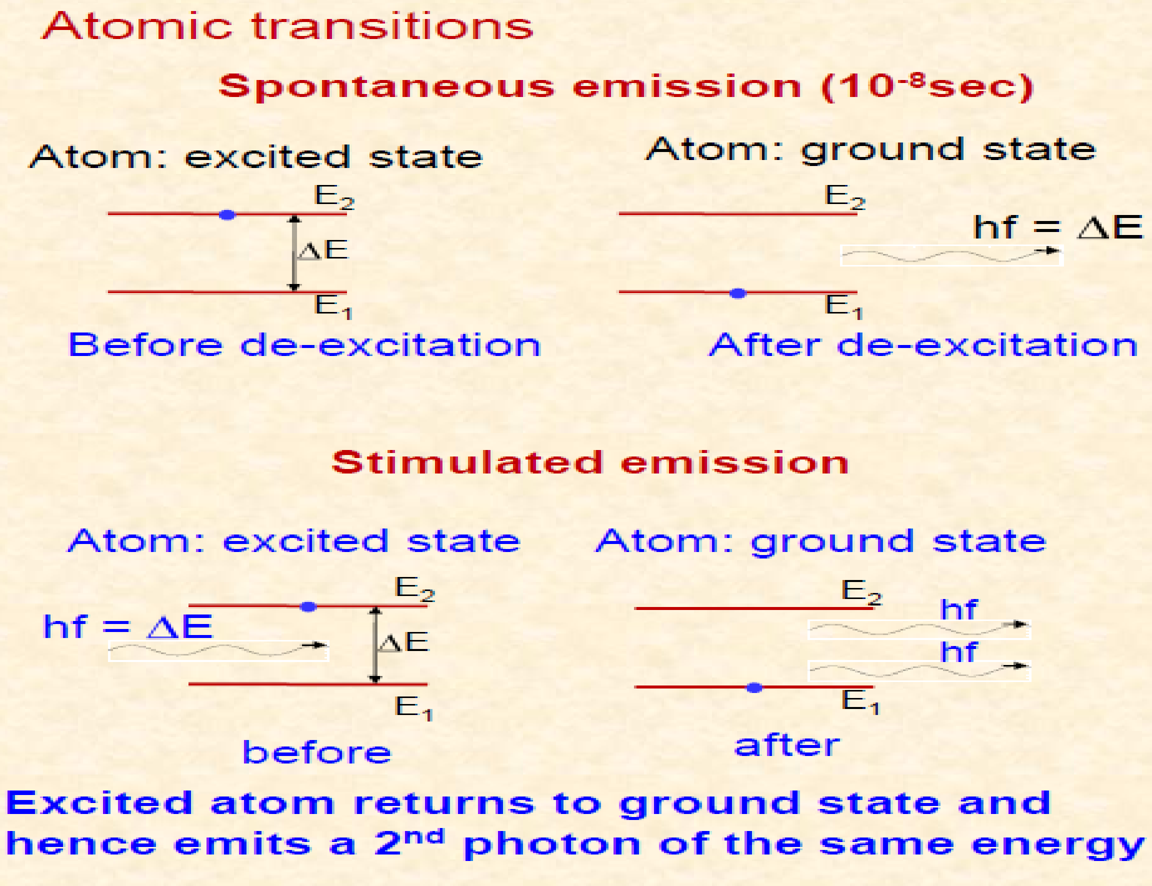


Photon energy $\Delta E=hf$
(energy absorbed)

# Population inversion

**Ordinarily more atoms in the ground state than excited state**

**Population inversion happens if there are more atoms in the excited state than the ground state**



Atomic transitions

Spontaneous emission ($10^{-8}$sec)

Atom: excited state

Atom: ground state

Before de-excitation

After de-excitation

Stimulated emission

Atom: excited state

Atom: ground state

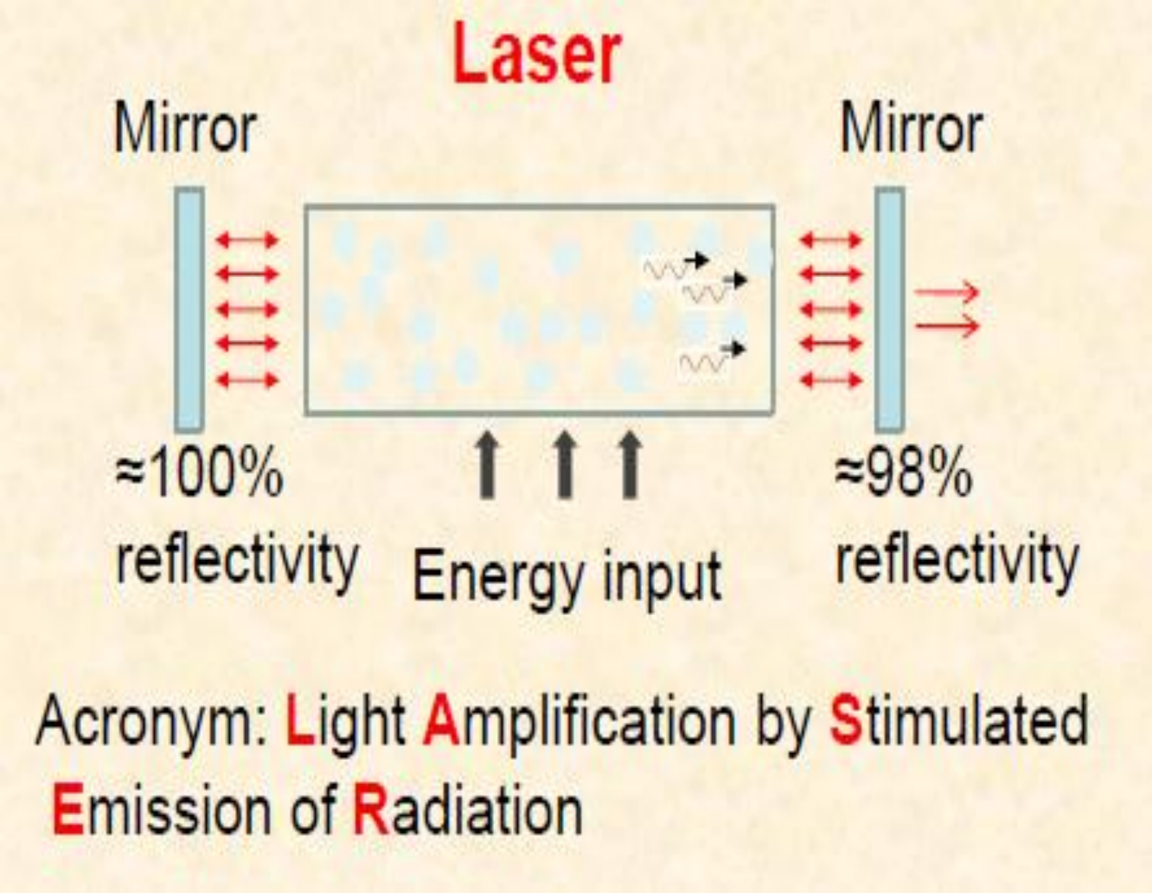
before

after

Excited atom returns to ground state and hence emits a 2nd photon of the same energy

**Both photons are in phase and have the same energy (color) (wavelength)**

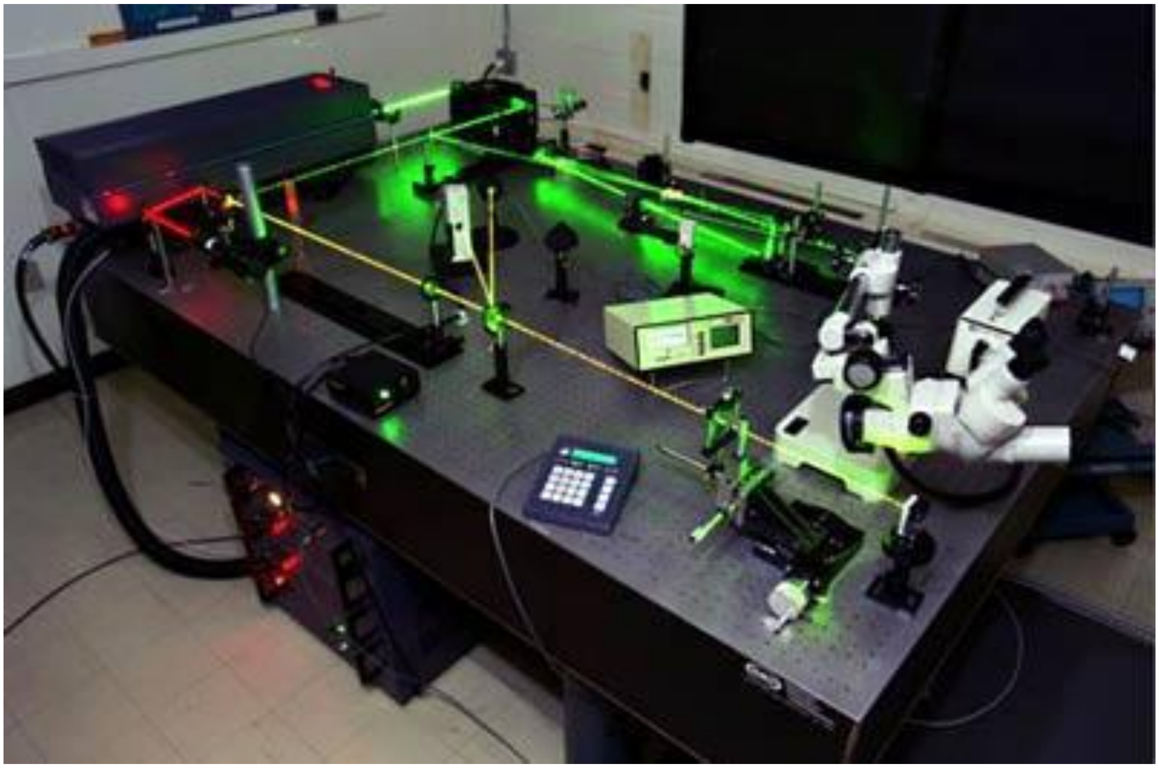
**Both photons can stimulate other atoms to emit photons that in turn stimulate the emission of more photons.**



## Laser Typical Characteristics

- Uni-directional; same direction
- Single wavelength in visible region; same frequency

- Same phase
- Intense beam



## General Applications

- CD players
- Pointers
- Printers

- Eye surgery (reshaping cornea)
- Soft tissue procedures excision of tumors/lesions, incision/ excision biopsies, burns tumours and so forth.
- Control of bleeding in vascular lesions.
- Arthroscopic joint surgery.
- Cuts metal
- Cuts patterns (many layers of cloth at once)
- Telecommunications (sent down optical fibers)

**Power of Laser**

1-5 mW laser pointers

30- 100 W surgical lasers

100-3000 W in industry; laser cutting

1.3 PW (1.3 x $10^{15}$ W) most powerful produced at Lawrence Livermore Lab.

# Laser Dental Applications

## 1- Reshape gum tissue (reduce prominence

Gum reshaping or contouring for some people who their gums may cover up too much of their teeth, that can make their teeth look smaller, and for some, it holds them back from smiling. This surgery can involve the use of a scalpel, a laser or radiosurgery. Gum reduction surgery requires a local anesthetic. Your dentist will assess the area that needs treatment and will choose the best method for it.

## Surgical gingivectomy:

Local anaesthetic is used to keep the patient comfortable during the procedure. The technique is completed with a surgical scalpel and involves trimming and removing the tissue around the teeth. The remaining gums are reattached in and around the teeth by sutures (stitches), and the area is cleaned with saline. After the procedure is completed, a surgical dressing, or pack, is placed in and around the teeth and gums. This dressing is left in place for about a week.

## Laser gingivectomy:

Dental lasers, and in particular diode lasers, are being increasingly used, and gingivectomy is the most common procedure performed with dental lasers. Several laser wavelengths can be used to precisely incise gingiva for restorative, cosmetic, and periodontal indications; however, diode lasers come with smaller set up and often better price. Rapid healing and reduced pain are commonly seen post-operatively and patients rarely need periodontal packing or sutures. The Laser types include:

- Nd:YAG (Neodymium: Yttrium Aluminium Garnet) laser
- $CO_2$ laser
- Diode laser

## 2- Laser aided teeth whitening

Laser teeth whitening is a bleaching procedure done in a dentist's office. It's different from other teeth whitening methods, as the procedure involves a bleaching gel and laser. A laser is a beam of high intensity light.

Laser teeth whitening is a procedure designed to brighten your teeth. It's also known as laser teeth bleaching. During the procedure, a bleaching gel is applied to your teeth. A laser is then directed onto your teeth, which heats up the gel. This activates its whitening properties and alters stain molecules on the teeth.

The goal of laser teeth whitening is to reduce discoloration and make your teeth look whiter.

Tooth discoloration can happen for many reasons, including:

- consuming certain foods and drinks, like coffee and tea
- using tobacco
- aging

- injury to the mouth
- certain medications, like antihistamines and chemotherapy

3. Laser Drill

- Preparation for fillings
- Capable of killing bacteria located in a cavity
- No vibration

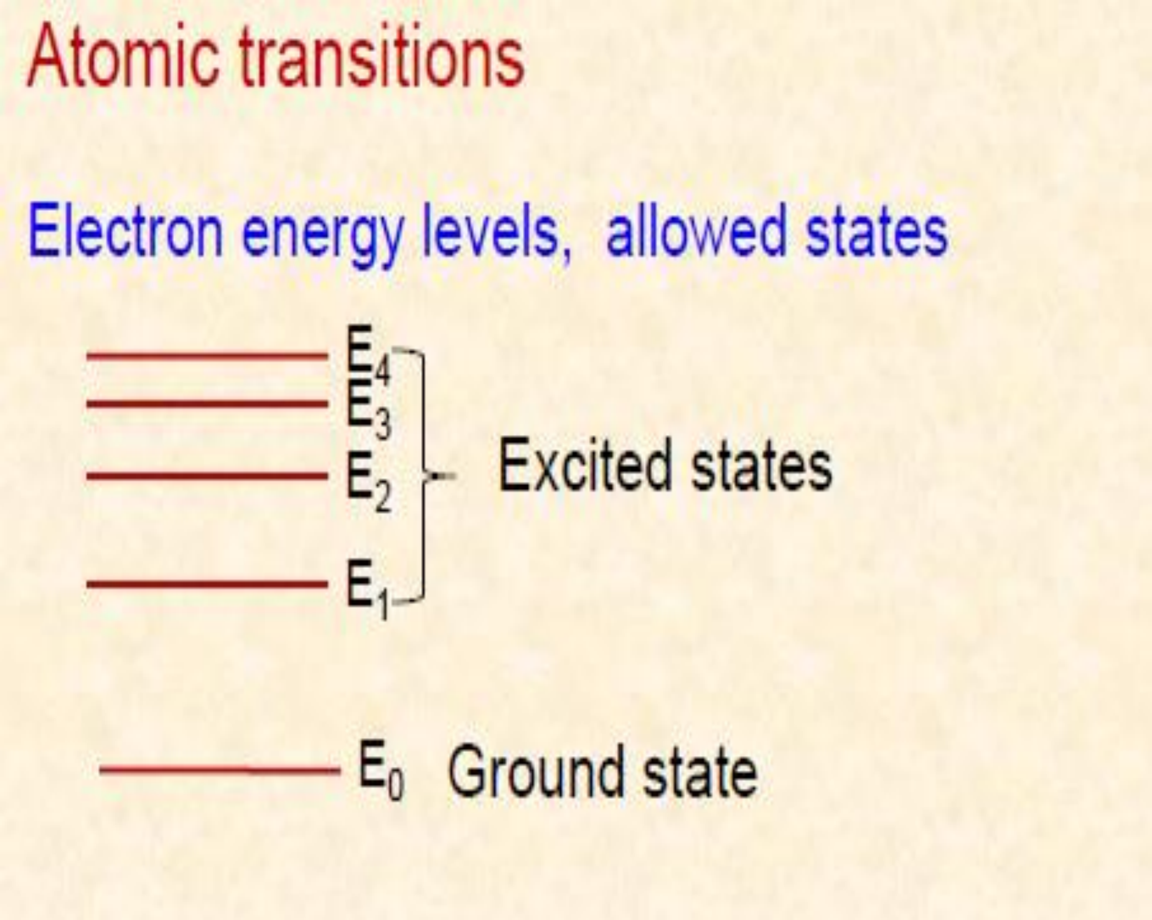
Laser: Erbium Yag (Er: YAG) Wavelength 2940 nm, light of this wavelength highly absorbed by water

Laser beam absorbed by decayed tissue because of large water content compared with healthy enamel

Result:

- selective ablation of decay,
- conservation of healthy tooth
- no increase in pulp temperature

# Principles of Laser



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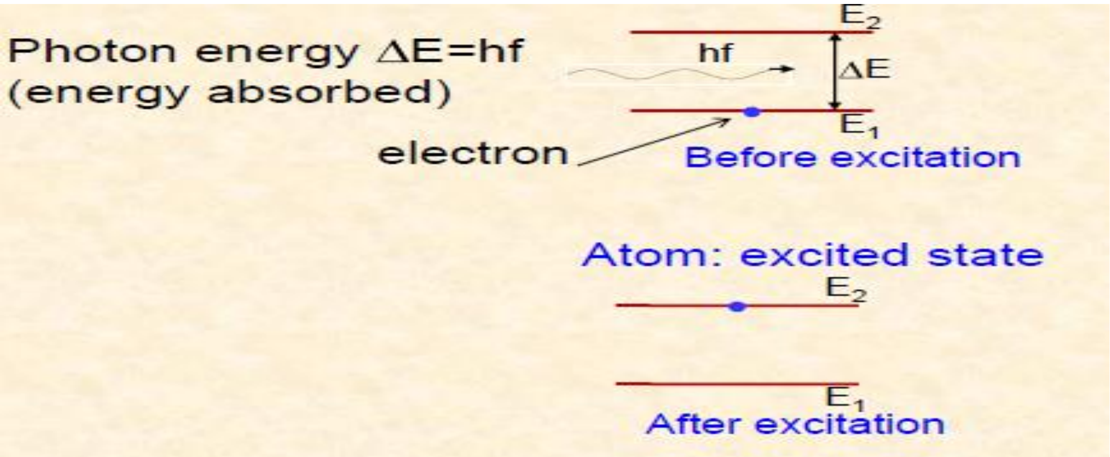

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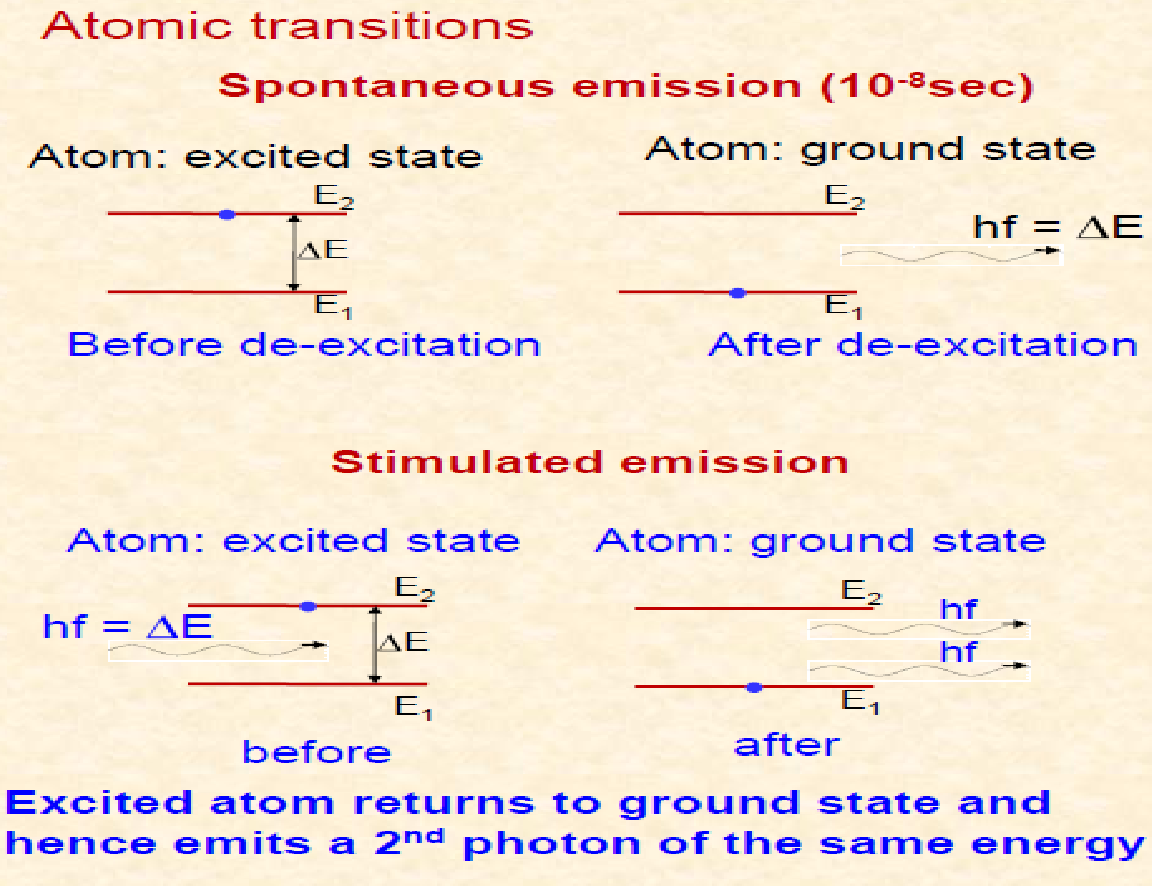

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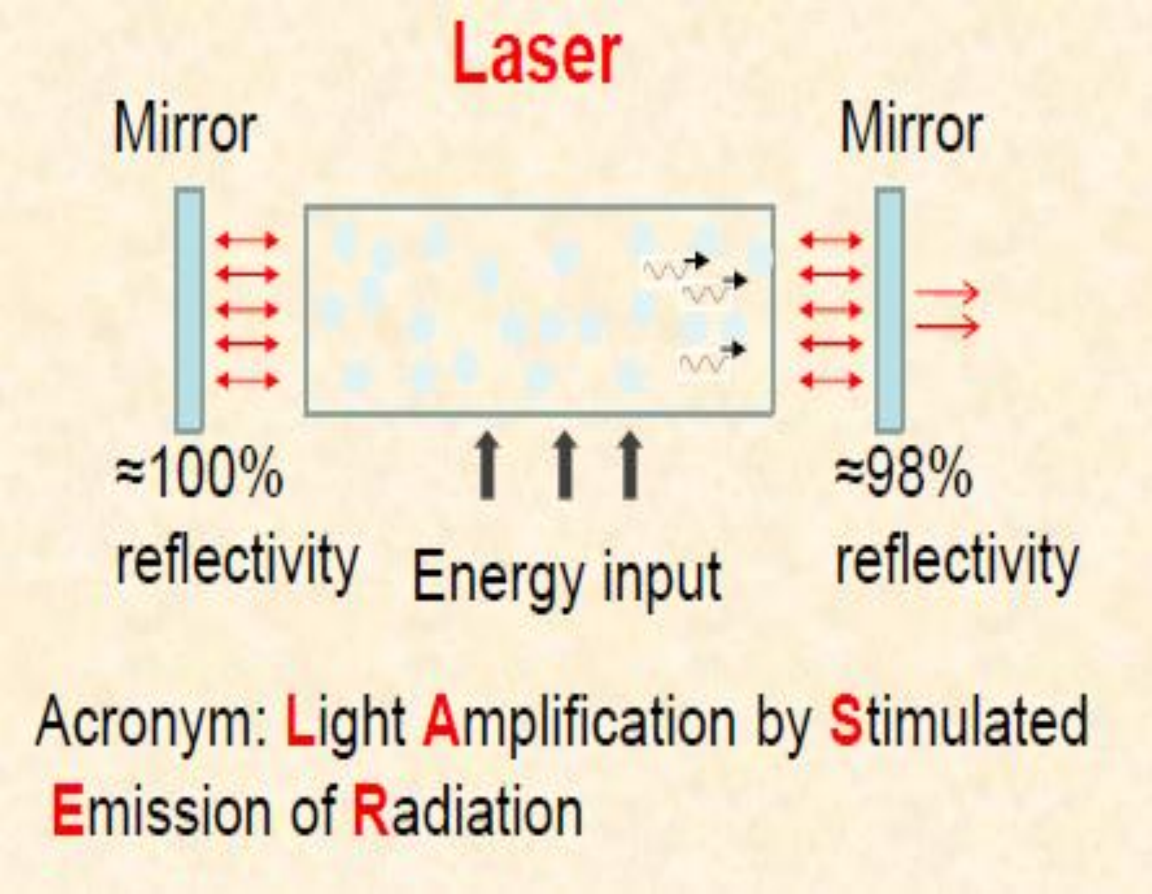

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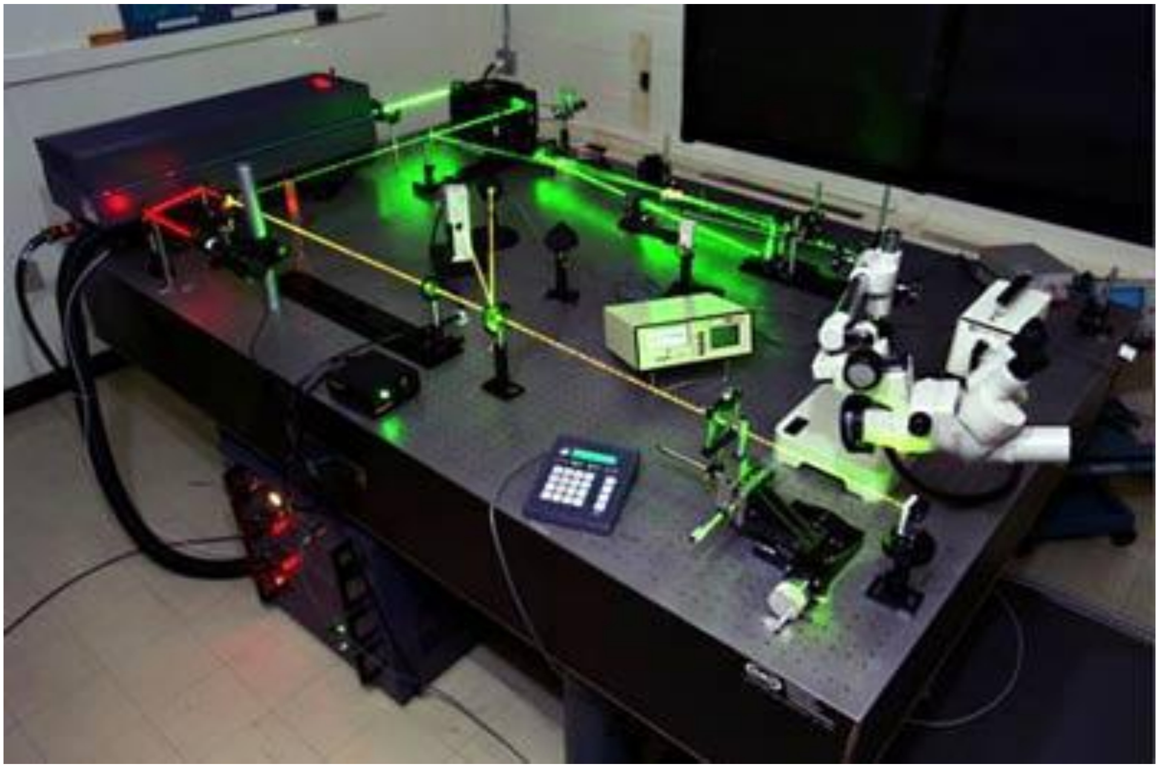

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MEDICAL PHYSICS
DR. SALIM ATTIA

# Light in medicine

Light could behave both as a wave and as particle. Max Blanck He drives an equation to explain the relationship between light energy and the frequency.

$$E = hf$$

Where

E = photon energy, f = frequency of light
H = Planck's constant

$$f = c/\lambda$$

Where

f= frequency, c = light velocity, $\lambda$ = the wave length

$$E = hc/\lambda$$

So light with long wavelength range has a small energy, while light with short wave length range has a higher energy.

There are three operations occurs when light strikes any surface:

Reflection (R), Refraction (r), Absorption (A)

$$R + r + A = 1 = 100\%$$

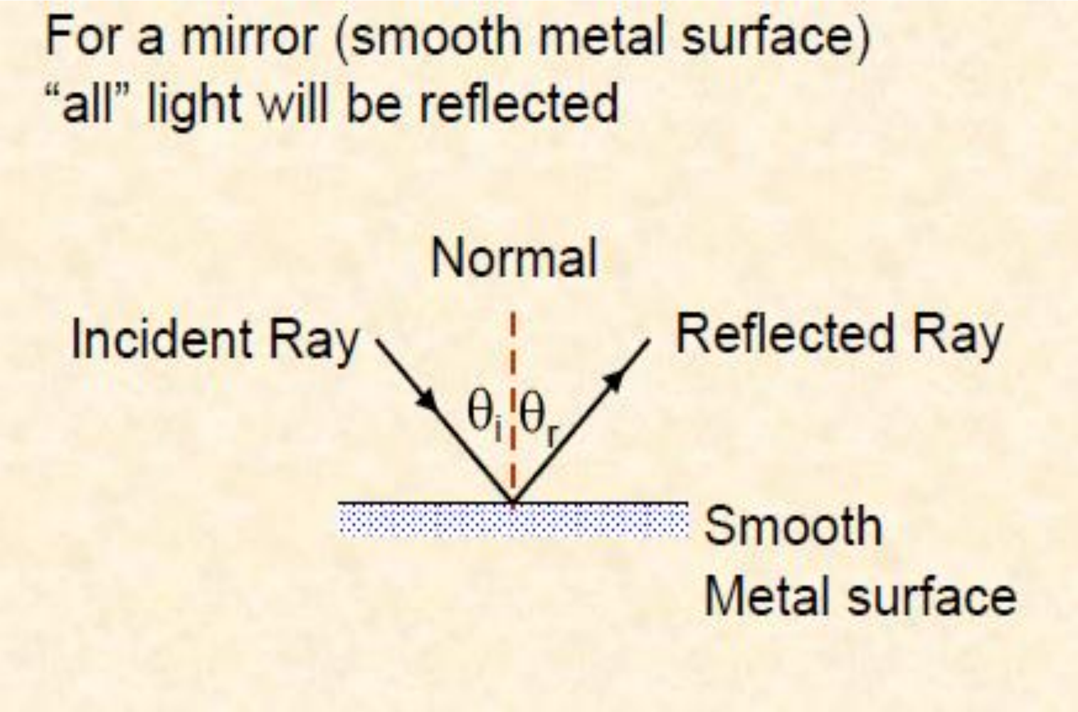
Even though man is now very efficient at making artificial light, the sun is still the major source of light in the world. The sun is both beneficial and hazardous to our health.

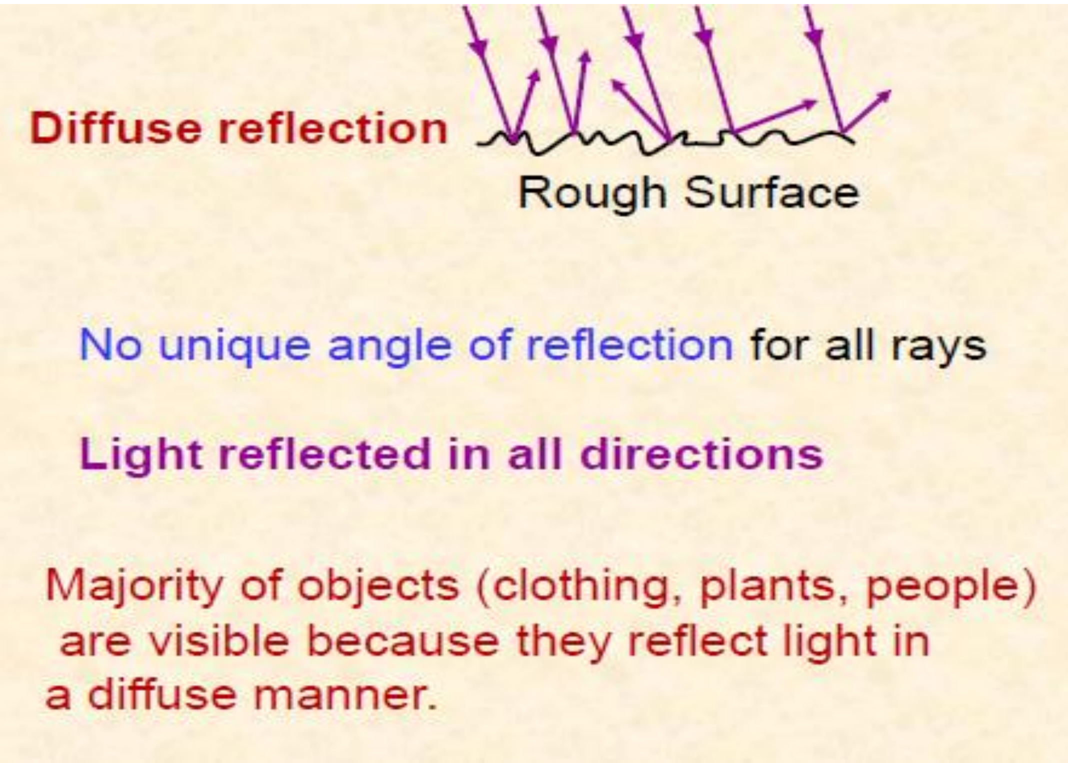
Light has some interesting properties, many of which are used in medicine:

1. The speed of light changes when it goes from material into another. The ratio of the speed of light in a vacuum to its speed in a given material is called the **index of refraction**. If a light beam meets a new material at an angle other than perpendicular, it bends, or is refracted.
2. Light behaves both as a **wave** and as a **particle**. As a wave it produces **interference** and **diffraction**. As a particle it can be absorbed by a single molecule. When a light photon is absorbed its energy is used in various ways. It can cause a chemical change in the molecule that in turn can cause an electrical change. This is basically what happens when a light photon-is, absorbed in one of the sensitive cells of the retina. The chemical change in a particular point of the retina triggers an electrical signal to the brain to inform it that a light photon has been absorbed at that point.
3. When light is **absorbed**, its energy generally appears as heat. This property is the basic for the use in medicine of IR light to heat tissues. Also, the heat produced by laser beams is used to "**weld**" a detached retina to the back of the eyeball and to coagulate small blood vessels in the retina.
4. Sometimes when photon is absorbed, a lower energy light photon is emitted. This property is known as **fluorescence**; it is the basis of the fluorescent light bulb. The amount of

fluorescence and the color of the emitted light **depend** on the chemical composition of the material that is fluorescing. Fluorescence is used in fluorescent microscopes as very important medical application.

5. Light is **reflected** to some extent from all surfaces. There are **two** types of reflection. **Diffuse reflection** occurs when rough surfaces scatter the light in many directions. **Specular reflection** is more useful types of reflection; it is obtained from very smooth shiny surfaces such as mirrors where the light is reflected at an angle that is equal to the angle at which it strikes the surface. Mirrors are used in many medical instruments.





**Diffuse reflection**

No unique angle of reflection for all rays

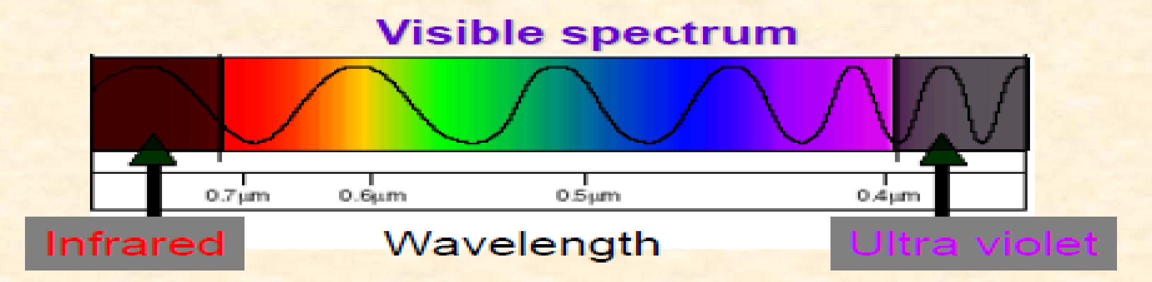
**Light reflected in all directions**

Majority of objects (clothing, plants, people) are visible because they reflect light in a diffuse manner.

Visible light has an important **therapeutic** use. Since light is a form of energy and is selectively absorbed in certain molecules, it should not be surprising that it can cause important physiological effects. Many premature infants have **jaundice**, a condition in which an excess of bilirubin is excreted by the liver into the blood. Relatively recently (1958) it was discovered that most premature infants recover from jaundice if their bodies are exposed to visible light (**phototherapy**).

## Applications of ultraviolet and infrared rays in medicine

The wavelengths adjacent to the visible spectrum also have important uses in medicine. Ultraviolet photons have energies greater than visible photons, while IR photons have lower energies, because of their higher energies, UV photons are more useful than IR photons.



Ultraviolet light with wavelengths below about 290 nm is **germicidal**-that is, it can kill germs-and it is sometimes used to sterilize medical instruments. Ultraviolet light also produces more reactions in the skin than visible light. Some of these reactions are beneficial, and some are harmful. One of the major beneficial effects of UV light from the sun is the conversion of molecular products in the skin into vitamin D.

Ultraviolet light from the sun affects the melanin in the skin to cause **tanning**. However, UV can produce sunburn as well as tan the skin. The wavelengths that produce sunburn are around 300 nm. The amount of 300 nm light in the sun's spectrum **depends** on the **amount** of field that the sunlight must pass through. Ordinary window glass permits some near UV to be transmitted but absorbs the sunburn component.

Solar UV light is also the major cause of **skin cancer** in humans. The high incidence of skin cancer among people, who have been exposed to the sun a great deal, such as fishermen and agricultural workers, may be related to the fact that the UV wavelengths that produce sunburn are also very well absorbed by the DNA in the cells. Skin cancer usually appears on those portions of the body that have received the most sunlight, such as the tip of the **nose**, the tops of the **ears**, and the back of the **neck**.

About half of the energy from the sun is in the IR region. The warmth we feel from the sun is mainly due to the IR component. **Heat lamps** that produce a large percentage of IR light with wavelengths of 1000 to 2000 nm are often used for physical therapy purposes. Infrared light penetrates further into the tissues than visible light and thus is better able to heat deep tissues.

# Medical Physics
# **Nuclear Radiation**

Dr. Amal Yousif Al_Yasiri
College of Dentistry-University of Baghdad

## Radiation

- Radiation is the emission or transmission of energy in the form of waves or particles.
- This includes: electromagnetic radiation, such as radio waves, microwaves, infrared, visible light, ultraviolet, x-rays, and gamma radiation (γ)
- Ionizing radiation is any type of particle or electromagnetic wave that carries enough energy to ionize or remove electrons from an atom (such as, x-rays, and gamma radiation (γ))
- Non-ionizing radiation is any type of electromagnetic radiation that does not carry enough energy to ionize atoms (to completely remove an electron from an atom). Such as radio waves, microwaves, infrared, ultraviolet, and visible light

# Nuclear Radiation

- Nuclear radiation is defined as the particles or photons that are given off from a nucleus of the radioactive element.
- The particles and photons emitted by nuclear reactions are sufficiently energetic that they can remove electrons from atoms and molecules and ionize them.
- Therefore, Nuclear radiation is also known as ionizing radiation

# **Discovery of radioactivity**

- In 1896,  Henri Becquerel discovered that uranium-containing crystals emitted rays that could fog photographic plates.
- He found that these “rays” originated from changes within the atomic nuclei of the U atoms.
- He proposed that the uranium atoms were unstable. These atoms emitted particles and/or energy to become more stable.
- For his discovery of radioactivity, Becquerel was awarded Nobel prize in Physics in 1903

## Discovery of radioactivity

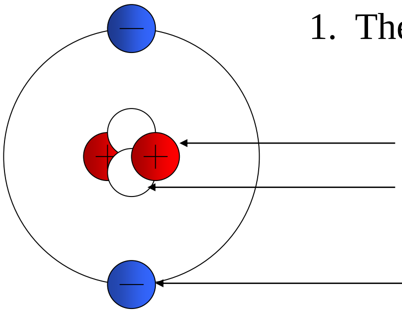
- In 1898, Pierre and Marie Curie discovered two elements, polonium and radium, which emitted high levels of radioactivity.
- They shared the Nobel prize in physics with Becquerel for discovering the radioactivity

## Atom

- All matters are made up of elements (e.g. carbon, hydrogen, etc.). The smallest part of an element is called an atom
- Every atom of any element has protons and neutrons in its nucleus.
- Atom of different elements contain different numbers of protons.
- The mass of an atom is almost entirely due to the number of protons and neutrons.

# Atom

- The atom consists of two parts:



1. The nucleus which contains:

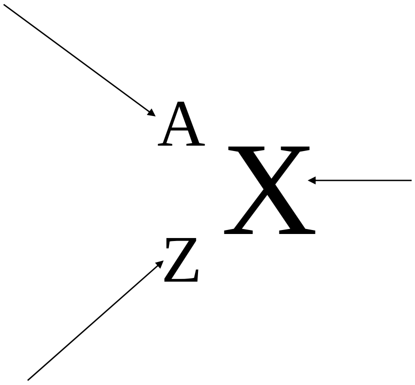
protons

neutrons

2. Orbiting electrons.

# Definitions

Mass number = # of protons + # of neutrons



$${}^{A}_{Z}X$$

Element symbol

Atomic number = number of protons

## Definitions

Number of protons = atomic number = Z

Number of neutrons = N

Mass number = A

# of protons + # of neutrons = mass number= A

Z+N=A

According to Z, N, A, elements are classified to

## Definitions

1- **Isotopes**---- Same Z, Different N, Different A

Example: $^{11}_{6}C$ , $^{13}_{6}C$ , $^{14}_{6}C$ -------- Z=6

Note: Isotopes are variants of a particular chemical element which differ in neutron number. They have the same symbol and same chemical and physical properties.

# Definitions

2- **Isobars** --------- Same A, different Z

Example: $^{40}_{19}K$ , $^{40}_{20}Ca$ ---------- A = 40

Note: Isobars are atoms (nuclides) of different chemical elements that have the same number of nucleons(P+N). They have different chemical and physical properties.

# Definitions

3- **Isotones**------Same N, different A and Z

Example: $^{39}_{19}K$ , $^{40}_{20}Ca$ -------- N=20

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4- Isomeric state -------Same Z, N, and A, different energy levels

Example: $^{99m}_{43}\mathrm{Tc} \longrightarrow {}^{99}_{43}\mathrm{Tc}$

Note: A nuclear isomer is a metastable state of an atomic nucleus caused by the excitation of one or more of its nucleons (protons or neutrons).

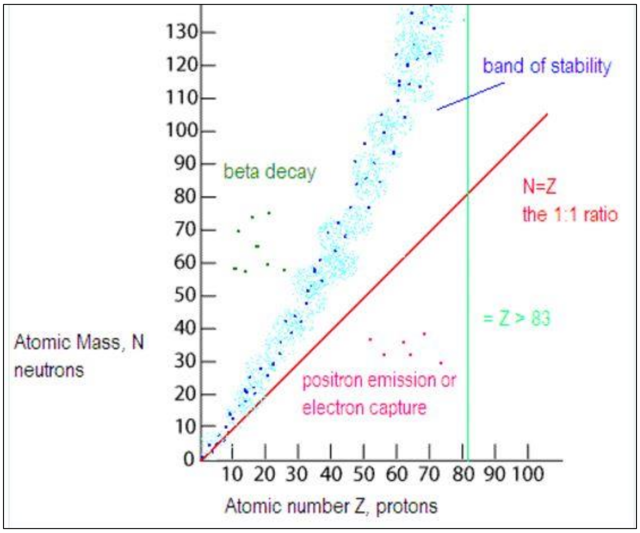
# Stability of nuclides

- As mentioned previously, nucleus consists of protons and neutrons which are called nucleons. protons have positive charge while the neutrons have no charge (neutral).
- There are two forces work in nucleus

1- Coulomb repulsive force between protons

2-Nuclear force (attractive) between nucleons. It is so strong that it cancel the effect of the force of repulsion between the protons and helps bind the nucleus together.

# Stability of nuclides



The graph shows that nuclides with more than 20 protons must have more neutrons than protons in order to be stable. Why?? Because Extra neutrons mitigate the effect of repulsive force between the protons

# Stability of nuclides

- If nucleus is stable, it does not spontaneously emit any kind of radioactivity (radiation).
- If the nucleus is unstable, it has the tendency of emitting some kind of radiation, (i.e., it is radioactive). Therefore the radioactivity is associated with unstable nucleus:

Stable nucleus – non-radioactive

Unstable nucleus – radioactive

- Unstable nuclides can become stable by releasing different types of particles
- This process is called **radioactive decay** and the elements which undergo this process are called **radioisotopes/radionuclides**.

# Radioactive Decay

Types of radioactive decay

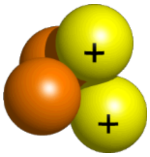
1. alpha decay ($\alpha$)
2. beta minus decay ($-\beta$)
3. positron decay ($+\beta$)
4. gamma decay($\gamma$)
5. electron capture
6. fission

# Alpha decay ($\alpha$)

- Radioactive nuclei eject alpha particles in order to reach the stable state. This decay occurs only in heavy nuclei ($Z > 83$).

- Characteristics of alpha particle($\alpha$) :

1. a helium nucleus ( )
2. two protons and two neutrons
3. charge +2e
4. can travel a few inches through air
5. can be stopped by a sheet of paper, clothing.



# Alpha decay (α)

$$\underset{\text{unstable nucleus}}{\underset{\uparrow}{{}^{A}_{Z}X}} \longrightarrow \underset{\text{more stable nucleus}}{\underset{\uparrow}{{}^{A-4}_{Z-2}Y}} + \underset{\text{alpha particle}}{\underset{\uparrow}{{}^{4}_{2}He}} + \underset{\text{Energy}}{\underset{\uparrow}{Q}}$$

Example: Uranium ⟶ Thorium + α + Energy

$${}^{234}_{92}U \longrightarrow {}^{230}_{90}Th + {}^{4}_{2}He + Q$$

# Beta decay (-β)

- This type of decay occurs in neutron rich nuclei. one neutron converts to proton and electron, then the electron (beta particle) will be ejected from the radioactive nucleus.

- Characteristics of Beta particles (- β)

1. Beta particles have the same charge (-e) and mass as "normal" electrons.
2. Can be stopped by glass plate, aluminum foil or a block of wood.

# Beta decay (-β)

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Ex: molybdenum ⟶ Technetium + β + energy

$${}^{99}_{42}\mathrm{Mo} \longrightarrow {}^{99\,m}_{43}\mathrm{Tc} + {}^{0}_{-1}\beta + Q$$

# Positron decay (+β)

- This type of decay occurs in proton rich nuclei only if Q >1.02 Mev. If Q less, Electron capture will occur
- One proton converts to neutron and positron, then the positron (Beta plus particle) will be ejected from the radioactive nucleus.

- Characteristics of positron particles (+ β)

1. Positron is antiparticle of an electron/beta
2. Has same size as an electron but with a positive charge.
3. It will collide with any electron. The result of the collision is the annihilation of the electron and positron, and the creation of gamma ray photons

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$$\underset{\substack{\uparrow\\ \text{unstable nucleus}}}{{}^{A}_{Z}X} \longrightarrow \underset{\substack{\uparrow\\ \text{more stable nucleus}}}{{}^{A}_{Z-1}Y} + \underset{\substack{\uparrow\\ \text{positron particle}}}{{}^{0}_{+1}\beta} + \underset{\substack{\uparrow\\ \textbf{Energy}}}{Q}$$

Ex: Fluorine ⟶ oxygen + positron + Q

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## Gamma decay(γ)

- Gamma decay is an emission of nuclear photon from excited nucleus. The unstable nucleus has excess of energy. It expels this energy as Gamma ray in order to be stable
- The nuclide retains its identity.
- Characteristics of gamma ray (γ)

1. Gamma rays are electromagnetic radiation with high frequency. (have NO mass and NO charge)
2. Most Penetrating, can be stopped by 1m thick concrete or a several cm thick sheet of lead

## Gamma decay(γ)

$$\underset{\text{unstable nucleus}}{{}^{A*}_{Z}X} \longrightarrow \underset{\text{stable nucleus}}{{}^{A}_{Z}X} + \underset{\text{Gamma}}{\gamma} + Q$$

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## Gamma decay(γ)

- Note: Both Gamma and X-rays are electromagnetic radiation. But they come from different sources
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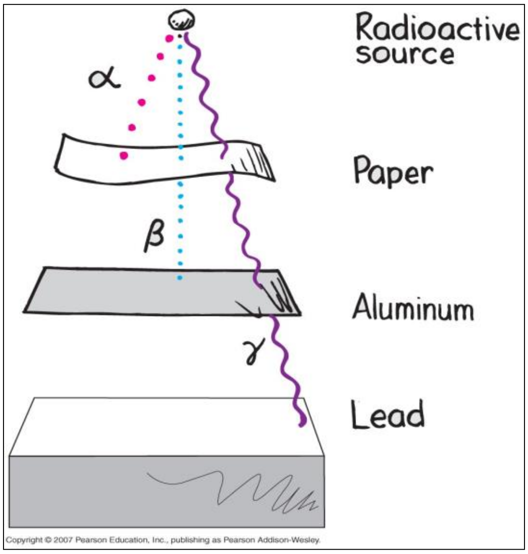
# Penetration of radiation



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- Which one is more penetrating? Why ?Beta, Alpha, Gamma
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## The range of charged particles (Alpha, Beta, positron)

- The range of charged particles at a given energy is defined as "the average distance they travel before they come to rest".
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## Conservation of Energy

- The law of conservation of energy states that the total energy of an isolated system remains constant— (it is said to be conserved over time). Energy can neither be created nor destroyed; rather, it transforms from one form to another.
- Einstein's equation : $E = mc^2$

E: energy, C: speed of light($3 \times 10^8$ m/s),m: mass

## Conservation of Energy in nuclear reactions

- In nuclear reactions, matter changes to energy, but the total amount of mass and energy together does not change.
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## Conservation of Energy in nuclear reactions

$$E = \Delta mc^2$$

- E: energy,
- C: speed of light(3 x$10^8$ m/s)
- $\Delta$m: mass difference between the parent nucleus and the daughter.
- The equation gives the energy released

- In a nuclear reaction, mass decreases and energy increases. However, the sum of mass and energy is always conserved in a nuclear reaction. Mass changes to energy, but the total amount of mass and energy combined remains the same.

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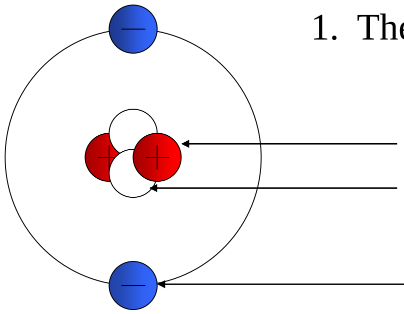

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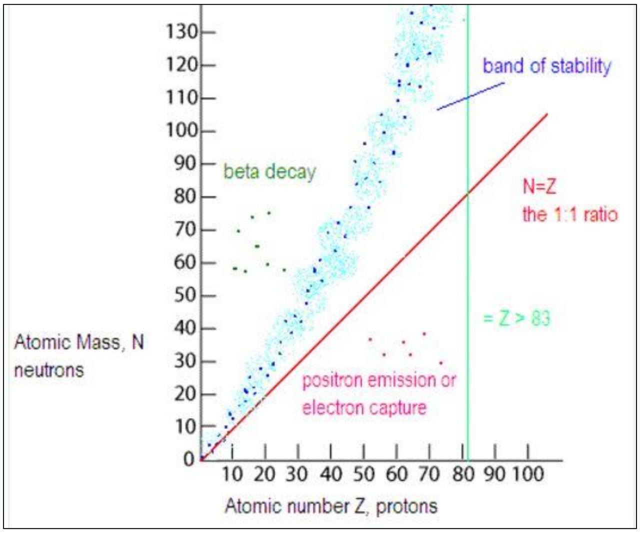

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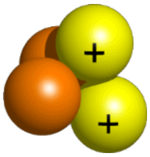

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unstable nucleus stable nucleus Gamma

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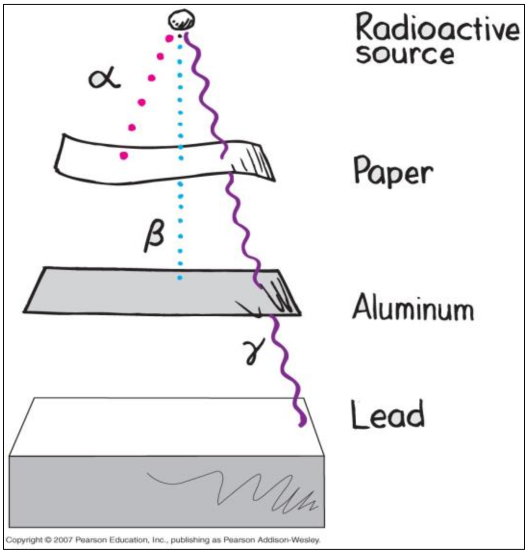

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- The equation gives the energy released

- In a nuclear reaction, mass decreases and energy increases. However, the sum of mass and energy is always conserved in a nuclear reaction. Mass changes to energy, but the total amount of mass and energy combined remains the same.

***Dr.Jaffar M.Moosa***

# *PRESSURE*

***Pressure*** is defined as the force per unit area in a gas or a liquid. For a solid, the quantity force per unit area is referred to as stress. The pressure is measured in N\ $m^2$ or dyne \ $cm^{2.}$

None of these units is in common use in medicine. The most common method of indicating pressure in medicine is the height of a column of mercury (Hg).

**Note:** The atmospheric pressure is about 760mmHg.

The density of water is 1 g \ $cm^3$, and for mercury is13.6 g \ $cm^3$.

The pressure (p) under a column of liquid can be calculated from:

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

Where **ρ** is the density of the liquid.

**g** is the acceleration due to gravity.

**h** is the height of the column.

**Example:** What height of water will produce the same pressure as 120mmHg?

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

$$\text{For 120mm Hg } P = 13.6\ g\backslash\ cm^3 x\ 980\ cm\backslash\ sec^2\ x\ 12\ cm$$

$$=1.6\ x\ 10^5\ dynes\ \backslash\ cm^2$$

$$\text{For water } 1.6\ x\ 10^5\ dynes\ \backslash\ cm^2 = 1\ g\ \backslash\ cm^3\ x\ 980\ cm\ \backslash\ sec^2\ x\ h\ cm\ H_2O$$

$$h = 163\ cm\ H_2O$$

## *Gauge pressure* (G.P)

The excess pressure over the atmospheric pressure .it is the pressure read directly from the sphygmomanometer-not that the manometer tube is open to the atmosphere.

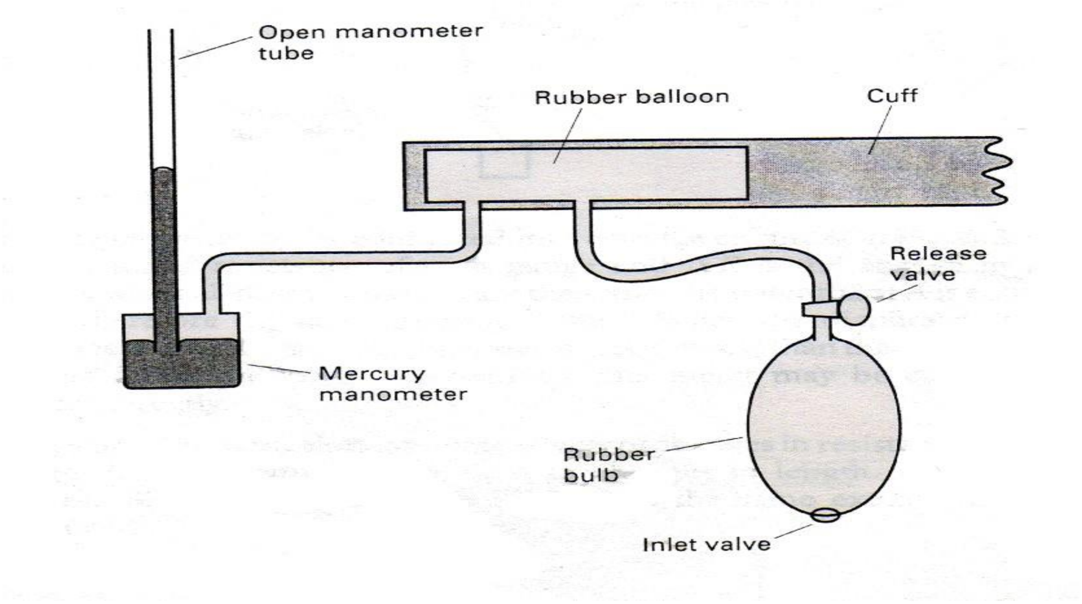
## *Negative pressure* (N.P)

Any pressure lower than atmospheric pressure .There are a number of places in the body where the pressures are lower than the atmospheric or negative.

## Examples:

1. When we breath in (inspire) the pressure in the lunge must be somewhat lower than atmospheric pressure or the air would not flow in, then the lunge pressure during inspiration is typically a few centimeters of water negative.
2. When a person drinks through a straw the pressure in his mouth must be negative by an amount equal to the height of his mouth above the level of the liquid he is drinking.

# Measurements of pressure in the body



## 1-*The sphygmomanometer*

The sphygmomanometer provides a simple, non-invasive method of measuring blood pressure. It consists of inflatable cuff connected to a mercury manometer by flexible tubing. The cuff is wrapped around the upper arm at the level of the heart. Air is pumped into the cuff (by repeatedly squeezing the bulb) until the pressure in it is more than sufficient to stop the blood flow in the brachial artery. If a stethoscope is placed on the same artery, below the elbow, no sound will be heard once the blood flow has stopped. The pressure is now gradually reduced by opening the released valve. When the ***systolic pressure*** (the maximum arterial pressure) is reached, a series of clicks can be heard, corresponding to the artery being forced open momentarily once each heartbeat. The cuff pressure is further reduced, and eventually a point is reached at which the sounds suddenly become very faint.The external pressure is now equal to the ***diastolic pressure***

(The minimum pressure) and the artery is able to remain open for the whole of the cardiac cycle. Blood pressure measurements can provide valuable information concerning the condition of the heart and the blood vessels.

# For a normal young adult male, systolic pressure = 120mmHg, diastolic pressure = 80mmHg. This is expressed as 120 \ 80. The corresponding value for a female is about 110 \ 70.

# The various sounds that are heard are called ***Korotkoff sounds***.

# It is important that the blood supply to the lower arm and hand is restored as quickly as possible.

# Although it is non-invasive and easy to use, the sphygmomanometer has a number of limitations.

1-***It does not measure blood pressure directly.***

***2-It is less accurate than invasive methods.***

***3-It measures only the systolic and diastolic pressure; it provides no information on how the pressure changes over the whole of the cardiac cycle.***

**Exam-1**: The average pressure recorded by sphygmomanometer at the level of a woman' s heart is $1.20 \times 10^4$Pa.Assuming that she is in an upright position, calculate the average pressure that would be recorded at a point in her leg 110cm below the level of her heart. Assume that the pressure difference is due entirely to gravity?

Density of blood = $1.04 \times 10^3$ $kgm^{-3}$, g = $9.81ms^{-2}$

$$\Delta p = \rho g h$$

$$= 1.04 \times 10^3 \times 9.81 \times 110/100$$

$$= 1.12 \times 10^4 Pa$$

Pressure in leg = $1.2 \times 10^4 + 1.12 \times 10^4$

$$= 2.32 \times 10^4 \text{ Pa}$$

**2-** ***Pressure measurement using invasive techniques***

**A- Internal pressure transducer.** A pressure transducer can be mounted in the end of a catheter (a tube) inserted in a blood vessel at the point where the pressure measurement is required. The technique is not restricted to the measurement of blood pressure – it can be used to measure fluid pressure in the bladder and the gastrointestinal trace, for example.

**B- External pressure transducer.** Are used in some circumstances. The transducer remains outside the body, connected to the site of the pressure measurement by means of a saline – filled catheter. The pressure inside the chambers of the heart is normally measured in this way.

There are various types of pressure transducer that chosen for any particular pressure measurement which depends on:

1. ***The site of the measurement.***
2. ***How large the pressure is.***
3. ***How rapidly the pressure is fluctuating.***

For example the pressure in vein is low (0 to 10 mmHg) and changes only slowly. While in arterial pressure is much higher (up to 120mmHg) and fluctuates rapidly.

### 1- ***Pressure in the skeleton***

The highest pressures in the body are found in the weight-bearing bone joints. When all the weight is on one leg, such as when walking, the pressure in the knee joint may be more than 10 atm. The surface area of a bone at the joint is greater than its area either above or below the joint.

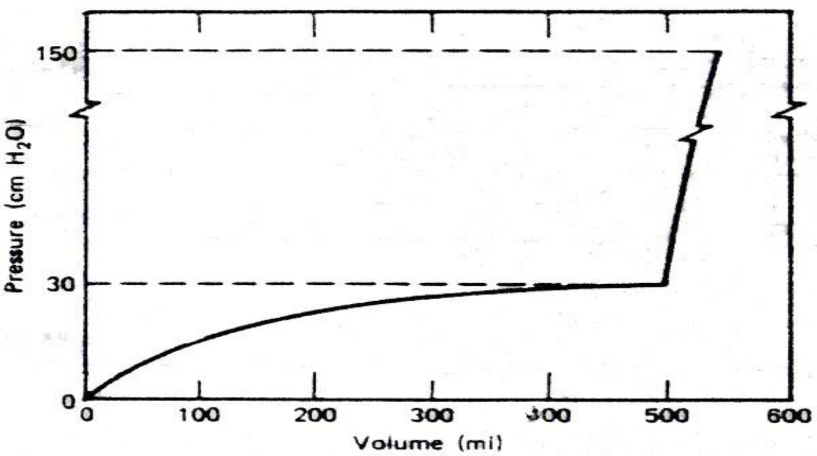
$$\mathbf{P = F/ A}$$

The larger area at the joint distributes the force and thus reducing the pressure .Bone has adapted in another way to reduce pressure. The finger bones are flat rather than cylindrical on the gripping side, and the force is spread over a large surface, this reduces the pressure in the tissues over the bones (when we carry something heavy like a suitcase), according to the above formula.

### 2-***pressure in the urinary bladder***

The pressure in the bladder is one of the most noticeable internal pressures which occur due to the accumulation of urine.

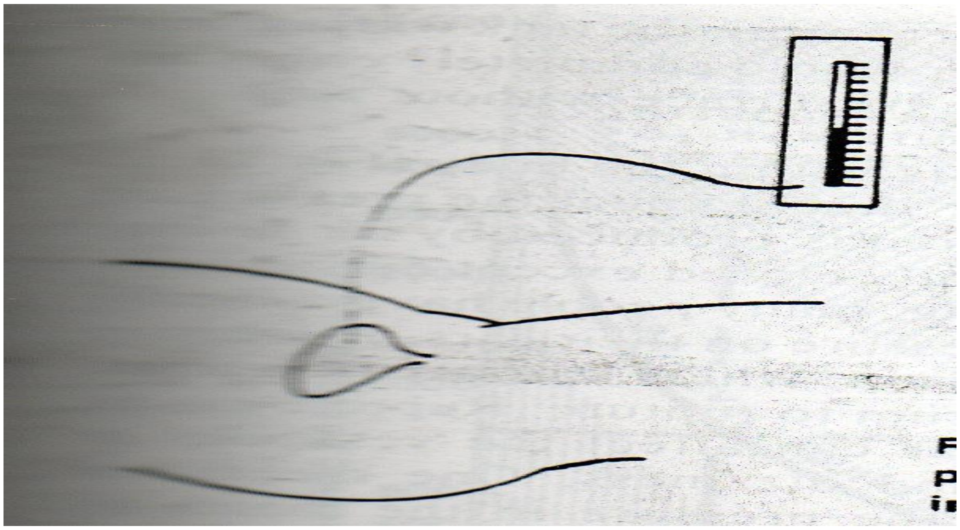
The typical pressure volume curve for the bladder which stretches as the volume increases.



For a given increase in radius (r), increases volume ($r^3$), then increases pressure as ($r^2$) for adults the typical maximum volume in the bladder before voiding is 500ml. At some pressure (≈ 30 cm $H_2O$) the micturition (gotta go) reflex occurs. The resulting sizable muscular contraction in the bladder wall produces a momentary pressure of up to 150 cm $H_2O$. Normal voiding pressure is fairly low 20 to 40 cm $H_2O$, but for men who suffer from prostatic obstruction of the urinary passage it may be over 100 cm $H_2O$.

The pressure in the bladder can be measured by passing a catheter with a pressure sensor into the bladder through the urinary passage (urethra), ***indirect method***, or the pressure is measured by means of the abdomen directly into the bladder, **direct *method.*** The technique shown in figure below gives information on the function of the exit valves (sphincters) that cannot be obtained with the catheter technique.

The bladder pressure increases during ***coughing, straining, sitting up and during pregnancy,*** and the weight of the fetus over the bladder increases the bladder pressure and causes frequent urination. Some stressful situation may also produce a pressure increase, studying for example.



### *3-__Pressure effects while diving__*

The body is composed primarily of solid and liquid, while are nearly incompressible, pressure changes do not greatly effect most of it. However, there are gas cavities in the body where sudden pressure
Changes can produce profound effects.

***Bayle's law*:** for a fixed quantity of gas at a fixed temperature, the product of the absolute pressure and volume is constant. (PV= constant)
(PV = nRT).

$$\mathbf{P_1V_1= P_2V_2}$$

If the absolute pressure is doubled the volume is halved.
The middle ear is one air cavity that exists within the body. For comfort the pressure in the middle ear should equal the pressure on the outside of the eardrum.

**P** in the middle ear = **P** on the outside of the eardrum

This equalization is produced by air flowing through the Eustachian tube, which is usually closed except during: ***swallowing***, ***chewing*** *and* ***yawning***.
When diving: many people have difficulty obtaining pressure on their ears. A pressure differential of **120** mm Hg across the eardrum, which can occur in about 1.7 m of water, can cause the eardrum to rupture, which can be serious cold water in the middle ear.
One method of equalization used by a diver is to raise the pressure in the mouth by holding the nose and trying to blow out, as the pressure equalizes the diver can often hear both ears pop.

### *4- <u>The pressure in the lungs</u>*

The pressure in the lungs at any depth is greater than the pressure in the lungs at sea level. This means that the air in the lungs is denser under water and that the partial pressures of all the air components are proportional higher.

**P** in lungs at any depth **>** **P** in the lungs at sea level

The higher partial pressure of Oxygen causes more Oxygen molecules to be transferred into the blood, and Oxygen poisoning results if the partial pressure of Oxygen gets too high. Usually Oxygen poisoning occurs when the partial pressure of Oxygen is about 0.8 atm. (when the absolute air pressure is about 4 atm or at a depth of about 30m).

Breathing air at a depth of 30m is also dangerous because it may result in excess Nitrogen ($N_2$) in the blood and tissues. This can produce two serious problems:

1- ***Nitrogen narcosis which is an intoxication effect.***

2- ***The bends or decompression sickness which is an ascent problem*.**

$O_2$ is transported by chemical attachment to the red blood cells.N2 is dissolved in the blood and tissues.

***According to Henry's law***

The amount of gas that well dissolves in a liquid is proportional to the partial pressure of the gas in contact with the liquid.

Thus more Nitrogen is dissolved in the blood and tissues as a diver go deeper **P** air and **P.P** of $N_2$ are increasing.

***Hyperbaric Oxygen therapy (HOT)***

The body normally lives in an atmosphere that is about one – fifth Oxygen and four – fifth Nitrogen. In some medical situation it is beneficial to increase the proportion of $O_2$ in order to provide more Oxygen to the tissues.

Gas gangrene is a disease that killed more than half of its victims before hyperbaric Oxygen (HOT) was developed.

The bacillus that causes gas gangrene cannot survive in the presence of Oxygen, almost all gas gangrene patients treated with HOT are cured without the need for amputation the previous best method of treatment.

### *CO-carbon monoxide poisoning*

In this case, the red blood cells cannot carry Oxygen to the tissues because the Carbon monoxide fastens to the Hemoglobin at the places normally used by Oxygen. The presence of even a few Carbon monoxide molecules on a red blood cell greatly reduces the ability of the cell to transport $O_2$.

Normally the amount of Oxygen dissolved in the blood is about 2% of that carried on the red blood cells, with HOT the partial pressure of Oxygen can be increased by a factor of 15, permitting enough $O_2$ to be dissolved top fill the body's need .Many victims of carbon monoxide poisoning are saved with this technique.

***The treatment of cancer***

HOT has been used in conjunction with radiation in the treatment of cancer, the patient was placed inside a transparent plastic tank, and the radiation was that more Oxygen would make the poorly Oxygenated radiation – resistant cells in the center of the tumor more susceptible to radiation damage.

## ***5-*****_Pressure inside the skull_**

The brain contains approximately $150cm^2$ of cerebrospinal fluid (CSF) in a series of interconnected opening called ventricles. CSF fluid is generated inside the brain and flows through the ventricles into the spinal column and eventually into the circulatory system.

CSF→ Ventricles→ Spinal column→ Circulatory system
↓
One of the ventricles, the aqueduct, is especially narrow.

If at brain this opening is blocked for any reason, the CSF is trapped inside the skull and increases the internal pressure. This serious condition called **hydrocephalus, (literally, water head).**

### *Measuring the CSF pressure*

It is not convenient to measure the CSF pressure directly; there are two methods to measure it:

***1-Crud method of detecting.***

Hydrocephalus is to measure the circumference of the skull just above the ears. Normal values for newborn infants are from 32 to 37cm, and a larger value may indicate hydrocephalus.

***2-Transillumination*****.**

Make use of the light scattering properties of the rather clear CSF inside the skull (qualitative method of detection).

## ***6-*** ***_Eye pressure_***

The clear fluids in the eyeball (the aqueous and vitreous humors) that transmit the light to the retina (the light sensitive part of the eye), are under pressure and maintain the eyeball in a fixed size and shape. The dimension of the eye are critical to good vision, a ***change of only 0.1mm in its diameter has a signification effect on the clarity of vision***. The pressure in normal eyes ranges from **12 to 23mmHg**. The fluid in the front part of the eye, the aqueous humor, is mostly water.

The eye continuously produces aqueous humor and a drain system allows the surplus to escape. If a partial blockage of this drain system occurs, the pressure increases and the increased pressure can restrict the blood supply to the retina and thus affect the vision, this condition called (glaucoma).

***There are two cases of glaucoma.***

1. ***Early physicians estimated the pressure inside the eye by feel as They pressed on the eye with their fingertips.***
2. ***Now pressure in the eye is measured with several different Instruments called tonometer, which are sometimes calibrated in arbitrary units rather than in mm of Hg.***

# Radioactive Decay

Dr. Amal Al_Yasiri
College of Dentistry

## Decay process
## (Activity )

- Radioactive decay is a random process. We cannot predict when an individual nucleus will decay but with large numbers of nuclei we can use a statistical approach.
- One of the most important quantities associated with a sample of radioactive material is its activity.
- Activity is the rate at which the nuclei within the sample undergo decay (disintegrations) and can be expressed in terms of the number of disintegrations per second (dps).

# Activity

- **Activity** : It is the average number of disintegrations per second (dps)

- The SI unit of activity is the becquerel:

1 becquerel (1 Bq ) = 1 disintegration/second ( 1dis/sec).

1 Bq= 1dis/sec= 1dps

- Another unit of activity is the curie (Ci):

1 curie = 1 Ci = $3.7x10^{10}$ dis/s

1 Ci = $3.7x10^{10}$ Bq

# Radioactive Decay Laws

- Experimental measurements show that the activities of radioactive samples fall off exponentially with time. As the sample decays, less of the radioactive sample remains, so the activity decreases.
- The following equations can be used to calculate the activity of a radioactive material at any time.

$$A = A_0 e^{-\lambda t}$$

$$A = \lambda N$$

$$A_0 = \lambda N_0$$

A = Activity remaining in the radioactive material after time (t)

$A_0$ = Initial Activity of the radioactive material

N = Number of radioactive nuclei present at a time t

$N_0$ = the initial number of radioactive nuclei present at time t=0

λ = Decay constant

t = Time

# Radioactive Decay Laws

We can also calculate the number of remaining radioactive nuclei in the radioactive sample after period of time from the following equation

$$\boxed{N_t = N_0 e^{-\lambda t}}$$

N = Number of radioactive nuclei present at a time t

$N_0$ = the initial number of radioactive nuclei present at time t=0

λ = Decay constant ($s^{-1}$)

t = Time (s)

# Radioactive Decay Laws

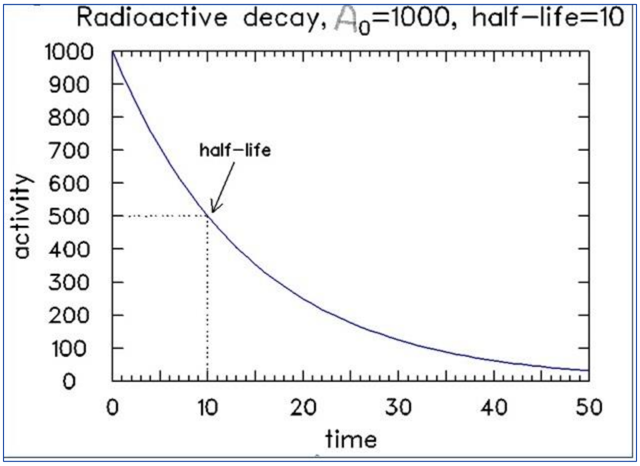
- Decay constant (λ ): The probability that a nucleus will decay per unit of time. Its unit is $s^{-1}$ , $min^{-1}$ , $h^{-1}$ , $day^{-1}$
- Half-Life ($t_{1/2}$): The time for half of the radioactive nuclei in a given sample to undergo decay. (i.e. the time it takes for the activity to drop by ½)
- Each radioactive nuclide has a particular decay constant and half life. The relationship between λ and $t_{½}$ is

$$\boxed{\lambda = \frac{0.693}{t_{½}}}$$

a plot of the activity of a radionuclides versus time.

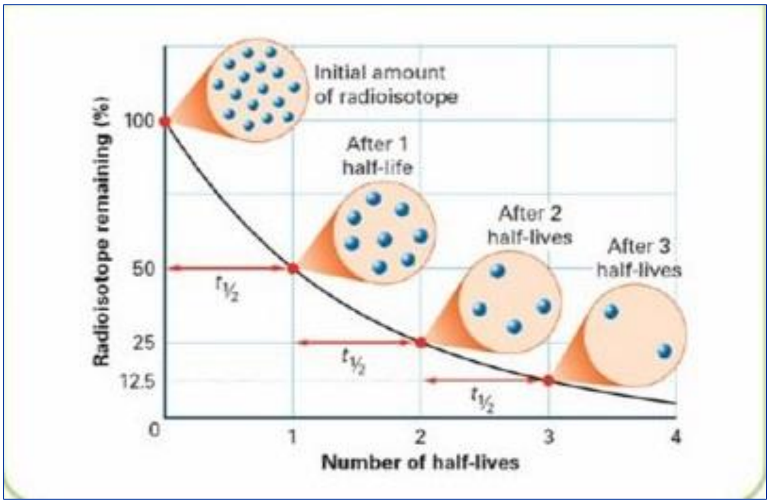
The initial activity was chosen to be 1000 for this plot.

The half-life is 10 (in whatever time units we are using).



***Note:*** All decay curves look like this; only the numbers on the axes will differ, depending on the radionuclide (which determines the half-life) and the amount of radioactive material (which determines the initial activity).

a plot of number of a radionuclides versus half life.



# Common Radioactive Isotopes

| *Isotope* | *Half-Life* | *Radiation Emitted* |
|---|---|---|
| Technetium-99 | 6 hours | $\gamma$ |
| Radon-222 | 3.8 days | $\alpha$ |
| Carbon-14 | 5,730 years | $\beta$, $\gamma$ |
| Uranium-235 | $7.0 \times 10^8$ years | $\alpha$, $\gamma$ |
| Uranium-238 | $4.46 \times 10^9$ years | $\alpha$ |

Note: You do not need to memorize these numbers

# Examples

Ex.1: A sample of $3\text{x}10^7$ Radon atoms are trapped in a basement that is sealed. The half-life of Radon is 3.83 days. How many radon atoms are left after 31 days?

Answer:

Info: $N_0 = 3\text{x}10^7$ atom, $t_{½}$ = 3.83 days, t=31 days

To find N after 31 days, we will use this eq. $N_t = N_0 e^{-\lambda t}$

First, we should calculate $\lambda$ from this eq. $\lambda = \frac{0.693}{t_{½}}$

$\lambda$= (0.693/3.83 d) = 0.1809 $d^{-1}$

Next step, we will find N by using $N_t = N_0 e^{-\lambda t}$

$N_t$ = $3\text{x}10^7$ atom x exp(- 0.1809 $d^{-1}$ x 31d)

$N_t$ =$1.1\text{x}10^5$ atom

Ex.2: We received 10 millicuries (mCi) of I-125. The half-life of I-125 is 60 days. . How much activity remains after 3 months

Answer:

Info: $A_0$ = 10 m Ci, $t_{½}$ = 60 d, t = 3 months= 90 d

we are asked to calculate $A_t$= ???

Therefore, we will use this eq. $A_t = A_0 e^{-\lambda t}$

$t_{½}$ = 60 d $\Longrightarrow$ λ = (0.693/60 d ) = 0.01155 $d^{-1}$

$A_t = A_0 e^{-\lambda t}$ $\Longrightarrow$ $A_t$ = 10 mCi x exp( - 0.01155 x 90)

$A_t$ =3.53 mCi the activity after 3 months

---

Ex.3: A sample of $3x10^6$ Radon atoms are trapped in a basement that is sealed. The half-life of Radon is 3.83 days. How much the current activity?

Answer:

Info: N= $3x10^6$ , $t_{½}$ = 3.83 d → λ= (0.693/ $t_{½}$ )

We are asked to find the activity (A) ??

Therefore, we will use this eq: $A = \lambda N$

Before solving this problem, you have to make the unit of λ in $s^{-1}$

$t_{½}$ = 3.83 d x 24 h/d x 60 min/h x 60 s/min = 330912 sec

λ = (0.693/330912) = 2 $x10^{-6}$ $s^{-1}$

A= 2 $x10^{-6}$ $s^{-1}$ x 3 $x10^{6}$ atom = 6 atom/s = 6 Bq

Ex.4:A sample of Radon has an activity of 10 Bq. The half-life of Radon is 3.83 days. How many radioactive nuclides are in this sample?

Answer

Info: $A_0$ = 10 Bq = 10 dis/sec, $t_{½}$ = 3.83 d

$$\boxed{A = \lambda N}$$

$t_{½}$ = 3.83 d x 24 h/d x 60 min/h x 60 s/min = 330912 sec

$\lambda$ = (0.693/330912) = 2 $\times 10^{-6}$ $s^{-1}$

N= A/ $\lambda$ = (10dis/sec)/(2 $\times 10^{-6}$ $s^{-1}$)

N= 5 $\times 10^{6}$ atoms

Ex.5: A medical center received Tc-99 (half life = 6 h). The initial activity of Tc-99 was 3 mCi when it was delivered, . Calculate the activity of Tc-99 after 2 days ?

Answer:

Info: $A_0$ = 3 mCi, $t_{½}$ = 6 h, t= 2 d =48 h

$$A_t = A_0 e^{-\lambda t}$$

$t_{½}$ = 6 h $\longrightarrow$ $\lambda$ = (0.693/6 h ) = 0.1155 $h^{-1}$

$A_t$ = 3 mCi x exp( - 0.1155 x 48) = 3mCi x 0.0039

$A_t$ = 0.0117 mCi the activity after 2 days

## Radiation Dose

- The magnitude of radiation exposures is specified in terms of the radiation dose.

- There are two important categories of dose:

1. *Absorbed dose*
2. *Dose equivalent*

## 1- *Absorbed dose*

- *Absorbed dose:* the amount of energy deposited in a unit mass in human tissue or other media.
- SI unit used to measure absorbed dose is the gray (Gy)

1 Gy = 1 J/kg

- another unit used to measure absorbed dose is rad

1 Gy = 100 rad

Absorbed dose can be calculated from the following formula

$$\boxed{D = \frac{E}{m}}$$

Where: D=dose (Gy), E =energy(J), m= mass(Kg)

## 1- *Absorbed dose*

Example: 0.1 J of radiation energy was deposited in 30 g of tissue. Find the absorbed dose in Gy and in rad

Answer

Info: E=0.1 J, m=30g =30/1000 =0.03 Kg

$$\boxed{D = \frac{E(J)}{m(Kg)}}$$

D = 0.1J/0.03Kg = 3.3 Gy

Since 1 Gy = 100 rad

D = 3.3 Gy x 100 rad/Gy

D= 330 rad

## 2- *Dose equivalent*

Dose equivalent: A measure of the biological damage to living tissue as a result of radiation exposure. Also known as the " biological dose”.

- SI unit used to measure Dose equivalent is *sievert* (Sv)
- another unit used to measure Dose equivalent is rem

1 Sv = 100 rem

Dose equivalent can be calculated from the following formula

$$\boxed{H\,(Sv) = D\,(Gy) \times Q} \qquad \boxed{H\,(rem) = D\,(rad) \times Q}$$

Where: H = Dose equivalent , D= absorbed dose

Q= weighting factor(previously called quality factor)

# 2- *Dose equivalent*

- Weighting factor (Q): is dimensionless factor used to convert physical dose (Gy) to equivalent dose (Sv).
- Example: If the absorbed dose is 20 rad and Q is 10. What is Dose equivalent in rem and in Sv

Answer:

H (rem) = D( rad) x Q = 20 rad x 10 = 200 rem

Since 1 Sv = 100 rem $\longrightarrow$ 1 rem = (1/100) Sv = 0.01 Sv

H (Sv) = 200 rem x 0.01 Sv/rem= 2 Sv

Or, we can solve it by this:

H (Sv) = D (Gy) xQ =20 rad x(1/100) Gy/rad x10

H = 0.2 Gy x 10 = 2 Sv

# Factors Affecting Radiation Dose

- Target organ/tissue, i.e., radiation sensitivity of the tissue
- Type and energy of the radiation
- Rate of Delivery
- Interaction Volume
- Biological status: difference between young/old, male/female, population/individual, healthy/diseased

## Radiation Interaction In Cells

- There are two principle ways to characterize the ways in which radiation interacts with cells. These ways are through direct effects and indirect effects.

1- Direct Effect - Direct ionization of DNA or other structure by radiation. The result may lead to the break-up or chemical change in the molecule.

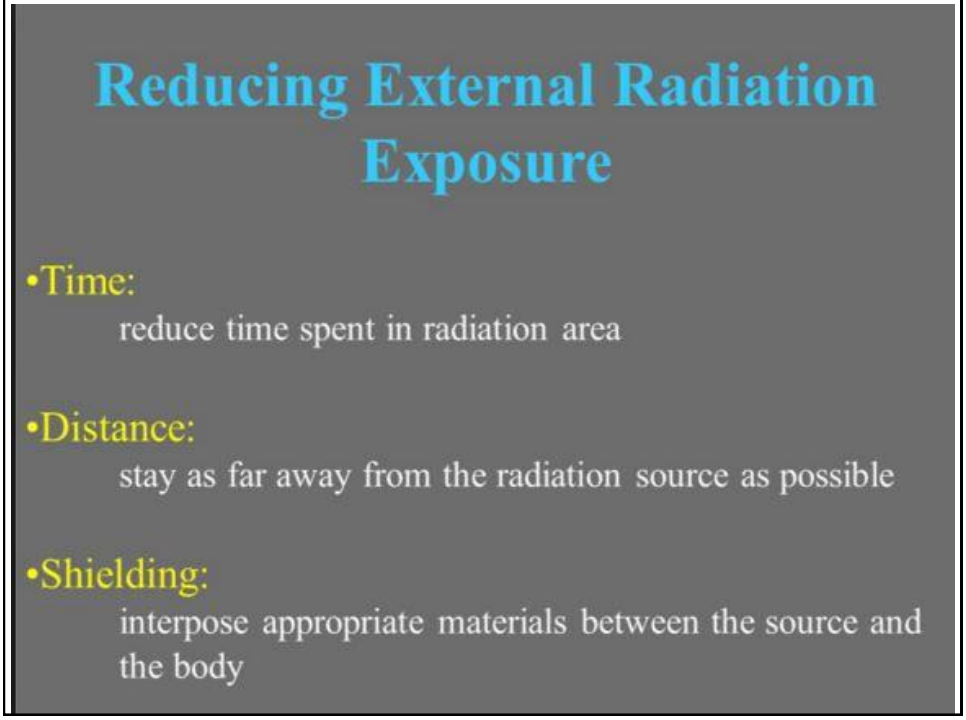
2- Indirect Effect - Ionization of water molecules within the cell creates very chemically active agents (free radicals) which can chemically attack other molecules in their immediate vicinity. If a DNA molecule is located in this area, alteration to the DNA molecule could occur.

## Radiation Safety and ALARA

- What is ALARA ?
- ALARA is an acronym for “As Low As Reasonably Achievable”. This is a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods.
- ALARA is not only a sound safety principle, but is a regulatory requirement for all radiation safety programs.
- Three of the most basic and easy to follow principles of radiation protection are time, distance, and shielding. We can greatly reduce our exposure by following these principles.

## Radiation Safety and ALARA

- **Time:** As the length of time a person is exposed increases, the dose received increases.
- **Distance:** The most effective of the principles is distance. The further a person is from the source the less intense the radiation source is.
- **Shielding:** When the use of the time and distance principles are not possible, shielding should always be used. Wearing protective lead shielding and thyroid collars can protect the radiosensitive areas of the body when it is required for the technologist to be near the source of radiation.



## Reducing External Radiation Exposure

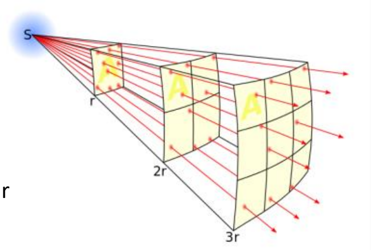
- Time:
  reduce time spent in radiation area
- Distance:
  stay as far away from the radiation source as possible
- Shielding:
  interpose appropriate materials between the source and the body

# Inverse square law applied in radiation

**Inverse Square law:** The radiation Intensity is inversely proportional to the square of the distance from the source. The radiation source must be a point source

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$I_1 \times D_1^{\,2} = I_2 \times D_2^{\,2}$



**$I_1$** = Intensity at a distance D1 measured as (R/hr or mR/hr)

**$D_1$** = first Distance
**$I_2$** = Intensity at Distance D2
**$D_2$** = second Distance

# Radiation intensity

- The radiation intensity is defined as the amount of energy emitted per unit solid angle per unit area of the radiating surface.

$$\text{Radiation intensity } I = \frac{P}{A\omega}$$

- Where, P is emissive power, A is the area, and ω is the solid angle.
- The SI unit for emissive power is W and the SI unit for the area and solid angle is **m²** and **steradian** respectively.
- Therefore unit of radiation intensity is W/m2.sr
- Also, can be measured as(R/hr or mR/hr)

Example 1: If the intensity of point source = 100 IU at 1cm, what is its intensity at 10 cm?

Answer:
Given Information: $I_1$=100 IU, $D_1$=1 cm, $D_2$=10 cm, $I_2$=?

$$\boxed{I_1 \times D_1{}^2 = I_2 \times D_2{}^2}$$

$100 \times (1)^2 = I_2 \times (10)^2$
$100 = I_2 \times 100$
$I_2 = 1$ IU

Example 2: A reading of 100 mR/hr is obtained at a distance of 1 cm from a point source. What would be the reading at a distance of 1 mm?

Answer:

Given information
$I_1$= 100 mR/hr, $D_1$= 1 cm, $D_2$=1 mm =0.1 cm, $I_2$=?

$100 \times (1)^2 = I_2 \times (0.1)^2$

$100 = I_2 \times 0.01$

$I_2 = 100/0.01$

$I_2 = 10000$ mR/hr

## Terminology, Modeling

- **Terminology**

### Medical Physics

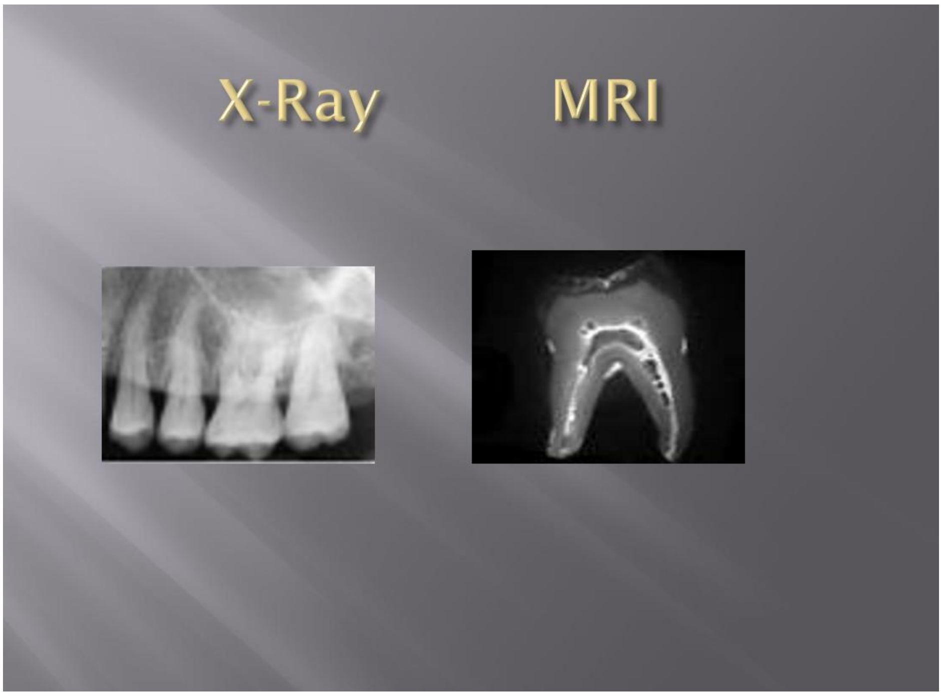
What about the forces of the body during various activities, or how much useful work can be done by the body, or the relationship of an electrocardiogram to the heart's electrical activity, or how a medical x-ray works, or how much radiation you receive from an x-ray? These questions and many others 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: -

1. The applications of physics to the function of the human body in health and disease.
2. 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.


X-Ray MRI

The word **physical** appears in a number of medical contexts. Only a generation ago in England a professor of physic was actually a professor of medicine. The words physicist and physician have a common root in the Greek word Physike (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 by means of 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. In fact, 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, 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. There are other mathematical expressions of this law that may look quite different to a lay person 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 $\Delta$ indicates a small change of the quantity. The quantity my is the momentum, and the part of the equation $\Delta/\Delta t$ means 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 negative feedback that it 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 the 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 have been found to be 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.

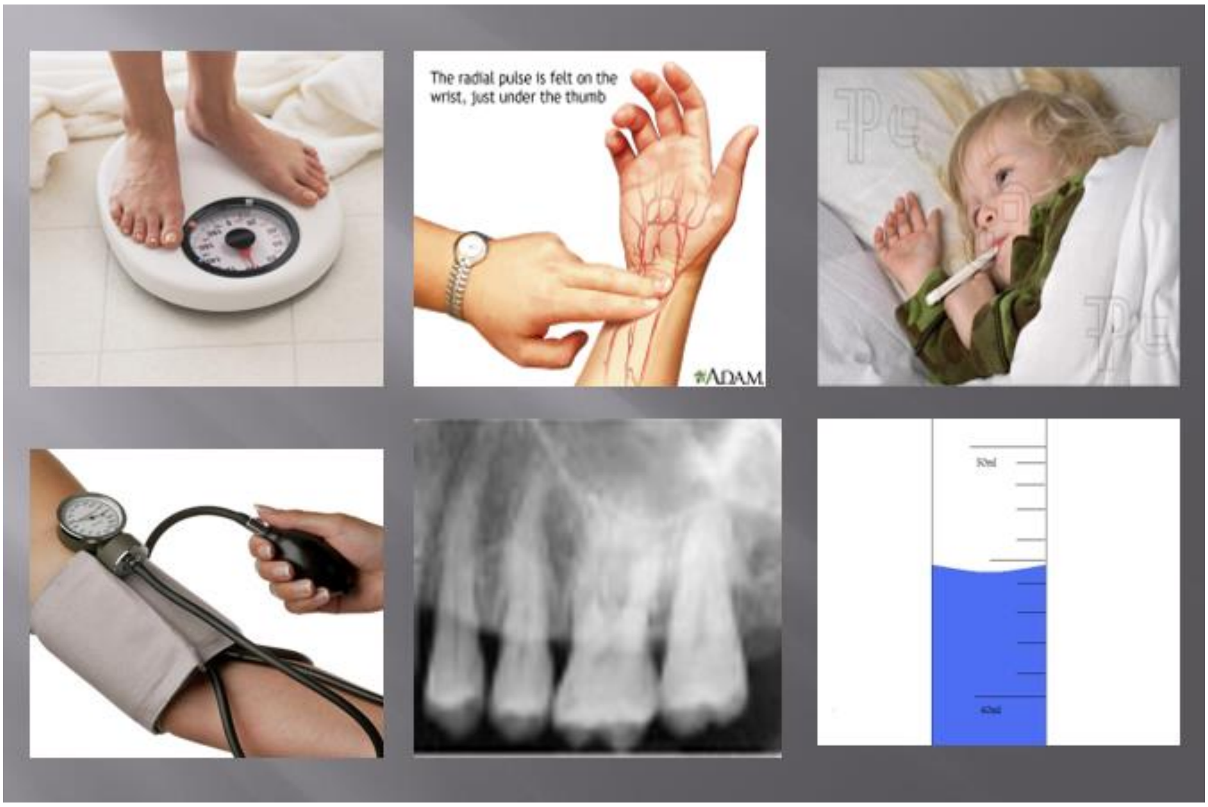
In the practice of medicine, early efforts to measure quantities of clinical interest were often scorned as detracting from the skill of the physician.

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 (1msec) 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 the 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.

### ***<u>When the physician decides if the patient is ill or not?</u>***

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.

***Note:*** **-** 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-she really had 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.

***<u>In summary: -</u>***

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.

**Medical Physics**

**Lecture**

# Ultrasound Imaging

Dr. Amal Yousif Al-Yasiri
College of Dentistry- University of Baghdad

## History of Ultrasound Imaging

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- End of 1960's: Boom of Ultrasound in medical imaging.
- Early 1970s: Gray scale static images of internal organs
- Mid 1970s: Real-time imaging
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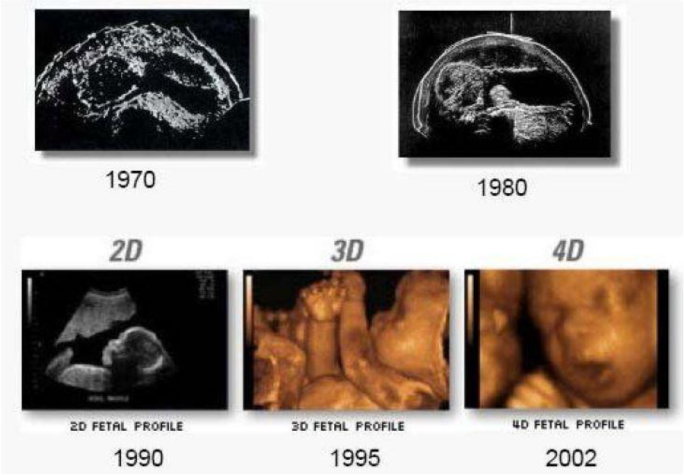
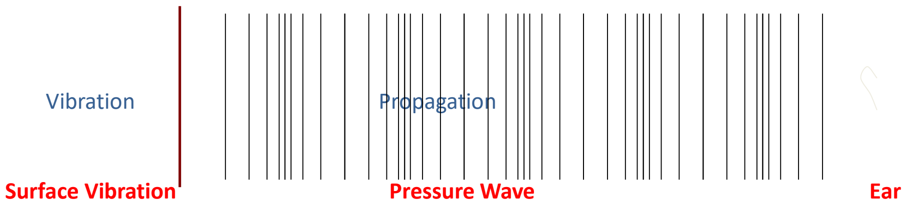


Development of the B-mode Ultrasound image quality

# Sound Wave

- Sound is a mechanical and pressure wave . Sound is a Longitudinal Wave.
- Mechanical vibration transmitted through an elastic medium
- Sound waves when propagate through air at appropriate audible frequency produce sensation of hearing



Vibration

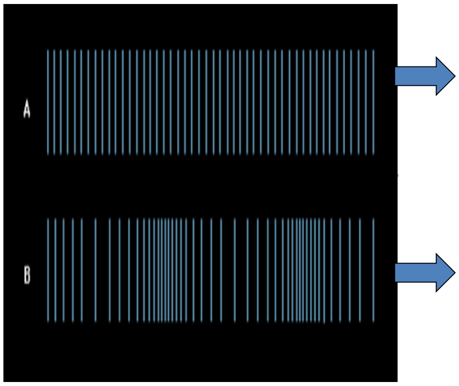
Propagation

**Surface Vibration**

**Pressure Wave**

**Ear**

# Sound Wave



*Air at equilibrium, in the absence of a sound wave*

*Compressions and rarefactions that constitute a sound wave*

# Velocity of Sound

- *Velocity = frequency x Wavelength*

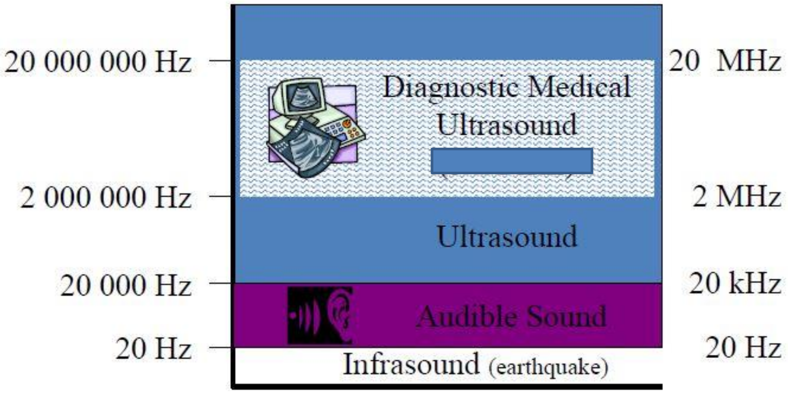
  $V=f\lambda$
- ***Frequency*** *– No. of wavelengths per unit time.*
- *Unit of measurement: 1 cycle/ sec = 1 Hz.*
- *Frequency is inversely related to wavelength*

- ***Velocity*** **–** *Speed at which waves propagate through a medium*
  - *Depends on the physical properties of the medium through which it travels*
  - *Directly proportional to the stiffness of the material*

# Velocity of Sound in different materials

| Material | Velocity ( m/s) |
|---|---|
| Air | 330 |
| Water | 1497 |
| Fat | 1440 |
| Blood | 1570 |
| Soft tissue | 1540 |
| Bone | 4060 |
| Metal | 3000 - 6000 |

# Frequency of Sound



# Ultrasound

- Ultrasound is sound with a frequency over 20,000 Hz
- The frequencies of medical Ultrasound waves are several magnitudes higher than the upper limit of → human hearing.
- Frequencies used for diagnostic ultrasound are between 2 to 20 MHz

- The basic principles and properties are same as that of audible sound

# Acoustic Impedance

The resistance that a material offers to the passage of a sound wave.

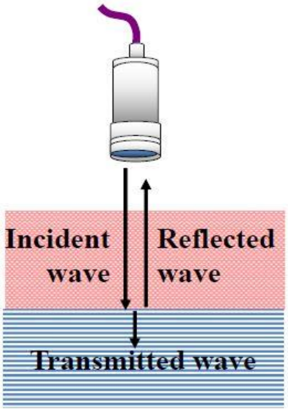
The difference between the acoustic impedances of the different tissue types are responsible for the echoes on which ultrasound imaging is based.

Unit of mesurement: Rayl = kg/m2.s

## Reflection at boundaries

The laws of optics apply to ultrasound

- At the boundary between tissues ultrasound is partially reflected
- The relative proportions of the energy reflected and transmitted depend on the acoustic impedance between the two materials

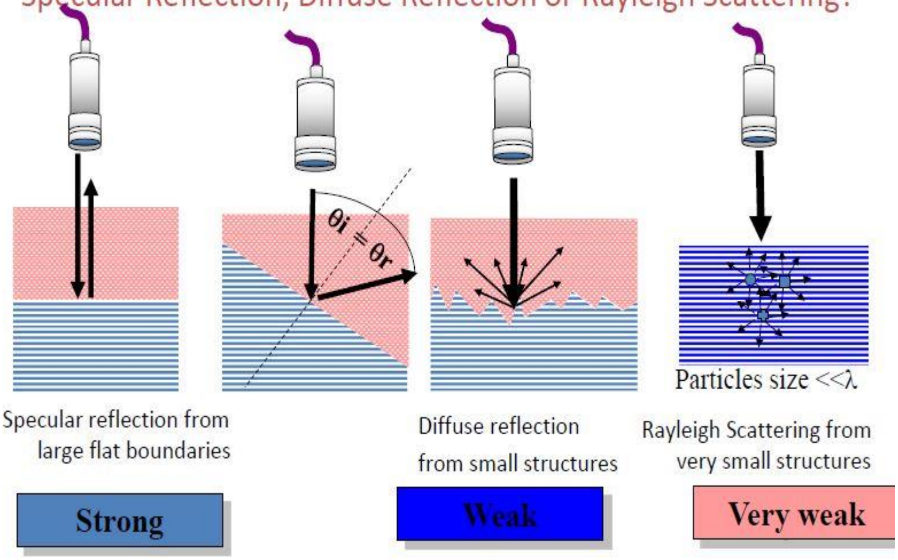


*Reflection : Basis of all ultrasound imaging.*

## Reflection at boundaries

- **Specular Reflection** (large, regularly shaped objects with smooth surfaces): Perpendicular Incidence to get → strong signal
- **Diffuse Reflection** (Small structures): Reflected waves travel in various directions away from the interface → weak signal
- **Rayleigh Scattering** (Particles size << λ): Waves are scattered and travel off in all directions → Very weak signal

## In tissue:
## Specular Reflection, Diffuse Reflection or Rayleigh Scattering?



Specular reflection from large flat boundaries

Diffuse reflection from small structures

Rayleigh Scattering from very small structures

**Strong**

**Weak**

**Very weak**

# *Attenuation*

*Attenuation: Loss of intensity and amplitude of ultrasound wave as it travels through the tissues, due to reflection, scattering and absorption( dissipation as heat).*

*Proportional to Frequency and the distance the wave front travels*

- *Higher frequency, more attenuation*
- *Longer the distance (Depth), more the attenuation*

# Ultrasound generation

1- Equipment and principle

- Ultrasound scanners consist of a console containing a computer, a screen, and a transducer that is used to do the scanning.
- The transducer, which can convert one form of energy into another, is a small hand-held device that resembles a microphone, attached to the scanner by a cord.
- The transducer converts electrical impulses into ultrasound waves and sends them into the body. Then listens for the returning echoes from the tissues in the body and converts these echoes into electrical impulses.
- The ultrasound image is immediately visible on a video display screen that looks like a computer or television monitor

The most important component of the transducer is a thin piezoelectric crystal or material

transducer uses a piezoelectric to generate and receive ultrasound waves

The piezoelectric element vibrates to generate a sound wave when applied with a voltage.

Currently, the most widely used piezoelectric material is lead zirconate titanate (PZT).

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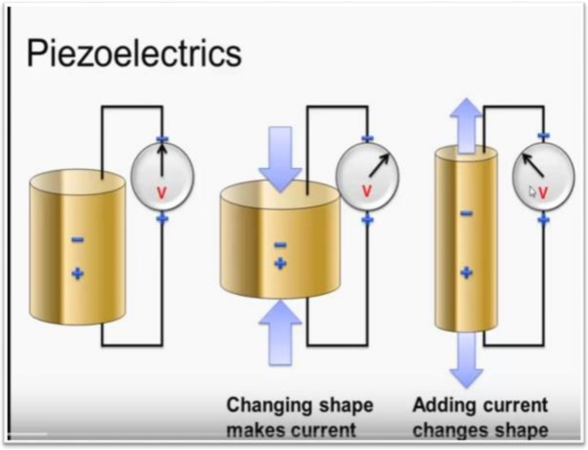
2- Piezoelectric effect:

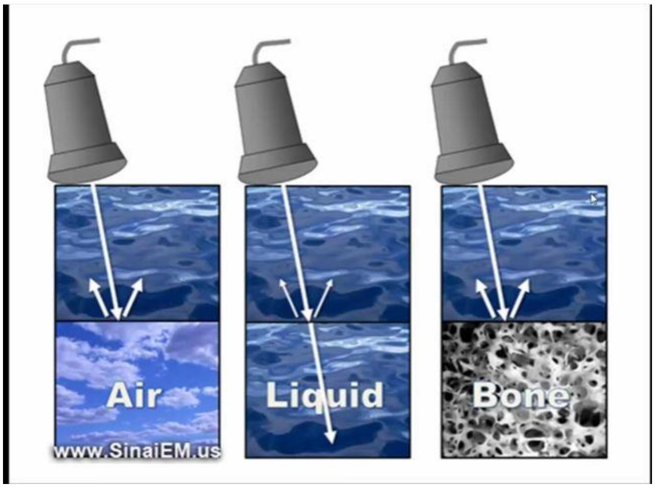
*piezoelectric crystal or material has the ability to generate an electric charge in response to applied mechanical stress and vise versa.*



# Image formation

- As the ultrasonic beam passes through or interacts with tissues of different acoustic impedance, it is attenuated by a combination of absorption, reflection, refraction, and diffusion.
- Sonic waves that are reflected back (echoed) toward the transducer cause a change in the thickness of the piezoelectric crystal, which in turn produces an electrical signal that is amplified, processed, and ultimately displayed as an image on a monitor.
- The fraction of the beam that is reflected back to the transducer depends on the acoustic impedance of the tissue

# Image formation



The fraction of the beam that is reflected back to the transducer depends on the acoustic impedances of the two tissues.
See the Figure

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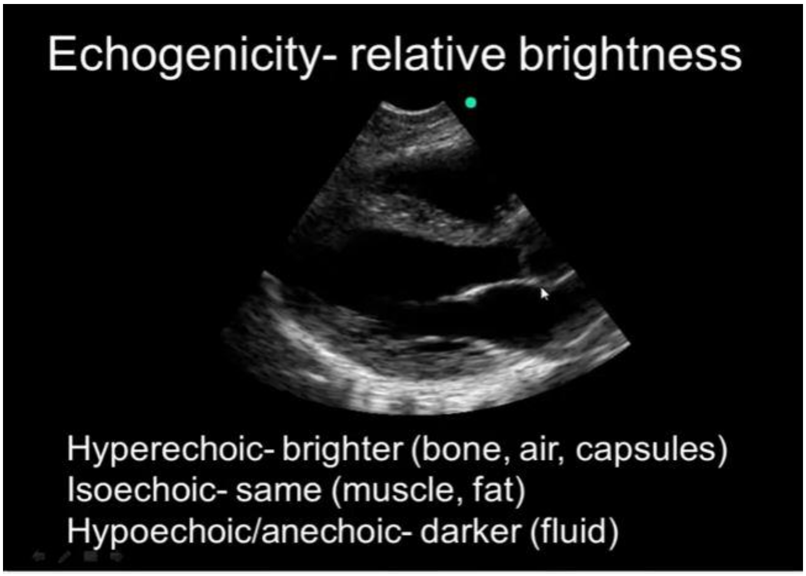

Echogenicity- relative brightness

Hyperechoic- brighter (bone, air, capsules)
Isoechoic- same (muscle, fat)
Hypoechoic/anechoic- darker (fluid)

# How is the US procedure performed?

- For most ultrasound exams, the patient is positioned lying face-up on an examination table.

- A clear water-based gel is applied to the area of the body being examined to eliminate air pockets between the transducer and the skin that can block the sound waves from passing into your body.

- The sonographer (ultrasound technologist) or radiologist then presses the transducer firmly against the skin in various locations to better see an area of concern.

# Benefits vs. Risks

- **Benefits**
- Most ultrasound scanning is noninvasive (no needles or injections) and is usually painless.
- Ultrasound imaging does not use any ionizing radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Ultrasound provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle biopsies and needle aspiration.
- **Risks**
- For standard diagnostic ultrasound there are no known harmful effects on humans.
- Sound waves can increase body temperature (This is known as cavitation). Significant only for long exposure time.

## Limitations of General Ultrasound Imaging

- Ultrasound waves are disrupted by air or gas; therefore, ultrasound is not an ideal imaging technique for air-filled bowel or organs obscured by the bowel. In most cases, CT scanning, and MRI are used.
- Ultrasound has difficulty penetrating bone and, therefore, can only see the outer surface of bony structures and not what lies within. For visualizing internal structure of bones or certain joints, other imaging modalities such as MRI and X-rays are typically used.
- Large patients are more difficult to image by ultrasound because a greater amount of tissue attenuates (weakens) the sound waves as they pass deeper into the body.

## References

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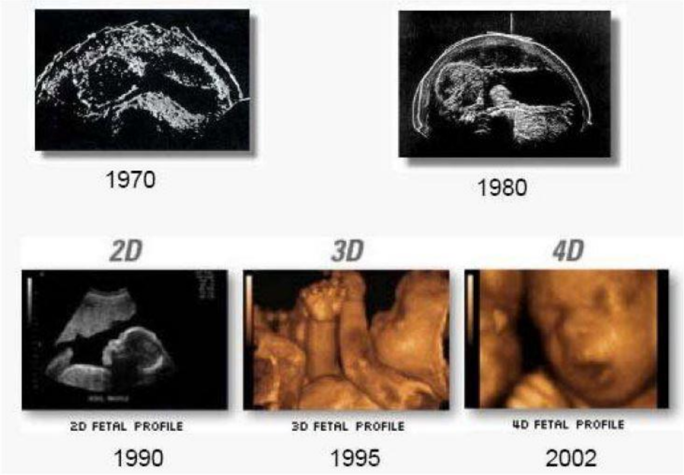

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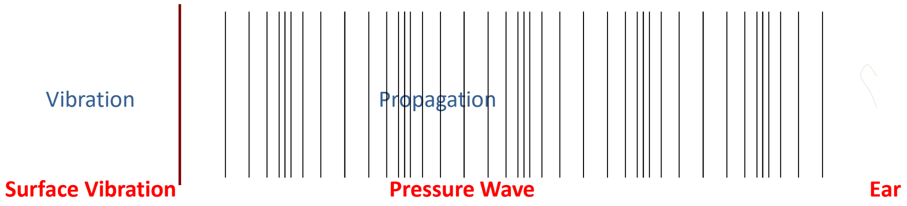

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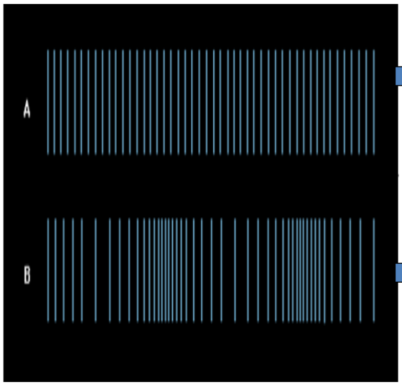

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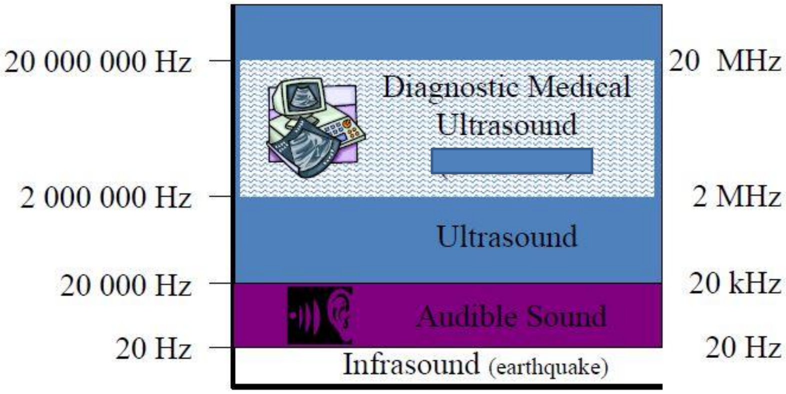

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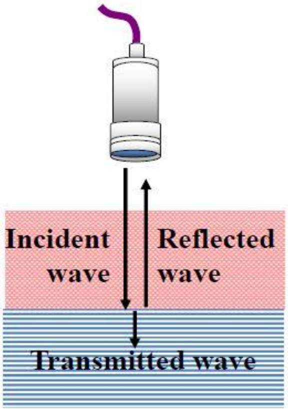

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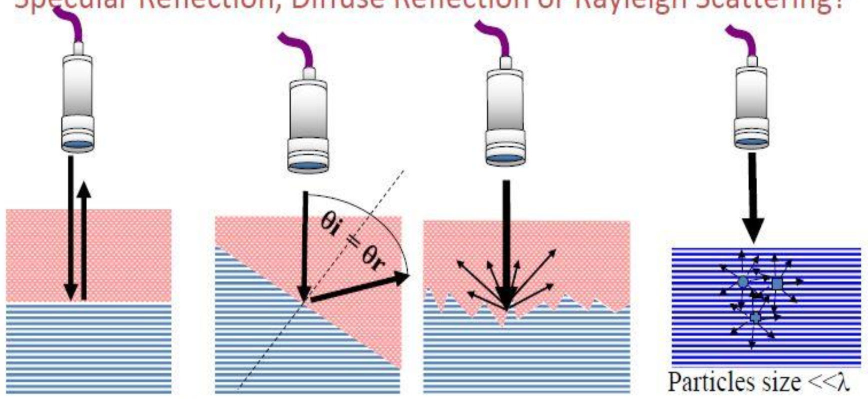

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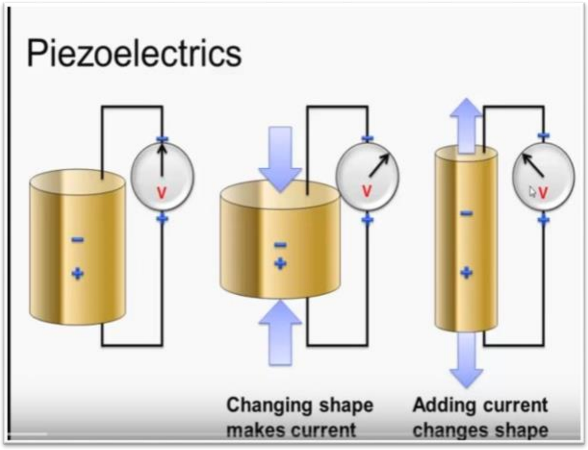

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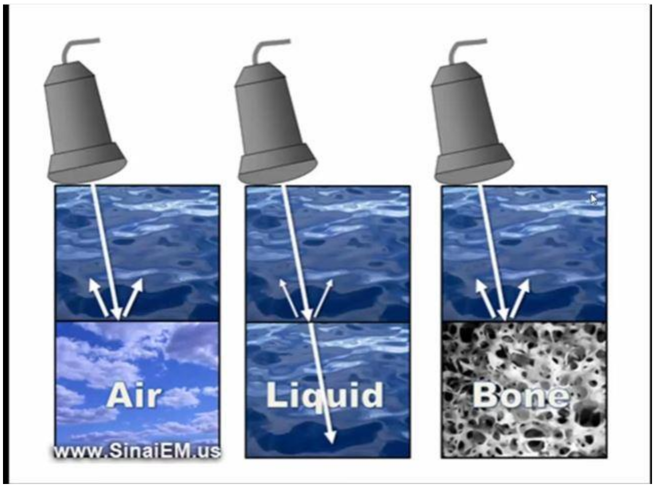

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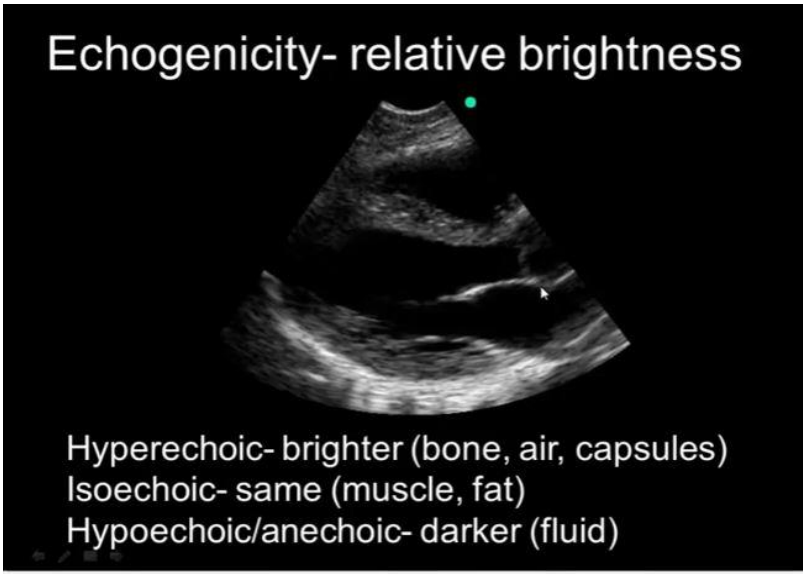

Echogenicity- relative brightness

Hyperechoic- brighter (bone, air, capsules)
Isoechoic- same (muscle, fat)
Hypoechoic/anechoic- darker (fluid)

## How is the US procedure performed?

- For most ultrasound exams, the patient is positioned lying face-up on an examination table.
- A clear water-based gel is applied to the area of the body being examined to eliminate air pockets between the transducer and the skin that can block the sound waves from passing into your body.
- The sonographer (ultrasound technologist) or radiologist then presses the transducer firmly against the skin in various locations to better see an area of concern.

## Benefits vs. Risks

- **Benefits**
- Most ultrasound scanning is noninvasive (no needles or injections) and is usually painless.
- Ultrasound imaging does not use any ionizing radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Ultrasound provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle biopsies and needle aspiration.
- **Risks**
- For standard diagnostic ultrasound there are no known harmful effects on humans.
- Sound waves can increase body temperature (This is known as cavitation). Significant only for long exposure time.

## Limitations of General Ultrasound Imaging

- Ultrasound waves are disrupted by air or gas; therefore, ultrasound is not an ideal imaging technique for air-filled bowel or organs obscured by the bowel. In most cases, CT scanning, and MRI are used.
- Ultrasound has difficulty penetrating bone and, therefore, can only see the outer surface of bony structures and not what lies within. For visualizing internal structure of bones or certain joints, other imaging modalities such as MRI and X-rays are typically used.
- Large patients are more difficult to image by ultrasound because a greater amount of tissue attenuates (weakens) the sound waves as they pass deeper into the body.

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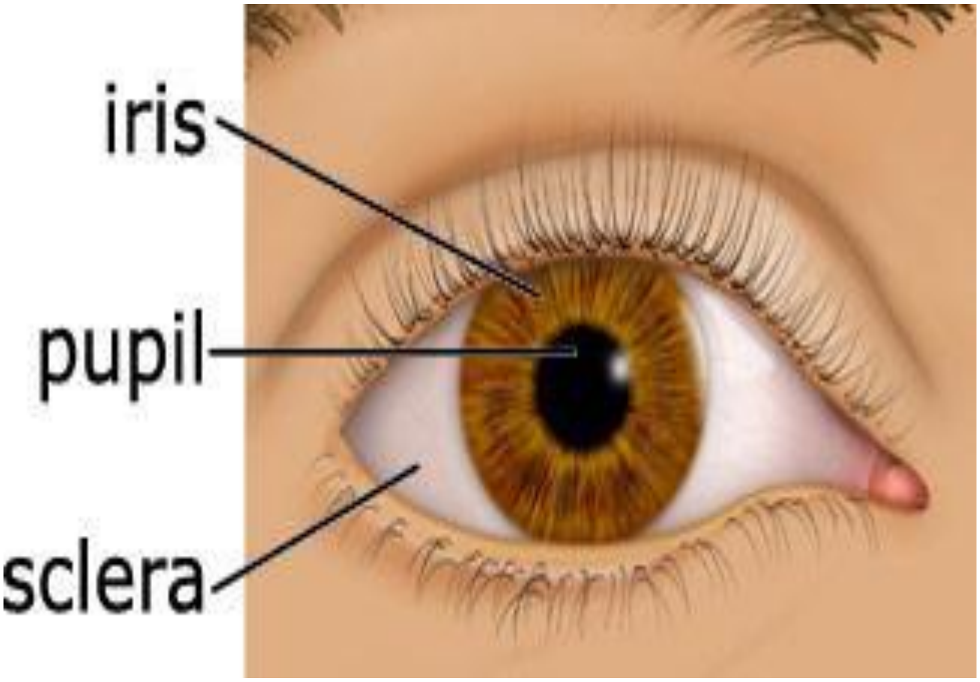
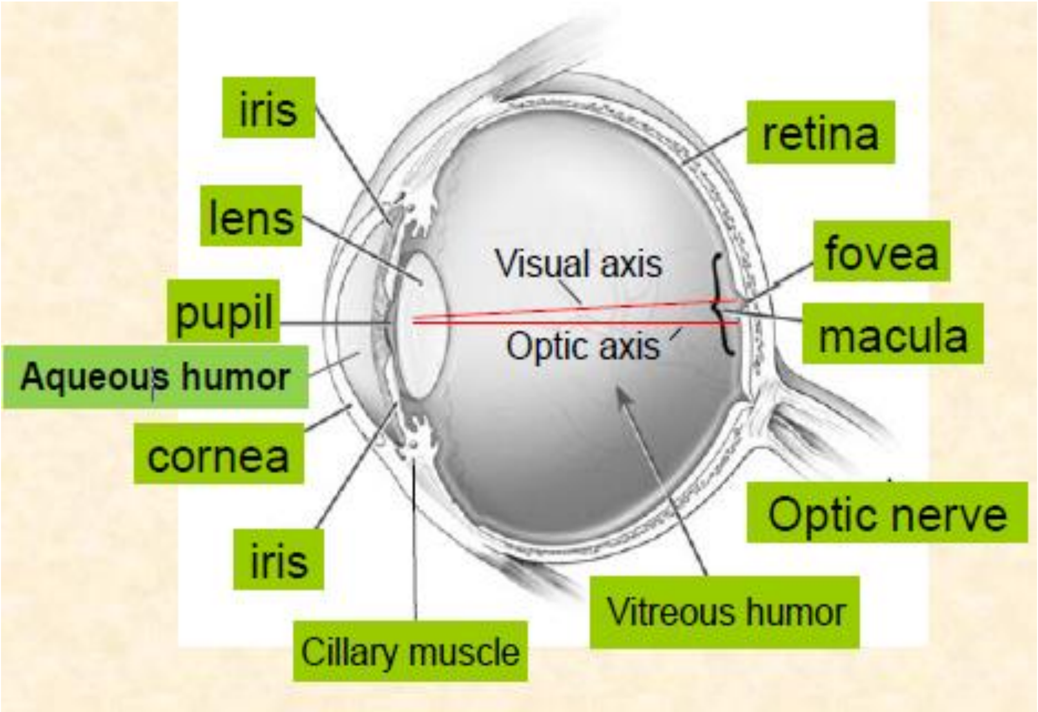
# Vision

## Eye


iris
pupil
sclera


iris
lens
pupil
Aqueous humor
cornea
iris
Cillary muscle
Visual axis
Optic axis
retina
fovea
macula
Optic nerve
Vitreous humor

The eye produces a real, inverted image of the object being viewed. The image is produced on the **retina** the light-sensitive region at the back of the eye.

**The cornea**: It is a fixed focusing element, and it is a clear transparent bump in front of the eye, it does≈ 2/3 of the focusing, it focuses by refracting the light rays.

**The pupil:** Is the opening in the center of the iris where light enters the lens. Under normal condition of light intensity the opening is about 4mm in diameter. It can change from about 3mm in diameter in bright light to about 8mm in diameter in dim light.

**The iris:** Is a (pigmented) diaphragm that controls the intensity of the light reaching the retina. It does this by adjusting the size of the pupil in response to signal from the retina. In other words Iris regulates the amount of light entering the eye by controlling the diameter of the pupil.

**The sclera:** (the white of the eye) is the eyes tough outer cover. Its inner lining, the **choroid**, provides the blood supply for the retina. It contains a large amount of black pigment in order to reduce reflection of the light within the eye and so prevent blurring of the image.

**The aqueous humor**: It is a fluid fills the space between the cornea and the lens. This fluid is mostly water. It is continuously being produced and the surplus escapes through a drain tube (canal of schlemm). Blockage of the drain tube result in increased pressure in the eye, this is called **glaucoma**. It maintains the internal pressure of the eye at about 20mmHg.

**The vitreous humor**: Is a clear jelly – like substance that fills the large space between the lens and retina. It helps keep the shape of the eye fixed and permanent. It is sometimes called the vitreous body.

**The lens:** Lens contributes only about 25% of the refractive power of the eye.

**Ciliary muscles:** The shape, and therefore the focal length, of the eye lens can be altered by the action of the ciliary muscles attached to it. This makes it possible for light from objects which are at different distances from the eye to be brought to a focus on the retina which is at a fixed distance from the lens.

**Retina** consists of millions of **photo-receptors** called **rods** ($1.3x10^8$) and **cones** ($7x10^6$) **c**onverts light energy into electrical energy. These structures send electrical impulses to the brain via the optic nerve.

**Fovea** is the most sensitive part of retina slightly off center and it contains only cons.

**Macula** is a larger area including and surrounding the fovea and contains rods and cons.

**Blind spot** on retina at **optic disk.** At the **optic disk** there are no photo-receptors. **Blind spot** not noticeable because each eye compensates by seeing what the other doesn't. Blind spot is the point at which the optic nerve joints the eye (from the brain).

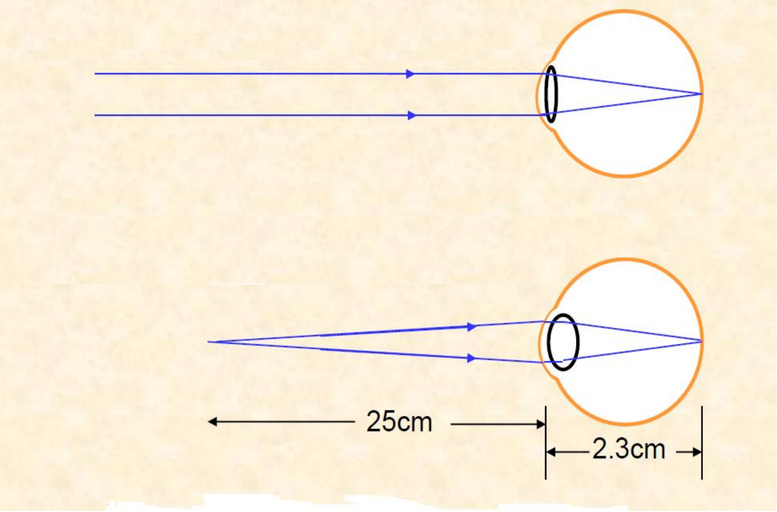
**Q- Why do we call the blind spot?**

Because: there are no light-sensitive receptors there.

## Accommodation

Lens to retina distance is fixed. **Focal length** (and hence the power) of the lens **must vary** to ensure objects at various distances can be brought to a focus at the retina process called **Accommodation**

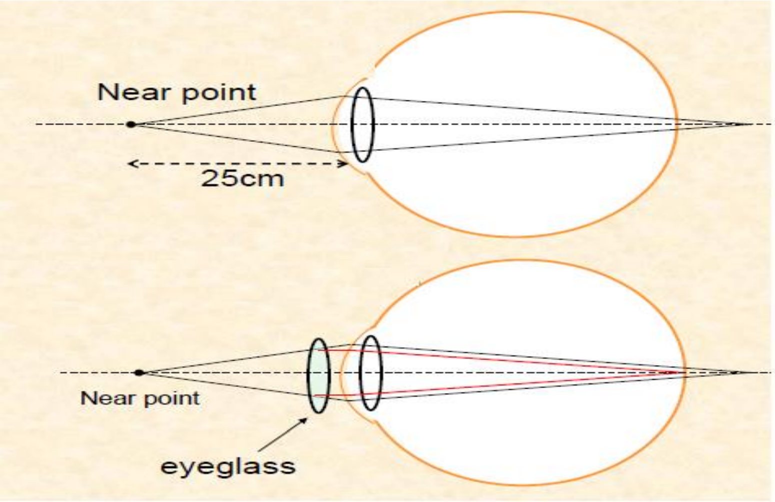
**Normal eye** is capable of focusing on objects over a range from infinity (far point) (eye muscles relaxed) to the near point of 25 cm. Near point increases with age.



# Eye defects

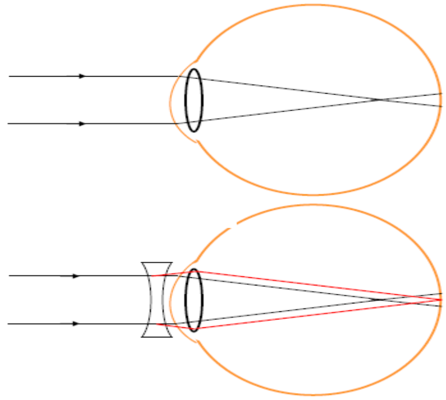
## Farsightedness (hyperopia)

Object at normal near point, eye lens cannot be made sufficiently converging to bring object to focus on retina; lens to weak (focal length to long). Converging eyeglass lens required to ensure focus at retina.



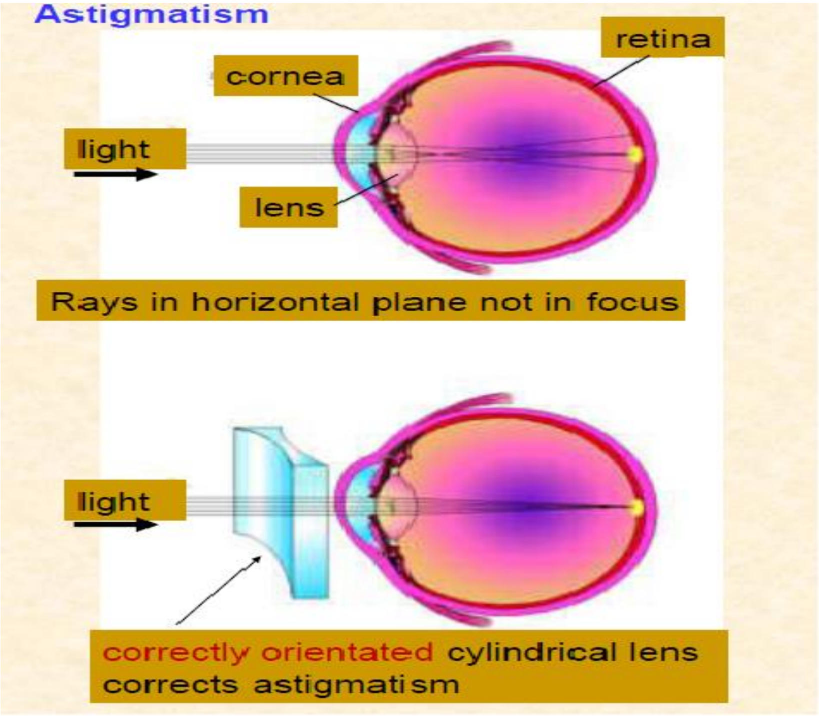
## Nearsightedness (myopia)

Eye lens cannot relax sufficiently to focus a very distant object on the retina, **lens to strong** (focal length to short). Diverging eyeglass lens required to ensure focus at retina.



## Astigmatism

Results from an asymmetry in the cornea (irregular curvatures). Cornea: different curvature in different directions. Astigmatism can be corrected using cylindrical lenses, correctly orientated



# Presbyopia

**Loss of accommodation** (presbyopia) Inability for eye to **accommodate** increases with age. Lens becomes less flexible and can no longer change its strength over the normal range. Eventually affects nearly everyone; difficulty in seeing near and distant objects clearly.

# Visual Acuity

Visual acuity is ability of the eye to see fine detail; also known as spatial resolving power.

**The factors that limit visual acuity are:**

- Illumination,
- Contrast
- Location of image on retina.

Someone with 6/6 or 20/20 vision (visual acuity) is just able to decipher an object (letter) that another one with 6/9 vision is not.

6/6 not perfect
Young adults 9/6 or 10/6
Hawk 60/6

# Electromagnetic Waves

## Visible waves

- Wavelength: ≈ 400 nm -700 nm

The only waves the eye can see

Red light has the highest wavelengths and violet has the lowest.

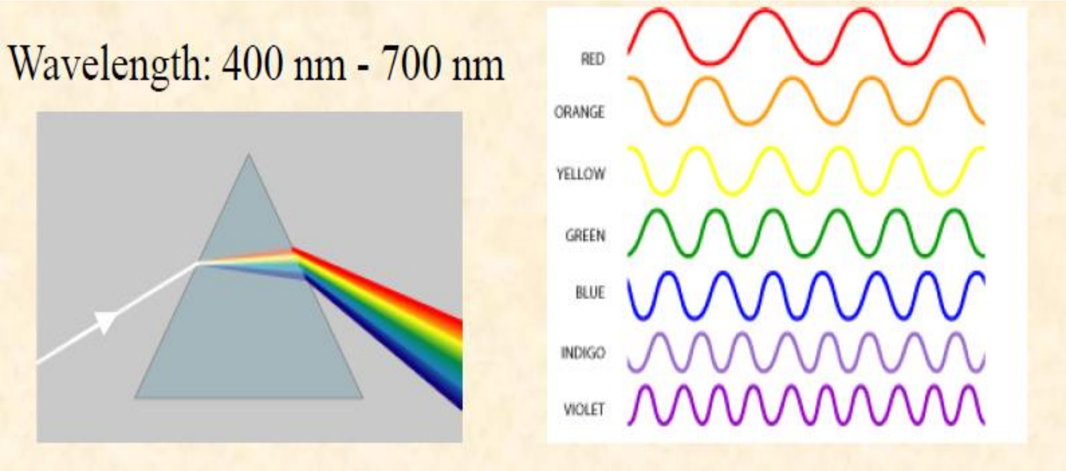
# Color Vision

Isaac Newton (1643—1727) demonstrated that white light is composed of several colors.

White light passing through a prism is separated into its constituent colors.

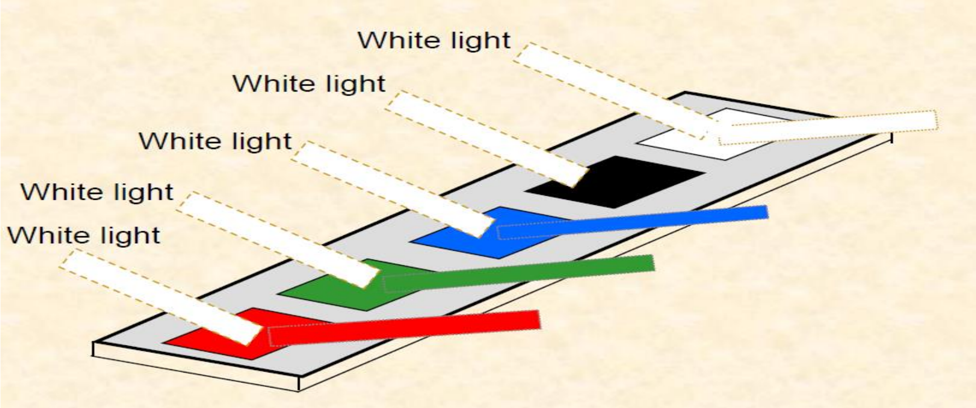
Reason: refractive index of the glass in the prism varies with wavelength (colour)

This variation of refractive index with wavelength is called **Dispersion**



Objects have a particular colour because of their **reflection/absorption** characteristics.

For example; an apple appears green because all wavelengths except green are absorbed; **green** is reflected.



Various levels of absorption will result in an object having more complex shades of colour.

**Rods and Cones** are light sensitive cells in the retina:

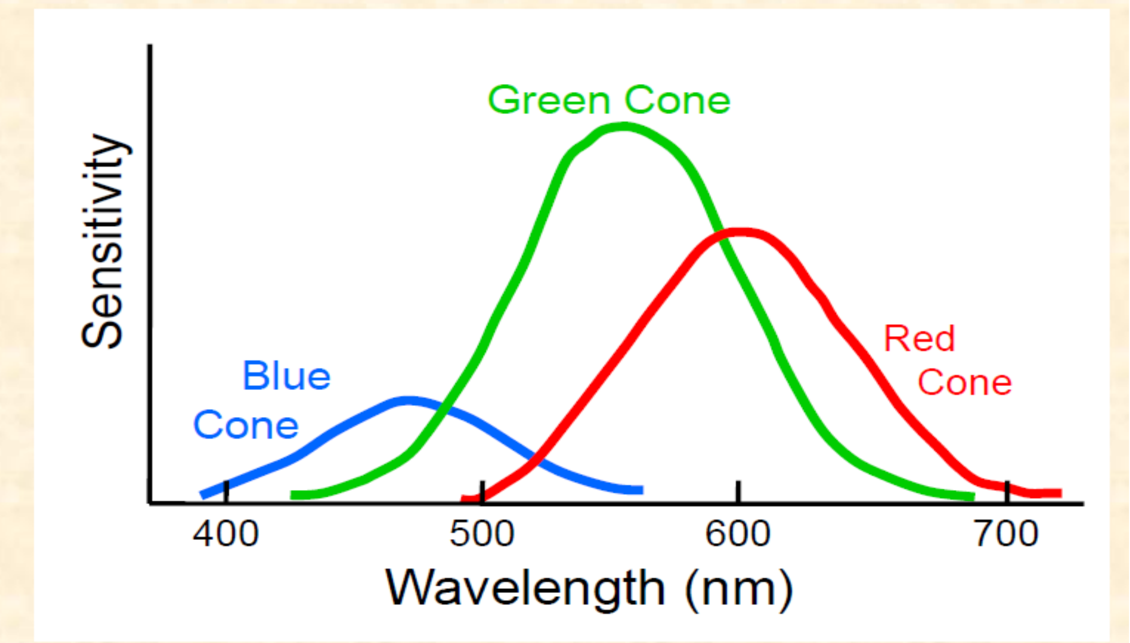
**Cones**

- Less sensitive
- Colour vision
- Concentrated in fovea

**Rods:**

- Highly sensitive
- Low light level vision
- Peripheral vision
- Almost no colour information

**3 kinds of cones:** each one sensitive to a different array of wavelength



**Color blindness** results from absence of one or more types of cones

The sensitivities of the three cones overlap and the perceived color is due to the relative response of the three cones.

## Color matching

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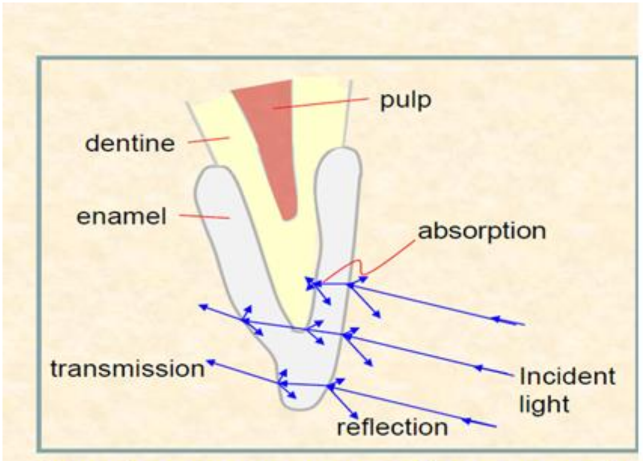
- Colour matching impaired by colour blindness which results from absence of one or more types of cones as mentioned.
- **Colour fatigue** is resulted from prolonged exposure to one colour reduces the response of the eye to that colour.

- **Perceptual Psychology**: For example appearance of an object depends on the background colour. Dark backgrounds make materials appear brighter.

- In dentistry color matching must be taken in account in restorative work.
- Tooth enamel is translucent when the light passes through it. So the main colour of tooth is that of dentine colour.



Dentine more opaque than enamel

# Medical Physics

# Production and Characteristics of X- Rays

Dr. Amal Al-Yasiri

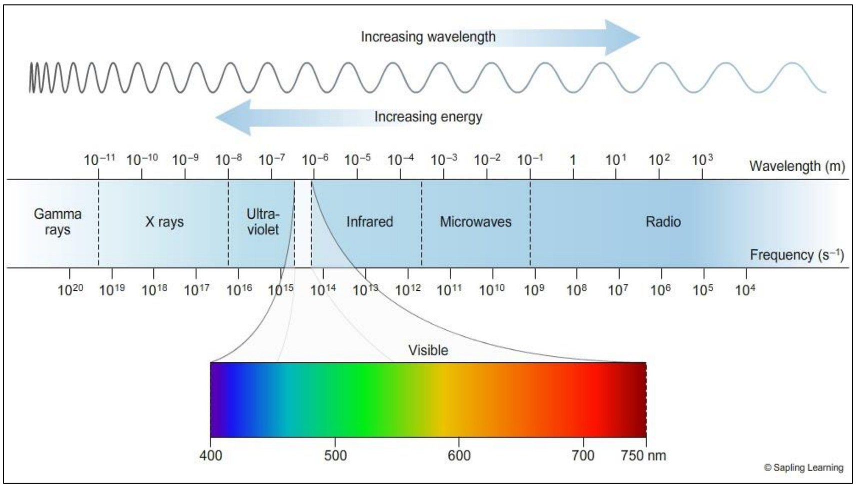
College of Dentistry-University of Baghdad

## Electromagnetic Radiation

- Electromagnetic radiation can be described in terms of a stream of photons, each traveling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy.
- The different types of radiation are defined by the amount of energy found in the photons. Radio waves have photons with low energies while gamma-rays the most energetic of all.
- Electromagnetic radiation can be expressed in terms of energy, wavelength, or frequency.

## General Properties of all electromagnetic radiation

- Electromagnetic radiation can travel through empty space.
- They travel at speed of light (Speed of light : 2.99792458 x $10^8$ m $s^{-1}$)
- Consist of photons which are uncharged and nearly massless.
- They all have wavelike characteristics
- λ = c/F where λ= wavelength, c=velocity of electromagnetic wave(3x$10^8$m/sec), and F= Frequency



X - Ray: - It is an electromagnetic radiation with wavelength range (0.01 – 10 nm)

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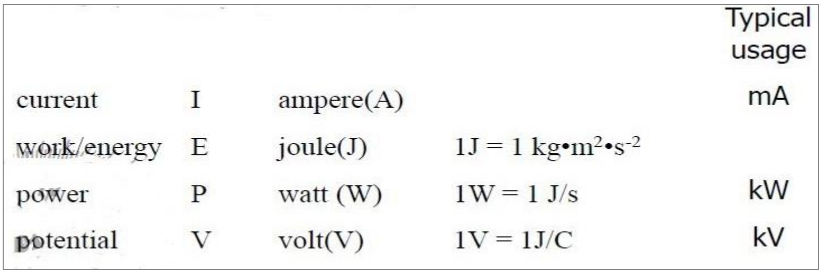
# Fundamental units (Review)



| | | | | Typical usage |
|---|---|---|---|---|
| current | I | ampere(A) | | mA |
| work/energy | E | joule(J) | $1J = 1\ kg \bullet m^2 \bullet s^{-2}$ | |
| power | P | watt (W) | $1W = 1\ J/s$ | kW |
| potential | V | volt(V) | $1V = 1J/C$ | kV |

- Electron Volt (eV) : e- accelerated through 1 V attains an **energy** of 1eV. Used to describe energy of a single electron or photon or population of monoenergetic particles

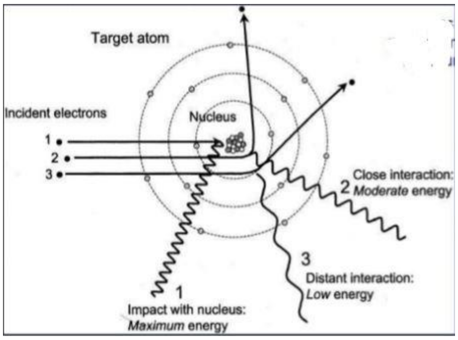
# X-rays

- X-rays are one of the main diagnostic tools in medicine since its discovery by Wilhelm Roentgen in 1895.
- Nowadays, X-rays with very high energy (around 10 MeV) is used for therapeutic applications
- X-rays are produced when high energetic electrons interact with matter.
- The kinetic energy of the electrons is converted into electromagnetic energy by atomic interactions

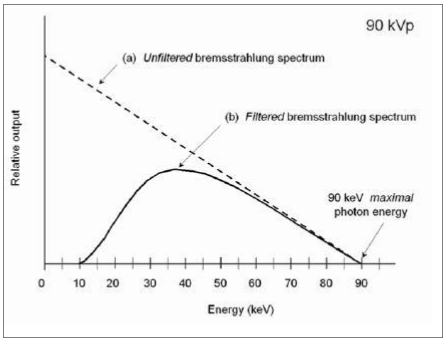
# X-ray production

- Two types of electron interactions are responsible for x-rays production.
- Bremsstrahlung mechanism
- Characteristic mechanism

# Bremsstrahlung "braking radiation"



An electron interaction with nucleus to produce Bremsstrahlung



Bremsstrahlung spectrum created from 90 keV electrons

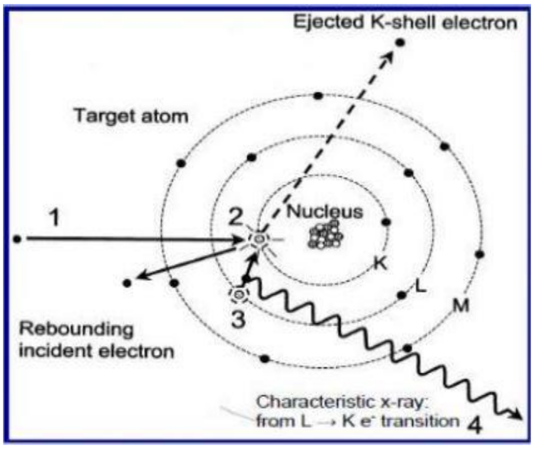
## Bremsstrahlung “braking radiation”

- Incoming electron is both energetic (high kinetic energy) and charged (negative)
- This electron comes within the proximity of a positively charged nucleus in the target.
- Columbic forces attract and decelerate the electron, causing a significant loss of kinetic energy and a change in the electron's trajectory.
- An x-ray photon with energy equal to the kinetic energy lost by the electron is produced (conservation of energy). This radiation is termed Bremsstrahlung “braking radiation”

## Bremsstrahlung “braking radiation”

- The X-ray energy depends on the interaction distance between the electron and the nucleus.
- A direct collision of an electron with the target nucleus results in loss of all of the electron’s kinetic energy ⟶ the highest x-ray energy is produced ( very low probability)

# Characteristic Radiation



# Characteristic Radiation

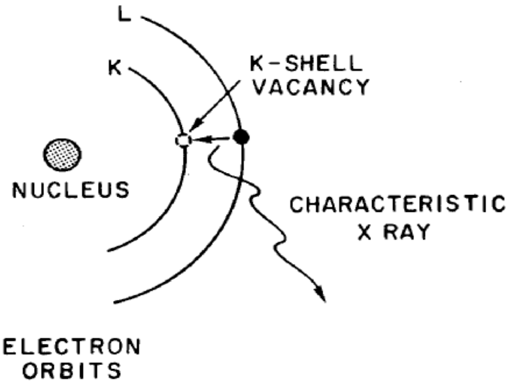


Fig. . **Emission of characteristic x rays occurs when orbital electrons move from an outer shell to fill an inner-shell vacancy. ($K_\alpha$ x-ray emission illustrated.)**

# Characteristic Radiation

- Energetic electrons can also interact with other electrons occupying orbital shells, which results in X-ray photons (Characteristic Radiation)
- Generation of a Characteristic X-ray in a target atom occurs in the following sequence:

1- The incident electron interacts with the K-shell electron via a repulsive electrical force

2- The K-shell electron is removed (only if the energy of the incident electron is greater than the K-shell binding energy), leaving a vacancy in the K-shell.

3- An electron from L- shell (or from a different shell) fills the vacancy.

4- A characteristic X-ray photon is emitted with an energy equal to the difference between the binding energies of the two shells.

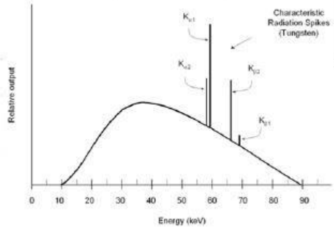
# Characteristic Radiation

- Resultant X-ray energy is dependent on the difference in energy levels between electron orbits
- For a given target material (i.e. tungsten), the orbital energy levels are constant.
- Therefore, the emitted X-rays have discrete energies that are characteristic of the element (i.e. the characteristic x-ray photons can identify the target material

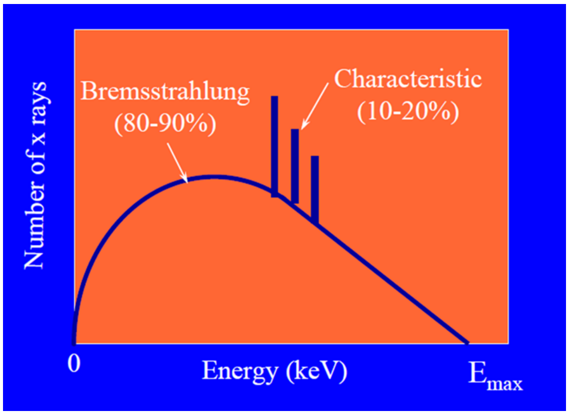
# Characteristic Radiation

Tungsten
W

| Binding Energy (keV) | | | X-ray photon (keV) | |
|---|---|---|---|---|
| K | L | M | | |
| 69.5 | 12.1 | | $K_{\alpha1}$ | 57.4 |
| | 11.5 | | $K_{\alpha2}$ | 58.0 |
| | | 2.3 | $K_{\beta1}$ | 67.2 |



# Typical x-ray Spectrum

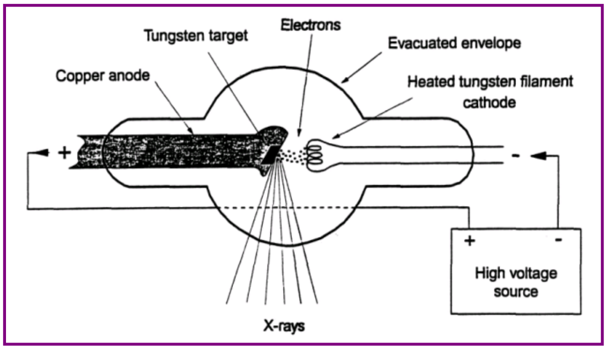


# X-Ray production

- Not all of the lost kinetic energy is converted to photon energy
- Vast majority of energy is converted to thermal energy (heat)
- <1% of kinetic energy is converted to photons
- Conversion is more efficient at higher energy levels (i.e. therapy)

# X-Ray Tube

- The X-ray tube provides an environment for X-ray production via Bremsstrahlung and characteristic radiation mechanisms.



# X-Ray Tube

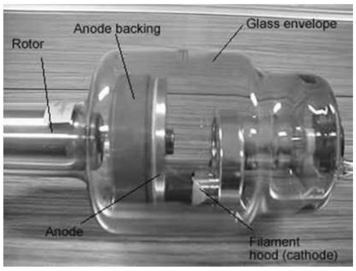
- Major Components of an X-Ray Tube are

1- Cathode (Electron Source)

2- Anode (target for X-ray production)

3- Glass or metal envelope

4- Tube Housing



# X-Ray Tube

1- Cathode

- The source of electrons in the X-ray tube is the cathode, which is filament of tungsten wire
- The cathode is the negative pole of the tube potential
- Electrons are accelerated from the negative cathode to the positive anode (target)

# X-Ray Tube

2- Anode (Target)

- What are the two primary considerations when considering target material?
  - ► Characteristic X-ray energy
  - ► Thermal properties of the target
- Remember, 99% of the imparted energy is dissipated as heat
- Tungsten has excellent thermal properties (high melting point, thermal dissipation)
- Tungsten has a high atomic number (74) producing useful characteristic x-rays

# X-Ray tube

3-Tube Envelope

- Maintains vacuum in electron pathway. The high vacuum prevents electrons from colliding with gas molecules.
- Typically made of glass, sometimes metal
- Specialized tube port is provided through which the useful x-rays emerge

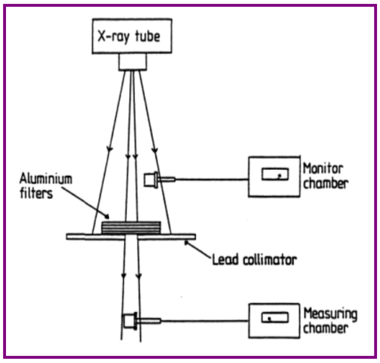
# X- Ray Tube

4-Tube Housing

- Supports, insulates, and protects tube envelope
- Tube enveloped is contained within a oil bath to assist in dissipating heat
- Micro-switches in the housing will shut down the unit in event of excessive heat
- Lead shielding attenuates x-ray photons not exiting through the port

# Filtration

- Large abundance of low energy x-rays will increase patient dose while not contributing to image quality.
- These lower energies are therefore filtered out by aluminum or copper absorbers of various thickness.



# Attenuation of X-rays

- The intensity of X-Ray drops exponentially with the thickness x

$$I = I_0 e^{-\mu x}$$

I = intensity of the transmitted beam

$I_0$= intensity of incident beam

x = thickness of attenuator

μ = linear attenuation coefficient

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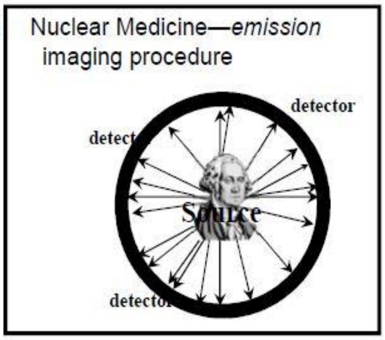
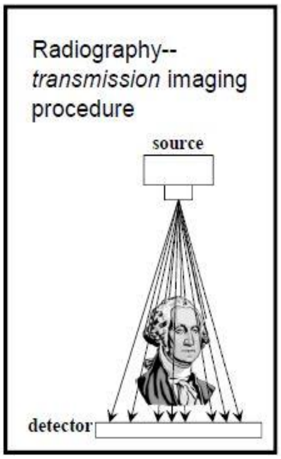
- The linear attenuation coefficient is determined in terms of the Half-Value Layer (HVL)
- (HVL) is the thickness of a material necessary to reduce the intensity of radiation to 50% of its original value.

$$\mu = \ln(2) / HVL$$

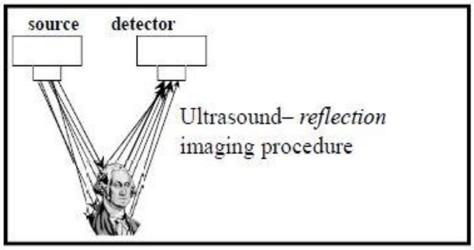
# Imaging Procedure Types



Nuclear Medicine—*emission* imaging procedure



Radiography-- *transmission* imaging procedure

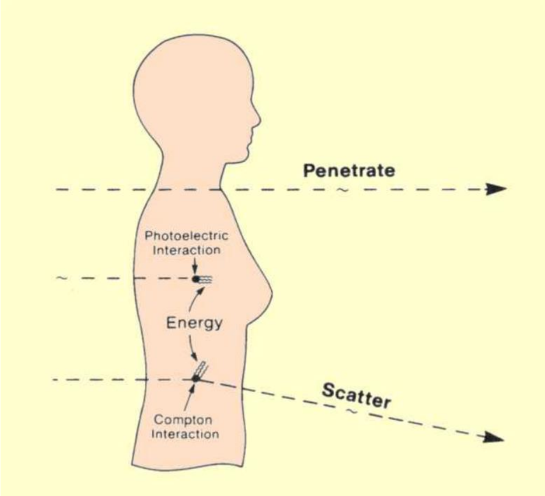


Ultrasound– *reflection* imaging procedure

# Radiography Imaging

- The radiographic image of the X-ray exposure is determined by the interaction of the X-rays, which are transmitted through the patient, with a photon detector (film, camera etc.) .
- As an x-ray beam passes through an object (patient), three possible fates await each photon.
- 1. It can interact with the matter and be completely absorbed by depositing its energy.
  2. It can penetrate the section of matter without interacting. It is called primary X-ray photon (it carry useful information).
- 3. It can interact and be scattered or deflected from its original direction and deposit part of its energy. It is called secondary photon. They create background noise which degrades the contrast of the image. Scattered photons are often absorbed in grids between the patient and the image receptor.

# Radiography Imaging



# Radiography Imaging

# Radiation Protection

There are three principle methods by which radiation exposures to persons can be minimized.

This system is called AS Low As Reasonably Achievable (ALARA)

1- Time (Should be reduced)

2- Distance ( Should be increased), Apply inverse square law in which doubling the distance will reduce the radiation exposure by $(1/2)*^2$

3- Shielding: Shielding is used to reduce exposure to patients, staff, and the public

# Homework

- 1- X-rays used in a dental clinic typically have a wavelength of 0.03 nm. What is the frequency of these rays?
- 2- The HVL for Pb for a particular energy x-ray is 0.1mm. By how much will an x-ray beam be reduced, if a lead sheet 1.5mm thick is placed in its path?

# Homework

- Explain briefly (no more than two sentences). Why do the lungs appear dark or black while the bones appear bright or white in this radiographic film.(hint: How Does the atomic number of the lungs and bones have an effect on the X-rays interaction and eventually on the appearance of the image

Answer: bones attenuate almost of x-ray beam because they have high atomic number. Therefore, the area represents bones, appears bright. While the Lungs have very low atomic number, therefore, most of x-ray pass through them without attenuation, so they will interact with film and form dark area

# References

- The Essential Physics of Medical Imaging. JT Bushberg, JA Seibert, EM Leidholdt, JM
- https://sites.google.com/site/chempendix/em-spectrum