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Medical physics

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Textbook

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Physics of the Human Body

Second Edition

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Medical physics

Medical physics overlaps two very large fields of medicine and physics, which aims to study;

- The application of physics to understand the function of the human body in health and disease, it is called the physics of physiology.
- The physics of the instruments that are used in medicine.
- The medical application of; laser light, UV light, IR light, Nuclear radiation, radiological physics

Course Weekly Outline

weeks	Topic Covered
1st week	An introduction to medical physics
2nd week	Forces on and in the human body
3rd week	Physics of the skeleton
4th week	Heat and cold in medicine, Heat therapy
5th week	Energy, work and power of the body
6th week	Pressure and pressure in body organs,
7th week	Blood pressure and measurements
8th week	Physics of the cardiovascular system
9th week	Bernoullli's principle applied to cardiovascular system
10th week	Physics of the lungs and breathing
11th week	Measurements of the lungs volume
12th week	Instrumentation related of respiratory system
13th week	Instrumentation related of cardiovascular system
14th week	Magnetism in Medicine and Electricity within the body,
15th	The nervous system and neuron
16th week	Sound in medicine and physics of hearing
17th and 18th week	Light in medicine and physics of vision
19th week	An introduction to nuclear radiation
20th and 21th week	Physics of nuclear medicine
22th week	Physics of x- rays
23th week	Diagnostic x- rays
24th week	Physics of radiation therapy
25th week	Radiation protection
26 th and 27th week	Introduction to laser and optics
28 th and 29th week	Laser in medicine

Forces on and in the Body

The fundamental origins of forces, only the gravitational and electrical forces are importance in our study of the forces affecting the human body.

1. The gravitational force
From Newton law, there is a force of attraction between any two objects.

$$F = mg$$

Where, F is the force, m is the mass, g is the acceleration of gravity.
Example**;** our weight is due to the attraction between the earth and our bodies.

The medical effects of gravitational force;
I. The formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart.
II. The medical effect of gravity on the skeleton (on the bones), in some way contributes to healthy bones.

2- The electrical force
This force is more complicated than gravity since it involves attractive and repulsive forces between static electrical charges as well as magnetic produced by moving electrical charges (electric currents).

Example1: the electrical force between an electron (e) and a proton (P) in hydrogen atom is about 10^{39} times greater than the gravitational force between them.

Example2: our bodies are basically electrical machines; the forces produced by the muscles are electrical charges attracting or repelling other electrical charges, and the control of muscles.

3- The nuclear force
It acts as the force to hold the nucleus together against the repulsive forces produced by the protons on each other.

Forces in the body
- Muscular forces that cause the blood to circulate and the lungs to take in air.
- Molecular forces (bone, calcium atom).
- Electric forces.
- Gravitational forces.

The types of forces on the body
I. Statics, when the body in equilibrium.
II. Dynamics, when the body is accelerated.
III. Friction is involved in both statics and dynamics.

Statics

Objects are stationary (static) they are in a state of equilibrium when the sum of forces in any direction is zero

$\sum \vec{F_i} = 0$, $f_1 + f_2 + f_3 + f_4 = 0$ (First condition of equilibrium)

The sum of the torques about any axis is zero;

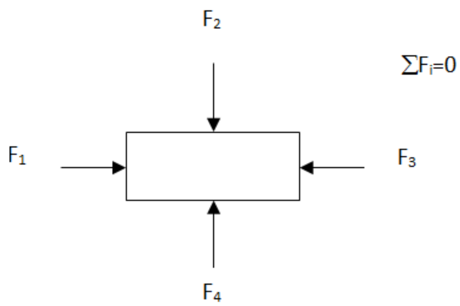
$\sum \tau = 0$ (Second condition of equilibrium)

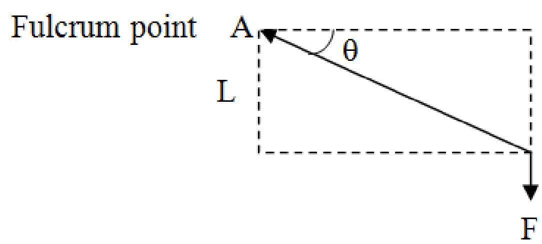
$\tau = F \cdot \vec{l}$

Where, τ = The torque, F = the force, l = The vertical distance from the pivot, (fulcrum point) to the line action of the force.

$\tau_{cw} = \tau_{ccw}$

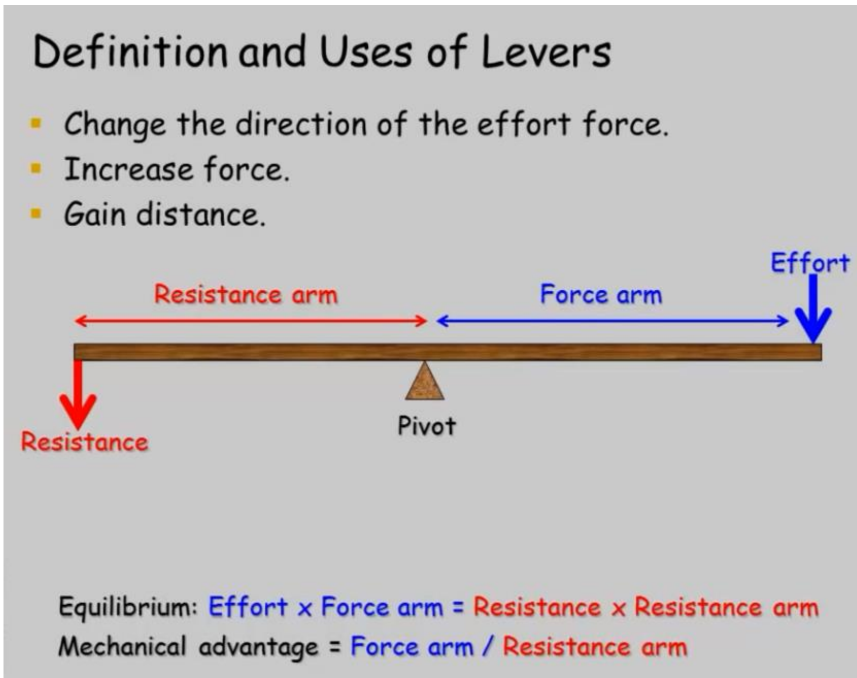
The sum of clock wise torque = sum of counter clock wise torque.

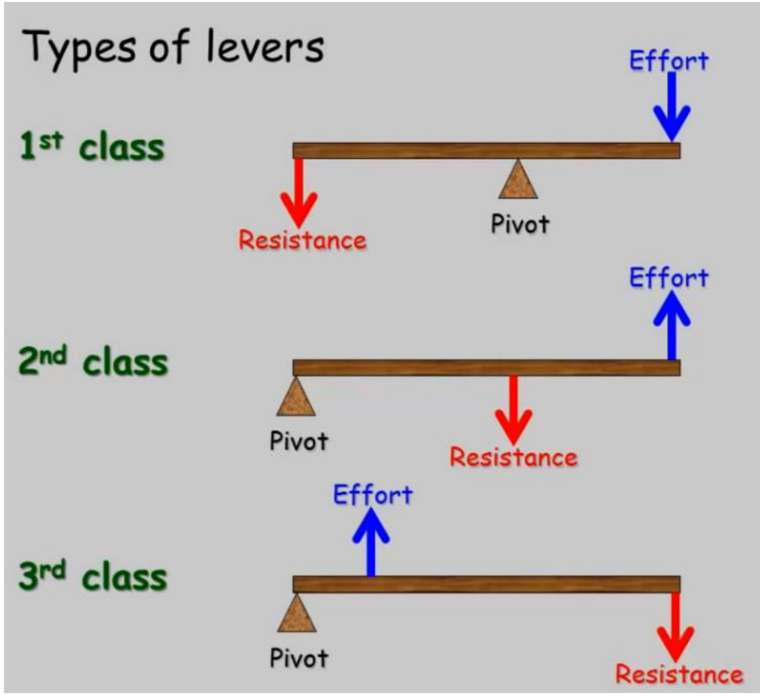


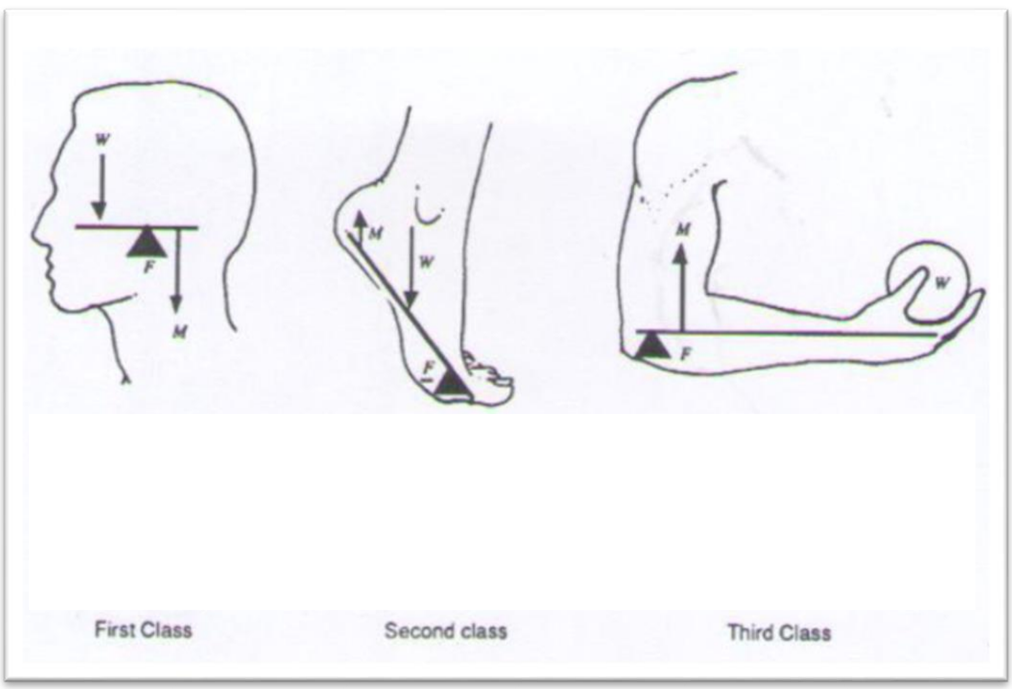


The kind of levers in the body

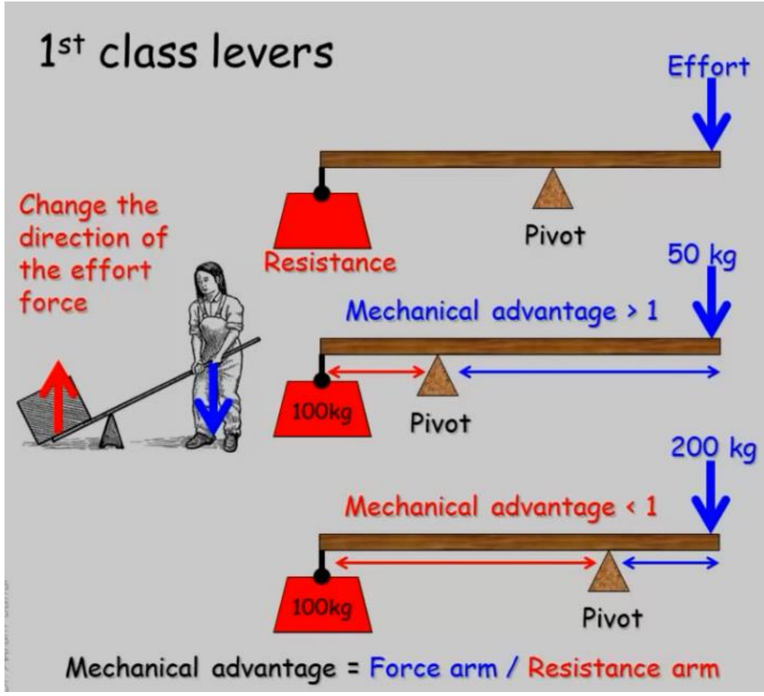
Many of the muscle and bone systems of the body act as levers.



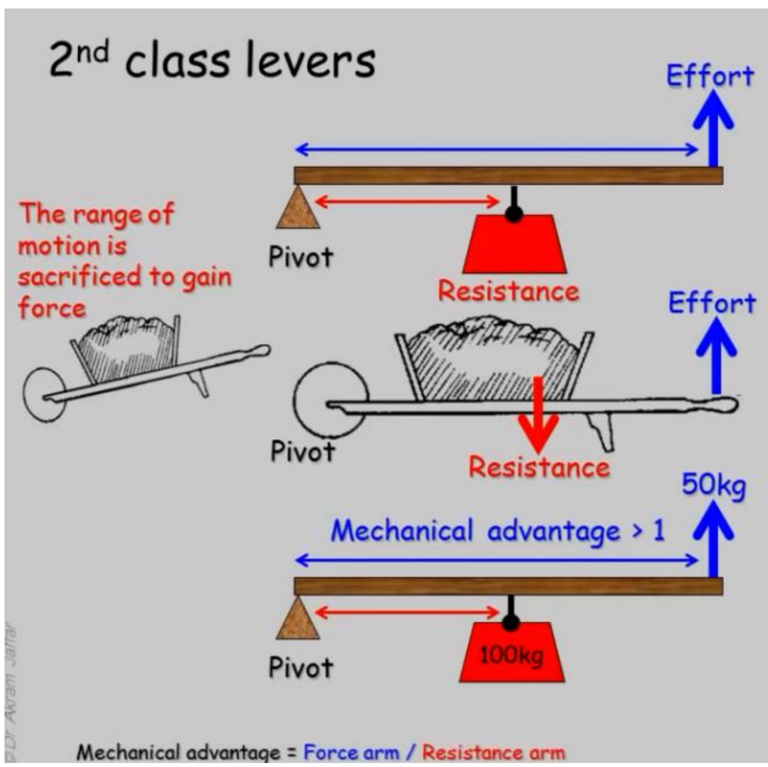


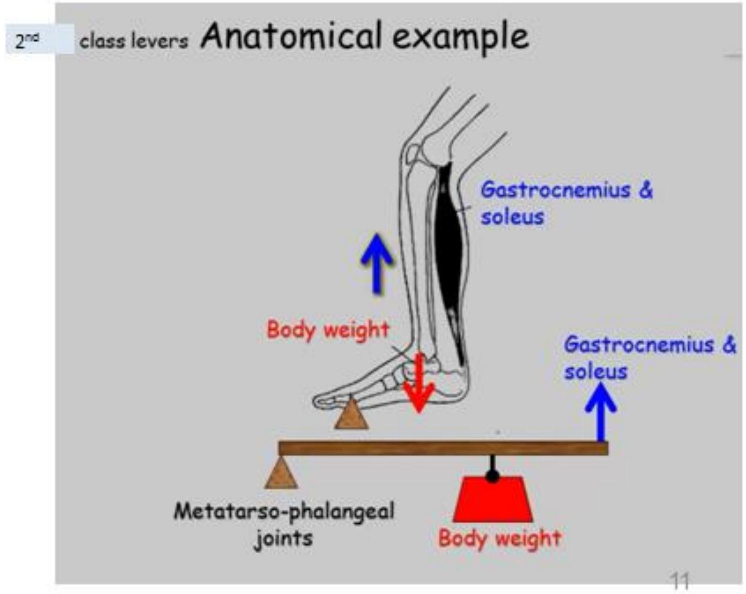


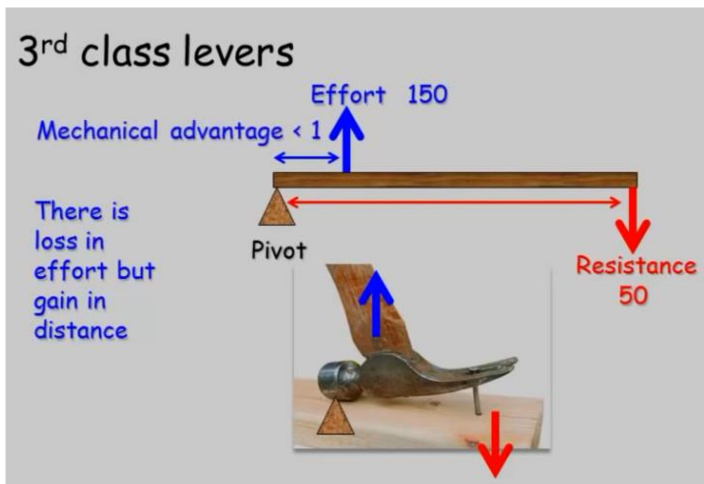
The three lever classes and schematic examples of each in the human body. W is a force that could be the weight, F is the force at the fulcrum point and M is the muscles force.

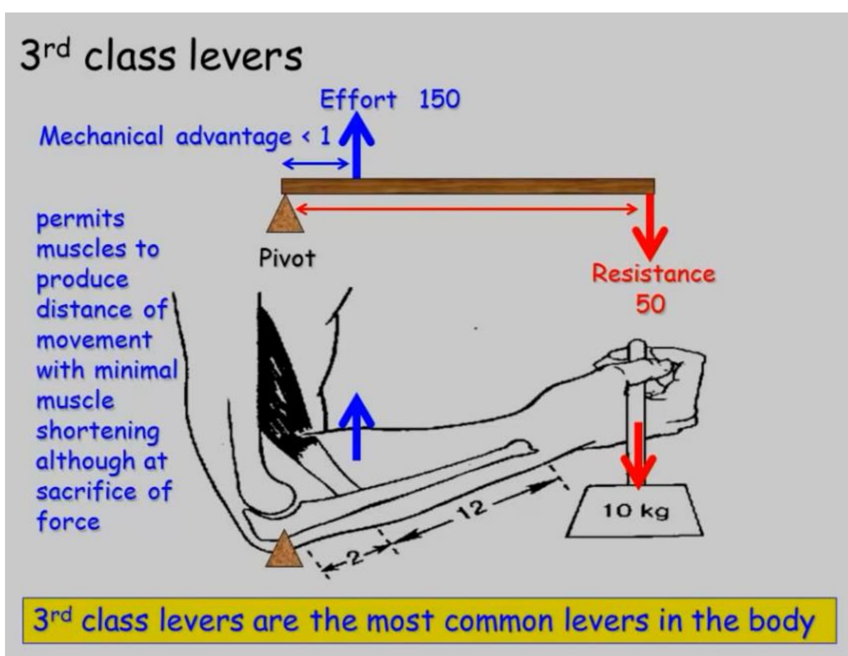


In first class lever; the fulcrum point P between the resistance force W (weight) and the effort force the muscle force M. In the head of human; W is the weight, M is the muscle force, F is the force at the fulcrum point P.

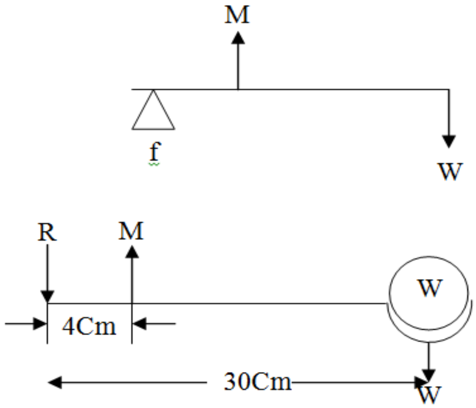


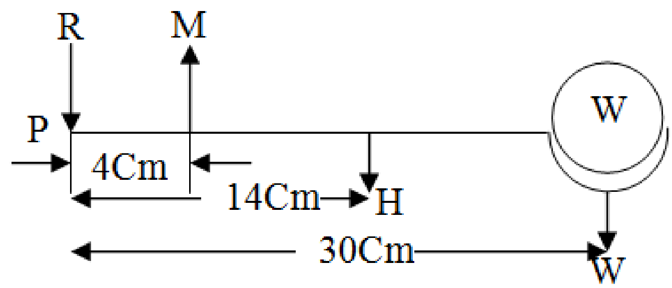

2nd class levers Anatomical example
Gastrocnemius & soleus
Body weight
Gastrocnemius & soleus
Metatarso-phalangeal joints
Body weight
11


3rd class levers
Effort 150
Mechanical advantage < 1
There is loss in effort but gain in distance
Pivot
Resistance 50


3rd class levers
Effort 150
Mechanical advantage < 1
permits muscles to produce distance of movement with minimal muscle shortening although at sacrifice of force
Pivot
Resistance 50
12
2
10 kg
3rd class levers are the most common levers in the body

In third class lever, the hand, the lever system in the body is the case of the biceps muscle and the radius bone acting to support a weight W in the hand. Where R is the reaction force of the humerus on the ulna, M is the muscle force supplies by the biceps, and W is the weight in the hand. The force and dimensions where the weight of the tissue and bones of the hand and arm H at their center of gravity.





Question; from this example, find the value of M ? **Solution;** Two torques; due to the weight W, torque about point P

0.04 X ? = 0.03 X 50 X 9.8
? = 0.03 X 50 X 9.8 / 0.04
? = 367.5 kg

Frictional Forces

A force which resists the motion between two surfaces in contact and depends on the nature of the surface and independent on the area of the surface.

1- Static friction F_s

The effective force between surfaces that are at rest with respect to one another.

$$F_s = \mu_s N$$

2- Kinetic friction F_k

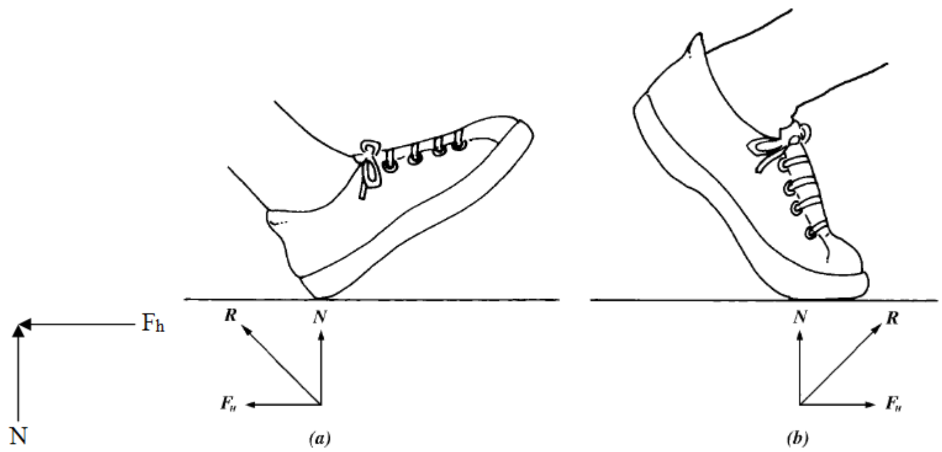
The effective force between surfaces that are in relative motion.

$$F_k = \mu_k N \Rightarrow F_k \propto N$$

Where, μ_s is coefficient of static friction (*used to find the maximum resistance force on an object can exert before it starts to move*), μ_k is coefficient of kinetic friction. $\mu_s > \mu_k$ (Force to start the motion is a greater than needed to keep it moving), and N is the normal force.

Friction in the body

For example during the walking; as the heel of the foot touches the ground a force is transmitted from the foot to the ground, we can analyze this force into horizontal and vertical components. The vertical reaction force is applied by the surface and is labelled N (normal force). The horizontal reaction component must be applied by frictional forces. Friction between the heel and surface prevents the foot from slipping forward. F_h is the horizontal reaction component supplied by frictional force. N is the normal force supplied by the surface. The maximum force of friction is $F = \mu N$. When the foot leaves the ground, F_h prevents the toe from slipping backward. The frictional force is large enough both when the heel touches down and when the toe leaves the surface to prevent a person from slipping.



Normal walking, (a) Both a horizontal frictional component of force, FH, 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. (b) When the foot leaves the ground, the frictional component of force, FH, prevents the foot from slipping backward and provides the force to accelerate the body forward.

Measurement of the horizontal component F_h

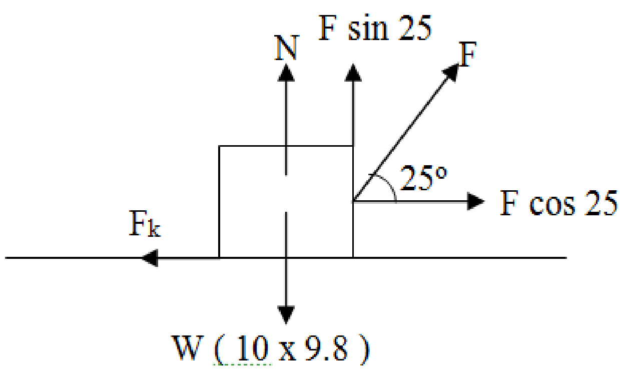
The value of the horizontal force component of the heel as it strikes the ground when a person is walking. $F_h \approx 0.15W$, $W = mg$ the person's weight, hence, when μ less than 0.15 , his foot slips.

For another example, the coefficient of friction in the bone joints is usually much lower than the engineering type materials. If a disease in the joint the friction may become large, the synovial fluid in the joint is involved in the lubrication. Some of organs of human body are lubricated by slippery mucus covering to minimize the friction. The saliva used when we chew food acts as a lubricant.

Example: The mass of 10 Kg is pulled along a horizontal surface at constant velocity by a force 50N at an angle of 25^o with horizontal. What is the coefficient of μ_k between the block and plane?

$F_k = \mu_k N \;\; \therefore \mu_k = \frac{F_k}{N}$

F_k = F cos (25) = 50 x 0.906 = 45.3 Newton
W(mg) = N + F sin 25
10x9.8 = N + 50 x 0.422
N = 98 - 21.13 = 76.87 Newton
$\mu_k = F_k / N$ = 45.3 Newton / 76.87 Newton
μ_k = 0.59



Dynamics forces

The forces on the body under the constant acceleration or deceleration of one dimensional motion. The Newton's second law without vector notation;

F = ma where, F is the force, m is the mass, a is the acceleration

units, F { N , dyne } , m { g , Kg } , a { $\frac{cm}{s^2}$, $\frac{m}{s^2}$ }

another definition, F is the change of momentum over a short interval of time,
$F = m \; \Delta v/\Delta t$

Δmv = change of momentum, m is the mass, v is the velocity of this mass, Δt is the time interval.

Example: A 60 Kg person walking at 1 m sec^{-1} bumps into a wall and stops in a distance of 2.5 cm in about 0.05 sec. What is the force developed on impact?

Δ (mv) = momentum before impact = momentum after impact
60 Kg x 1 ms^{-1} = 60 Kg x 0
Δ (mv) = 60 Kg x 1 m s $^{-1}$ – 0 = 60 Kg m s^{-1}

$$\because F = \frac{\Delta(mv)}{\Delta t} = \frac{60 kgms^{-1}}{0.05 s} = 1200 Kgm/s^2 = 1200 N$$, Newton = Kg m s^{-2}

The centrifuge

Is away to increase apparent weight, it is especially useful for separating a suspension in a liquid, it speed up the sedimentation that occurs at a slow rate under the force of gravity.

$m \, dv/dt = kx$
$d^2x/dt = dv/dt$

Stoke law

Let us consider sedimentation of small spherical objects of density ρ in a solution of density ρ_o in a gravitational field g. We know that falling objects reach a maximum terminal velocity V due to viscosity of liquid effects. Stoke has shown that for a spherical object of radius a, the retarding force F_d and terminal velocity V are related by;

$F_d = 6\pi a \eta V$ **stoke law**

When the particle is moving at a constant speed, the retarding force is in equilibrium with the difference between the downward F_g and the upward buoyant force F_b;

$\mathbf{F_d = F_g - F_b}$

The force of gravity, $F_g = 4\pi\ a^3\rho g/3$

The buoyant force, $F_b = 4\pi\ a^3\rho_o g/3$

$F_d = 6\pi a\eta V = 4\pi\ a^3\rho g/3 - 4\pi\ a^3\rho_o g/3$

$\therefore$ The terminal or sedimentation velocity is;

$$V = \frac{2a^2}{9\eta} g(\rho - \rho_o)$$

The Medical use of terminal velocity

From some disease such as rheumatic heart disease, the red blood cells clump together and the effective radius increase and also increase sedimentation velocity. From the disease such as Hemolytic jaundice and sickle cell. Anemia, the red blood cells change shape, the radius decrease, and then the rate of terminal of these cells is slower than normal.

Determination of the hematocrit:

The effective acceleration $\mathbf{g_{eff} = 4\ \pi^2 f^2 r}$

Where f is the rotation rate in revolutions per second, and r is the position on the radius of the centrifuge where the solution is located. Thus, hematocrit depends on; radius of centrifuge, speed and duration of centrifugation. Ultracetrifuge used for molecular weight or large macromolecules, for protein research use 40.000 – 100.000 rpm. The velocity depends on gravitational acceleration g and it is increased by means of a centrifuge.

τ_W = W x 30 cm = 30 W acting clockwise …………(1)

due to M (Muscle force); τ_M= 4M counter clockwise …………..(2)

Thus the arm in equilibrium :

$\tau_W = \tau_M$, then 4M – 30W = 0

$\therefore$ M = 7.5 W

If W = 100 N, then M = 7.5 x 100 = 750 N

If neglected the weight of the forearm and hand (H) .

If we H = 15 N : W = 5 N

In equilibrium $\sum\tau = 0$

$5N \times 30 \times 10^{-2}\ M + 15N \times 14 \times 10^{-2}\ M = M \times 4 \times 10^{-2}\ M$

clockwise = counter clockwise

360 N . M = 4 M . N

$\therefore$M = 90 N

Questions

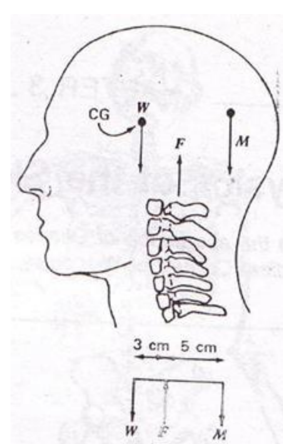
Question1: A muscle is capable of supplying a maximum force per unit area of 3.1×10^7 N/m^2. If the cross sectional area muscle is 20 cm^2, what is the maximum force that can be supplied at the muscles normal length?

Force/ area = 3.1 x 107 N/m^2
Cross sectional area = 20 x 10- 4 m^2
Force = (20 x 10- 4 m^2)(3.1 x 107 N/m^2)4
Maximum force = 6.2 x 10 N

Question2: The action of chewing involves a third – class lever system. The figure shows the jaw and chewing muscle and the lever diagram. Here, M is the force supplied by the chewing muscles that close the jaw about the fulcrum F and W is the force exerted by the front teeth.
I. If $l_2 = 3l_1$ and W = 100 N, find M.
II. If the front teeth have a surface area of 0.5cm^2 in contact with an apple, find the force per unit area for part A.

I. The sum of the torques about F = 0.
$Ml_1 – W(11 +l_2) =0$
Where $l_2 = 3l_1$
$Ml_1 = W(l_1 +3l_1)$
M = 4 W
M = 400 N
II. 100 N / 0.5 x 10 m^2= 2 x 10 N / m^2

Question3: One first class lever system involves the extensor muscle, which exerts a force M to hold the head erect, the force W of the weight of the head, located at its center of gravity, lies forward of the force F exerted by the first cervical vertebra. The head has a mass of about 4 kg or is about 40N.
I. Find F and M.
II. If the area of the first cervical vertebra, is 5 cm^2, find the stress on it.
III . What is this stress for a 70 Kg person standing on his head?
How does this stress compare with the maximum compression strength for bones (1.7×10^8 N/m^2).
The distance between F and W =3 cm, The distance between F and M =5 cm
3W = 5M
M = 0.6 W, W= 4 kg, Or W= 40 N
M= 0.6 x 40 = 24 N
F = W + M = 64 N
The stress is $64/5 \times 10^{-}$
Stress = 1.28 x 10 N/m^2
The mass of body is 70 kg, The mass of head is 4 kg
In standing position = 70 – 4 = 66 kg
The stress = $66 \times 9.8/5 \times 10^{-4}$



The stress = $1.3 \times 10^6 N/m^2$
Which is less 1 % of the maximum compression strength.

Question4: A 50kg person jumping from a height of 1 m is travelling at 4.5 m/sec just prior to landing. Suppose she lands on a pad and stops in 0.2 sec. What maximum force will she experience?

$F = \Delta (mv) / \Delta t$
$F = 50 \times 4.5 / 0.2 = F = 1125$ N

Question5: Estimate the force on the forehead if the mass of the head is 4 kg, its velocity is 15 m/sec, and the padded dash stops it in 0.002 sec .
$F = \Delta (mv)/\Delta t$
$F = 4 \times 15/0.002 = 3 \times 10^4$ N

The physics of skeleton

The function of the bone:

1. Support the body, the muscles are attached through tendons and ligaments.
2. Locomotion; bone joints (hinges or articulations).
3. Protection of organs; Rib cage (lungs, heart). Skull (Brain, eyes, ears). Vertebrae (Spinal cord).
4. Storage of chemicals; control of calcium in blood.
5. Nourishment; baby teeth and permanent teeth.
6. Transmission of sound (middle ear); the middle ear impedance matching between sound in air and sound in the fluid in cochlea.
7. Walking, lifting, manipulation

Bone remodeling by specialized bone cells

- Osteoclasts destroy the bone by about 0.5 g of calcium each day.
- Osteoblasts build the bone by about 0.5 g of calcium each day.
- Bones have about 1 kg of calcium to build a new skeleton in every seven years.
- Osteoblasts dominate until 35 to 40 years old.
- Osteoporosis: porous bones in older women.
- Osteocytes; cells that maintain the bone in a healthy condition, which is 2% of bone volume, at poor blood supply the osteocytes die then bone dies and loss of its strength.

Shapes of bones

- Flat, plate-like bones; shoulder blade (scapula), some bones of the skull, etc.
- Long hollow bones; bones in the arms, legs, and fingers.
- Cylindrical bones; bones from the spine (vertebrae).
- Irregular bones; bones from the wrist and ankle.
- Other bones; ribs, etc.

Types of bones

- Solid or compact bones; found in the central shaft of bones.
- Spongy bones (trabecular bones); found at the ends of long bones, weaker than compact bones.

Composition of Bone

Collagen, Mineral $Ca_{10}(PO_4)_6(OH)_2$, Water

Large percentage of calcium with heavier nucleus, high x-ray absorption. Collagen; major organic fraction, 40% of the weight of solid bone and 60% of its volume. Collagen remainder; flexible and bends easily, large tensile strength, produced by osteoplastic cells. Bone mineral remainder: fragile, can be crushed with fingers, formed on the collagen, a

very large surface area of $4x10^5$ m^2, rapid interaction with chemicals in the blood and other boy fluids.
Collagen makes bones flexible (elastic), Mineral makes bones rigid, Water in interstitial spaces stores nutrients.

How Bones Break (fractures)

By Compression, Tension, Shear, Bending, and Torsion

Stress and Strain

Stress: external force (which causing deformation) per unit area, $\sigma = F/A$
Force in Newton, area in meter square.
Type of stress:

- **Tension** of an object: pulling it apart
- **Compression** of an object: pushing it together
- **Hollow cylinder**: maximum strength with a less amount of material for forces any direction.
- **Shear**, shear or spiral fracture, compound fracture, easy to be infected
- **Tensile**, bone has a smaller ultimate stress for tension than compression.

Strain: fractional change in length in meter to the original length, due to stress, $\varepsilon = \frac{\Delta L}{L}$

For small deformations Stress and Strain are proportional to each other this known as **Hooke's law**: $\sigma = Y \varepsilon$, which is an empirical law, see stress-strain diagram

Young's modulus of elasticity

How much forces are needed to break the bone by compression, tension and twisting. When the bone placed under tension or compression there is change in its length.

Stress $= \frac{F}{A} =$ **N/mm²** approximately, 120 N/m^2

The strain increases linearly at first with the stress (***Hooks's law***). If the force increases then the length increases more rapidly and the bone breaks at stress of 120 N mm^{-2}. Therefore, the ratio of stress to strain in the initial linear portion is called ***Young's modulus*** Y;

$$Y = \frac{\sigma}{\varepsilon} = \frac{LF}{A\Delta L} \quad ,$$

For bone *Young's modulus* Y, $\mathbf{Y_{compact} = 1.8 \times 10^{10}\ N/m^2}$ $\mathbf{Y_{trabecular} = 7.6 \times 10^{7}\ N/m^2}$.

Example: Man with mass of 100 Kg standing on the one leg has a 1 m shaft of bone with average cross-sectional area of 3 cm^2. Find the pressure in Pa, and the amount of shortening in this bone.

$P = \frac{F}{A}$. $F = mg = 100 \times 10 = 10^3$ N

$P = 10^3$ N/ 3 x 10^{-4} m^2 = $\frac{1}{3}$ x 10^7 Pa = 3 x 10^6 Pa

$\Delta L = \frac{LF}{AY} = \frac{1x10^3}{3x10^{-4}x1.8x10^{10}}$ ≈10^{-4} m compression

$Y = \frac{LF}{A\Delta L}$ tension elongate in L due to $\frac{F}{A}$ stress. Shorting in the length of the bone of its length.

Elastic Modulation

The ratio of stress and stress and strain, called modulus of elasticity, is found to be a characteristic of the material.

$$\text{Elastic modulus} \equiv \frac{\text{stress}}{\text{strain}}$$

Deformation types and define an elastic modulus

1. **Young's modulus, which measures the resistance of a solid to a change in its length.**

$$Y = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L_0}$$

2. **Shear modulus, which measures the resistance to motion of the planes within a solid parallel to each other.**

$$Y = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta x/h}$$

3. **Bulk modulus, which measures the resistance of solids or liquids to changes in their volume.**

$$Y = \frac{\sigma}{\varepsilon} = -\frac{\Delta F/A}{\Delta V/V_i} = -\frac{\Delta P}{\Delta V/V_i}$$

A negative sign is inserted in this defining equation so that Y is a positive number. This maneuver is necessary because an increase in pressure (positive ΔP) causes a decrease in volume (negative ΔV) and vice versa.

Measurements of bone mineral

1. X – ray technique:

In this technique x – ray beam is used with different energies and the absorption of radiation by calcium varies rapidly with range of the energy. x – ray beam contains much scattered radiation when it reaches the film, the film is not a reproducible detector, then this technique is not useful for measurement of bone mineral due to beam, and the film is a poor detector with nonlinear characteristics.

2. Photon absorptiometry

The problems with x – ray techniques were eliminated by using;

- Mono-energetics x – ray or gamma ray source, monochromatic light.
- Narrow beam to reduce the scatter.
- Using a Scintillation detector that detects all photons.

The strength of bone depends on the mass of bone mineral present [decreases, 1 to 2% per year]. Osteoporosis: lower bone mineral mass.

The absorption:

I^*_o is the intensity of beam before enters the bone .
I is the intensity of beam after enters the beam [transmition beam]

$\therefore$ The bone mineral mass MB at any point in the beam is proportional the Log (I^*_o/I)

$\therefore MB \propto \text{Log}\left(\frac{I^*_o}{I}\right)$

$MB = K\ \text{Log}\left(\frac{I^*_o}{I}\right)$ [g/cm^2]e

Where K = constant.

Mechanical properties of bone

Density of compact bone is about 1.9 g/cm^3 (1.9 times as dense as water), constant throughout life even in old age. In old age, the bone becomes more porous and thinner, reduced strength. Ultimate tensile stress: 120 N/mm^2.

Forces on the bone and safety factor

- Running four times the body weight on the hip bone when the heel strikes the ground.
- Normal walking two times the body weight on the hip bone when the heel strikes the ground.
- Stiff-legged landing, about 1.42x10^5 N, 215 N/mm^2 for each tibia with 3.3 cm^2 in area at the ankle, may result in a fracture if the force is applied for enough time
- Viscoelasticity; withstand a large force for a short period.

- **Safety factor**

Ultimate compressive stress of compact bone is 170 N/mm^2; mid-shaft of the femur with cross-sectional area of 3.3 cm^2 can withstand about 5.7x10^4 N or 6 tons.

Example1: Assume a leg has a 1.2m shaft of bone with an average cross sectional area of 3 cm2. What is the amount of shortening when all of the body weight of 700 N is supported on this leg?

Solution: $\Delta L = LF/AY$ = (1.2 m)(7 × 10^2 N) / (3 × 10^{-4} m²)(1.8 × 10^{10} N/m²)

= 155.5 × 10^{-4} m = 15 mm.

***Example1*:If a compressive force of(3×10^4N) is exerted on the end of(20cm) bone ,of cross-section area ($3.6cm^2$),find if the bone will break and or the deformation in bone is($77\times10^8 N/m^2$)** and Young's modulus of bone =$1.5\times10^{10} N/m^2$)?

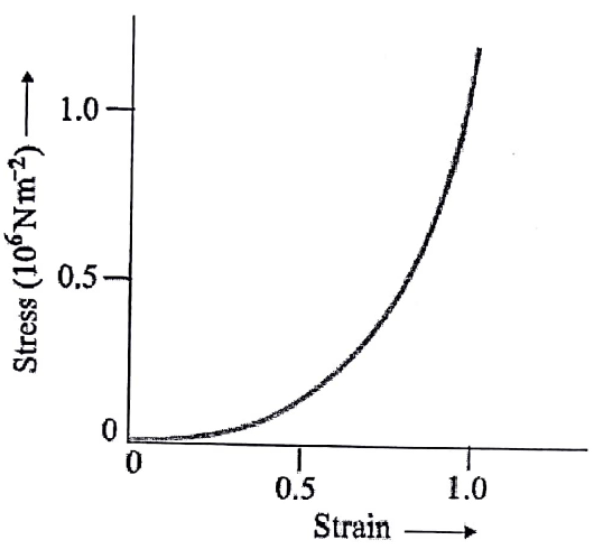
Solution:

Stress developed in **bone is**$\sigma = \frac{F}{A} = \frac{3\times10^4}{3.6\times10^{-4}} = 8.33 \times 10^7 \frac{N}{m^2}$

σ < compressive strengthen of bone ‹it will not break deformation in bone is Δl than we use :

$$y = \frac{stress}{strain} = \frac{\sigma}{\frac{\Delta l}{l}} =$$

$$\Delta l = \frac{\sigma l}{y} = \frac{8.33 \times 10^7 \times 0.2}{1.5 \times 10^{10}} = 1.11 \times 10^{10} m = 1.11mm$$



stress-strain diagram

Heat and Cold in Medicine

Heat and cold are simple and very effective therapeutic tools. They can be used locally or over the whole body. The proper application of heat and cold can provide pain relief, decrease swelling, help injuries heal faster than they normally would do, and help raise or lower body temperature. Improper application of heat and cold, like any improper application of a therapeutic technique, can be harmful and cause tissue damage and other injuries. Some of the uses of heat and cold are safe and simple, but there are other ways to use heat and cold as therapies that are complex.
In order to understand the temperature as physical phenomena we should understand it on a molecular scale. As molecules of all materials are moving, so they are hitting one another or the walls of the container, so they have kinetic energy. The average kinetic energy of an ideal gas can be shown to be directly proportional to temperature. The same thing is for liquids and solids. The movement of gas molecules are more free than liquid and liquid molecules are more free than solid. An increase of temperature of any material means an increase in the kinetic energy of molecules of that material. So adding heat to substance will increase the kinetic energy of its molecules and hence increase its temperature.
Temperature is related to kinetic energy through the Boltzmann constant. Typically when using Kelvin as a unit of energy, the energy of the system is the Boltzmann constant multiplied by the temperature: $\mathbf{E=3k_bT/2 = 0.5\ mv^2}$. The Boltzmann constant can be expressed in any units. If electron volts are use then the Boltzmann constant has the following value:

$\mathbf{k_b = 8.61733 \times 10^{-5}\ eVK}$
1 electron-volt [eV] = 11604.5250061657 kelvin [K]

In order to increase the temperature of a gas it is necessary to increase the average kinetic energy of its molecules by putting the gas in contact with a heating source (flame), the energy transferred from the flame to the gas causing temperature rise is called **heat**. If enough heat added to a solid, it melts, forming a liquid. The liquid may be changed to a gas by adding more heat. Adding still more heat converts gas to ions (plasma). While adding heat to substance increase its molecular kinetic energy, which increase its temperature, the reverse is also true, heat can be removed from a substance to lower the temperature.
What is an ideal gas?
What is the difference between heat and temperature?
What are the plasma properties?

Temperature units

The Celsius (°C): the freezing point is 0°C and the boiling point is 100°C, in between is divided into 100 divisions.
Fahrenheit scale (°F): in this scale the freezing temperature is 32°F and boiling point is 212°F, and normal body temperature is about 98.6°F.
Kalvin scale (°K): or the absolute scale this scale has the same *divisions* as the Celsius but takes the 0° K at the absolute zero which is -273.15°C.

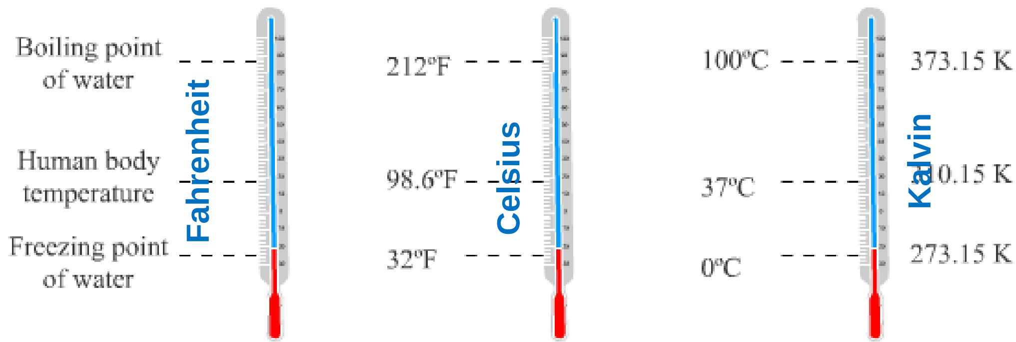
To change between °C and °F

[°C= (°F-32) 5/9] or [°F=°C (9/5)+32]

[(C-0°)/100] = [(F-32°)/180]

Also **°C=°K-273 or °K=°C+273**

where, C the value of a particular temperature in Celsius F value of that temperature in Fareinheit, and K the value of that temperature in Kelvins.



Thermometry and temperature scales

Types of thermometers

Temperature is difficult to measure directly, so we usually measure it indirectly by measuring one of many physical properties that change with temperature. Then the physical properties are related to temperature by a suitable calibration.

Glass-liquid thermometer

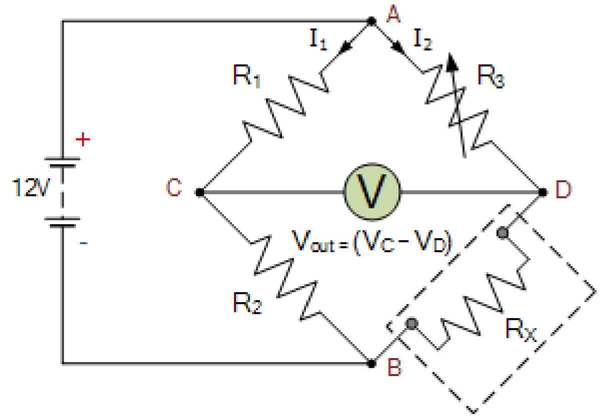
This thermometer composed of glass capillary tube ends with a bulb a store for liquid, the liquid can be mercury or alcohol for low temperature measurement. When the thermometer is heated the liquid inside will expand more than the glass causing the liquid to rise in the capillary, for mercury it expand 1.8% from (0 - 100°C). As the *fever temperature* is needed to be precise it has a thin capillary less than 0.1mm in diameter, which makes the mercury to rise higher per degree. In addition to that the fever thermometer has *a restriction above the bulb making the mercury not to return if the thermometer is exposed to low temperature unless the thermometer is moved rapidly*.

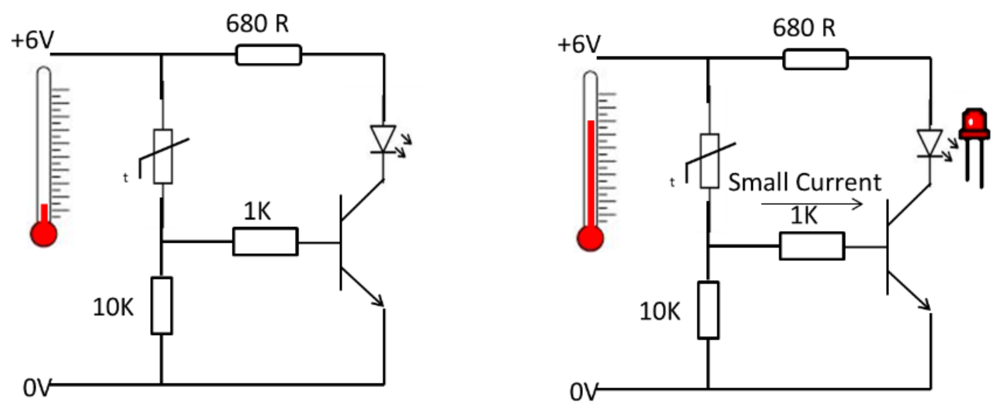
Why mercury and alcohol are used in temperature measurements?

Thermistor

It is a specialized resistor which changes resistance value depending on the amount of heat which it is exposed to. Its main characteristic is that it is thermally sensitive; in response to the heat it is exposed to, it alters its electrical resistances to changes in temperature. This resistor as any other resistance changing with heat but this particular resistance has the property of rapid change with heat (5 %/°C). It can be used to measure temperature, or to sense temperature changes and act accordingly for the temperature changes, depending on its designed use for the circuit.

The circuit composed from a bridge of four resistances with a source of electricity. These resistors are in balance and one of them is used for temperature measurement. Initially the four resistors are equal, the bridge is balanced, by symmetry, the voltages at each end of the meter are equal and no current flows through the meter. A temperature change causes the thermistor resistance to change. This unbalance the bridge, the voltages at each end of the meter become unequal, causing a current to flow through the meter, and the resulting meter deflection can be calibrated for temperature. With thermistors it is easy to measure temperature changes of 0.01°C, therefore, are used quite often in medicine because of their sensitivity. Thermistor can be used to monitor the breathing rate of patients by showing the temperature changes between inspired cool air and expired warm air.
There are two main types of thermistors; negative temperature coefficient NTC thermistors and positive temperature coefficient PTC thermistors. NTC thermistors are thermistors whose resistance *decreases* when the temperature they are exposed to increases. PTC thermistors are thermistors whose resistance *increases* when the temperature they are exposed to increases.



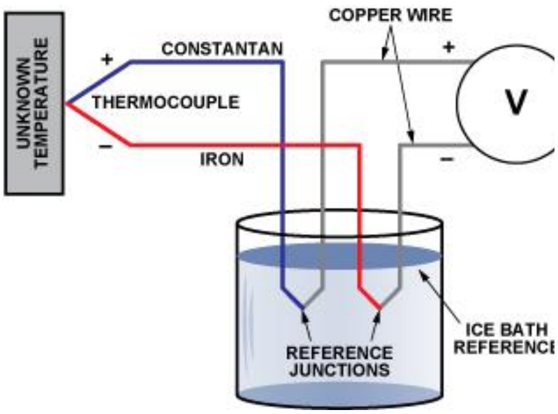


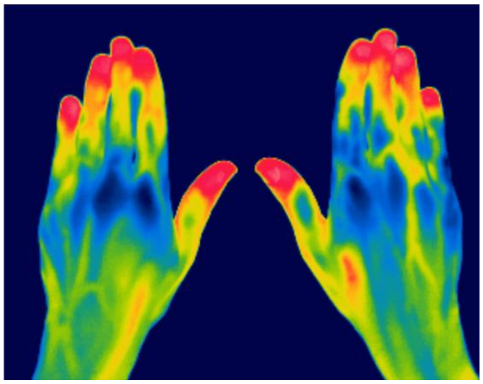
Cold Condition (No Heat) **Hot Condition (Heated)**

Thermocouple

A Thermocouple is a sensor used to measure temperature. Thermocouples consist of two wires made from different metals. The wires are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, two junctions are at different temperature a voltage is created that depends on the temperature difference. Usually one of the junctions is kept

at a reference temperature such as in an ice-water bath. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.
There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility. The copper-constantan thermocouple can be used to temperature from -190 to 300°C. For 100°C temperature difference, the voltage produced is only about 0.004V. Thermocouple can be made small enough to measure the temperature of individual cells.



Thermograph-mapping the body's temperature

The surface of the body temperature is slightly different in different parts. Depending on external physical factors and internal metabolic and blood supply to the skin. Measurement of surface temperature is useful in diagnosis of some diseases, which may change locally the skin temperature. All objects regardless on the temperature emit heat radiation. The body heat can give infrared radiation (IR) of long waves, which are not visible unlike the red-hot object, which is visible.

Wavelength	Frequency (Hz)	Photon Energy (eV)
700 nm – 1 mm	430 THz – 300 GHz	1.24 meV – 1.7 eV

By using this principle the thermograph instrument was designed to measure the radiation emitted from a part of the body. Heat radiation power can be expressed by the following which relate between the emissivity and temperature of black bodies:
$W = e\,\sigma\,k\,T^4$ Stefan Boltzmann law
Where, T is the absolute temperature of the body. σ is the emissivity depends upon the emitter material and its temperature for radiation from body e is almost 1, and k is the Boltzmann constant=5.7×10^{-12} $W.cm^{-2}$ $°K^4$

Example: What is the power radiated per square centimetres from skin at a temperature of 306°K.? What is the power radiated from a body skin $1.75m^2$ (1.75×10^4 cm^2) in area?
$W= e\sigma kT^4= 1 \times 5.7\times10^{-12} \times 306^4= 0.05W.cm^{-2}$
$W= (0.05)\,(1.75\times10^4\ cm^2)= 875$ W

Body temperature is a balance between the heat our bodies produce and the heat we lose. There are many ways we can increase or decrease the amount of heat we produce. There are also many ways we can increase or decrease the amount of heat we lose. Some of these we can consciously control (e.g., drinking hot or cold liquids, putting on or taking of clothing), but the ones we are concerned about here are involuntary and involve the blood vessels of the circulatory system. The blood vessels of the circulatory system are a very effective tool for conserving or losing body heat, and they do this by dilating (expanding) or constricting (narrowing). When the blood vessels dilate, more blood is brought closer to the surface of the skin. When that happens, the body heat we produce is transferred through the blood and escapes to the environment. When the blood vessels constrict, blood is kept away from the surface of the skin, so our body heat cannot escape.

Note: The dilation and constriction of blood vessels is and involuntary reaction and is one of many methods the body has for maintaining a stable and optimal internal environment.

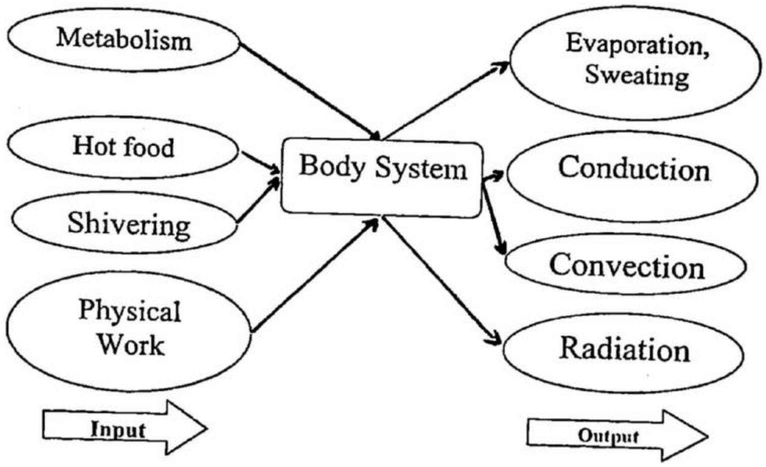
Heat therapy

Heat was recognized as therapeutic agent several thousand years ago. It has two primary therapeutic effects. Increase in metabolism which is resulting in relaxation of the blood capillaries. Increase in blood supply to cool down the heated area.

How and why, explain the physical principle of the two therapeutic effects?

Heat production for therapy

Constant body temperatures permit metabolic processes to proceed at constant rates. Because the body at a constant temperature is contain stored heat energy that is essentially constant as long as we are alive. The normal body core temperature is often given as 37°C, only small percentage of people has exactly that temperature. If we measured the temperature of a large number of healthy people, we would find a distribution of temperature with ±0.5°C of normal temperature. The temperature depends upon the time of the day (lower in the morning); the temperature of the environment; and the amount of recent physical activity, the amount of clothing, and the health of individual. The heat is generated in the organs and tissues of the body; most of it is removed by several processes that take place on the skins surface. There are several ways in which heat energy is transferred from body tissue to the surrounding environment, (the main heat loss mechanisms):



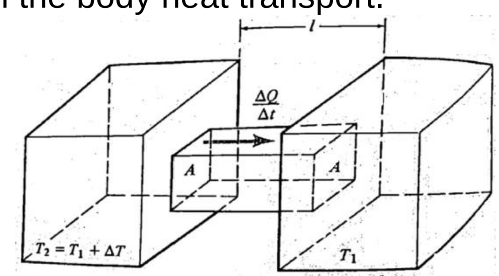
Heat losses from the Body

1. The conductive method

Heat can transfer by conduction; the quantity of heat transfer depends on the temperature difference, the time of contact, the area of contact, and the thermal conductivity of the materials. Energy is transferred by molecular vibration and electrons.This can be done by several ways such as hot bath, hot packs, and electric heating pad. This can lead to local surface heating and using in the treatment of arthritis, neuritis, strains, sinusitis and back pain. The heat loss due to conduction

$H_D = \Delta Q/\Delta T = KA\,(T_2 - T_1)/L$

Where, H is heat flow, K thermal conductivity, A is the cross section area, $(T_2-T_1)/L$ temperature gradient. Body tissue is good insulator, when the environment is warm the interior body temperature is quit uniform. Because body tissues are poor conductors the inner core of the body can be kept warm in cold environment. Heat is removed from the body by conduction through the tissue from interior to exterior of the body to the cooler exterior is the major factors in the body heat transport.



2. Convection

Heat transfer by actual motion of material from one region of the space to another, flow of the blood. When a material is heated its volume increase because increase the amplitude of the molecular vibration, the density of material decrease where the mass of material remain constant. The heat loss due to convection

$H_C = \Delta Q/\Delta T = q\,A\,\Delta T$

Where, H is heat flow, ΔT is temperature difference between the surface and air distance. $\Delta \mathbf{T} = T_s - T_a$, T_s is the temperature of the skin and Ta is the temperature of the air. A is the cross section area, q convection heat transfer constant which depends on the shape and orientation of the surface and also on ΔT.

When the body is resting and there is no apparent wind, q is about 2.3 Kcal /m² hr c°. When the air is air is moving, the constant q increases according to equation $q = 10.45 - v + 10 \sqrt{v}$ Where the wind speed *v* is in meter per second This equation is valid for speeds between 2.23 ms^{-1} and 20 ms^{-1}. The equivalent temperature due to moving air is called wind chill factor and is determined by the actual temperature and wind speed.

3. Radiant heat

Heat radiation, which is a form of electromagnetic wave, can be achieved by using infrared radiation IR or x-ray or radio wave … . It penetrates about 3mm in the skin. It can be produced glowing coils and by 250 watts incandescent lamps. The excessive exposure can cause reddening and sometimes swelling longer exposure can cause skin hardening. It is considered to be more effective than conductive heating because it can penetrate deeper. A beam of light incident on tissue may be reflected, absorbed, or scattered. The penetration of light through human tissue:

$$I = (1 - R)\, I_o \exp(-\alpha x)$$

I : the intensity of the light penetrating to depth x. I_o : the intensity of the incident light. R : the reflection coefficient. α : Absorption coefficient.

The heat loss due to radiation is

$$H_r = K_r\, Ar\, e\, (T_s - T_w)$$

Where, H_r is the rate of energy loss or gain due to radiation. A_r is the effective body surface area emitting radiation. *e* is the emissivity of the surface. T_s is the skin temperature c° T_w is the temperature of the surrounding walls. K_r is the constant that depends upon various physical parameters and is about 5 Kcal / m².Hr.C°. The parameter *e* in the infrared region is independent of the color of the skin and is very nearly equal to one, indicating that the skin at this wavelength is almost a perfect absorber and emitter of radiation.

4. Evaporation:

The method of heat loss that all of us familiar with is the evaporation (sweating). Under normal temperature condition and in the absence of hard work or exercise, this method is rather unimportant compared to the radiative and convective cooling. Under extreme conditions of heat and exercise, a man may sweat more than 1 liter of liquid per hour. Since each gram of water that evaporates carries with it the heat of vaporization 580 calories, the evaporation of 1 liter carries with it 580 Kcal. The sweat must evaporate from the skin in order to give the cooling effect. The amount evaporated depends upon the air movement and the relative humidity.

The actual heat lost by radiation, convection, evaporation of sweat and respiration dependents on a number of factors; such as, the temperature of the surrounding, humidity, the motion of the air, the physical activity of the body, the amount of the body exposed, and the amount of insulation on the body (cloth and fat in the body).

Short wave diathermy

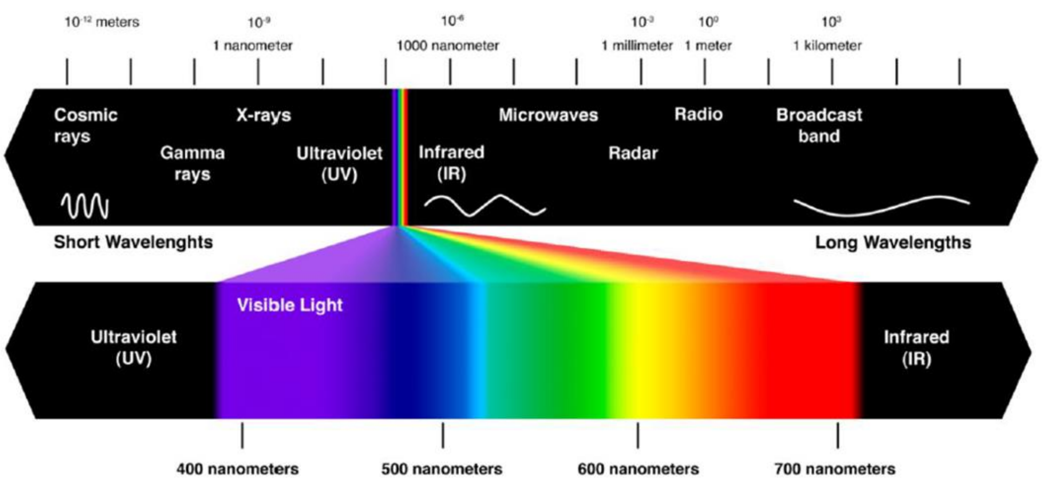
SWD id utilized electromagnetic wave in radio range (0.01-1km) and microwave range (0.01-10m), short wave diathermy penetrate deep into tissue (more than conductive and radiant). Heat from diathermy penetrates deeper into the body than radiant and conductive heat, thus it is useful for internal heating and has been used in the treatment of inflammation of skeleton and neuralgia.

Different methods are used for transferring the electromagnetic energy into the body:
I. The part of the body to be treated is placed between two plates (electrodes) connected with high frequency power supply. The charged particles of the tissue will be attracted to one plate and to other depending upon the sign of the alternating voltage on the plate. This movement will produce resistive (joule) heating.

II. By transferring short wave energy into the body by magnetic induction. This can be done by either placing a coil around the region to be treated or by a coil placed near the part of the body to be treated. The alternating current in the coil produces an alternating magnetic field in the tissue, consequently an alternating currents are induced, producing joule heating in the region b treated. Short wave diathermy can penetrate deep into tissue. It can be used in relieving muscle spasms, protruded intervertebral disc pain, joints with minimal soft tissue coverage such as knee, elbow.

III. Microwave diathermy can be produced in special tube called (magnetron) and emitted from the antenna which can be placed several inches from the region to be treated. Microwave can penetrate deeper into the tissue causing heating. It is used in fractures, sprains, strains, bursitis, and injuries to tendons. The frequency used is 900MHz, which is found more effective than other frequencies in therapy. It causes more uniform heating around bony region.

What is joule heating?



Electromagnetic radiation

Cryogenics

Cryogenics is a science and technology that deals with the very low temperature, which is used in biology and medicine and has advantages. Low temperature can be produced by *liquefying* gases. Such as producing liquid air -196 °C and liquid helium -269°C and for solid carbon dioxide -79°C and liquid nitrogen (-196°C). The storage of liquefied gases is rather difficult because it can take heat rapidly from the environment by conduction, convection, and radiation. A special container has been designed, this composed from two cylindrical bottles made of glass or stainless steel one inside the other and a vacuum in between. This can prevent heat transfer by *conduction* and *convection.* The two bottles are both silvered so that radiation striking the surface is reflected rather than absorbed, they are as good reflector and poor radiation for heat.

for short term preservation moderate low temperature was successful in some types of tissue and blood, low temperature have been used for long term preservation of blood, bone marrow, and tissue. It has been found that for long-term, survival the tissue should be stored at very low temperature, since the biochemical and physical processes that sustain life are temperature dependent, lowering the temperature reduce the rates of the processes, liquid nitrogen (-196 °C) proved to be much better for preservation than solid carbon dioxide (-79°C).

For *conventional blood storage* it can be stored with anticoagulant at 4°C, about 1% of the red blood cells break each day so the blood will not be suitable for use after 21 day. For rare blood types should be stored for longer periods, other procedures were used. Blood can be preserved for very long periods of time if it frozen rapidly in liquid nitrogen (-196°C).The rate of freezing is very important to revive the cell after thawing them. The preservation of large tissue like bone, muscles is still under searches as storage of them involves some problems. Because of its large physical dimensions it is difficult to cool down all the cells at the same rate. Adding and removing protective agents is difficult.

Cryosurgery

The cryogenic methods are used to destroy cells called cryosurgery. It has several advantages; cause a little bleeding; the volume of the tissue destroyed can be controlled by temperature, little pain because low temperatures desensitize the nerves, and very short recovery. Cryosurgery is used in several types of eye surgery. One of the first uses of cryosurgery is in the treatment of Parkin’s disease. This disease causes uncontrolled tremors in the arms and legs. It is possible to stop it by destroying parts of the thalamus of the brain that controls nerve impulse to the other part of the nerve system. The treatment undergoes while the patient in conscious, the probe at (-10°C) moved into the appropriate parts of the thalamus causing temporary freezing, the frozen area can recover if the probe tip is removed in less than 30 sec.

Energy, Work and power of the body

All body activities including thinking, doing work, or keeping the body temperature constant involve *energy changes*, for example under resting conditions the skeletal muscles and the heart using 25% of the body's energy, another 19% is being used by the brain,10% is being used by the kidneys, and 27% is being used by the liver and the spleen. A small percent of about 5% of food energy is being excreted in faces and urine. Extra food energy will be stored mainly as fat. External heat energy from environment can help maintain the body temperature, but it has no use in body function.

Energy change in the body

The body's basic source of energy is the food energy; it must be chemically changed by the body to make molecules that can combine with oxygen in the body's cells. The units are *joule* or *calorie* **1cal= 4.184J**. The *power* is defined as energy or work per unit time ***joules***$^{-1}$ or **watt**. In the oxidation process within the body, heat is produced as energy of metabolism. The rate of oxidation is called metabolic rate.
For ***example*** the oxidation of one mole of glucose can be shown as:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2 + 686\ \text{Kcal}$$

1 mole	6 mole	6 mole	6 mole
180g	192g	108g	264g

Co_2 and O_2 are gases (1 mole of a gas at normal temperature and pressure has a volume 22.4 liters). From the above equation we can calculate useful quantities for glucose metabolism:
So the ratio of moles of CO_2 produced to moles of O_2 used, called the (respiratory quotient), ratio=1; number of moles of CO_2 / number of moles of O_2 =1 Similar calculation can be done for fats, proteins, and other carbohydrates**.** By measuring the energy released per litter of O_2 we can get a good estimation of the energy released. Table 1 shows the caloric values for different types of foods.

Basal Metabolic Rate

When the body is completely at rest, it will have the lowest rate of energy consumption this is called the **basal metabolic rate BMR**, which is the amount of energy needed to perform minimal body functions (such as breathing and pumping the blood through the arteries) under resting conditions, and for typical person 92 Kcal/hr ≈ 107W. BMR depends on man / women, age, height, and weight; it depends primarily on thyroid function, overactive thyroid gives higher BMR. Since the energy used for basal metabolism becomes heat which is mainly dissipated from the skin, so the basal rate is related to the surface area or to the mass of the body. In figure 1 the graph represents the change between BMR (kcal/day) and the mass of different animals, the slope of the graph indicates that the BMR is proportional to mass. When the animals gets larger the BMR increases faster than their increases in surface area but BMR increases even more faster with their mass. The BMR depends to large extent on the body temperature, for an increase of 1°C it will change by

10% in the metabolic rate, so for 3°C the change will be 30% greater than normal. Similarly, if the body temperature drops 3°C below normal, the metabolic rate decreases by about 30%. For this reason *hibernating* animals at low body temperature will reduce the metabolic rate very much.

A man who is taking food energy equivalent to his BMR plus his other physical activities will keep on constant weight. Less food will cause weight lose and for longer time cause starvation. While excess food of body needs will cause food storage and increase in weight. BMR is sometimes determined from oxygen consumption when resting, we can also estimate the food energy used in various physical activities by measuring the oxygen consumption.

The efficiency of human body is **E_{ff} = work done/ energy consumed**. Efficiency is usually lowest at low power but can increase to 20% for trained individuals in activities such as cycling and rowing. The maximum work capacity of the body is variable, for short period of time the body can perform at very high power levels,(like running very fast but it is more limited for longer periods). It is found that long term power is proportional to the maximum rate of oxygen consumption in the working muscles. For healthy man this consumption is 50ml/kg m of body weight each minute. The body can supply an instantaneous energy for short term power needs, this can be done by splitting energy rich-phosphates and glycogen leaving an oxygen deficit in the body.

Work and power

Chemical energy stored in the body is converted into external mechanical work as well as into life-preserving functions. Mechanical work is usually defined by **$\Delta w = F . \Delta x$**; where F is the force on the same line of displacement x, or it can be also written as: **$\Delta w = F \Delta x \cos \Theta$**; where Θ is the angle between F and the direction of movement, the power is work per unit time;

$P = \Delta w / \Delta t = F \Delta x / \Delta t = F v$. where v is the velocity. When the force is perpendicular to the displacement work will be zero, such as walking body, his weight is perpendicular to distance of movement but practically it will not be zero because the uses energy against friction and other movement of his body, but in the case of climbing person for distance (h) the weight is on the same line of displacement then the **work = mgh**. The efficiency of human body is **E_{ff} = work done/ energy consumed**. Efficiency is usually lowest at low power but can increase to 20% for trained individuals in activities such as cycling and rowing. The maximum work capacity of the body is variable, for short period of time the body can perform at very high power levels,(like running very fast but it is more limited for longer periods). It is found that long term power is proportional to the maximum rate of oxygen consumption in the working muscles. For healthy man this consumption is 50ml/kg m of body weight each minute. The body can supply an instantaneous energy for short term power needs, this can be done by splitting energy rich-phosphates and glycogen leaving an oxygen deficit in the body. This process can only last about a minute and is called anaerobic (without oxygen).

Human Energy and Power

The energy intake of humans in the form of food is often expressed in Calories. The daily intake of food energy can be expressed in other units:

If the daily intake is ???? dietary Calories (kilocalories) it is equivalent to ???? joules = ??? BTU = ???? kilowatt hours = ????? gallons of gasoline

Questions

Question1: Suppose you wish to lose 4.54 kg either through physical activity or by dieting. How long would you have to work at an activity of 15 Kcal/min to lose 4.54 kg of fat?

From table 1 maximum of 9.3 kcal/g of fat, if you worked for T minutes, then T (15 kcal/min) = $(4.54\times10^3$ g)(9.3 kcal/g) = 4.2×10^4 kcal, T = 2815 min ≈ 47hr

It is much easier to lose weight by reducing your food intake. If you normally use 2500 kcal/day, how long must you diet at 2000 kcal/day to lose 4.54 kg of fat?

T= (energy of 4.54 kg fat/energy deficit per day) $4.2\text{X}10^4$ kcal / 5×10^2 kcal/day ≈ 84 days.

Question2: For a hypothetical animal that has a mass of 700 kg (the basal metabolic rate is 10000 kcal/ day). Assuming 5 kcal/g of food, estimate the minimum amount of food needed each day?

The basal metabolic rate of mass 700kg is 10000 kcal/day

10000 / 5 = 2×10^3 g/day

Amount of food needed each day = 2 kg/day

Question3: What is the energy required to walk 20 km at 5 km/hr?

From the table, the energy rate of walking activity at 5km/hr is 3.8 kcal /min.

The energy required to walk (20 km) is = $\dfrac{3.8 \text{ kcal/min} \times 20\text{km} \times 60 \text{ min/hr}}{5\text{km/hr}}$ = 912 kcal

Question4: Assuming 5 kcal /g of food, calculate the grams of food needed for walk?

The amount of food needed for walk =[Energy] / [Energy /gm]

= 912 kcal / 5 kcal/gm = 182 gram

Question5: Suppose that the elevator is broken in the building in which you work and you have to climb 9 stories – a height of 45 m above ground level. How many extra calories will this external work cost you if your mass is 70 kg and your body at 15% efficiency?

External work = m g h = 70 x9.8x 45

Since 1 kcal = 4.2×10^3 J

External work = 70 x 9.8 x 45 / 4.2×10^3 = 7.3 kcal

Calories needed = 7.3 kcal/ efficiency = 7.3 / 0.15 = 49 kcal

Question6: a 100 kg male distance runner measured a power output of 280 watts in the process of running an 8 minute mile. How many calories does he burn in a mile, and how many miles would he have to run to burn off a 1 kg of body weight?

Energy = power output x time

280 joule s^{-1} x 8 min x 60 s min^{-1} = 134.4 k joule
134.4 k joule /4186 joule $kcal^{-1}$ =32 calories does he burn
1 pound of body fat is equivalent to about 4200 calories, so this rate would have to run about 33 miles to burn off a 1 kg.

Question7: A canned peas provides 12 grams of carbohydrate and 5 grams of protein. How many calories does one serving provide?

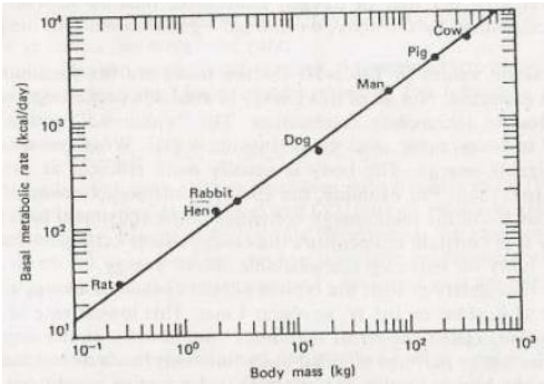
12 grams of carbohydrate x 4 kcal/gram = 48 kcal 5 grams of protein x 4 kcal/gram = 20 kcal
48 kcal + 20 kcal = 68 kcal

Question8: Calculate % of total kcal provided by carbohydrate, protein and/or fat.
A person usual diet provides an average intake of 342 grams of carbohydrate, 110 grams of protein, and 25 grams of fat. How many kcalories does he consume? What percentages of his calories are consumed from each one?

342 grams of carbohydrate x 4 kcal/gram = 1368 kcal
110 grams of protein x 4 kcal/gram = 440 kcal
25 grams of fat x 9 kcal/gram = 225 kcal
1368 + 440 + 225 = 2033 kcalories
carbohydrate: 1368 ÷ 2033 = .67 x 100 = 67%
protein: 440 ÷ 2033 = .22 x 100 = 22%*
fat: 225 ÷ 2033 = .11 x 100 = 11%*

Home work

Question1: A 70 Kg hiker climbed a mountain 1000 m high. He reached the peak in 3 hr. Calculate the external work done by the climber?
Question2: Assuming the work was done at a steady rate during the 3 hr period, calculate the power generated during climb?
Question3: Assuming the average O_2 consumption during the climb was 2 liter /min (corresponding to 9.6 Kcal /min), find the efficiency of the hiker's body .



Food or Fuel	Energy Released per Liter of O_2 Used (kcal/liter)	Caloric Value (kcal/g)
Carbohydrates	5.3	4.1
Proteins	4.3	4.1
Fats	4.7	9.3
Typical diet	4.8–5.0	—

First Law of Thermodynamics

The first law of thermodynamics is the application of the conservation of energy principle to heat and thermodynamic processes; if ΔU the change in internal stored energy of a system is equal to Q the heat added to the system minus W the work done by the system; $\mathbf{\Delta U = Q - W}$. In another word Internal energy *U* is equal to kinetic energies of all constituent particles + potential energies of particle-particle interactions. Change in the stored energy (i.e. food energy, body fat and the body heat) is equal to; **Heat lost** from the body **+ Work** done. Chemical energy stored in the body is converted into external mechanical work as well as into life-preserving functions.

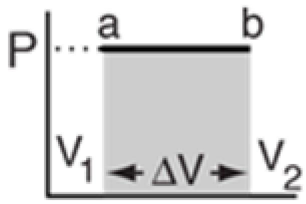
The standard unit for all these quantities would be the joule, although they are sometimes expressed in calories. It is typical for chemistry texts to write the first law as $\Delta U=Q+W$. It is the same law, the thermodynamic expression of the conservation of energy principle. It is just that W is defined as the work done *on* the system instead of work done *by* the system. In the context of physics, the common scenario is one of adding heat to a volume of gas and using the expansion of that gas to do work, as in the pushing down of a piston in an internal combustion engine. If a body doing no work $\Delta w = 0$ and at constant temperature continues to lose heat to its surroundings, and ΔQ is negative. Therefore, Δu is also negative, indicating a decrease in stored energy.

System Work

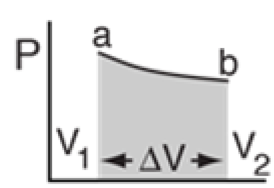
When work is done by a thermodynamic system, it is usually a gas that is doing the work. The work done by a gas at constant pressure is shown in the figure. For non-constant pressure, the work can be visualized as the area under the pressure-volume curve which represents the process taking place. Work done by a system decreases the internal energy of the system, as indicated in the first law of thermodynamics.

$$W = P\Delta V$$

Example



$$W = \int_{V_1}^{V_2} P\,dV$$



Enthalpy

Four quantities called "thermodynamic potentials" are useful in the chemical thermodynamics of reactions and non-cyclic processes. They are internal energy. Enthalpy is defined by $H = U + PV$. where P and V are the pressure and volume, and U is internal energy. It is somewhat parallel to the first law of thermodynamics for a constant pressure system $Q = \Delta U + P\Delta V$ since in this case $Q=\Delta H$. It is a useful quantity for tracking chemical reactions. An increase in the enthalpy might be associated with an increase in internal energy, or with work done by the system, or a combination of the two. The internal energy U might be thought of as the energy required to create a system in the absence of changes in temperature or volume. But if the process changes the volume, then work must be done to produce the change in volume.

Kinds of Thermodynamic Processes

Isochoric: at constant volume, $W = 0$, $\Delta U = Q$, $Q=nC_V\Delta T$

Isobaric: $Q=\Delta U+W$, $nC_p\Delta T= nC_V\Delta T + W$, at constant pressure, $W = p(V_2-V_1)$

Isothermal: constant temperature.

Adiabatic: No heat transfer in or out, $Q=0$, $\Delta U= - W$, then, if $W>0$, $\Delta U<0$, and, if $W<0$, $\Delta U>0$

Adiabatic expansion $\Delta V>0$, $\Delta T<0$, temperature drops and Adiabatic compression, $\Delta V<0$, $\Delta T>0$, temperature rises.

The work $W = nC_V (T_1-T_2) = C_V (p_1V_1 - p_2V_2)/R$

Isolated system, $W=Q=0$, $\Delta U=0$. Total U for isolated system is constant therefore energy can be exchanged between various component and convert from mechanical to chemical to heat energy

Note *:* $Q=n C\Delta T$

Where, C_V: molar heat capacity at constant volume, C_p: molar heat capacity at constant pressure. n mole number.

		W work done by system	Q heat into system	ΔU
Isochoric:	$\Delta V=0$	0	$nC_V\Delta T$	$nC_V\Delta T$
Isobaric:	$\Delta p=0$	$p(V_2-V_1)$	$nC_p\Delta T$	$nC_V\Delta T$
Isothermal:	$\Delta T=0$	$\int_{V_1}^{V_2} pdV$	$\int_{V_1}^{V_2} pdV$	0
Adiabatic:	$Q=0$	$-nC_V\Delta T$	0	$nC_V\Delta T$

summery for ideal gas

$$\Delta U = -W$$

State equations

Adiabatic process $a \rightarrow b$:
$Q = 0, \Delta U = -W$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

or:

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma}$$

Home work

Question1: A cylinder with a piston contains 0.25 mol of O_2 (treat as ideal gas) at 2.40 x 10^5 Pa and 355K. The gas first expands isobarically to twice its original volume. It is then compressed isothermally back to its original volume, and finally cooled isochorically to its original pressure. Find

A) the maximum pressure? B) the total ΔU during the cycle? C) The total work done by the piston on the gas during the processes?

Question2: A monatomic ideal gas initially at p=1.50 x105 Pa and V=0.0800 m3 is compressed adiabatically to a volume of 0.0400 m^3. A) final pressure? B) Work done by the gas? C) $T_{final}/T_{initial}$?

Pressure

Pressure is defined as the force per unit area in a gas or a liquid. For a solid the quantity of force per unit area is referred as **stress**. This weight (W) is the force downward of the column on the area (A) at the bottom.
In U-tube manometer, figure 1, the weight of the column of a liquid at height (h) equals to the force of column on the bottom mass (m). The mass of the liquid equals Ah times its density. Where g is the acceleration of gravity, $g=980\ cm/s^2 = 9.8\ m/s$, A is the area, h the height, ρ the density of liquid.

$W = F$, $W = mg$, $m = \rho V$, $m = \rho Ah$, $W = Ah\rho\, g$
$P = F / A$
$P = W/A = \rho gh$

The pressure in a liquid at a point due to its own weight is proportional (depends) to the density of the liquid and to the depth of the point below the surface of the liquid at which we measure it.

Unit of the pressure:

($Newton/m^2$, or $dynes/cm^2$), or the unit of pressure is Pascal (Pa)
1 **Newton** ≡ 1 $kg.m/s^2 = 10^5$ dynes, 1 **dynes**= 10^{-5} Newton≡ 1 $gm.cm/s^2$
1 atmospheric pressure (atm) = $1.013 \times 10^5\ N/m^2 = 1.013 \times 10^5$ Pa

If this column is open to atmosphere (P_o), then the pressure on the bottom of liquid column is; from figure 2, at balance, Absolute pressure in the liquid = atmospheric pressure + gauge pressure.
$PA = P_o A + \rho g h A$, or, $P = P_o + \rho g h$.
A is cross sectional area of the cylinder, and h, is height of the cylinder. The pressure in the liquid at depth h exerts on the cylinder an upward force = **PA**. The atmospheric pressure exerts a down ward force on the top of the cylinder of amount = **P_oA.** The volume of the cylinder is **h A**. The mass of the liquid in the cylinder = **ρhA**. The weight of this mass of liquid is **ρhAg** which gives a down ward force figure 2. The atmospheric pressure is equal to **1.01×10^5 dyne/cm^2**

Types of recording pressures:

Total (absolute) pressure; $P = P_o + \rho gh$
Gauge pressure $P - P_o = \rho gh$

Pressure below P_o is called negative pressure. Example; pressure inside the Lung below P_o (at inspire). The pressure above P_o is called positive pressure.

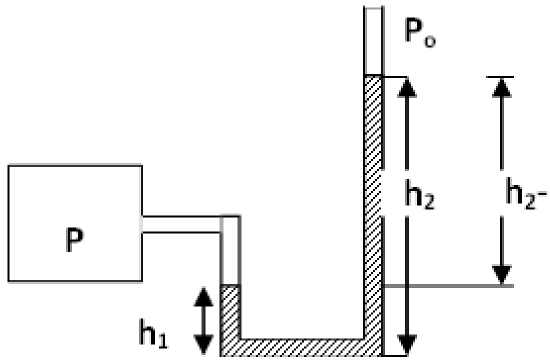


Figure 1

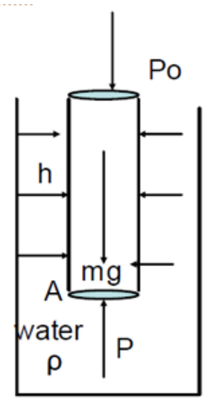


Figure 2

In medicine the unit of pressure is mm.Hg. The density of blood = 1.04 g/cm^3 , of Hg- mercury = 13.6 g/cm^3 , and of H_2O – water = 1.0 g/cm^3

Example: What height of water will produce the same pressure as 120 mm.Hg?

Gauge pressure P (120 mm Hg) = ρ g h = 13.6 g/cm^3 X 980 cm/s^2 X 12 cm
= 1.6 x 10^5 g/cm. sec^2 or dynes / cm^2
For water to produce the same pressure;
1.6 x 10^5 g/cm.sec^2 = 1 g/cm^3 X 980 cm /sec^2 X h cm H_2O
h = 163 cm. H_2O
The h of H_2O can be obtained by multiplying the h of Hg 12 cm by 13.6 g/cm^3
What is the pressure of air at 100 m above the earth surface? Where the density ρ of air = 1.3 x 10^{-3} g /cm^3

Pressure effects while diving

Boyle's law states that for a fixed quantity of gas at a fixed temperature the product of the absolute pressure and volume is constant (PV = constant). If the absolute pressure is doubled, the volume is halved. See figure 2.

Boyle's law definition: 'The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system'.

The combined gas law or the ideal gas law: **PV = nRT**

Where, *p* is pressure, *V* is volume, *n* is the number of moles, *R* is the universal gas constant, the proportionality constant, with a value of 8.3144598 (kPa·L)/(mol·K)*T* is temperature (K), where.
An equivalent formulation of this law is: **PV = NKT**
Where, *p* is the pressure, *V* is the volume , *N* is the number of gas molecules, *k* is the Boltzmann constant (1.381×10^{-23} J·K^{-1} in SI units), *T* is the temperature (K)

Example: What volume of air at atmospheric pressure of 1.01 x 10^5 N/ m² is needed to fill a 14.2 liter scuba tank to a pressure of 1.45 x10^7 N/ m² ?

$P_1 v_1 = P_2 V_2$

$1.01 \times 10^5 \times v_1 = 1.45 \times 10^7 \times 14.2$

$V_1 = 2 \times 10^3$ liters

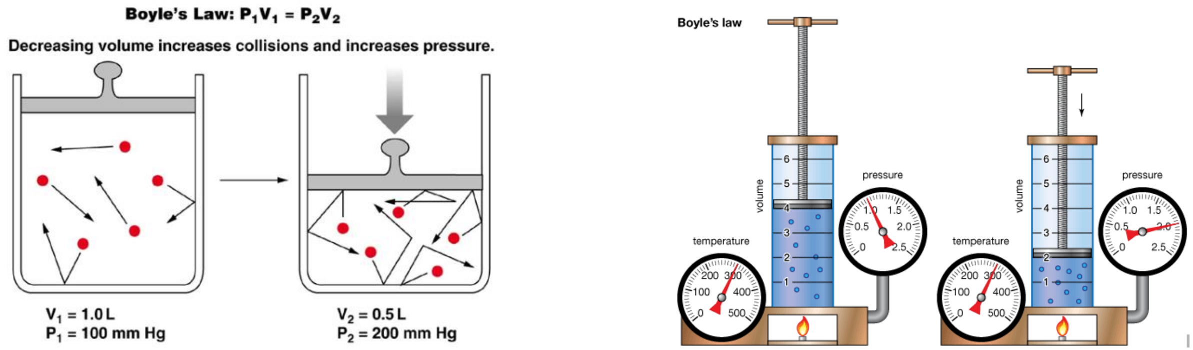


Figure 2. Boyle's law

Measurement of body pressure

The classical method of measuring pressure is to determine the height of a column of liquid (mercury) that produces a pressure equal to the pressure being measured. An instrument that measures pressure by this method is called a **manometer**. Manometer is a U-shaped tube containing a fluid that is connected to the pressure to be measured .The levels in the arms change until the difference in the levels is equal to the pressure. This type of manometer can measure both positive and negative pressure figure 3.

The most common method of indicating pressure in medicine is by the height of a column of mercury (Hg). The pressure in fluid: If we have a column of liquid (blood or water) of across section A (U tube manometer for measuring the pressure (P). The most common clinical instrument used in measuring pressure is the **sphygmomanometer**, which measures blood pressure. In a mercury manometer the pressure is indicated by the height of a column of mercury inside a glass tube. In an aneroid type, the pressure changes the shape of a sealed flexible container which causes a needle to move on a dial.

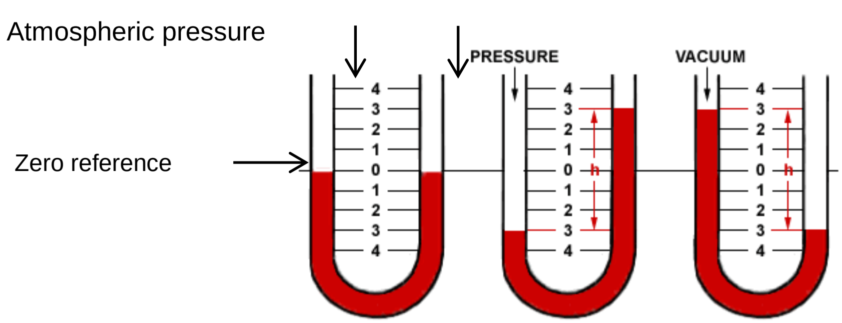


Figure 3 : Manometer

Figure 4 : Sphygmomanometer

There are a number of places in the body where the pressures are *lower* than atmospheric, or negative. For example, when we breathe in (inspire) the pressure in the lungs must be somewhat *lower* than atmospheric pressure or the air would not flow in. 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 drinking. The heart acts as a pump, producing quite high pressure to force the blood through the arteries. The returning venous blood is at quite low pressure and needs help to get from the legs to the heart. The failure of this return system in the legs often results in varicose veins.

Pressure in the digestive system

The pressure is greater than atmospheric in most of the gastrointestinal system however, in the esophagus, the pressure between the lungs and chest wall and usually less than atmospheric.

Pressure in the skeleton

The highest pressures in the body in on one leg, such as when walking, the pressure in the knee joint may be more than 10 atm. The finger bones are flat rather cylindrical and the force is over a larger surface; this reduces the pressure in the tissues over the bones.

1. The pressure in the bladder can be measured by passing a catheter with a pressure sensor into the bladder through the urinary passage.
2. Direct cystometry a needle is passed through the wall of the abdomen directly into the bladder. (cystometric method) give information about the bladder and the pressure more than the catheter technique.

Some of the Common Units Used to Measure Pressure

	Atmospheres	Pa	cm H_20	mm Hg	lb/in^2 (psi)
1 atmosphere	1	1.01×105	1033	760	14.7
1 Pa	0.987×10^{-5}	1	0.0102	0.0075	0.145×10^{-3}
1 cm H_20	9.68×10^{-4}	98.1	1	0.735	0.014
1 mm Hg	0.00132	133	1.36	1	0.0193
1 lb/in^2 (psi)	0.0680	6895	70.3	51.7	1

Questions

Question 1 Positive pressure is used in blood transfusion suppose a container is placed 1m above a vein with a venous pressure of 2 mm Hg; if the density of the blood is 1.04 g/cm^3, what is the net pressure acting to transfer the blood into the vein?

The gauge pressure of 1 m blood above a vein = ρ g h = 1.04 x 980 x 100
The gauge pressure of this height 1m in mercury is = 13.6 x 980 x h
1.04 x 980 x 100 = 13.6 x 980 x h
OR ($\rho_1 h_1 = \rho_2 h_2$, then 100 x 1.04 = 13.6 x h_2)
h = 7.65 cm OR h_2 =76.5mm Hg
another solution pressure of blood = $\frac{\rho_{blood}}{\rho_{Hg}} x 10^3 mm$ = 76.5 mm Hg
Since, the venous pressure = 2 mm Hg
The net pressure = 76.5 – 2 = 74.5 mm Hg

Question 2 Suppose you are a deep – diver preparing for a dive to 30m. What absolute pressure and gauge pressure will you experience?

Gauge pressure = ρ g h = 1000 x 10 x 30 = 3 x 10^5 N/m^2 = 3 atm
Absolute pressure = gauge pressure + atmospheric pressure
absolute pressure= 3 atm + 1 atm = 4 atm

Question 3 Negative pressure or suction is often used to drain body cavities .In the drainage arrangement for the gastrointestinal region, the negative pressure supplied to the collection bottle is 100 mmHg and the top end of the tube is 37 cm above the end of the tube in the body. Find the negative pressure at the lower end of the tube.
Solution 1:
$p_1 = p_2$
p_1 is the pressure of 37 cm of water, $p_1 = \rho_1 h_1$
p_2 is the pressure in mercury, $p_2 = \rho_2 h_2$
$\rho_1 h_1 = \rho_2 h_2$
1 x 37 = 13.6 x h_2
h_2 = 2.7 cm Hg (the height of mercury correspond to 37cm of water)
The negative pressure = 100 - 27 = 73 mm Hg = 7.3 cm Hg

Solution 2:

Pressure of 37 cm of water = $\frac{\rho_{H_2O}}{\rho_{Hg}} x 370 mm$

$\therefore$Net pressure = 100 mm Hg – 370 $\left(\frac{1.0}{13.6}\right)$ = 73 mm Hg

1 mm Hg = 1.3 x 10^3 dyn g / cm^2
1 mm Hg = N/m^2
1 Pa = 9.869 x 10^{-6} atm

1 atm = 1 atmosphere = 1.013×10^5 N/M^2 = 1.013×10^5 Pa
1 cm Hg = 1.333×10^3 N/M^2 = 1.316×10^{-2} atm
1 Pa = 7.501×10^{-4} cm Hg
1 atm = 76 cm Hg = 760 mm Hg

Question 4 Atmospheric pressure is due to weight of the air above us. The density of air is 1.3×10^{-3}g/ cm^3 what is the weight in dynes of 1 cm^3 of air? If this weight were spread over 1 cm^3 what would be the pressure? What fraction of 1 atm would it be?

The weight of air in dynes of 1 cm^3 is
Density = mass/Volume ($\rho = m/v$)
1.3×10^{-3} g/ cm^3 =mass/1 cm^3
Mass = 1.3×10^{-3} gm
W = mg = $1.3 \times 10^{-3} \times 980$ = 1.27 dyne
pressure = Force/area = 1.27 dyne/1 cm^2 = 1.27 dyne /cm^2
The pressure of air = $\rho g h$ = $1.3 \times 10^{-3} \times 980 \times 1$ = ? dyne /cm^2
Pressure of mercury of 1 cm height of air = 13.6 x 980 x`1
P(air) / P(Hg) = $1.3 \times 10^{-3} \times 980 \times 1$ / 13.6 x 980 x`1 = 9.6×10^{-5}
1 atm = 760 mm Hg, 1cm of air = 9.6×10^{-5} cm Hg
1cm of air = $9.6 \times 10^{-4}/760$
The pressure of 1 cm of air = 1.3×10^{-6} atm

Question 5
A 6.2 liters of an ideal gas are contained at 3.0 atm and 37°C. How many moles of this gas are present?

The ideal gas law PV = nRT
Because the units of the gas constant are given using atmospheres, moles, and Kelvin, it's important to make sure you convert values given in other temperature or pressure scales.
Convert °C temperature to K using the equation: T = °C + 273; T = 37 °C + 273 = 310 K
Solve ideal gas law for number of moles
n = PV / RT
n = (3.0 atm x 6.2 L) / (0.08 L atm /mol K x 310 K)
n = 0.75 mol
There are 0.75 mol of the ideal gas present in the system.

Physics of the cardiovascular system

The blood, blood vessels and the heart. The blood is 7% of the body mass or 4.5 Kg and approximately 4.5 Liters in a 64 Kg person.

The component of the blood

Red blood cell (erythrocytes); flat disk (7 μm in diameter), 45% of the volume of the blood, and 5×10^6 cells/mm^3 of the blood.
The blood plasma; Clear fluid 55% of the blood
White blood cell (Leukocytes); (9 – 15 μm), 8000 cell's/mm^3, in some infection in the body , the number of this cell's increases like, cancer, Leukemia.
Platelets; 1- 4 μm in diameter, 3×10^5 platelets /mm^3 of blood.
The blood vessels; arteries, veins, and capillary.

The heart is a double pump. The heavier and stronger muscular walls on the left side of the heart and the circular shape of the left ventricle produces the high pressure to circulate the blood. The first pump carries oxygen-poor blood to your lungs, where it unloads carbon dioxide and picks up oxygen. It then delivers oxygen-rich blood back to your heart. The second pump delivers oxygen-rich blood to every part of your body.

The valves of the heart: Natural valves, flow of blood only in the correct direction.

Work done by the heart:

The work of the heart muscle from the contraction of the heart muscles forces, 80 mL of blood through the Lungs from the right ventricle and a similar volume to the systemic circulation from the left ventricle. The work done by the heart;

$$\mathbf{W = \int F\,dr = \int F/A\,Adr = \int F/A\,dV = \int P\,dV = P\Delta V}$$

Physical W is the average pressure x volume of the pumped blood during each compression. Where P is constant pressure, ΔV is volume pumped. The pressures in two pumps of the heart are not the same, in the *pulmonary system* the pressure is very low due to the low resistance of the blood vessels in the Lungs. The pressure increases from diastolic pressure slowly up to systolic pressure and falls rapidly back to diastolic pressure after the heart muscle releases, see figure 1B.

Example: If the average pressure is 100 mmHg and 80 mL of blood is pumped each second at a pulse rate of 60/min, what is the work done by the heart.
1 atm = 1.013×10^5 N/m^2 =1.013×10^5 Pa = 760mmHg
(100 mmHg=1.4×10^5 dynes /cm^2)
1 erg=10^{-7} joules
work per second = P V = 1.4×10^5 dynes cm^{-2}x 80 cm^3 = 1.12×10^7 ergs = 1.1 J/sec = 1.1 W .

Blood pressures and measurement

The measurement of blood pressure by two methods; direct method and indirect method

Direct method: Hollow needle in a blood vessel (pressure of blood transmits through Cather (hollow plastic tube) to the pressure transducer.

Indirect method: The instrument is used to measure the pressure is called a *sphygmomanometer* (manometer), gauge on the upper arm with a stethoscope.

Blood pressure $\equiv \dfrac{Systolic\,(contraction)}{Diastolic\,(relaxation)}$

The diastolic pressure is affected by blood viscosity, arterial distensibility, systemic resistance, and the length of the cardiac cycle. The pulse pressure is the difference between systolic and diastolic pressure. A normal pulse pressure in the brachial artery is approximately 40 mm Hg.

Normal blood pressure = $\dfrac{120}{80}$ mm Hg = Arterial blood pressure $\equiv \dfrac{12}{8}$ cm Hg

Mean of blood pressure = diastolic pressure + $\dfrac{1}{3}$[systolic pressure – diastolic pressure]

Pulse of blood pressure =[systolic – diastolic]

If the blood pressure is 120/80, then the pulse pressure is 40, the difference between 120 mm Hg and 80 mm Hg.

The mean arterial pressure (MAP) and pulse pressure for a person with a blood pressure of 115/73 are calculated as below:

The formula to calculate the mean arterial pressure (MAP) is:

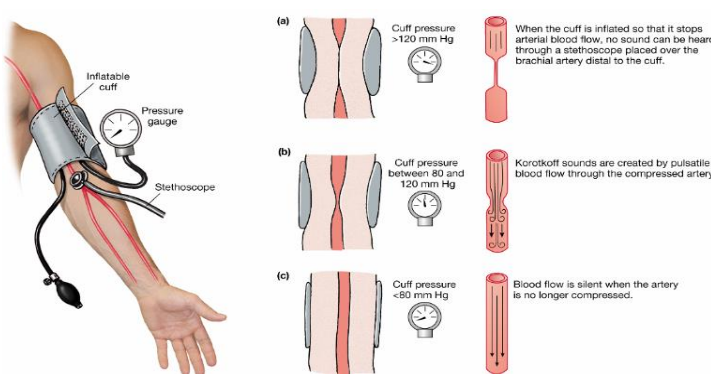
$$\text{MAP} = \text{diastolic P} + \frac{1}{3}(\text{systolic P} - \text{diastolic P})$$

For the given values, the formula is:

$$\text{MAP} = 73 + \frac{1}{3}(115 - 73)$$

$$= 73 + \frac{1}{3}(42)$$

$$= 73 + 14 = 87 \text{ mm Hg}$$



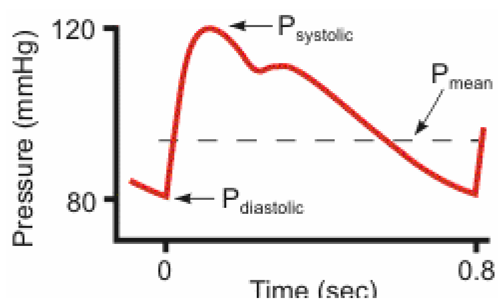


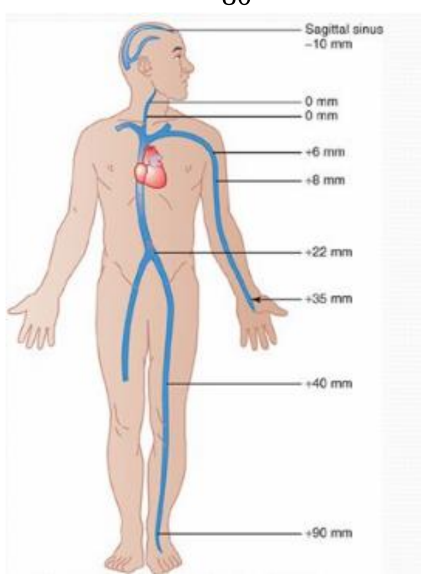
Figure 1A Figure 1B

The effect of acceleration:

The pressure in the body arteries varies from one point to another due to the gravitational forces. Figure 2 shows direct measurements of blood pressure made on a standing person. Pressure is the same on all point in the body when the body is horizontal (not standing).

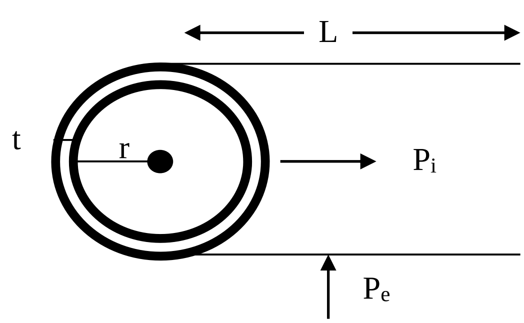
The blood pressure in the foot for a person, height from feet to heart 125 cm;
$P_1 = \rho gh$ [by column of blood (of height h) between heart and foot **] + pressure of the heart.**
Here ρ is the blood density (1.04 g/cm^3 or 1.04x10^3 kg/m^3).
$P = h\rho g = 1.25\ m \times 1.04 \times 10^3\ kg.m^{-3} \times 9.8\ m.s^{-2} = 12.5\ kPa = 90\ mm\ Hg$

The blood pressure in the brain for a person standing on his head;
$P = h\rho g = 0.5\ m \times 1.04 \times 10^3\ kg.m^{-3} \times 9.8\ m.s^{-2} = 5\ kPa = 38\ mm\ Hg$
$\therefore$ h of blood = 13 times of h_{Hg}, If P of blood $\equiv \frac{120}{80}$ mm Hg $\equiv \frac{1560}{1040}$ mm of blood



Laplace Law:

How the tension in the wall of a tube related to the radius of the tube and the pressure inside the tube. Consider a long tube of radius r carrying blood at pressure P with a uniform section of a tube of length L and wall thickness t. The larger the vessel radius, the larger the wall tension required to withstand a given internal fluid pressure. For a given vessel radius and internal pressure, a spherical vessel will have half the wall tension of a cylindrical vessel. The pressure across the blood vessel (or tube) wall is P_{tm}. $P_{tm} = P_i - P_e$;
P_i is the internal blood pressure or P (mean) = P_{atiral} , P_e is the external tissue pressure. If P_e is very small, $P_{tm} = P_i = P$



The pressure inside the tube is uniform on the wall, and can mathematically divide the tube in half. The force trying to separate the upper and lower halves is the P_{tm} times an area A. F = P_{tm} A. A by integration, that area against the pressure acts is the diameter R of the tube times l.

$\therefore F = P_{tm}\ (Rl)$ R=2r $\therefore F = 2rl\ P_{tm} = 2rl\ P$ $P_{tm} = P = P$

If the tube in equilibrium pushing force = tension force T, holding two halves

2rl P = 2Tl T = tension force per unit length **∴T = rP** **Laplace law**

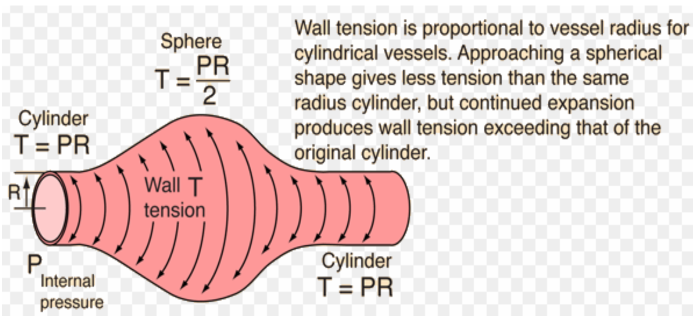


Figure 4A

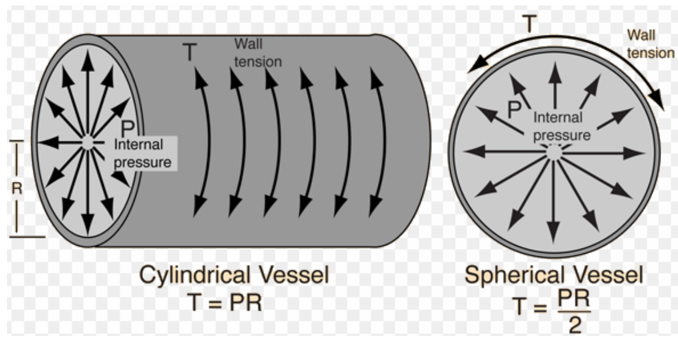


Figure 4B

Table (1) Typical pressures and T	
Aorta (r = 1.2 cm)	P = 100 mm Hg T=156,000 dynes/cm = 1.3×10^5 dynes/cm^2
Typical artery (r = 0.5 cm)	P = 90 mm Hg ⇒ T = 60,000 dynes/cm
Small capillary (r = 6×10^{-4} cm)	P = 30 mm Hg ⇒ T = 24 dynes/cm
Small vein (r = 2×10^{-2})	P = 15 mm Hg ⇒ T = 400 dynes/cm
Vena cava (r = 1.5 cm)	P = 10 mm Hg ⇒ T = 20,000 dynes/cm

Bernoulli's Principle

Based on the low of conservation of energy, the velocity of blood (or fluid) increase at the narrow section of the tube. The work done on the any system;

$\Delta W = \Delta KE + \Delta PE$

$\Delta W = P\ \Delta V = P\ \frac{\Delta M}{\rho}$

ΔKE = Kinetic energy = $\frac{1}{2}\Delta MV^2$

ΔPE = Potential energy = ΔMgh

$\therefore P\frac{\Delta M}{\rho} = \frac{1}{2}\Delta MV^2 + \Delta Mgh$

$P = \frac{1}{2}\rho V^2 + \rho gh$

$P_1 – P_2 = \frac{1}{2}(\rho V_2^2 - \rho V_1^2) + \rho g (h_2 – h_1)$

$P_1 + \rho gh_1 + \frac{1}{2}\rho V_1^2 = P_2 + \rho gh_2 + \frac{1}{2}\rho V_2^2$

If there is no friction with the walls of a tube, the pressure decrease where the velocity of fluid flow increase; $P \propto \frac{1}{V}$. If the system is heart, the work W, is used for; raise the pressure in the arteries, impart KE to the blood, work against friction, and increase the velocity of blood

Example: From the left side of normal human heart, the difference in height from the ventricle to the aorta is 15 cm, the velocity of the blood at this point is 40 cm/sec. Find the work done for each 1 cm^3 of 1 g of blood? According to the following data.
$\rho_{blood} = 1.04\ g/cm^3 \cong 1.0\ g/cm^3$
P_l artery = 80 mm Hg (diastolic)
P_l aorta = 120 mm Hg (systolic)

Initial velocity before systole = 0
Venous drain pressure = 0
Left arterial pressure prior to contraction = 0
V_1, P_1 , $h_1 \equiv$ velocity , pressure and height of the blood *entering* the heart .
V_2, P_2 , $h_2 \equiv$ velocity , pressure and height of the blood *leaving* the heart .

The work done by heart is; $W = P\ \Delta V$
According to Bernoulli's principle
$W = \Delta KE + \Delta PE + \Delta P$

ΔKE = work of velocity change = $\frac{1}{2}m\left(V_2^2 - V_1^2\right) = \frac{1}{2}$ x 1g (40 cm/sec)^2 = 8 x 10^2 dyne cm

ΔPE = work of height change = mg $(h_2 – h_1)$ = 1g x 980 cm s^{-2} x 15 cm = 0.15 x 10^5 dyne cm

ΔP = work of pressure change = $\frac{m}{\rho}(P_2 – P_1) = \frac{1g}{1g/cm^3}$ x 120 mm Hg = 1 cm^3 x 12 cm Hg

= 12 x 1.3 x 10^4 dyne/cm^2 = 1.6 x 10^5 dyne cm

$\Delta P >> \Delta KE$, P.E $\approx$ 10% of ΔP
$\therefore$The work per 1 cm^3 of blood pumped = 1.758 x 10^5 dyne cm
The work per 60 cm^3 of blood pumped = 1.055 x 10^7 dyne cm

The work by RV = $\frac{1}{6}$ work by LV, Total work by the leavt = (1 + $\frac{1}{6}$) $10^7 = 1.16 \times 10^7$ dyne cm

Note : the pressure in pulmonary artery is 120 mm Hg

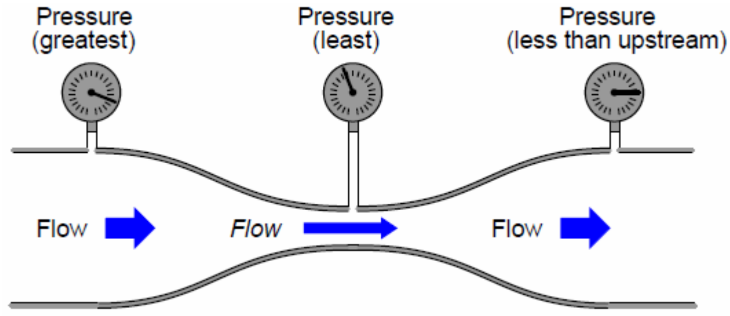


Figure 5A

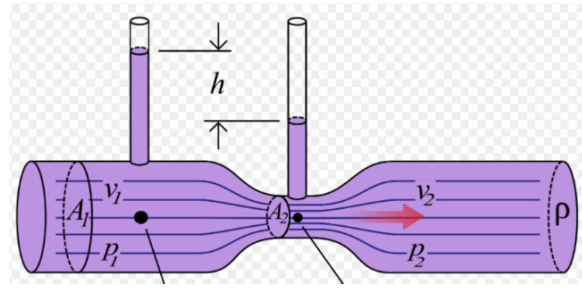


Figure 5B

The medical important of Venturi effect

The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of a pipe. If any artery is narrowed by internal plagues or by external pressure resulting from a tumor, then the blood pressure in the constricted region of the artery will fall very dramatically

$A_1 > A_2$, $V_1 < V_2$ $\Rightarrow P_1 > P_2$, $\therefore$ **$V_1A_1 = V_2A_2$ equation of continuity**

The venturi tube method has been adapted to measure the flow velocity of blood in arteries.

Example: A liquid of density 950 Kg m^{-3} flows in a horizontal pipe of radius 4.5 cm in a section of the tube of restricted radius 3.2 cm, the liquid pressure is 1.5×10^3 Nm^{-2} less than in the main pipe, calculate the velocity of the liquid in the pipe.

Let the pressure in the main tube is P_1 and the pressure in the restricted tube is P_2

$P_1 > P_2$ $\Rightarrow$ $V_1 < V_2$ $\Rightarrow r_1 > r_2$

$P_1 = P_2 + 1.5 \times 10^3$ N m^{-2}

From Bernoulli's principle

$P + \frac{1}{2}\rho V^2 + \rho gh$ = constant

The pipe is horizontal, *there is no P.E*

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

$$P_1 - P_2 = \frac{1}{2}\rho(V_2^2 - V_1^2)$$

$P_2 + 1.5 \times 10^{+3} - P_2 = \frac{1}{2}\rho(V_2^2 - V_1^2)$

$1.5 \times 10^{+3} = \frac{1}{2}\rho(V_2^2 - V_1^2)$

$(V_2^2 - V_1^2) = \frac{\rho}{3x10^3} = \frac{950}{3x10^3} = 31.6 \times 10^{-2}$ …………(1)

From equation of continuity;
$A_1V_1 = A_2V_2$

$\pi r_1^2 V_1 = \pi r_2^2 V_2$ $r_1^2 V_1 = r_2^2 V_2$ $\therefore V_1 = \left(\frac{r_2}{r_1}\right)^2 V_2$ …………… (2)

From equation 1 and equation 2 we get

$V_2^2 - \left(\frac{r_2}{r_1}\right)^4 V_2^2 = 31.6 \times 10^{-2}$

$1 - \left(\frac{r_2}{r_1}\right)^4 = \frac{31.6 \times 10^{-2}}{V_2^2}$

$1 - \left(\frac{3.2}{4.5}\right)^4 = \frac{31.6 \times 10^{-2}}{V_2^2}$

$1 - 0.3 = \frac{31.6 \times 10^{-2}}{V_2^2}$ then, $0.7\, V_2^2 = 31.6 \times 10^{-2}$ $V_2 = \sqrt{\frac{31.6 \times 10^{-2}}{0.7}} = 0.67\text{m}$

The flow of blood:

The volume rate of flow through the tube of a liquid of viscosity η is given by Poiseuille's Equation. Determinants of resistance to flow, there are three primary factors that determine the resistance to blood flow within a single vessel; vessel diameter (or radius), vessel length, and viscosity of the blood. In contrast, an increase in radius will reduce resistance.

$Q = \frac{\pi r^4 P}{8\eta L}$ **Poiseuille's equation**

$Q = V = \frac{Volume}{time} \left(\frac{cm^3}{\sec}\right)\left(\frac{cm^3}{\min}\right)$ $Q = \frac{V}{t} = \frac{AL}{t} = A\,\nu$

Where; Q is the volume rate of flow, A is the cross section area of tube, ν = velocity of liquid (or blood).

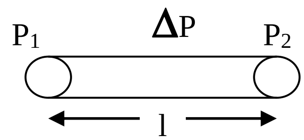
The physical factors effect of the flow rate $Q = A\,\nu$; $\therefore Q \propto \nu$

The blood velocity ν is related in an inverse way to the total cross sectional area of the vessels carries the blood, ν (average velocity) = $\frac{Q}{A}$

ν in aorte $\approx$ 30 cm/sec, ν in capillary = 1 mm/s. The relation between the velocity of blood and the cross sectional area A in the circulatory system.

The pressure difference ΔP from one end to the other end of the blood vessel.

$Q \sim (P_1 - P_2) = \Delta P$



The length of the vessel $Q \sim \frac{1}{L}$

The pressure gradiant $Q \sim \frac{\Delta P}{L}$, $\frac{mmHg}{cm}$

The radius of the blood vessel $Q \propto r^4$

$\therefore Q = \frac{\pi a^4}{8\eta} \frac{\Delta P}{l}$ [applied to rigid tubes]

But not applied exatly to blood vessel due to change of radius through the heart rate .

The viscosity of blood:

In the real fluid (blood, water) is characterized by being compressible and by there being internal forces acting on it, there is frictional forces when the fluid is moving and such forces lead to a loss of mechanical energy. The property of a blood that determines the magnitude of these dissipative forces is known as the viscosity η.

$Q \propto \frac{1}{\eta}$

The unit of viscosity

Cgs unit is poise P, **SI unit** is pascal second P_aS
Pa.S = 10 P =1 Newon.S.m^{-2} = 1 $kg^{-1}S^{-1}$
1 P = 0.1 Pa.S = 1 dyne. cm^{-1}.sec^{-1}

The dependence of viscosity

Viscosity depends on percentage of red blood cell in the blood (hematocrit), hematocrit increase then viscosity increase. If viscosity increase when hematocrit > 75% (polycrthemia) then a decrease in Q. η depend on the temperature T; If T is large, η is small and Q is high, If tmperature is small, η is high and Q is small. T of human from normal 37^{o}C to 0^{o}C, Increase the η of blood by a factor of 2.5. The flow rate through a tube depends on the; pressure difference. P = pressure, f = Q = flow, $F_2 = 2F_1$. The length of the tube: $F_2= 2F_1$ at the same pressure, the viscosity of the (fluid or blood), water $F_2= 2F_1$. The radius of the tube; $F_2 = 16 F_1$, $Q = f = r^4$. The radius has the largest effect on Q of the liquid.

Kind of blood flow:

Laminar flow: It is a slow, smooth and quietly flows of blood in most blood vessels. The layers of blood in contact with the walls of the blood vessels are essentially stationary. The next to the outside layer is moving slowly and the layer in center of the vessel is moving more rapidly. The effect of Laminar flow on the distribution of red blood cells in the circulatory system is not uniform. There are more in the center than at the edges, and this produces two effects; Red blood cells in small vessel from the side of a main vessel will be slightly due to the skimming effect. Hematocrit in the extremities is high.

Turbulent flow:

It is a rapid and noisy flow of blood, for example, where the blood is flowing rapidly past the heart valves. The heart sounds heard with a stethoscope are caused by turbulent flow, measurement of blood pressure, the constriction produced by the pressure cuff on the arm produces a turbulent flow and the resulting vibrations can be detected by stethoscope on the brachial artery.

Critical flow:

The velocity of blood increase by reducing the radius of the tube, it will reach a critical velocity V_c when Laminar flow changes into turbulent flow; V_c is the critical velocity of blood

$V_c \propto \frac{\eta}{\rho r}$, or $V_c = K\frac{\eta}{\rho r}$,

where η = viscosity of blood , ρ = density of blood , r = radius of vessel, and K = constant of proportional.

K = Reynold number, we can determine whether fluid flow is laminar or turbulent based on the Reynolds number. If the Reynolds number is less than 2300, the flow is laminar. Any Reynolds number over 4000 indicates turbulent flow. K = 1000 (fluid, blood , ….) flowing (in long tube of constant diameter).But if there is bend or obstruction, $K < 10^3 \Rightarrow V_c$ is lower.

Example : Find the the critical velocity of blood V_c in the aorta of radius 1 cm (adult)

$V_c = K\frac{\eta}{\rho r}$ at normal state $\eta = 4 \times 10^{-3}$ pas , $\rho_{of\ blood} = 1.04\ g\ cm^{-3} \approx 10^3\ Kg/m^3$, r=1cm , $K=10^3$

$\therefore V_c = \frac{10^3 x 4 x 10^{-3}\ pas}{10^3 Kgm^{-3} x 10^{-2} m}$ V_c = 0.4 m/sec ,

The range of velocity of blood in Aorta 0– 0.5 ms^{-1} and thus the flow is turbulent during part of the systole.

The efficiency of flowing:

From Poiseuille's equation:

$\left[Q = \frac{\pi r^4 \Delta P}{8\eta L}\right]$ $\quad$ $Q \propto \Delta P$ and $R = \frac{8\eta L}{\pi r^4}$

The volume flow depends upon the pressure drop ΔP per unit length of the tube :

At critical point at $P = P_c$, the flow becomes turbulent and a great deal of energy is converted to the KE of eddies. From the curve $(\text{ slope })_{Lf} >> (\text{ slope })_{Tf}$

$$\left(\frac{\Delta Q}{\Delta P}\right)_{Lf} >> \left(\frac{\Delta Q}{\Delta P}\right)_{Tf}$$

Increase in pressure lead to increase in Laminar flow rate than in the turbulent flow rate. The laminar flow is more efficient than turbulent flow.

Flow through an artery with an obstruction, at normal artery 1

$V_A = Q_A$ at P_1

$V_A = Q_A$ at P_2 for artery 2, $P_2 > P \Rightarrow$ give the same Q

If $Q = V_B$ at ΔP_1 for (1), at ΔP_2 for (2) $\Rightarrow$ need much pressure to give the same Q.

Questions

1. A liquid of density 950 Kg m^{-3} flows in a horizontal pipe of radius 4.5 cm in a section of the tube of restricted radius 3.2 cm the liquid pressure is 1.5×10^3 Nm^{-2} less than in the main tube find the velocity of the liquid in the pipe ?
2. The level of blood in the bottle using for blood transfusion is 1.3 meter above the needle which has an internal diameter of 0.36 mm and 3 cm in length . In one nunute 4.5 cm^3 of liquid pass through the needle . Find the viscosity of blood at 37^o C.
3. The radius of the aorta in human is 1 cm and the cardiac output is 5×10^{-3} m^2 /minute. What is the average velocity of flow in the aorta?
4. An artery with a 3 mm radius is partially blocled with to plaque; in the constricted region the effective radius is 2mm and the average blood velocity is 50 cm sec^{-1} find:

a. What is the average velocity of the blood in the unconstricted region.

b. For the blood in the constricted region, find the equivelent pressure due to the KE of the lood.

The Physics of the Lungs and Breathing

The human “machine“consists of billions of very small “engines “ the living cells of the body. Each of these a miniature engines must be provided with fuel, O_2, and a method of getting rid of the products. The blood and its vessels (cardiovascular system) serve as the transport for these engines. The lungs (pulmonary system) serve as the supplier of O_2 and disposes of the main by product CO_2. The blood takes the O_2 to the tissues and removes the CO_2 from the tissues; it must come in close contact with the air in the lungs in order to exchange its load of CO_2 for a fresh load of O_2.

The function of the Lungs

1. Exchanging of O_2 and CO_2.
2. Keeping the PH (acidity) of the blood constant.
3. Heat exchange.
4. Keeping the fluid of the body balance by warming and moisturizing the air we breathe.
5. Controlled the flow of air for talking, coughing, sneezing, sighing, laughing, and sniffing.
6. Voice production.

Breathing

We breathe about 6 liters of air per minute. Men breathe about 12 times per minute at rest, women breathe about 20 times per minute, and Infants breathe about 60 times per minute. The air we inspired is about 80% N_2 and 20% O_2. Expired air is about 80% N_2,16% O_2 and 4% CO_2. We breathe about 10 Kg of air each day. Of this the lungs absorbs 400 liters of O_2 (0.5 Kg) and release a slightly smaller amount of CO_2. Each time we breathe, about 10^{22} molecules of air enter our lungs. Each liters of air contain about 6 $x10^{23}$ molecules (Avogadro’s number).

Air ways

The principal air passages into the lungs are shown in figure 1. Air normally enters the body through the nose where it is warmed, filtered and moisturized. The air then passes through trachea. The trachea divides into two to furnish air to each lung through the bronchi. Each bronchus divides and re divides about 15 times, the resulting terminal bronchioles supply air to millions of small sacs called alveoli. The alveoli is small interconnected bubbles are about 0.2 mm in diameter and have walls only 0.4 μm thick, see figure 2. They expand and contract during breathing; they are in the exchanging of O_2 and CO_2. Each alveolus is surrounded by blood so that O_2 can diffuse from the blood into the air in the alveolus.

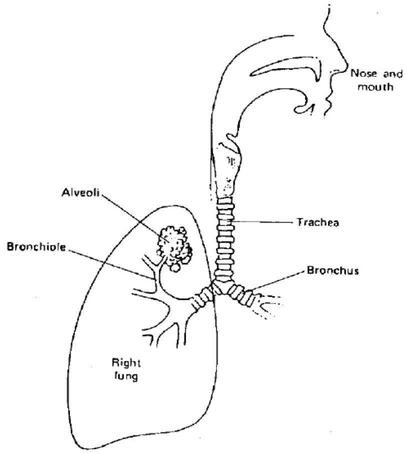


Figure 1. principal air passages into the lungs

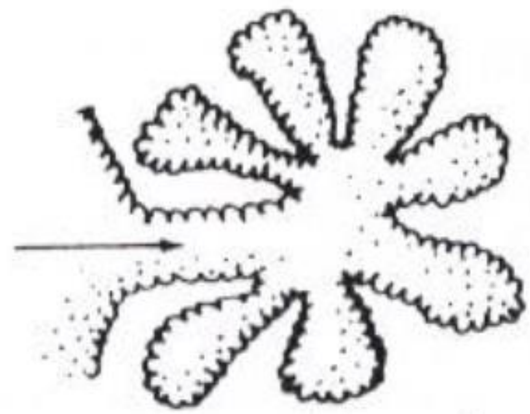
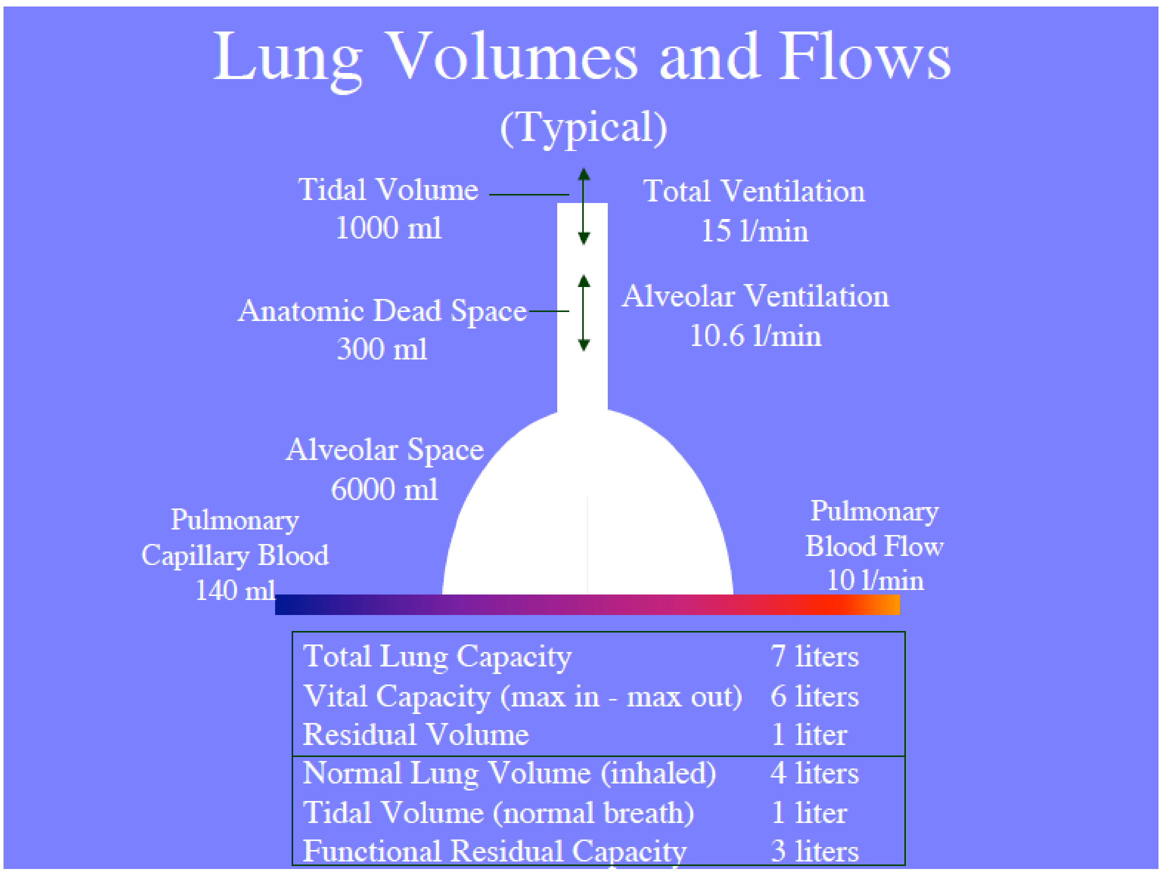


Figure 2. The structure of alveoli



The Physics of Exchanging of Gas between the Lungs and the Blood

The transfer of O_2 and CO_2 into and out of the blood is controlled by the physical law of diffusion. All molecules are continually in motion. In gases and liquids, and to certain extent even in solids, the molecules do not remain in one direction. Molecules of a particular type diffuse from region of higher concentration to a region of lower concentration until the concentration is uniform In the lungs we are concerned with diffusion in both gas and liquids. In the O_2 and CO_2 exchange in the tissues we are concerned only with diffusion in liquids. The molecules in a gas at room temperature move at about the speed of sound. Each molecule collides about 10^{10} times each second with neighboring molecules.

The distance D of molecule will travel from its origin after N collisions is **$D = \lambda\sqrt{N}$**
Where λ is the mean free path, and defined as the average distance between collisions. In air $\lambda = 10^{-7}$m, in tissue $\lambda = 10^{-11}$m.

Example 1
What is the typical value of distance travel by molecule in air and in tissue for an O_2 molecule after 1 sec if number of collisions 10^{10} in air and in tissue is 10^{12}?

Solution
In air $D = 10^{-7} (10^{10})^{½} = 10^{-2}$ m
In tissue $D = 10^{-11} (10^{12})^{½} = 10$ m

Diffusion depends on the speed of the molecules, the speed of molecules increases with temperature. Since N is proportional to the diffusion time Δt.
$N \propto \Delta t \rightarrow D \propto \sqrt{\Delta t} \rightarrow \Delta t \propto D^2$

In the lungs the distance to be travelled in air usually a small fraction of a millimeter, and diffusion takes place in a fraction of a second. The diffusion of O_2 and CO_2 in tissue is about 10,000 times slower than it is in air, but the tissue thickness of the molecules must diffuse through in the lungs is very small (0.4μm) and diffusion through the alveolar wall takes place in much less than 1 sec.

To understand the behavior of gases in lungs it is necessary to know Dalton' s law of partial pressures. Dalton's law state that if you have a mixture of several gases, each gas makes its own contribution to the total pressure as though it were all alone. The pressure exerted by any one of the gases is known as the partial pressure of that gas, and the total pressure of these gases is the sum of the partial pressures of the mixture gases.

p = p + p + p ……., where p is a partial pressure

Henry's Law of Solubility of Gases

Henry's law states that the quantity of a gas going into simple solution at constant temperature is proportional to the pressure. If we have a closed container of blood and CO_2, it found that some of O_2 molecules collide with blood and are dissolved. After a while the number of O_2 molecules that are escaping from the blood each second is the same as the number that are entering it. The blood then has a PO_2 equal to that of the O_2 in contact with it. If PO_2 in the gas phase is doubled, the amount of O_2 dissolved in the blood will also double. This proportionality is Henry's law of solubility of gases. The amount of gas dissolved in blood varies greatly from one gas to another. Oxygen is not very soluble in blood or water. The different solubility of O_2 and CO_2 in tissue affects the transport of these gases across the alveolar wall. A molecule of O_2 diffuses faster than a molecule of CO_2 because of its smaller mass. However, because of greater number of CO_2 molecules in solution, the transport of CO_2 is more efficient than the transport of O_2. The mixture of gases in the alveoli is not the same as the mixture of gases in ordinary air. The lungs are not emptied during expiration. During normal breathing the lungs retain about 30 % of their volume at the end of each expiration. This is called the functional residual volume (FRC). At each breath 500 cm^3 of fresh air (PO_2 of 150 mm Hg) mixes with 2000 cm^3 of stale air in the lungs to result in alveolar air with a PO_2 100 mm Hg. The PCO_2 in the alveoli is about 40 mm Hg. Expired air includes about 150 cm of relatively fresh air from the trachea that are not in contact with alveolar surface, so expired air has a slightly higher PO_2 and lower PCO_2 than alveolar air.

Table 1, the percentages and partial pressures of O_2 and CO_2 in inspired, alveolar and Expired.

	% O_2	PO_2 (mmHg)	% CO_2	PCO_2 (mmHg)
Inspired air	20.9	150	0.04	0.3
Alveolar air	14.0	100	5.6	40
Expired air	16.3	116	4.5	32

Measurement of Lungs Volume

The spirometer is an instrument used to measure airflow into and out the lungs and record it on a graph of volume versus time. This instrument consists of a counter balanced bell free to move in the vertical plane, as shown in Figure 1. It has water – seal so that it forms an airtight chamber of variable volume. The changes in volume of this chamber are recorded on a chart. When breathing through the mouth into the spirometer with a nose clip, the air in the lungs, air passage and the spirometer is a closed system. Thus, when the lungs volume increases in the inspiration the volume of gas in the spirometer is reduced, and when the lung volume decreases in expiration, the spirometer volume increases.

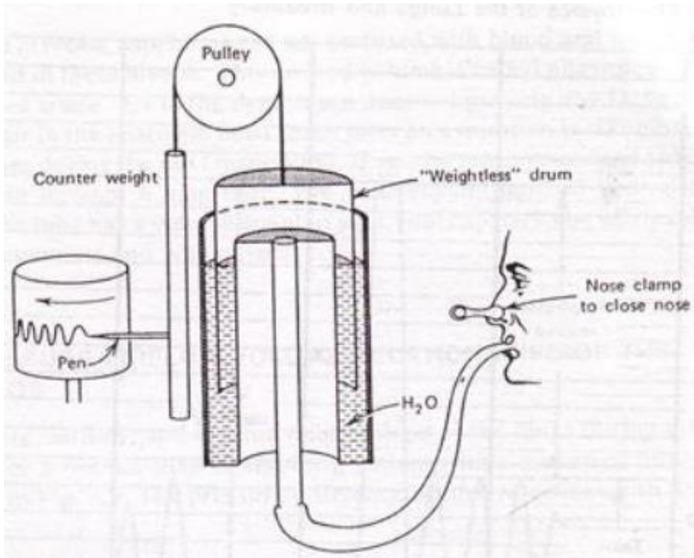


Figure 1

Tidal volume: is defined as the amount of air in or out per breath.
Inspiratory reserve volume: is the additional amount of air which can be inspired at the end of a normal inspiration.
Expiratory reserve volume: is the additional amount of air which can be expired at the end of a normal expiration.
Residual volume: is the amount of air remaining in the lungs at the end of a forced expiration.

Capacity

By adding all four types of volume together, we get the total lung capacity. If we add only inspiratory reserve volume, tidal volume, and expiratory reserve volume we get the **vital capacity**. If we add only the expiratory reserve volume and residual volume, we get *functional residual capacity **FRC***.

Ventilation

Ventilation is the continuous process of moving air in and out of the lungs. Ventilation is usually expressed in volume per unit minute, or litters per minutes.

Surface tension

Is defined as, the force per unit length acting across any line drawn in the surface and tending to pull the surface apart across the line. **S = F/L**, Newton/m. *Surface tension of a liquid* can be regarded as the potential energy per unit area of the surface.

Excess pressure inside a spherical air bubble; considers a spherical air bubble of radius R, inside a liquid of surface tension S. P_1 is the pressure inside the bubble, P_2 is the pressure outside the bubble $P_1 > P_2$. The bubble divided into two hemispheres; The circumference of the circle = $2 \pi R$.
Surface tension will exert a down ward force $2 \pi R S$ on the upper hemisphere, and equal upward force on lower hemisphere. $(P_1 - P_2) \pi R^2$ is the downward force on the upper hemisphere is balance by a thrust due to the excess pressure $P_1 - P_2$.
At equilibrium; $(P_1 - P_2) \pi R^2 = 2 \pi RS$; then,

$P_1 - P_2 = 2S/R$. For spherical drop of water, the excess pressure is;
$P_1 - P_2 = 4S/R$

Physics of the Alveoli

The alveoli are physically like millions of small interconnected bubbles. They have a natural tendency to get smaller due the surface tension of a unique fluid lining. This lining called *surfactant*, it is necessary for the lung to function properly. To understand the physics of alveoli we have to understand the physics of bubbles. According to *Laplace̕s law*, the pressure inside a bubble is inversely proportional to the radius and directly proportional to the surface tension, $P = 4S/R$, Laplace̕s law. The compliance of the lungs is made greater by the presence of surfactant in the alveoli. This substance acts like a detergent and reduce the surface tension of the water in the alveoli.

Elasticity of lungs

The lungs and chest wall are elastic structures. The combined elasticity may be measured by relaxing the respiratory muscles, and then by how much the volume increases, when the pressure in the lungs increased.
Elasticity = $\Delta P/\Delta v$. Where, ΔP = is the change in pressure, ΔV = is the change in volume. In respiratory mechanics it is usually to consider elasticity, but it's reciprocal.

Compliance: is the change in the volume produced by a small change in pressure. **Compliance = $\Delta v/\Delta p$**; Liters/cm of H_2O. Compliance in normal range is 0.18- 0.26 Liter/cm H_2O.

The Breathing Mechanism

Breathing is normally under unconscious control. The physiological control of breathing depends on many factors, but the respiratory centre of the brain exerts primary control. If a lung were removed from the chest all the air would be squeezed from it and it would collapse to about one third of its size much as a balloon collapses when air is let out of it. The lungs can be thought of as millions of small balloons, all trying to collapse. The lungs do not normally collapse because they are in an airtight container – the chest. As the diaphragm and rib cage move the lungs stay in contact with them.
Two forces keep the lungs from collapsing:

1. Surface tension between the lungs and the chest wall.
2. Air pressure inside the lungs.

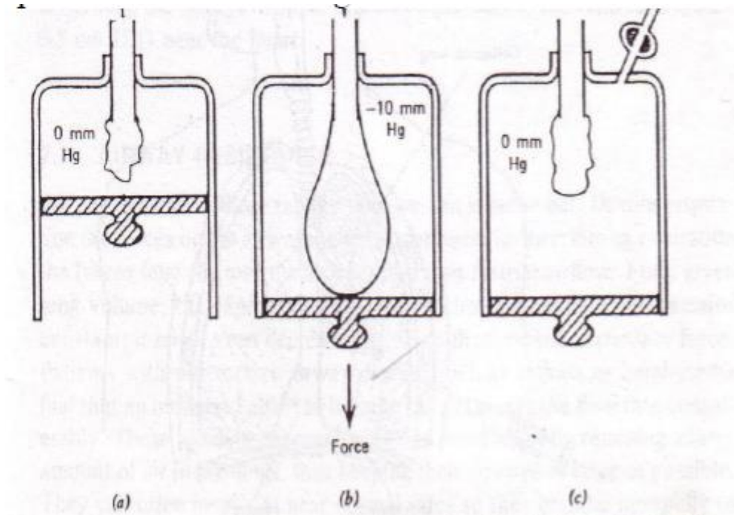


Figure 7.20. A simple model of the mechanisms of breathing (a) during expiration, (b) during inspiration, and (c) during pneumothorax.

If the lungs overcame the surface tension forces and pulled away from the chest wall a vacuum would be created since air cannot reach the inside space. Since the air inside the lungs is at atmospheric pressure (10^5 N/m²), it would push the lungs back in contact with the chest wall. Various muscles are involved in breathing. Normally most breathing is done by contracting the diaphragm muscles. These pull the diaphragm down expanding the lungs. During inspire, we pull the diaphragm down as shown in figure 2. This produces a slight negative pressure in the lungs and air flows in, while during expire, we relax the diaphragm muscles, the elastic forces in the lungs cause the diaphragm to return to its neutral position, and air flows out of the lungs without any active muscular effort. Since both the lungs and chest wall are elastic, we can represent them with springs. Under normal conditions they are coupled together "the lung" springs are stretched and "chest" springs are compressed. But the lungs and chest are independent and the springs representing them go to their relaxed positions as indicated in figure 2b. The lungs collapse and the chest wall enlarges.

Airways Resistance

We can breathe in more rapidly than we can breathe out. During inspiration the forces on the airways tend to open them further; during expiration the forces tend to close the airways and thus restrict air flow. The flow of air in the lungs is analogous to the flow of current in an electrical circuit. "Ohm s law" for air flow looks like ohms law for electrical circuit, with voltage replaced by pressure difference **ΔP** and current replaced by the rate of airflow **Δv/Δt** or **V**. Airway resistance R_g is the ratio of ΔP to V. $\mathbf{R_g = \Delta P/ V}$ cm H_2O / Liter/sec. The flow rate of air flow is V = Δv/ Δt. R_g depends on the dimensions of the tube and the viscosity of the gas. The time constant of lungs $\mathbf{R_gC}$, is related to the airway resistance R_g and the compliance C. This is analogous to the time constant **RC** or capacitor C to discharge through a resistance R in an electrical circuit. The time constant of the lung is complicated since many parts of the lung are interconnected. *If one part of the lung has a larger time constant than other parts, it will not get its share of the air and that part of the lung will be poorly ventilated*.

Osmosis

If we have two salts solutions of different concentrations separated by a membrane permeable to water not to salt, it is found that in time the solution on the two sides will have the same strength. This is due to the passage of water from the weak salt solution to the stronger. Such phenomenon is known *Osmotic Pressure* as *osmosis*. That is mean, the force under which a solvent moves from a solution of a lower concentration to a solution of higher solute concentration. When these solution are separated by a selectively permeable membrane. **PV =nRT**, where P is the osmotic pressure, V is the volume, n is the number of mole, R is the universal gas constant 8.3 J/mole, and T is the absolute temperature. The osmotic pressure is proportional to the concentration of the solution, which means inversely proportional to the volume of the solution. It is also proportional to the absolute temperature.

Cardiovascular instrumentation

The function of electrodes:

The electrical activity of the nervous system is detected by using electrodes which transfer the biochemical and physiological phenomena into electric currents. The electrolytes in biological solution and body tissue contain charge particles and electrode function is to transfer the charge between the ionic solution and metallic conductors. If the electrodes are made from ordinary metal bubbles form due to electrolysis, and the resulting electrode to solution interface is electrically unstable. This instability produces electrical noise and drifts which may be much larger than ECG signal or any biological signal. These problems may be avoided by using silver–silver electrodes. The chemical reactions at a skin – electrode interface are determined by the electrode composition (a) Electrode of platinum, an inert metal, cause gas bubbles to form (O_2 at the positive electrode and H_2 at the negative electrode), producing a high resistance and polarization at the interface. (b) Electrodes of silver – silver chloride enter into the chemical reaction. Thus no gas bubbles are formed, the resistance at the interface remains low, and the interface does not become polarized. The silver – silver chloride electrodes are made of by electro deposing a silver chloride coating on pure silver electrodes. Current is passing very readily through silver - silver chloride electrodes. The coating depletes on one electrode and builds up on the other. There is no formation of gas, and there is no electrical noise from the electrode to solution.

Defibrillator

Many heart attack patients undergo sudden changes in rhythm. The orderly heart muscle contracting associated with normal heart pumping change to uncoordinated twitching of ventricular fibrillation, which halts the heart pumping. Death follows within minutes unless the heart can defibrillate. A simple defibrillator consists of a transformer in which a line voltage is stepped to several thousand volts. A diode rectifies the alternating current into direct current to charge up the capacitor. Defibrillation process is as follows: the paddles are metal electrodes 7.5 cm in diameter that are coated with conductive paste and placed above and below the heart. The paddle handles are made of plastic and electrically insulated to prevent accidental shock to the operator. If the switch is thrown, a current of about 20 A flows through the heart for about 5 msec. This current contracts every muscle fiber in the heart at the same time. All the muscle fibers then recover at the same time, and the hearts initiate normal rhythm.

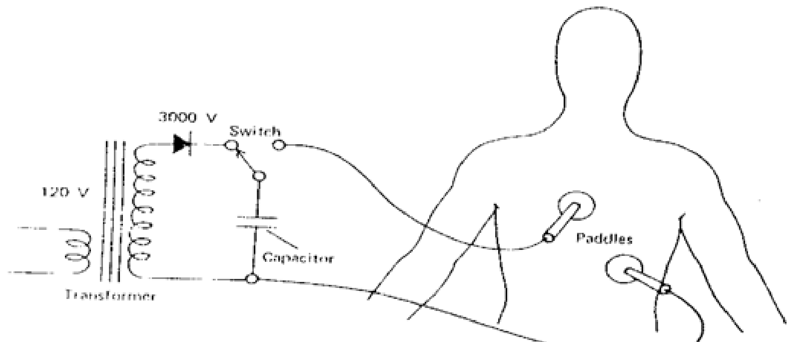


Figure 10.11. A simple defibrillator. The line voltage is stepped up to several thousand volts by a transformer. A diode rectifies the alternating current into direct current to charge up the capacitor. When the switch is thrown, the capacitor discharges through the paddles and the heart.

Artificial Pacemaker

The atria of the heart are separated from the ventricles by a fatty layer that does not conduct electricity or propagated nerve impulses. At a single location, the atriventricular nodes, impulse atria are conducted to the ventricles, which perform the heart's pumping action. If this node is damaged the ventricles receive no signals from the atria. However, the ventricles do not stop pumping; there are natural pacing centers in ventricles that provide a pulse if none has been received from the atria for 2 sec. The resulting heart rate, 30 beats /min, will sustain life, but the patient may have to live a life of semi-invalidism. To improve the quality of life for patients with faulty atriventricular nodes, artificial pacemakers have been developed. The pacemakers contain a pulse generator that puts out 72 pulse /min. These pulses are sent from an electrical circuit which consists of a capacitor charging up to a fixed voltage, at which point it discharges. The values of capacitance and resistance through which it charges determine the *repetition rates*. When the pacemaker is put in place, the patient is given local anesthetic and a flap of skin just below the right collarbone is lifted. The electrode wire is fed through a slit in shoulder vein and advanced under fluoroscopic control until the tip is imbedded in the wall of the right ventricle. Then the pacemaker is placed under the skin, and the flap is replaced. The pacemaker runs on batteries that last about, about 2 years.

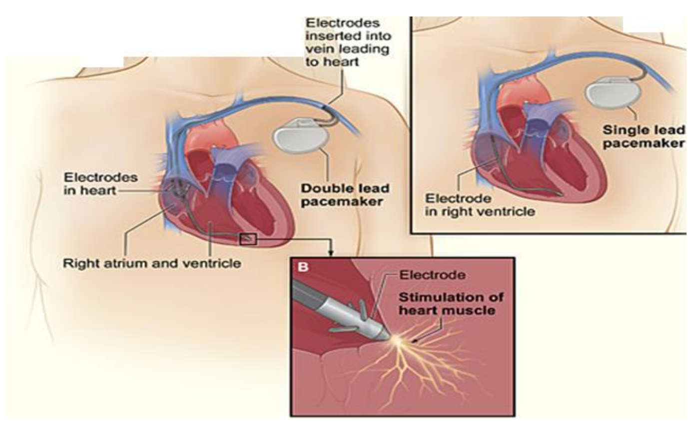
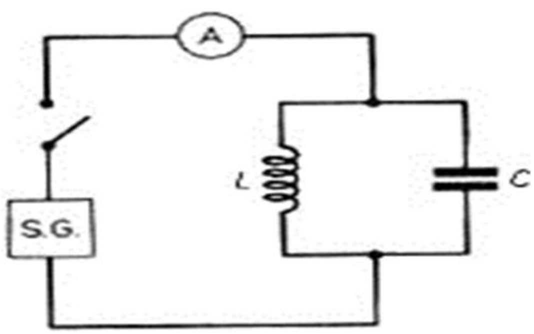


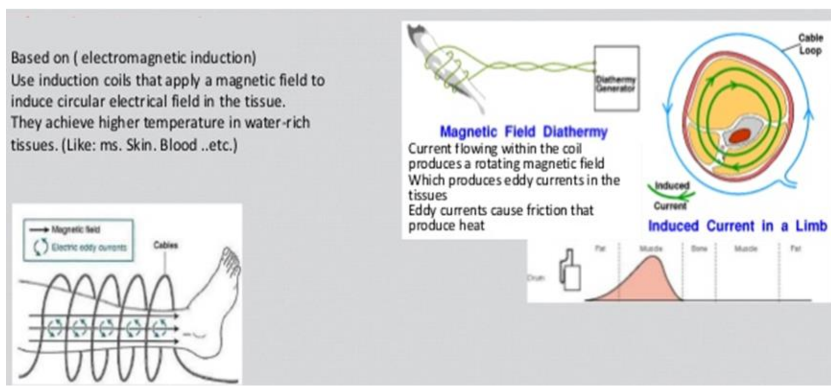
Figure : Artificial pacemaker

Application of electricity and magnetic in medicine

High Frequency Electricity in Medicine

The high frequency produced heating effects being used for therapy. The use of frequencies near 30 MHz for heating is called short wave diathermy. Long wave diathermy is at frequencies near 10K Hz. Microwaves diathermy is at frequencies of 2450 MHz and above this frequency. In short wave diathermy two methods are used to get the electromagnetic energy into the body, the capacitance method and inductance method. In both methods the body part to be heated becomes a part of a resonance circuit. A simple resonant circuit consists of a capacitor and inductor. Electrical energy from a power supply flows back and forth between the capacitor and inductor, thus providing an alternating electric field. In the capacitance method of short wave diathermy to be heated is placed between two capacitor plates that have an oscillating electric field across them. In the inductance diathermy the portion of the body to be heated is placed within or near the inductor. A30 MHz current in the coil produces an alternating magnetic field in the tissue that produces eddy current in it. The energy lost by the eddy currents appears as heat in the tissue.





Microwave diathermy is fundamentally different from short wave diathermy the tissue to be heated is part of a resonant circuit, while in MW diathermy the tissue absorbs electromagnetic waves that are incident upon it. The radiation is produced in a special high frequency tube called a magnetron. The output of the magnetron is fed to an antenna and the antenna emits the MW. A frequency of 2450 MHz with a wavelength of about 12 cm is usually used. Like light waves, MW can be transmitted, reflected or refracted at a surface, and absorbed by a medium. Several of the standard antennas arranged for MW diathermy make use of the reflection property to direct the radiation to the tissue, where part of it is reflected and part is transmitted. For 2450 MHz radiation the energy reflected from the skin may be over 50%. The transmitted radiation is absorbed by the body and produces heat. For homogenous tissue, this absorption can be described by this equation

$I = I_o e^{-x/D}$

Where I_o is the radiation intensity at the surface, I is the radiation intensity at depth x, D is the tissue thickness that absorbs 63 % of the beam, x is the depth of the beam.

The amount of energy absorbed depends upon the frequency of the microwaves. Because the energy is deposited more effectively in tissue with high water content, microwave energy is absorbed better in muscle tissue than in fatty tissues, which have less water. Microwave diathermy is used to heat joint and muscles. Damage can be results from over exposure to electromagnetic radiation. The eyes are more sensitive to high temperature than others parts of the body.

Surgical Diathermy

High frequency currents can also be used in operating rooms for surgical purpose involving “cutting and coagulation” The frequency of currents used in surgical diathermy units is the range of 1-3 MHz. Surgical diathermy machines depend on their currents. When high frequency current flows through the sharp edge of a wire loop or point of a needle into the tissue, there is a high concentration of current at this point, see the figure below. This tissue is heated to such an extent that the cell immediately under the electrode is torn apart by the boiling of the cell. The plate electrode provides an electric contact with a large area, and the current density at the probe electrode has a very small tip. By controlling the shape of the probe and the current density it is possible to deliver different amounts of heat to the tissue by means of *electrical arc*. Care must be taken that the plate electrode has adequate contact so that burning does not take place.

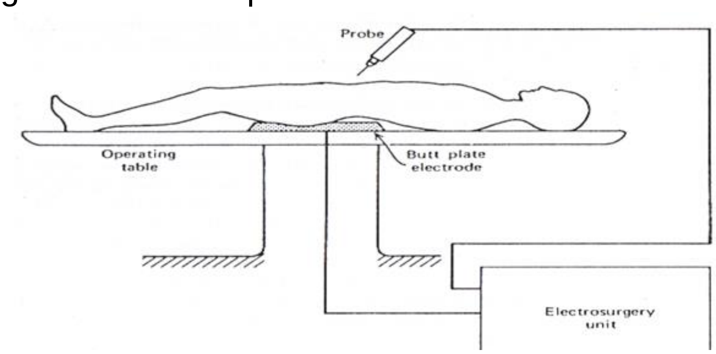


Figure: Basic arrangement for electro surgery and electro cautery

Magnetism in Medicine

When an electrical conductor is moved perpendicular to a magnetic field, a voltage is induced in the conductor proportional to the product of magnetic field and the velocity of the conductor ˝Faraday’s law˝. This law, which also holds for a conducting fluid moving perpendicular to a magnetic field, is the basis of magnetic blood flow. Blood acts as a conducting fluid, if it passes with mean velocity through a magnetic field a voltage V is induced between the electrodes such that **V = B d v**. Where d is the diameter of blood vessel, B is magnetic flux, v is the velocity of blood flow, V is the induce voltage. The volume of blood Q through the vessel can be calculated. Since Q is the product of the mean velocity times the area of the vessel. Since the area of the vessel = $\pi d^2 /4$

$Q = \pi d^2 \ V / 4 \ B d$

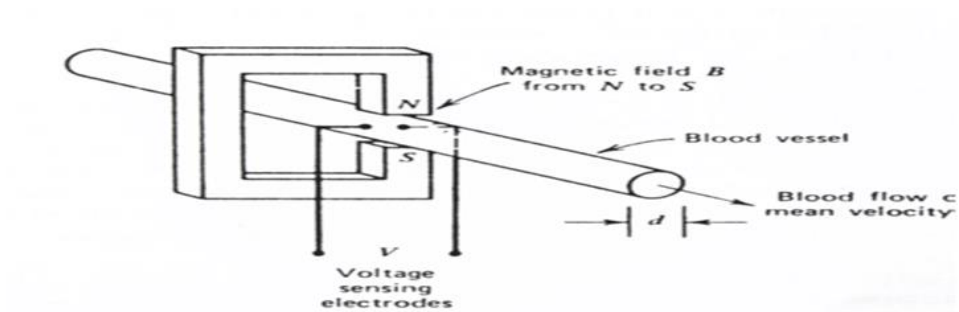


Figure: Schematic of a magnetic blood flow meter

Example: A magnetic blood flow meter is positioned across blood vessel $5x10^{-3}$ m in diameter. With a magnetic field of $3x10^{-2}$ Tesla (300 gauss), an induced voltage of 15 µV is measured. a) Find the mean velocity in vessel?

$V = B d v \rightarrow v = V/ B d = v = 1.5 \times 10^{-5} / (3x10^{-2}) (5x10^{-3}) = 1.5 /15 = 0.1$ m/sec

b) Assuming all the blood travels at the same velocity, what is the volume flow rate?

$Q = \pi d^2 V / 4 B d = [\pi (5x10^{-3})^2 / 4 (3x10^{-2}) (0.1) = 1.9 \ x10^{-6} \ m^3 / sec = = 1.9 \ cm^3 /sec$

Questions for physics of cardiovascular system

Q1) Estimate the volume of blood your heart pumps to your systemic circulation each day.

Volume of blood = $(80 \ cm^3 /beat)(72 \ beats/min)(1440 \ min/day) = 8.3x10 \ cm^3/day$

Q2) if white blood cells have an average diameter of 12 µm, what percentage of the blood volume is white blood cells?

Number of cell/mm^3=8 $x10^3/mm^3$

Volume of a cell in mm^3= $(4/3)\pi R^3$ = $(4/3)\pi(6x10^{-6})^3$=$0.875x10^{-6}$ mm^3

(Number of cells/mm^3)(Volume of a cell in mm^3)=fraction of cell

($8\ x10^3/mm^3$) ($0.875x10^{-6}mm^3$) =$7x10^{-3}$ = 0.7%

Q3) if a platelet has a diameter of about 2 μm, what percentage of the blood volume are platelets?

Number of platelet cells/mm^3 =$(3x10^3/mm^3)$=$(3x10^3/mm^3)$ (4/3) π $(10^{-3})^3$ mm^3 =12×10^{-6}

Q4) If the average power consumed by the heart is 10 W, what percentage of a 2500 kilocalorie daily diet is used to operate the heart?(4.2J =1 calorie).

H.W.

Q5) an artery with a 3 mm radius is partially blocked with plaque; in the constricted region the effective radius is 2 mm and the average blood velocity is 50 cm /sec.

(a) What is the average velocity of the blood in the un-constricted region?

R_1 = 3 mm, R_2 = 2 mm, $A = \pi R^2$

$A_1/A_2 = \pi (3mm)^2 / \pi (2\ mm)^2$

$A_1 V_1 = A_2 V_2 \rightarrow V_1 = A_2 V_2 / A_1$

$V_1 = (4/9)\ 50 = 22$ cm/sec

(b) Would there be turbulent flow in either region? **No**

(c) For the blood in the constricted region, find the equivalent pressure due to the kinetic energy of the blood.

Density of blood =1.04 gm /cm^3

$P = \frac{1}{2} \rho V_2^2 = \frac{1}{2} (1.04)(50)^2 = 1300$ ergs / cm^3 = 1 mm Hg

Q6) if the radius of an arteriole changed from 50 μm to 40 μm, how much would the flow rate through it decrease?

Flow rate Q = $\frac{(Pa - Pb)\pi R^4}{8\eta L}$ New Flow rate = $\frac{(Pa - Pb)\pi(40 \mu m)^4}{8\eta L}$ Old flow rate = $\frac{(Pa - Pb)\pi(50\ \mu m)^4}{8\eta L}$

$\frac{\text{New rate}}{\text{Old rate}} = \frac{(40\ \mu m)^4}{(50\ \mu m)^4}$ =0.41 ; 59 % decreases

Electricity within the Body

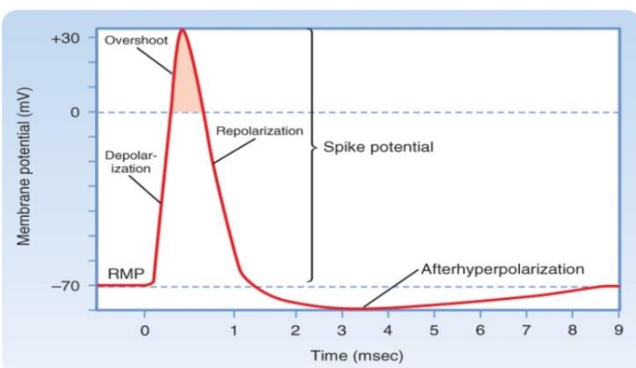
Electricity plays an important role in medicine. There are two aspects of electricity and magnetism in medicine; electrical and magnetic effects generated inside the body, applications of electricity and magnetism to the surface of the body. The electricity generated inside the body serves for the control and operation of the nerves, muscles, and organs. The forces of muscles are caused by the attraction and repulsion of electrical charges. The action of the brain is basically electrical. All nerve signals to and from the brain involve the flow of electrical current.

Membrane potential; when inside the cell being negative with respect to outside

Action potential; when inside the cell being positive with respect to outside.

Electrical Signals from Muscle

One means of obtaining diagnostic information about muscles is to measure their electrical activity. The transition of the action potential from the axon into the muscle causes muscle contraction. *Electromyography* is a technique of recording electric activity produced by the muscles at rest and during contraction. This technique is used for investigation of various neurological conditions and determinate the site and duration of action potential of muscle relaxants. Muscle action potential picked up by electrodes placed near the surface of interest. There are different types of electrodes surface, needle and disc electrodes, as shown in figure 2.



Koeppen & Stanton: Berne and Levy Physiology, 6th Edition.
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Figure 1: Potential waveform

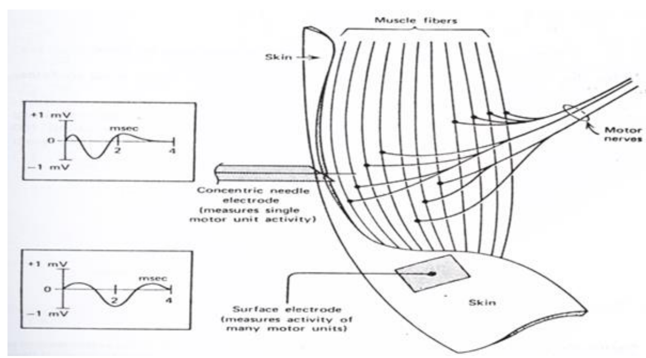


Figure 2:surface, needle and disc electrodes.

EMG signal can be recorded by applying stimuli to ulnar nerve with surface electrodes and observing the contraction of muscles, as shown in figure 3. One nerve supply 100–300 muscle fibers which make up a *motor unit*; so when a nerve is stimulated a large of muscle fibers are activated, figure 3. EMG electrodes record the electrical activity from several fibers. So, single muscle cell are usually not monitored in an EMG examination because it is difficult to isolate a single fiber. To record the action potential of a single muscle cell a very tiny electrode (microelectrode) is used which inserted in the muscle membrane. The reference electrode is immersed in the fluid surrounding the cell, figure 4. The amplitude of the response from a motor unit varies between 100µ V and 1.5 mV, depending on the size of the unit and the position of the electrodes. The response from single muscle fiber is last about 1 m sec while the response from motor unit is more complex has duration of 6 – 12 m sec, figure 5. *If there is a disease in muscle the amplitude of the signal decreased and there is a cut off in signal.* EMG signals are small in amplitude and can be amplified by an amplifier. The electrodes being the input of the amplifier figure 6, and the output of amplifier is connected to different monitoring. Oscilloscope to visual the signal and display it, audio speaker to allow acoustic monitoring of the potentials, and a recorder to record the signal and storage it. An EMG obtained during electrical stimulation of a motor unit is shown in figure 3. The action potential appear in the EMG after a latency period, figure 7. *Latency* is defined as the time between the stimulation and beginning response.

Nerve conduction velocity

The velocity of the action potential in motor nerves can be determined using EMG machine. Stimuli are applied at two locations, and the latency period for each response is measured, as shown in figure 8. The difference between the two latency periods is the time required for the action potential to travel the distance between them; the velocity of the action potential is this distance divided by this time. Typical velocities are 40 to 60 m /sec; a velocity below 10 m /sec would indicate a problem. The conduction velocity for sensory nerves can be measured by stimulating at one site and recording at several locations that are known distances from the point of stimulation, as shown in figure 9. Many times nerve damage results in a decreased conduction velocity.

Nerve conduction velocity=Distance between two stimuli / (Latency1 - latency2)

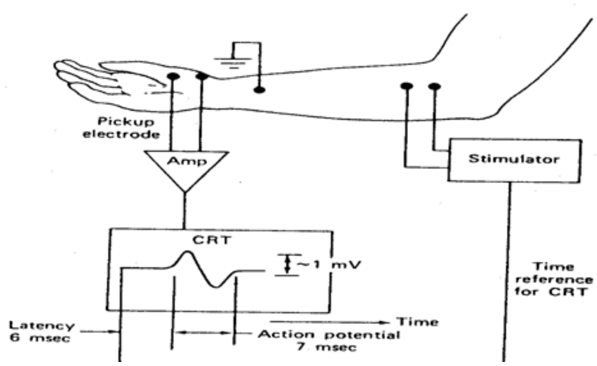


Figure 3: Instrument arrangement for obtaining an EMG during electrical stimulation of a motor unit.

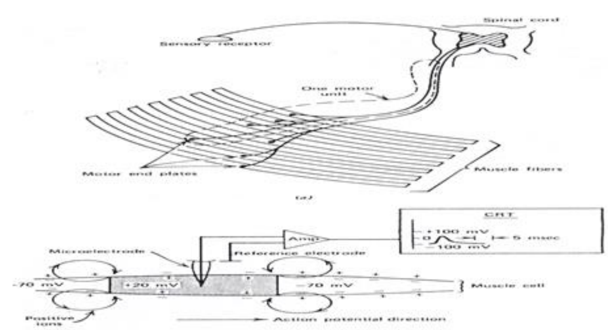


Figure 4: Instrument arrangement for measuring the action potential in a single muscle cell.

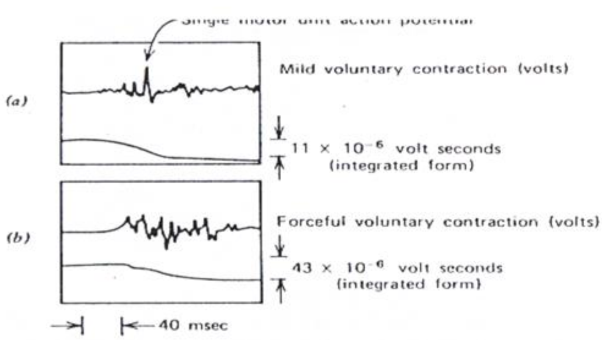


Figure 5: (a) minimal contraction showing the action potential from a single motor

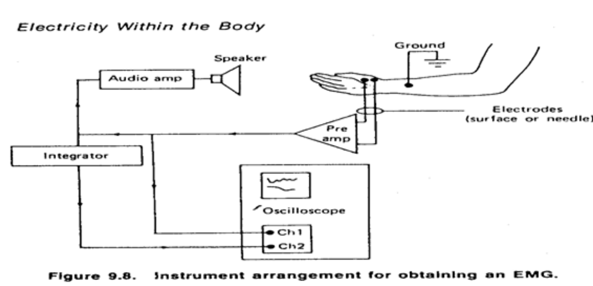


Figure 6: Instrument arrangement for EMG

unit. (b) maximal contraction showing the action potential from many motor units.

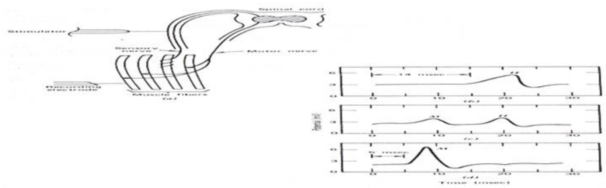


Figure 7: electrical stimulation of the sensory and motor nerves.

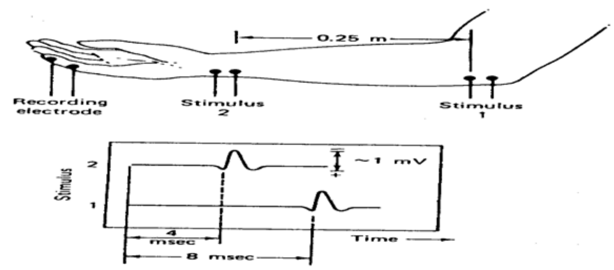


Figure 8. Measurement of nerve conduction velocity.

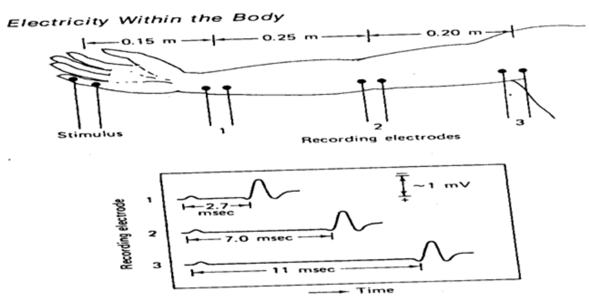


Figure 9: Sensory nerve and conduction vel

Electrical signals from the heart

The rhythmical action of the heart is controlled by an electrical signal initiated by spontaneous stimulation of special muscle cells located in the right atrium. These cells make up the senatorial (SA) node, or pacemaker figure 10. The SA node fires at regular intervals at regular intervals. The electrical signal from the SA node initiates the depolarization of the nerves and muscles of both atria causing the atria to contract and pump blood into the ventricles. Re -polarization of the atria follows. The electrical signal then passes into the atrioventricullar node AV node, which initiates the depolarization of the right and left ventricles, causing them to contract and force blood into the pulmonary and general circulations. The ventricle nerves and muscles then repolarize and the sequence begins again. The nerves and muscles of the heart can be regarded as sources of electricity enclosed in an electrical conductor. The nerves and muscles of the heart can be regarded as sources of electricity enclosed in an electrical conductor. The potentials produced by the heart spread to the surface of the body and detected by the electrodes. The potential lines are similar to the lines from an electric dipole figure 11.

Electrodes located at A, B, and C would indicate the potentials at that moment. An electric dipole is produced when equal positive and negative charges are separated from each other. It can be represented by a vector. The electrical (cardiac) potential that we measure on the surfaces of the body is merely the instantaneous projection of the electric dipole vector in a particular direction. As the vector changes with time, so does the projected potential. Figure 12: Typical ECG; P represents the atrial depolarization and contraction. The QRS complex indicates the ventricular depolarization. The ventricular contraction between S and T, and T represents the ventricular repolarization. The wave form of ECG is some time positive and in other cases it is negative. The sign of the waveform depends upon the direction of the electric dipole vector and the polarity and position of the electrodes.

Electrocardiograph (ECG)

The potentials produced by the heart spread to the surface of the body and detected by electrodes placed there. The process of recording these potentials is known as ECG. The potentials are small so that they require to be electrically amplified before they are recorded figure 13.

ECG Recording

In order to make a recording, two input connections must be made to the amplifier and there is usually a switch on the ECG apparatus which makes the appropriate connections internally when a particular lead is chosen.

To record the standard limb leads Bipolar:

First; Electrodes are applied to the left arm, right arm and left leg (figure 14, and figure 15). For electrical purposes the three electrodes (RA, LA, and LL) can be thought of as the points of a triangle, the Einthoven triangle. The potential in lead I at any moment is proportional to the projection of the dipole vector on the line RA – LA; the potentials in Leads II and lead III are proportional to the projections on the other sides of the triangle. When the switch of ECG apparatus is at lead I the electrodes on the R and L arms are connected to the amplifier. The amplifier then records record the potential difference between the right and left arm. Lead I measure the potential difference between the RA and LA. Lead II measure the potential difference between RA and LF. Lead III measure the potential difference between LA and LF. Lead I, Lead II, and Lead III are referred to as bipolar leads, because the measured signal is the difference in potential between two electrodes.

Second; Unipolar measurements are made by recording the potential at one electrode with respect to the average of the other two potentials. These are referred as a V_R, a V_L and a V_F leads. These leads are recorded by connecting the amplifier between one limb and the junction of two resistances which are connected to the other two limbs, which is an augmented lead obtained by placing a pair of resistors between two of the electrodes. The center of the resistor pair is used as one of the connection. a V_R measure the potential difference between RA and (LA + LF) /2 . a VL measure the potential difference between LA and (RA+LF) /2. a VF measure the potential difference between LF and (RA +LA) /2.

Third; chest leads, are recorded by connecting the amplifier between the chest electrode and resistance connected to all three limbs RA+LA+LF as shown in figure 17. So, the chest electrode is being one input of the amplifier and the other input is connected to an electrically neutral point V which is obtained by joining the three limb leads together through a resistance's. Such a recording is designed V1, V2, V3, V4, V5, and V6 according to the position of the electrode on the chest, see figure 17.

Electroencephalograph EEG

EEG is a technique of recording electrical activity of the brain through the intact skull. Electrodes are applied on the scalp and potential difference recorded and amplified and present for interpretation as an inked tracing on moving paper. Machines in common use have eight or sixteen or more channels so that it is possible to record the activity from different areas of the head simultaneously. The technique is relatively simple and entirely harmless and may give information which is of great important in neurological diagnosis. The frequency of the EEG signals is depends on the mental activity of the subject. For example a relaxed person usually has an EEG signal composed primarily of frequencies from 8 to 13 Hz, or alpha waves .When a person is more alert a higher frequency range, the beta wave range (above 13 Hz), dominates the EEG signal.

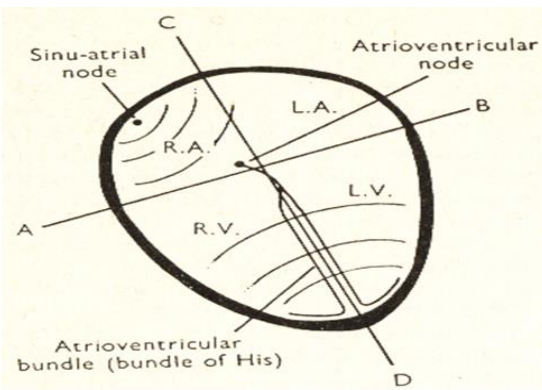


Figure 10: The spread of cardiac impulse.

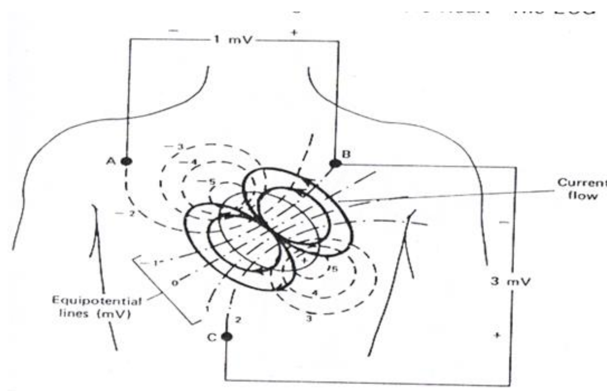


Figure 11: The potential distribution on the chest at the moment when the ventricles are one half depolarized.

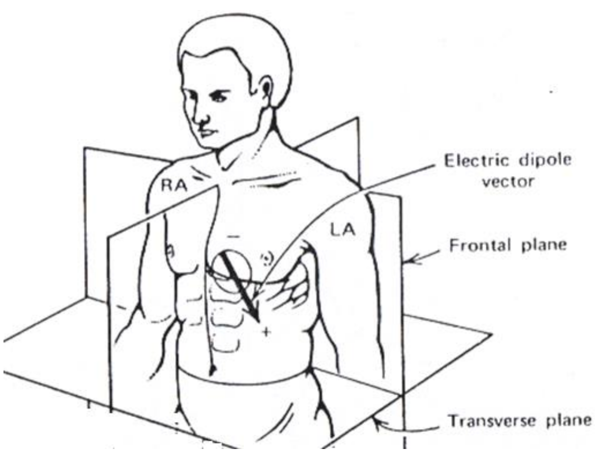


Figure 12: electrocardiographic planes and dipole vector. RA, LA, RL, and LL indicate electrode locations on the right and left arms and legs.

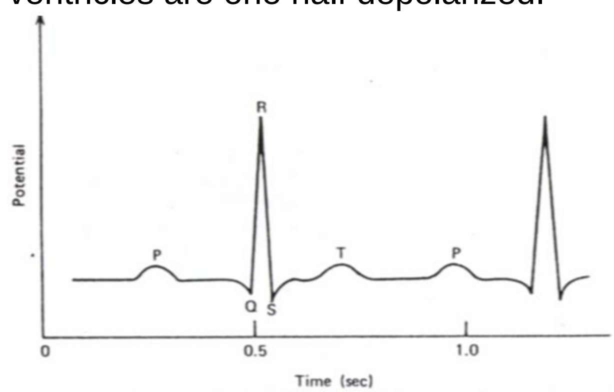


Figure 13: Typical ECG; P represents the atrial depolarization and contraction.

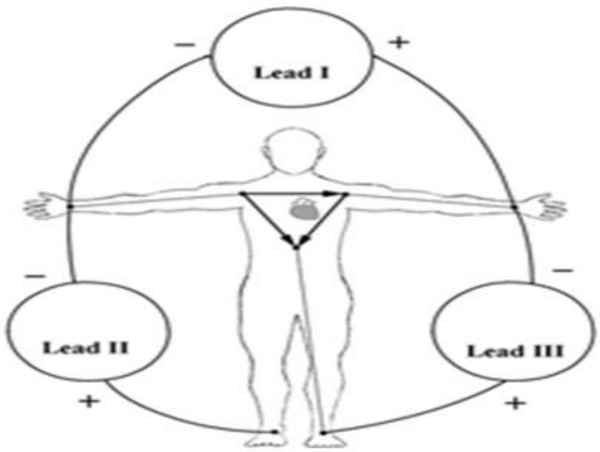


Figure 14: The position of lead I, lead II, and lead II.

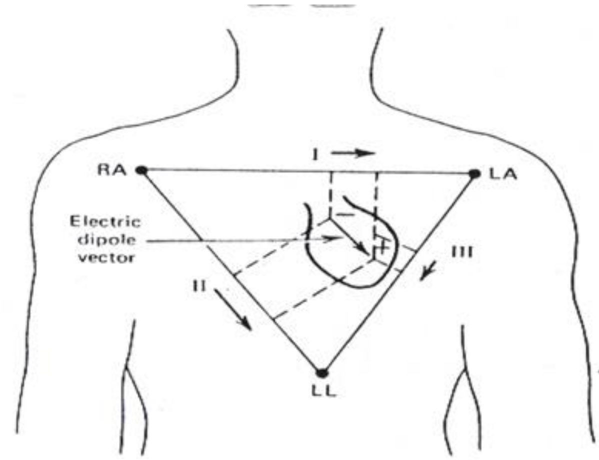


Figure 15: Schematic of the electric dipole of the heart projected on the frontal plane.

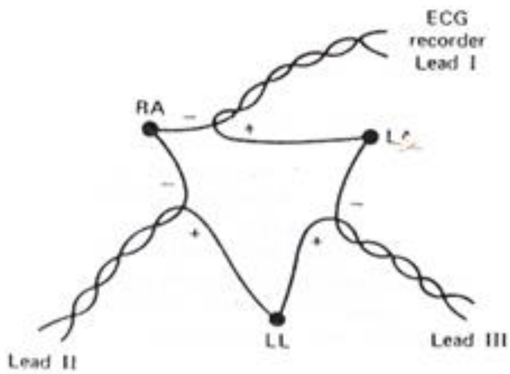


Figure 16: The electrical connections for lead I, II, and III. The usual polarities of the recording instrument are indicated for each lead.

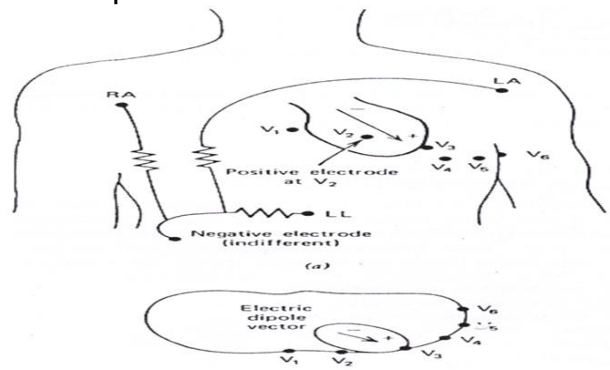


Figure17: Transverse plane ECG positions. (a) Frontal view (b) Top view.

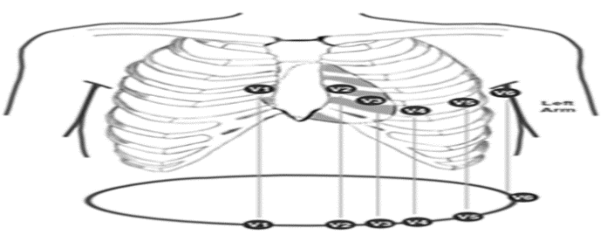
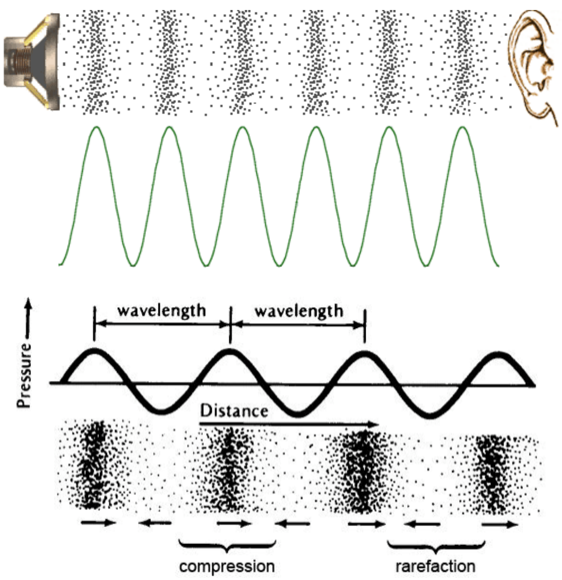
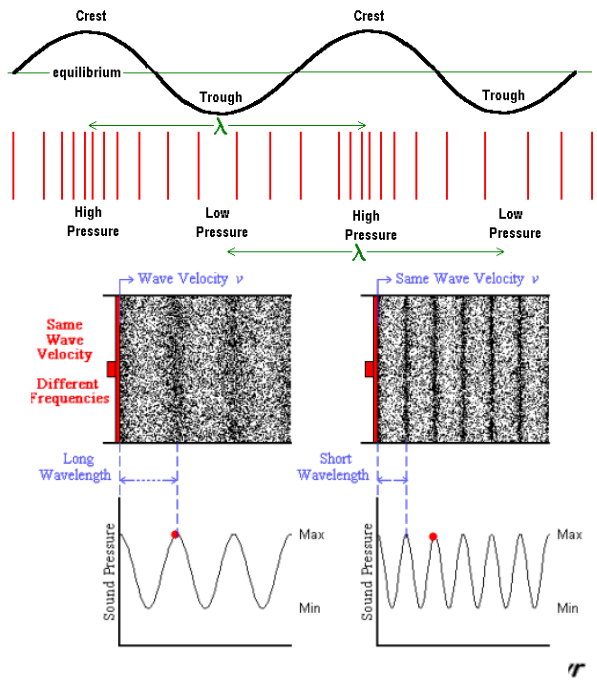


Figure 18 : Chest electrodes

Sound in Medicine

Sound is one kind of longitudinal wave in which the particles oscillate in the same direction of wave propagation. Sound waves cannot be transmitted through vacuum. The transmission of sound requires at least a medium, which can be solid, liquid, or gas. The back-and-forth vibration of an object creates the compression waves of sound, such as the motions of a guitar string. This is different than the up and down or transverse motion of a water wave Figure 1.





Characteristics of sound

A sound wave has characteristics just like any other type of wave, including amplitude, velocity, wavelength and frequency.

The **amplitude** of a sound wave is the same thing as its loudness. Since sound is a compression wave, its loudness or amplitude would correspond to how much the wave is compressed. It is sometimes called pressure amplitude.

Wavelength is the distance from one crest to another of a wave. Since sound is a compression wave, the wavelength is the distance between maximum compressions.

The **frequency** (*f*) of sound is the rate at which the waves pass a given point. It is also the rate at which a guitar string or a loud speaker vibrates.

Period (T) is the time taken by a crest to move forward one wave length.

Speed or velocity of sound

The relationship between velocity, wavelength and frequency is:

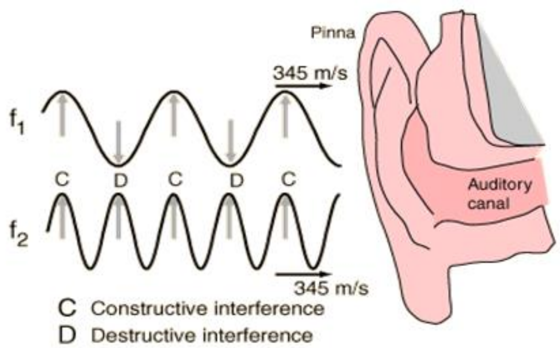
Velocity = wavelength x frequency

$v = \lambda f = \lambda / T$ (m/sec); Where $T = 1 / f$, Since a crest moves forward a distance λ in a time T.

Resonance: The ability of an object to vibrate by absorbing energy of its own natural frequency is called resonance

Beats

When two sound waves of different frequency approach your ear, the alternating constructive and destructive *interference* causes the sound to be alternatively soft and loud - a phenomenon which is called "*beating*" or producing beats. The beat frequency is equal to the absolute value of the *difference* in frequency of the two waves.



Many sound intensity measurements are made relative to a standard *threshold of hearing* intensity I_0; $\mathbf{I_o = 10^{-12}}$ **watts/m**$\mathbf{^2}$ **=** $\mathbf{10^{-16}}$ **watts/cm**$\mathbf{^2}$

The most common approach to sound intensity measurement is to use the decibel scale; Decibels measure the ratio of a given intensity I to the threshold of hearing intensity, so that this threshold takes the value 0 decibels (0 dB), breathing 10 dB whisper 20 dB and conversation 50 dB. Decibel is really 1/10 of a bel, Bell= 10 dB

$$\mathbf{dB = 10 \log_{10} (I/I_0)}$$

Transmission of Sound across Medium Boundaries

When an acoustic wave travelling in one medium encounters the boundary of a second medium, reflected and transmitted waves are generated. For example, when sound strikes upon a solid partition, part is reflected, part absorbed within the material, and part transmitted to the other side or to elsewhere in the building. The ratios of the pressure amplitudes and intensities of the reflected and transmitted waves to those of the incident waves depend on the following factors; an angle of incidence, the densities of the two media, and the speeds of sound in the two media.

The **acoustic impedance** Z of a material is defined as the product of its density ρ and acoustic velocity V; **Z = ρ V.** For a sound wave in air hitting the body, Z_1, is the acoustic impedance of air and Z_2 is the acoustic impedance of tissue. If $Z_1 = Z_2$, there is no reflected wave and transmission to the second medium is complete. If $Z_2 < Z_1$, the sign change indicate a phase change of the reflected wave.

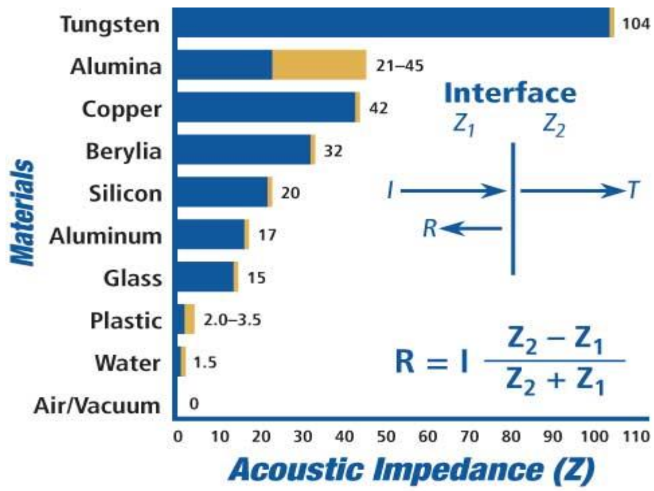


Figure 3

The ratio of the reflected pressure amplitude R to the incident pressure amplitude A depends on the acoustic impedance of the two media, z_1 and z_2, as shown in figure 3. For sound striking perpendicular to the surface; $\mathbf{R/A = Z_2 - Z_1 / Z_1 + Z_2}$

The ratio of the transmitted pressure amplitude T to the incident wave amplitude A is; $\mathbf{T/A = 2\,Z_2 / Z_1 + Z_2}$

The angle of refracted sound wave θ_t is determined by the velocities of sound in the two media v_1 and v_2 from the equation; $\mathbf{\sin\theta_i / v_1 = \sin\theta_t / v_2}$

θ_i incident = θ_r reflected

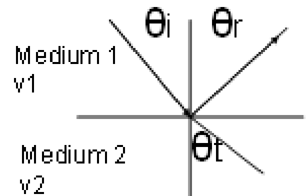


Figure7 :Two media of different velocities.

Ultrasound

Ultrasound is defined as any sound wave above 20 kHz, which is audible to humans. Sound waves of this frequency are above the human audible range and therefore cannot be heard by humans. All sound waves, including ultrasound are longitudinal waves. Medical ultrasounds are usually of the order 1-15MHz. Ultrasound as all sound waves is caused by vibrations and therefore causes no ionisation and is safe to use on pregnant women. Ultrasound is also able to distinguish between muscle and blood and show blood movement. When an ultrasound wave meets a boundary between two different materials some of it is refracted and some is transmitted. The reflected wave is detected by the ultrasound scanner and forms the image.

Producing ultrasound wave

Ultrasound waves are produced by a transducer. A transducer is a device that converts energy from one form to another form such as; electricity into sound waves. Else; converts variations in a physical quantity, such as pressure or brightness, into an electrical signal or vice versa.

Sonar is a technique that uses sound propagation to medium, communicate with or detect objects on or under a certain surface, such as water and detect other vessels. ***Sonograms***, are made by sending pulses of ultrasound into tissue using a probe. The sound echoes off the tissue; with different tissues reflecting varying degrees of sound. These echoes are recorded and displayed as an image to the operator. Medical ultrasound or diagnostic ***sonography*** or ultrasonography is a diagnostic imaging technique based on the application of ultrasound. It is used to see internal body structures such as tendons, muscles, joints, blood vessels, and internal organs. It's aim to find the source of a disease, or, to exclude any pathology. The practice of examining pregnant women using ultrasound is called *obstetric* ultrasound, and is widely used.

Piezoelectric effect

When a potential difference is applied across certain crystals (piezoelectric) the crystals deform and begin with the mechanical movement oscillations of a crystal that has been excited by electrical pulses. If the potential difference applied is alternating then the crystal vibrates at the same frequency and sends out ultrasonic waves. This process also works in reverse. The piezoelectric crystal acts a receiver of ultrasound by converting sound waves to converting alternating voltages and as a transmitter by converting alternating voltages to sound waves.

A-Scan (Amplitude scan)

Pulses of ultrasound sent into the body, reflected ultrasound, echoes, is detected then converted into electric signal and displayed as vertical spikes on a screen. The horizontal positions of the 'spikes' indicate the time it took for the wave to be reflected. A-scan gives no photo image. A-scan can be used to measure the depth of structures in the body. Then measure the time required to receive the signal. This time can be converted to distance by using the velocity of sound

A-scan Ultrasound is used for

Diagnostic testing in Opthalmology practices. This device can determine the length of the eye and can be useful in diagnosing common sight disorders. A-scans are also extremely beneficial in cataract surgeries, as they enable the Opthalmologist to determine the power of the intraocular lens needed for the artificial implant. Measure the size of foetal head.

B – Scan (Brightness – modulation)

The B-scan is a brightness modulation display. As a result each echo produces a dot on the oscilloscope at a position corresponding to the location of the reflecting surface. The brightness is proportional to the echo amplitude. B-scan provide information about the internal structure of the body.

Medical application of B – scan

B -scans have been used in diagnosis studies of; eye, liver at frequency 2-3 MHz; Breast at frequency 2-3 MHz; Heart; Spleen, pancreas; Detect pregnancy as early as fifth week and provide information on the size, location, and change with time and cases such as abnormal bleeding and threatened abortion. The frequency used is in the range 1.5-3 MHz.

Doppler Effect

If we know the frequency of the source f_o and we can measure the frequency that is received by a listener, we can determine how fast the sound source or listener is moving. The frequency change is called Doppler shift. This technique has been used to measure the velocity. The Doppler Effect can be used to measure the speed of moving objects or fluids within the body, such as the blood.

When the sound source is moving toward the listener, the sound waves are pushed together and the listener hears a frequency higher than f_o, $\mathbf{F_2 = f_o\,[c / (c - v)]}$

Else; when the listener is moving toward the source the sound waves are pushed together and the listener hears a frequency higher than f_o, $\mathbf{F_3 = f_o\,[(c + v) / c]}$

When the source is moving away from the listener, the listener hears a frequency lower than f_o. $\mathbf{F_1 = f_o\,[c/(c + v)]}$

The listener hear s a lower frequency from a sound source when it is moving away from him $\mathbf{F_4 = f_o\,[(c - v) / c]}$

Doppler shift ultrasound

The basic principle of Doppler shifted ultrasonic is that the ultrasound reflected from a moving target has its frequencies altered. Doppler shift frequency **$\Delta f = f_r - f_t$**

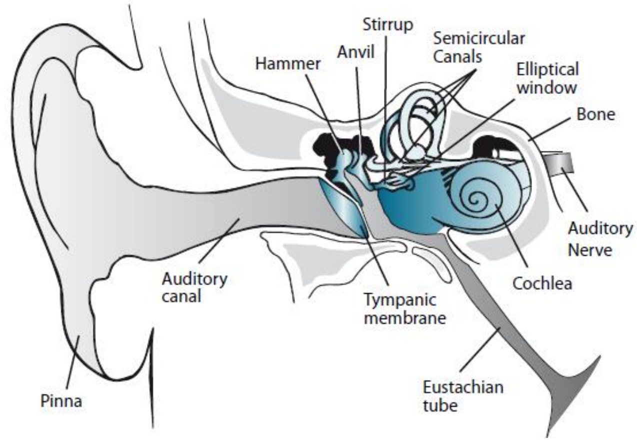
The Doppler shift in frequency of reflected ultrasonic may be used as a measure of the velocity of the movement of the reflected surface. In this method the ultrasonic wave is incident on the moving blood cells which scatter the incident radiation. The scattered wave is received by the second transducer. The transmitted and received signals are mixed and the resulting signals are the Doppler shift frequency. This shift in frequency is produced because the scatters are moving. The Doppler shift frequency is proportional to the blood velocity. When a continuous ultrasound beam is "received" by some red blood cells in an artery moving away from the source. The blood hears a slightly lower frequency than the original frequency f_o. The blood sends back scattered echoes of the sound moving away from the detector, there is another shift to a still lower frequency. The detector receives a back scattered signal that has undergone a double Doppler shift. When the blood is moving at an angle θ from the direction of the sound waves, the frequency change Δf (Doppler shift frequency) is

$$\Delta f = \frac{2 f v}{c} \cos\theta$$

Where f is the frequency of the initial ultrasonic wave, v is the velocity of the blood, c is the velocity of sound, and θ is the angle between the direction of movement and the effective.

Basic structure of the human ear

The human ear as shown in figure 4 consists of 3 sections. The **outer ear** consists of the pinna, the external auditory canal and the ear-drum (tympanic membrane). Sound waves reaching the ear are collected by the pinna – it has an important spatial focusing role in hearing. The sound waves are directed down the external auditory canal. It is closed at one end by the ear drum that consists of a combination of radial and concentric fibers about 0.1 mm thick with an area of about 60 mm^2 that vibrate with small amplitude. The ear canal is like a closed organ pipe as the canal is a shaped tube enclosing a resonating column of air that vibrates with an optimum resonant frequency around 3 kHz. The ear-drum acts as an interface between the external and middle ear. The **middle ear** consists of a small, irregular, air-filled cavity in which, suspended by ligaments, the ossicles - a chain of three bones more commonly known as the hammer, anvil and stirrup. They act as a series of levers with a combined mechanical advantage of 1.3. Because of their combined inertia, size and attachments, they cannot vibrate at frequencies much greater than 20 kHz. The bones are attached to the **inner** wall of the tympanic membrane.


Stirrup
Semicircular Canals
Hammer
Anvil
Elliptical window
Bone
Auditory Nerve
Auditory canal
Tympanic membrane
Cochlea
Eustachian tube
Pinna

Light in medicine

The properties of light are:

1. The speed of light changes when it goes from one 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 refracted as shown in figure 1.

2. Light behaves both as a wave and as a particle figure 2. As a wave it produces interference figure 3 and diffraction figure 4. As a particle it can be absorbed by a single molecule. When a light photon is absorbed its energy is used in a various ways. It can cause an electrical change.

3. When light is absorbed, its energy generally appears as heat. This property is the basis for the use in medicine.

4. Sometime when a light is absorbed, a lower energy light is emitted. This property is known *fluorescence*.

5. Light is reflected to some extent from all surfaces figure 5.There are two types of reflection figure 6. *Diffuse* reflection occurs when rough surfaces scatter the light in many directions. *Specular* reflection 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.

Fluorescence is the emission of light by a substance that has absorbed light, which is a luminescence that occurs where the energy is supplied by electromagnetic radiation, usually ultraviolet light. Thus invisible to the human eye, while the emitted light is in the visible region, which gives the fluorescent substance a distinct color that can be seen only when exposed to UV light. In most cases, the emitted light has a longer wavelength, and therefore lower energy, than the absorbed radiation. The energy source kicks an electron of an atom from a lower energy state into an "excited" higher energy state; then the electron releases the energy in the form of light when it falls back to a lower energy state.

Some medical uses of normal visible light

Pediatricians use a shine light into the bodies of infants and observe the amount of scattered light produced in order to detect water – head or collapsed lung. Pediatricians use visible light for treating jaundice in premature infants. Light source in endoscope uses to see inside the body. Physician use normal light to examine the skin. The visible light used in the ophthalmoscope for looking into eyes, and in the otoscope for looking into ears by using a concave mirror to direct light in the body and a hole in the middle of it for the physician to look through.

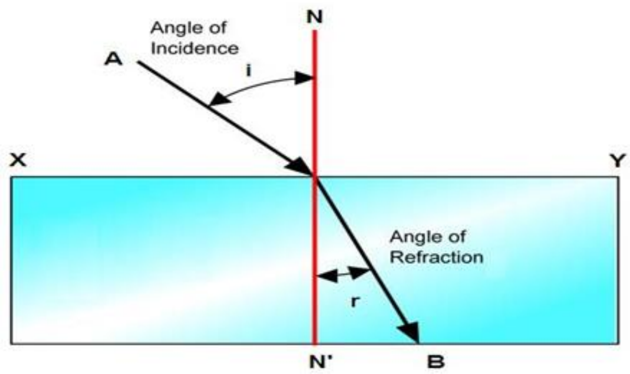


Figure (1)

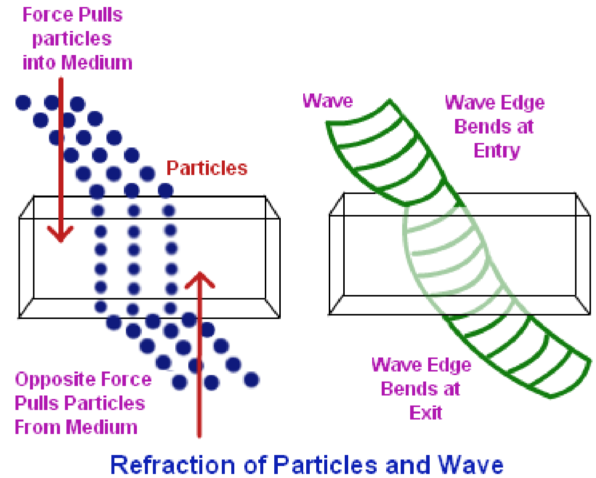


Figure (2)

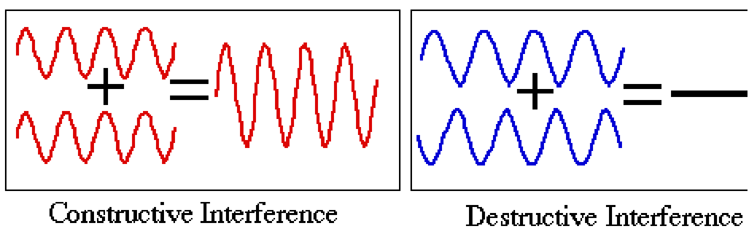


Figure (3)

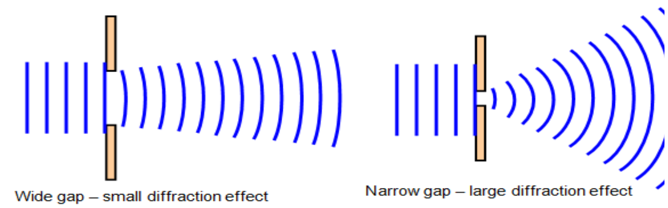


Figure (4)

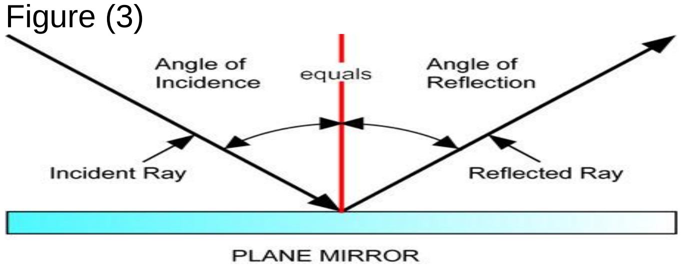


Figure (5)

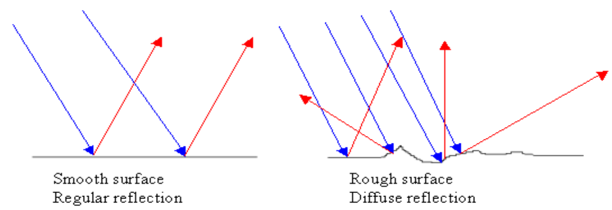


Figure (6)

Endoscope

An endoscope works by inserting a long, thin and bendable tube into the body figure7. On one end is a light source and in most cases also a video camera. The endoscope can be inserted through a natural opening in the body such as the throat or it can be inserted through a cut made in the skin. An endoscope consists of two or three optical cables. Each cable includes up to 50,000 separate optical fibers that are made from glass or plastic. One or two of these cables will carry light down into the patient's body, this illuminates where the endoscope has been inserted. The light is reflected along the walls of the cable into the patient's body. The light does this due to total internal reflection, which means that for this to happen the light ray must be at an a certain angle (the angle required for air to glass to be internally reflected). The other cable will carry reflected light that shines off the patient's body; this light is the image of the body. The light bounces off the glass walls as it goes up to the eyepiece or into a camera. If the reflected light is carried up to a camera it will then be displayed on a monitor.

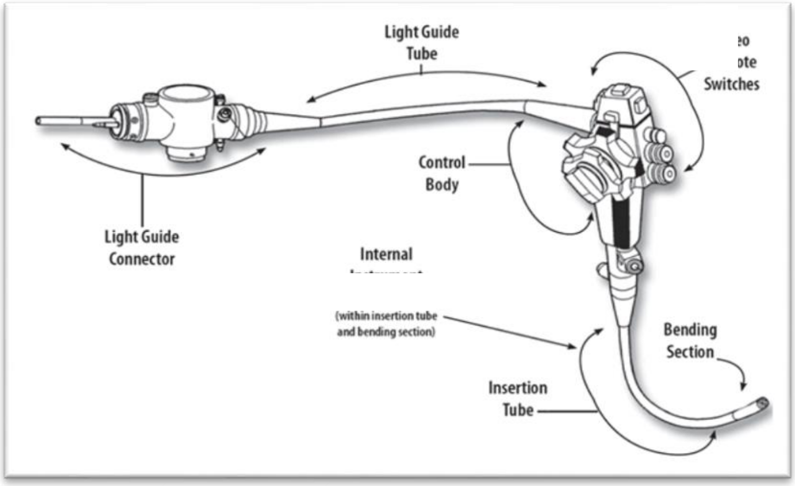


Figure (7)

Optical Fibre

Optical fibres are glass or plastics as thin as human hair, designed to guide light waves along their length. it works on the principle of total internal reflection. When light enters through one end of the fibre it undergoes successive total internal reflections from side wall and travels down the length of the fibre along a *zigzag path*. A small fraction of light may escape through side walls but a major fraction emerges out from the other end of the fibre. A practical optical fibre has in general three coaxial regions. The innermost region is the *light guiding* region known as the core. It is surrounded by a *coaxial* middle region known as the cladding. The outermost region is called the *sheath*. The refractive index of cladding is always lower than that of the core. The purpose of cladding is to make the light to be confined to the core. Light launched into the core and striking the core to cladding interface at greater than critical angle will be reflected back into the core. Since the angles of incidence and reflection are equal, the light will continue to rebound and propagate through the fibre. The sheath protects the cladding and the core from abrasions, contamination and the harmful influences of moisture, see figure 8.

Numerical Aperture of fibre optic

A glass fibre consists of a cylindrical central core. Light rays impinging on the core cladding interface at an angle greater than the critical angle are trapped inside the core of the wave guide rays making larger angle with the axis take longer amount of time to travel the length of the fibre. For a ray entering the fibre, if the angle of incidence at the core – cladding interface is greater than the critical angle, then the ray would undergo total internal reflection at that interface. Further because of the cylindrical symmetry in the fibre structure, the ray would suffer total internal reflections at the lower interface also and would therefore get guided through the core by repeated total internal reflections.

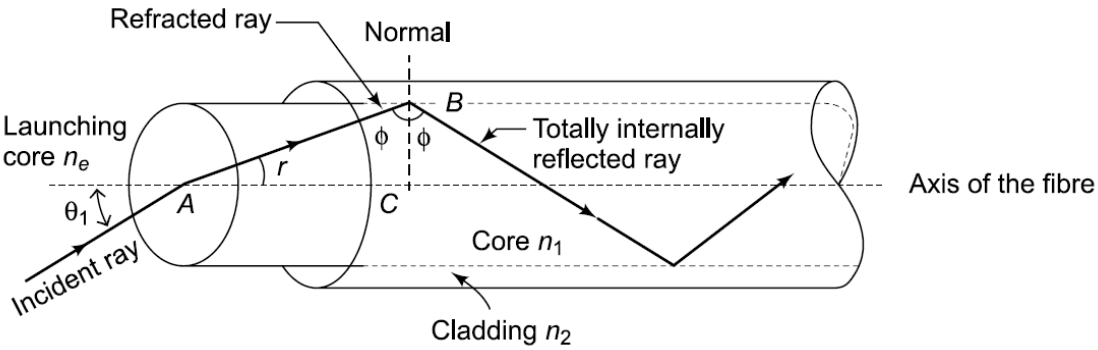


Figure (8)

Physics of lenses

There a relation between the focal length F, the object distance O, and the image distance i of a thin lens: **1/F = 1/O + 1/i**. If F is measured in meters, then 1/F is the strength in Diopters D, Thus, a positive (converging) lens with a focal length of 0.1 m has strength of 10 D. The focal length F of a negative (divergence) lens is considered to be negative. A negative lens with a focal length of - 0.5 m has strength of -2D. The focal length F of a combination of two lenses with focal length F_1 and F_2 is given by $1/F = (1/F_1) + (1/F_2)$. The strength of combination in diopters is equal to the sum of diopters of the various lenses.

Example 3: Assume lens A with focal length F_A = 0.33m is combined with a lens B with focal length F_B =0.25m. What is the focal length of the combination? What is the dioptric strength of the combinations?
The strength of combination in diopters is equal to the sum of diopters of the various lenses. **$1/F = 1/F_A + 1/F_B$** = 1/0.33 +1/0.25 = 1/0.143, or F = 0.143m. Note that lens A is 3D and lens B is 4D. The combination is the sum, or 7D. In a two-lens system, the image produced by the first lens serves as the object for the second lens.

Eye and vision:

Light passes through the cornea of the human eye and is focused by the lens on the retina. The ciliary muscles change the shape of the lens, so it can focus at different distances. Rods and cones on the retina convert the light into electrical impulses, which travel down the optic nerve to the brain. That is to say the cornea focuses by bending (refracting) the light rays. The amount of bending depends on the curvatures of its surfaces and the speed of light in the lens compared with that in the surrounding material. The index of refraction is nearly constant for all corneas, but the curvature varies considerably from one person to another and is responsible for most our defective vision, see figure 9. If the cornea is curved too much the eye is near sighted but, if not enough curvature results in far sightless. Uneven curvature produces astigmatism, see figure 10. The eye produces a real, inverted image on the retina. The brain adjusts the image to appear properly. The near point is the closest point to the eye that the lens is able to focus. For those with normal vision, it is about 25 cm from the eye, but increases with age as the lens becomes less flexible. The far point is the farthest point at which the eye can focus; it is infinitely far away, if vision is normal. The ciliary muscles adjust the shape of the lens to accommodate near and far vision.

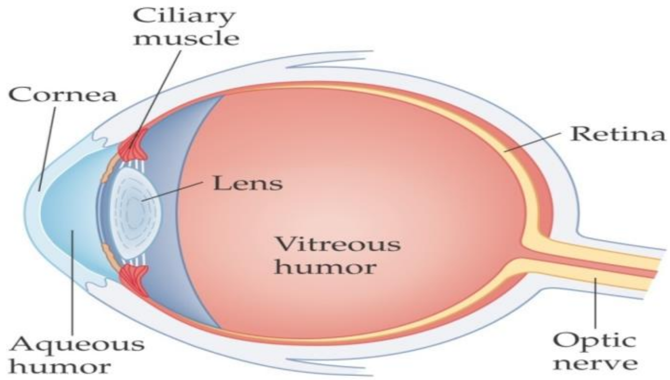


Figure (9)

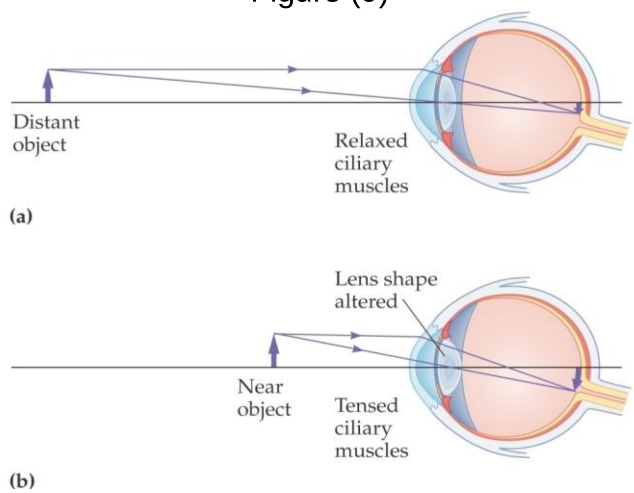


Figure (10)

THE RETINA-THE LIGHT DETECTOR OF THE EYE

The retina, the light sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain. The absorption of a light photon in photoreceptor triggers an electrical signal to brain-an action potential. The light photons apparently cause a photochemical reaction in the photoreceptor which in some way initiates the action potential. The photon must be above a minimum energy. Infrared photons have insufficient energy and thus are not seen. Ultraviolet photons have sufficient energy, but absorbed before they reach the retina and also are not seen. The image on the retina is very small. A convenient equation for determining the size of image on the retina comes from the ratios of the lengths of the sides of similar triangles, **O/P=I/Q**. I: is image size, Q: is image distance, O: is object size P: is object distance.

HOW SHARP ARE OUR EYES

The optometrists usually use a chart to test visual acuity. If they tell you that your eyes test normal at 6/6, that means you can read detail from 6 m that person with good vision can read from 6 m. If your eyes test at 20/40, you can just read from 20 ft the line that a person with good vision can read from 40 ft. The ability of the eye to recognize separate lines also depends on the relative" blackness "and "whiteness", the contrast between two areas is defined as optical density, OD = Log (I_o/I); where I_o is the light intensity without absorber and I is intensity with absorber.

Myopia: A nearsighted person has a far point that is a finite distance away; objects farther away will appear blurry. This is due to the lens focusing too strongly, so the image is formed in front of the retina this defect is known as myopia, see figure 11. To correct this, a diverging lens is used. Its focal length is such that a distant object forms an image at the far point, see figure 12.

Hyperemia : A person who is farsighted can see distant objects clearly, but cannot focus on close objects – the near point is too far away. The lens of the eye is not strong enough, and the image focus is behind the retina this defect is known as hyperemia, see figure 13. To correct farsightedness, a converging lens is used to augment the converging power of the eye. The final image is past the near point, see figure 14.

PRESBYOPIA (old sight):
As people get older the cillary muscles weaken and lens losses some of its elasticity. The power of accommodation diminishes with age. This defect is corrected by two parts of lenses upper half of each lens is diverging and corrects the myopia when the wears is looking ahead at distance objects, the lower half corrects the presbyopia with a suitable converging lens, and the wearer looks through this part when reading, see figure 15.

ASTIGATISM: When astigmatism is present, point objects do not form point images on the retina. This is normally due to the corneas unequal curvature in different directions. If the curvature is greater in a horizontal section than in the vertical section, rays brought to a focus more quickly in the horizontal than in the vertical plane. The defect is corrected by the use of cylindrical spectacle lenses, see figure 16.

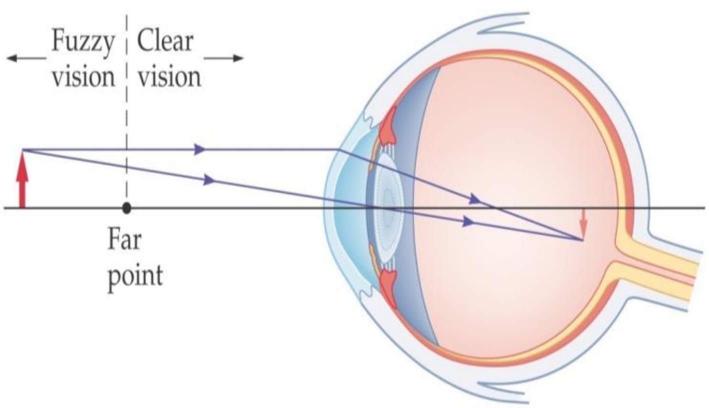


Figure (11)

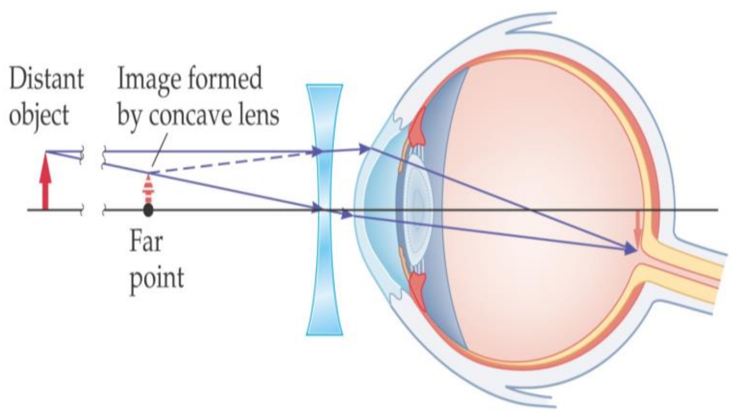


Figure (12)

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Figure (13)

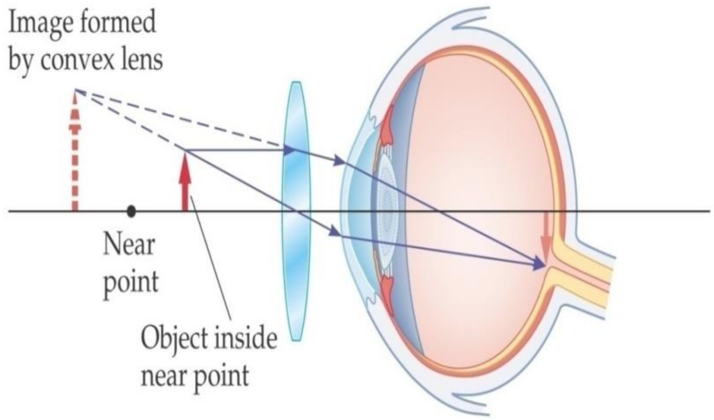


Figure (14)

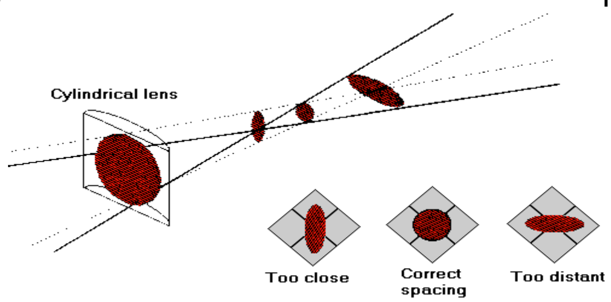


Figure (15)

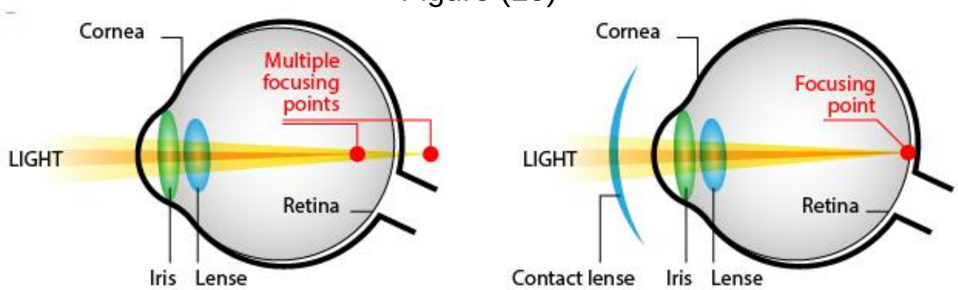


Figure (16)

Example 1: determine the strength of a lens needed to correct a myopic eye with a far point of 1m. Consider the image distance (lens to retina) to be 2cm.

A person who is focusing an object at 1m has lens strength of

$1/F = 1/O + 1/i \rightarrow 1/F = (1/1.0)+(1/0.02) = 51$ D

An eye able to focus at infinity has a strength of $1/F=(1/\infty)+(1/0.02) = 50$ D,

51 D – 50D =1D

Thus a myopic person with a far point 1m has 1 D, and a negative lens of -1.0 D will correct his vision.

Example 2: Consider a far sighted eye with a near point of 2.0 m, what power lens will let this person read comfortably at 0.25 m?

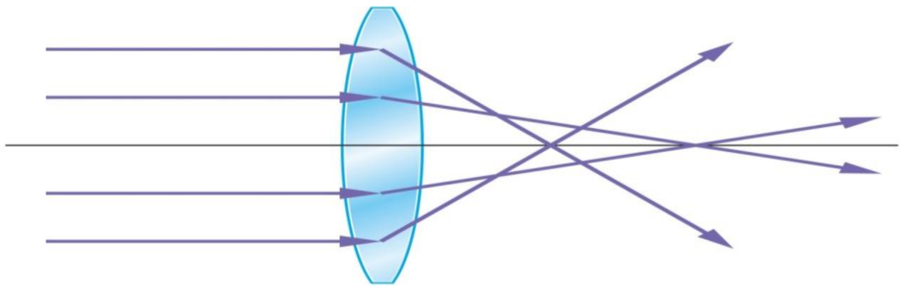
The strength of a good eye focused at 0.25 m is given by

$1/F=(1/0.25)+(1/0.02) = 4+50 = 54$D.

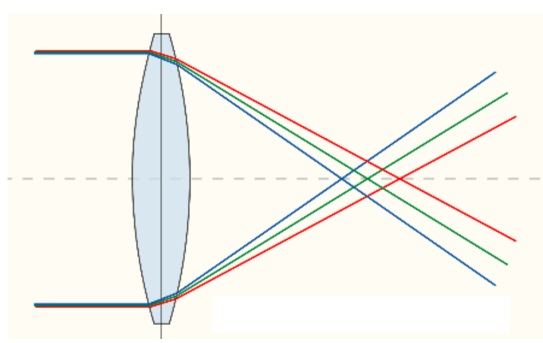
An eye focused at 2m has a strength of 1/F= (1/2.0) + (1/ 0.02) =0.5 + 50 =50.5 D
A corrective lens of 54-50.5= +3.5 D would prescribed for his eye.

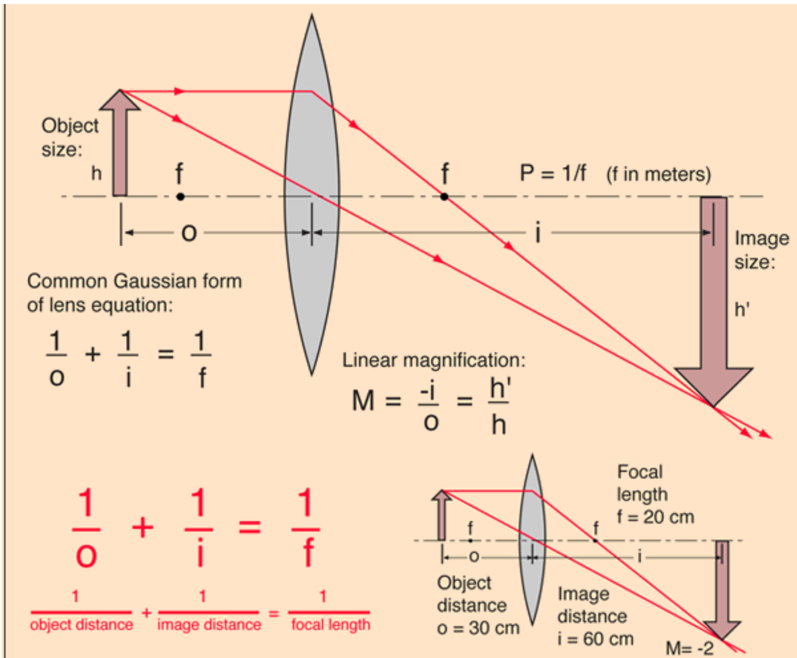
Lens aberrations can distort images. There are two types of lens aberration:

Spherical aberration occurs when light striking the lens far from the axis does not focus properly. It can be fixed by grinding the lens to a precision, non-spherical shape.



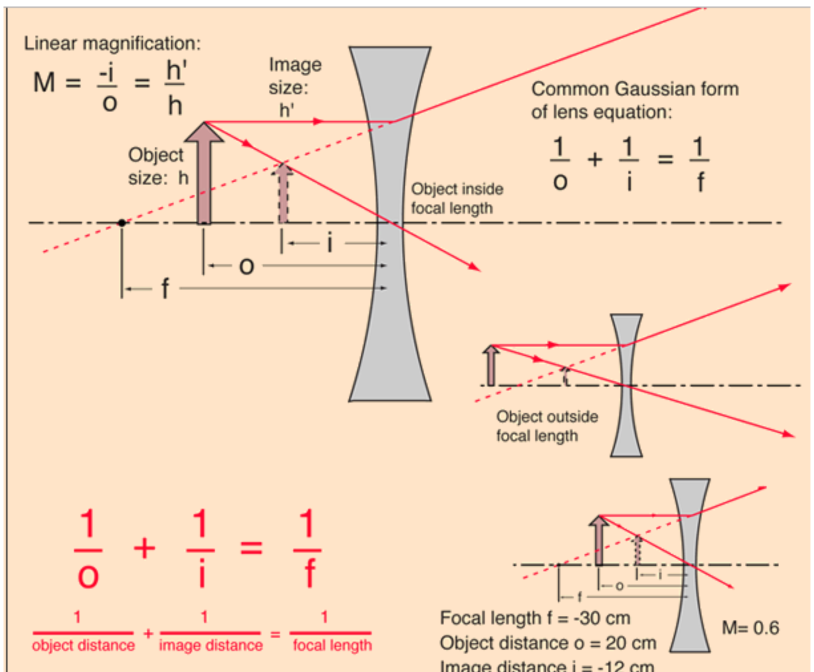
Chromatic aberration occurs when different colors of light focus at different points. Lens has different refractive indices for different wavelengths. Could cause color fringing: i.e, lens cannot focus all the colors at the same point. Chromatic aberration can be improved by combining two or more lenses that tend to cancel each other's aberrations. This only works perfectly for a single wavelength.





Enter data below, then click on the quantity you wish to calculate in the active formula above.

For a lens of focal length f = 20 cm,
corresponding to lens power P = 5 diopters,
an object distance of o = 30 cm
will produce an image at i = 60 cm.
The linear magnification will be M = ____.



Enter data below, then click on the quantity you wish to calculate in the active formula above.

For a lens of focal length f = ____ cm,
corresponding to lens power P = ____ diopters,
an object distance of o = ____ cm
will produce an image at i = ____ cm.
The linear magnification will be M = ____.

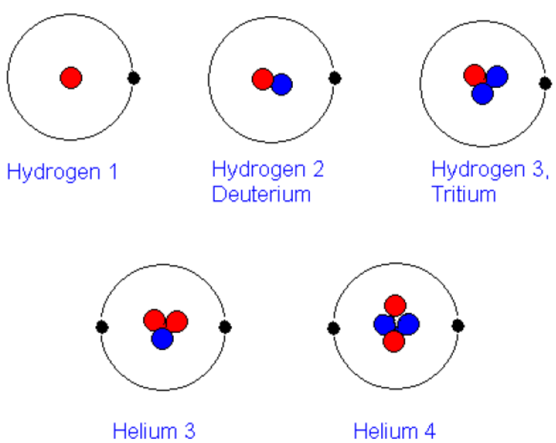
Introduction to Nuclear Radiation

All matter is composed of combinations of elements. There are 118 elements that have been discovered so far. The smallest "piece" of an element that retains it characteristics is an atom. Known elements are arranged on the periodic table according to their chemical characteristics. The chemical properties of an element depend on the electrons. Charge on an electron is equal but opposite the charge on a proton. A neutral atom has equal numbers of protons and electrons (zero net charge). Mass of a proton is 1836 times greater than the mass of the electron. Mass of a proton and the mass of neutron are approximately equal, (neutron is slightly heavier). Nucleus is composed of neutrons and protons, thus, most of the mass of an atom is in the nucleus. An ion is an atom that has either lost or gained electrons and therefore has a net charge.

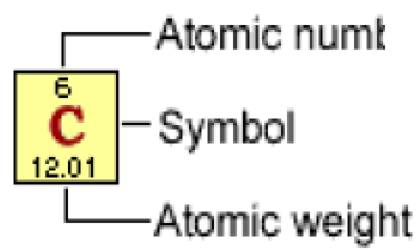
Atomic number (Z): Number of protons or electrons in a given neutral atom (determines what element we are dealing with).
Atomic mass (A): Number of neutrons ***plus*** the number of protons in a given atom.
Neutron Number (N): Number of neutrons in a given atom, N=A-Z. Neutral particles obtained from nuclear reactions since they cannot be accelerated electronically. Neutrons act as "spacers" to reduce electric repulsion between the protons in nucleus.
Isotope: Atoms with the same Z but different A. Light stable isotopes (Z<20), N approximately equal to Z. Heavy stable isotopes (Z>20), N greater than Z.

$^{A}_{Z}X$

How to write an element's symbol for a given isotope

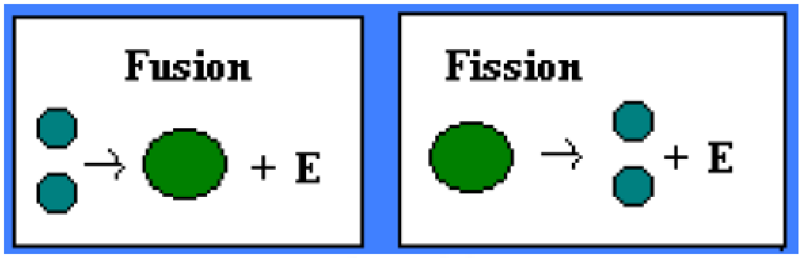


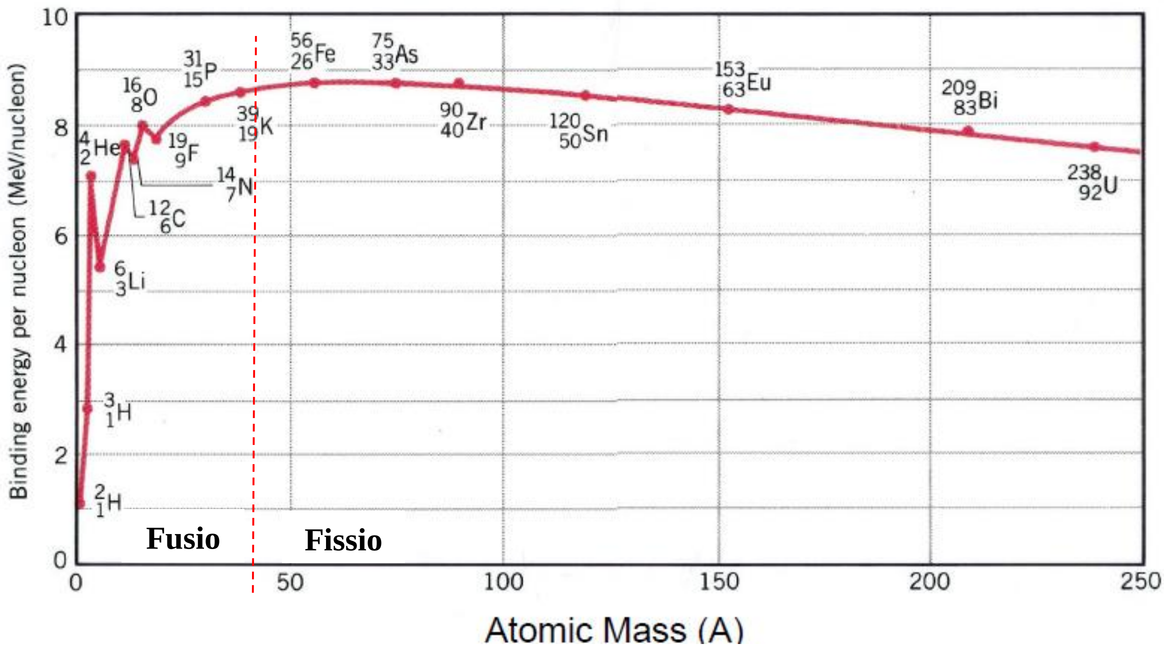
$^{236}_{92}U$



Proton mass is equal to 1.007277 u, and Neutron mass is equal to 1.008665 u. therefore, Neutron mass + Proton mass is equal to 2.015942 u. Deuterium mass is equal to 2.013553 u, missing mass (**N + P – D**) = 0.002389 u. So, what happened to the mass. It is converted into binding energy according to Einstein's mass energy relation, $E=mc^2$. For the deuteron example, this is 2.15 MeV of energy. If we want to break the deuteron apart we must give this energy back. **Atomic Mass Unit** (u) = 12th of the mass of 12C, where, 1 u=1.66´10^{-27} kg (very small).
Iron has the highest binding energy per nucleon. This is the most stable element in nature in that it requires more energy per particle to break it apart than anything else. ***Fusion*** energy comes from combining light elements to make heavier ones (increase binding

energy per nucleon for elements lighter than iron). ***Fission*** energy comes from breaking heavy elements into lighter ones (increase binding energy per nucleon for elements heavier than iron).





Biological effect of radiation is proportional to amount of ionization produced in tissue. Some organs are more sensitive to radiation than others. A tissue weighting factor is used to take this into account. From the point of view of the *effects that radiation produces on matter*, there are two classes of radiation; ionising and non-ionising radiations. ***Ionising*** radiation include cosmic rays, X-rays and the radiations emitted by the radioactive decay of radioactive substances. ***Non-ionising*** radiations include light, heat, radar, and radiowaves and microwaves. **Radioactive decay** is a natural *process*. An atom of a radioactive isotope will spontaneously decay into another element through one of three common processes; Alpha decay, Beta decay, Gamma rays, and sometime spontaneous fission or electron capture or Neutron rays (not always included). In a radioactive decay, the atomic number and atomic mass of the decay products must equal the atomic number and atomic mass of the original isotope.

In spontaneous fission, an atom actually splits instead of throwing off an alpha or beta particle. (very common for heavy elements, and usually also results in neutron emissions).

$$^{256}_{100}Fm \rightarrow ^{140}_{54}Xe + ^{112}_{46}Pd + 4\,^{1}_{0}n$$

Alpha Decay

An alpha α particle is composed of two protons and two neutrons, thus its atomic mass is 4 and its atomic number is 2. (Helium 4 nucleus).

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}Y + ^{4}_{2}\alpha$$

$$^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^{4}_{2}\alpha$$

Beta Decay

There are two types of beta β particles. They are either electrons or positrons (antimatter of electron). Their atomic mass is 0 and their atomic number is ±1.

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}\beta$$ Beta Minus Decay

$$^{A}_{Z}X \rightarrow ^{A}_{Z-1}Y + ^{0}_{+1}\beta$$ Beta Plus Decay

Gamma Rays

A gamma γ ray is pure energy. It essentially just high energy light, their atomic mass is 0 and their atomic number is 0. The isotope emits a gamma ray in relaxing from an excited state to a relaxed state but does not change into a different element.

$$^{A}_{Z}X^{*} \rightarrow ^{A}_{Z}X + ^{0}_{0}\gamma$$

The differences between the interactions of charged and uncharged radiation with matter

Directly ionizing radiation
Fast charged particles, which deliver their energy to matter directly, through many small Coulomb force interactions along the particle's track

Indirectly ionizing radiation
X-ray, γ-ray, photons or neutron. First transfer their energy to charged particles in the matter through which they pass in a relatively few large interactions. The resulting fast charged particles then in turn deliver the energy to the matter

Differ in their 'hardness' or ability to penetrate thickness of material
Soft radiation; Alpha particles; Low- energy X - rays
Harder radiation; Gamma rays and neutrons

Radioactive decay series

Radioactivity is the spontaneous emission of energy from a nucleus.Often times the products of a radioactive decay are themselves radioactive. These products will continue to decaying until we reach a stable isotope.

^{222}Rn

$\downarrow$ α decay 3.8 day

^{218}Po

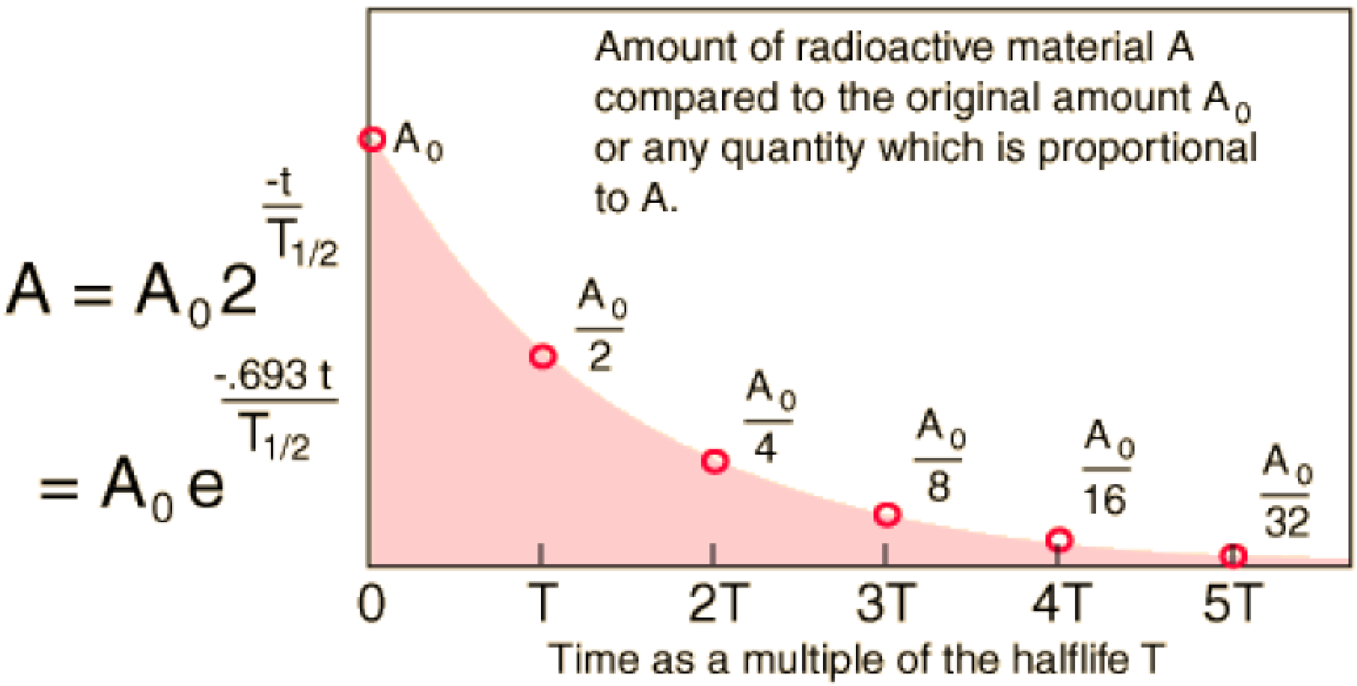
$\downarrow$ α decay 3.1 min

^{214}Pb $\rightarrow$ ^{214}Bi $\rightarrow$ ^{214}Po

β- decay 26.8 min β- decay 19.9 min $\downarrow$ α decay 164μsec

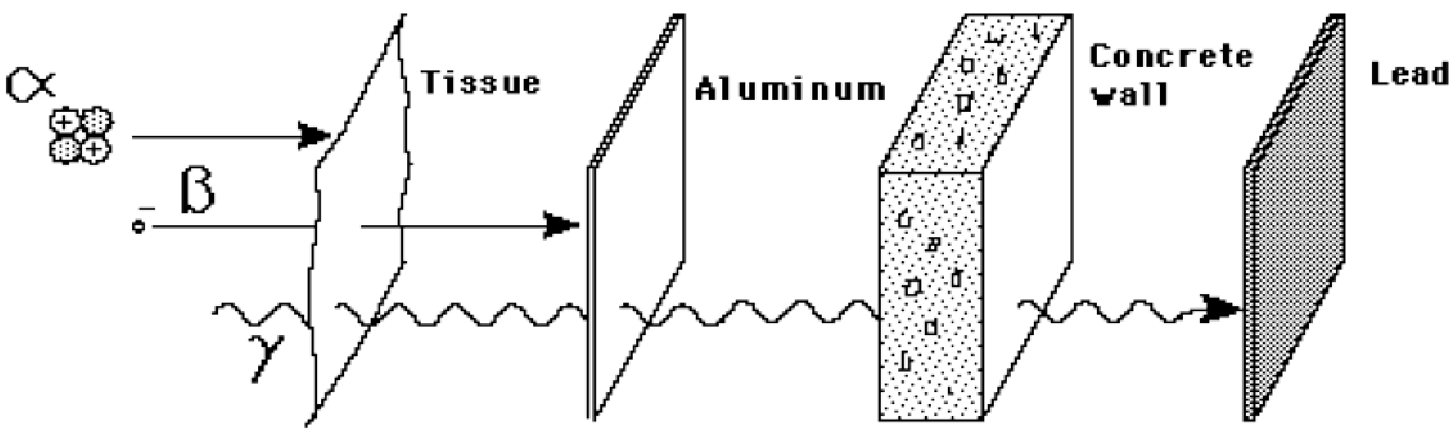
^{210}Pb

Half Life
The half-life of a radioactive isotope is the time required for a half of the original amount of the isotope to have decayed. **Example**; A radioactive source of 1×10^{10}Bq has a half-life of 12 yr and is considered safe if its activity is less than 3.7 $\times10^{4}$bq. How much time must pass before the source is safe?



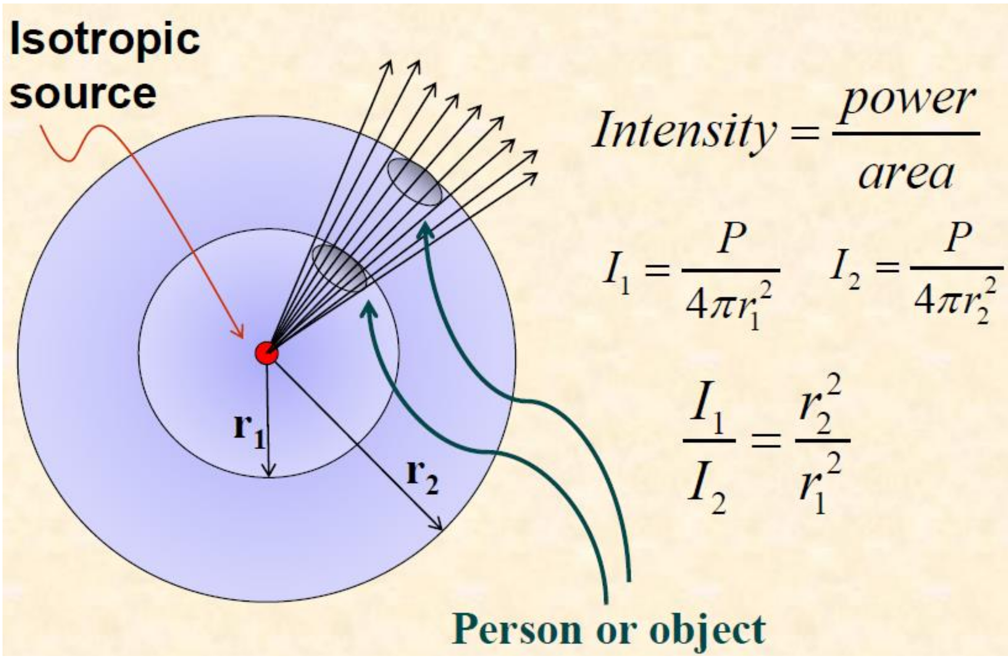
Penetration of Matter

Though the most massive and most energetic of radioactive emissions, the alpha particle is the shortest in range because of its strong interaction with matter. The electromagnetic gamma ray is extremely penetrating, even penetrating considerable thicknesses of concrete. The electron of beta radioactivity strongly interacts with matter and has a short range.



Radiation protection

Minimize the exposure by; reduce *the distance from source*, radiation levels around source (non-directional) decreases in proportion to distance squared. Radiation dose is reduced by moving away from source, according to Inverse Square Law. As the person gets further away, the sphere that intersects with them gets larger and larger. Reduce *the time of* *exposure*, constant activity source, dose is directly proportional to exposure time, the sensitive x-ray film helps keep note of exposure time. *Shielding*; is placed between person and source to absorb radiation. Shielding attenuation is the reduction due to the absorption and scattering of some of the photons out of the beam.



$I = I_o \exp(-\mu x)$

I is the intensity of beam, I_o is the intensity of beam with no attenuator, x is the thickness of attenuator, and μ is the linear attenuation coefficient, a constant dependent on the substance and the energy of x-rays. The Half Value Layer HVL is the thickness of a material that will reduce the beam intensity by half, let $I = I_o/2$, from the equation $I = I_o \exp(-\mu x)$, then $I_o/2 = I_o \exp(-\mu x)$, then ln2= μx, thus HVL = $x = \mu^{-1}$ ln2.

Questions

Question 1: 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?

Question 2: A person is working near a radioactive source and wants to decrease their dose rate by a factor of 10. How far away do they have to move?

Question 3: A person's hand receives a radiation dose at a rate of 50mSvh-1 at a distance of 1cm from a source. What would the dose rate be if the person's hand is 18cm from source?

UNITS OF RADIOACTIVITY

A Curie is the unit of absolute activity and is abbreviated Ci. It is expressed in terms of disintegrations per second (dps). A Curie is represented by a sample with a decay rate of 3.7 X 10^{10} dps or 2.22 X 10^{12} dpm. Where, 1 Ci=37 x 10^{9} dps, 1 mCi=37 x 10^{6} dps, 1 µCi=37 x 10^{3} dps, and 1 pCi=37 x 10^{-3} dps. One gram of Radium has an activity of 3.7x10^{10}Bq, which is 10^{6} times more active than many medical radiation sources. The strength of a radioactive source is determined by the number of disintegrations of its radioactivity per second. The unit is becquerel Bq which is one disintegration per second. This is a very small unit and usually larger units such as kilobecquerel (kBq) or megabecquerel (MBq) are used. 1 Bq = 1 disintegration per second (dps)

Specific Activity

Specific activity is defined as the activity per unit mass (e.g., mCi/g or KCi/mmol). It is unrelated to concentration in solution, which is activity per unit volume (e.g., mCi/ml). Specific activity must contain a term related to mCi or disintegrations and a term related to mass such as a gram or mole term. The activity of radiation source is the number of disintegrations per second. Since specific activity is defined as activity/unit mass, the numerator must be directly relatable to disintegrations. Counts cannot be related to disintegrations unless the detector efficiency is known.

Effect of radiation on human body "Biologically equivalent dose"

Energy per unit mass absorbed by material in the path of the radiation beam SI unit (joules per kg) called gray (Gy), 1Gy = absorbed energy of 1Joule /kg. Absorbed dose multiplied by weighting factor; compares the effect of the radiation with the effect of X-rays on tissue. Unit is the Sievert (Sv).

Equivalent dose (Sv) = weighting factor x absorbed dose (Gy)

Weighting factor for X-rays equals 1 Weighting factor alpha particles equals

QUESTION: which one of the following is NOT an example of specific activity?

• mCi/mg • kCi/µmole • cpm/mmole • dps/g

Detector Efficiency

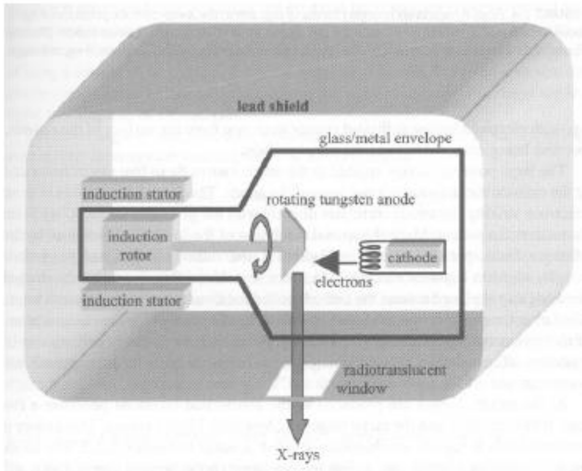
Detector efficiency indicates what fraction of total disintegrations is recognized by the detector. If we count a standard whose activity is precisely known, then mathematically,

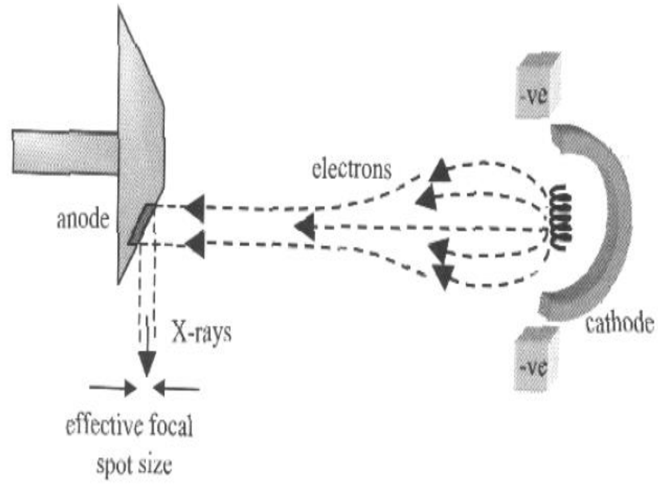
$$\text{Detector Efficiency} = \frac{\text{count rate x 100\%}}{\text{disintegration rate}}$$

For example, a 1.0 mCi standard of Co-57 has a count rate of 2.4 x 10^{7} c/s. What is the detector efficiency?

$$\text{Detector Efficiency} = \frac{2.4 \times 10^{7} \text{ c/s. x } 100\% = 64.86\,\%}{3.7 \times 10^{7} \text{ d/s.}}$$

X-Rays





Properties of x-rays:

The X-rays are a form of electromagnetic radiation similar to radio waves, microwaves, visible light and gamma rays. x-ray photons are highly energetic and have enough energy to break up molecules and hence damage living cells. When x-rays hit a material some are absorbed and others pass through. Generally, the higher the energy the more x-rays will pass through. This is what gives x-rays the power to “see inside” things. x-rays cannot be steered by electric and magnetic fields like alpha, beta and other charged particles.

Production of X-rays:

X-ray production whenever electrons of high energy strike a heavy metal target figure 1, like tungsten or copper. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electron to decrease, and this decrease in energy then results in forming an x-ray figure 2. In general a single electron can emit an X-ray photon having energy upon to its own kinetic energy

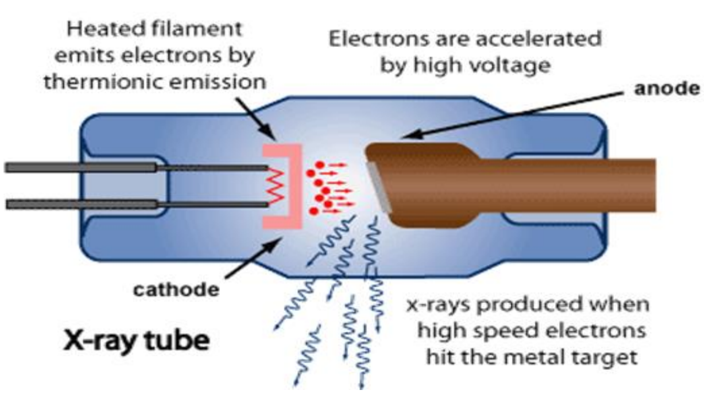


Figure 1

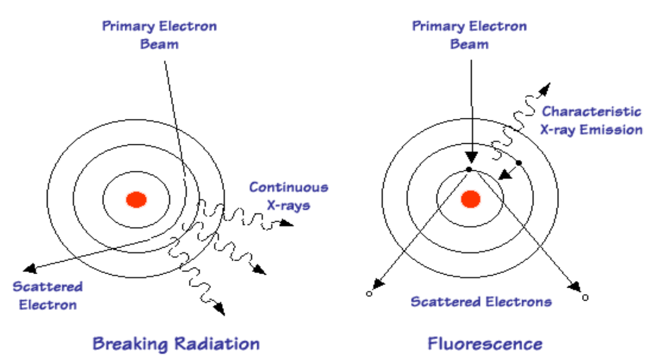


Figure 2

There are two types of ***X-ray generated***: characteristic radiation and bremsstrahlung radiation.

1. Characteristic X-ray generation

The discrete or k-shell emission spectrum, when a high energy electron collides with an inner shell electron both are ejected from the tungsten atom leaving a 'hole' in the inner layer. This is filled by an outer shell electron with a loss of energy emitted as an X-ray photon figure 2. Electron from higher shells fills the inner- shell vacancies. Characteristic X-ray are superimposed on the continuous spectrum. Designated K_α, K_β, and so forth when the K-shell vacancy is filled by an electron for L-shell, M-shell, and so on.

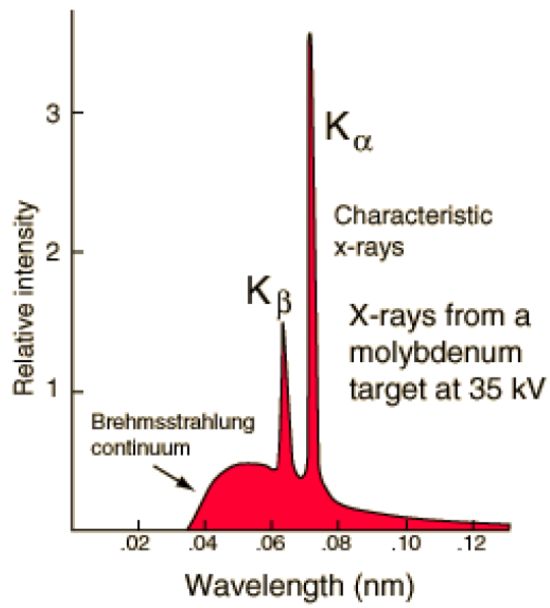
2. Bremsstrahlung or Breaking X-ray generation

The Continuous spectrum, when an electron passes near the nucleus it is slowed and its path is deflected. Energy lost is emitted as a bremsstrahlung X-ray photon. Bremsstrahlung radiation approximately 80% of the population of X-rays within the X-ray beam consists of X-rays generated in this way.

Maximum energy: all electrons' energy is converted into the photon's energy

- Kinetic energy = photon energy
- Kinetic energy = charge of electron × Voltage = eV = *hf*

h = Planck's constant, and… c = fλ, so, eV = *hc/λ*



Interaction (or Absorption) between X-rays and matter

occurs when x-rays pass through materials due to energy loss by: Compton Scattering, photo electric effect, and Pair Production.

Compton Effect: also called Compton scattering; is the result of a high-energy photon colliding with a target, which releases loosely bound electrons from the outer shell of the atom or molecule figure 3. It is a photon = photon + electron, ionization. Most frequent in X-ray imaging, especially for high energy.

Coherent (Rayleigh) scattering: Low-energy radiation, About 5 - 10% of tissue interactions.

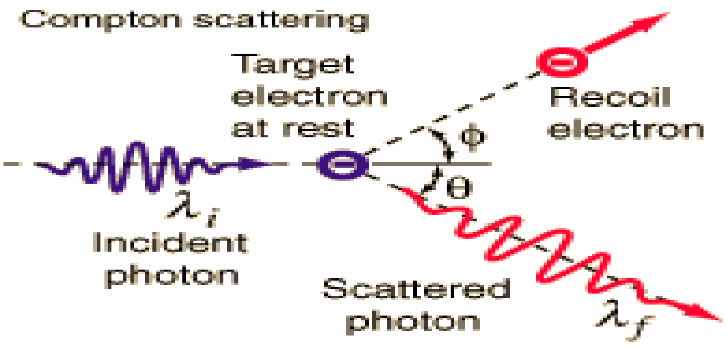


Figure 3

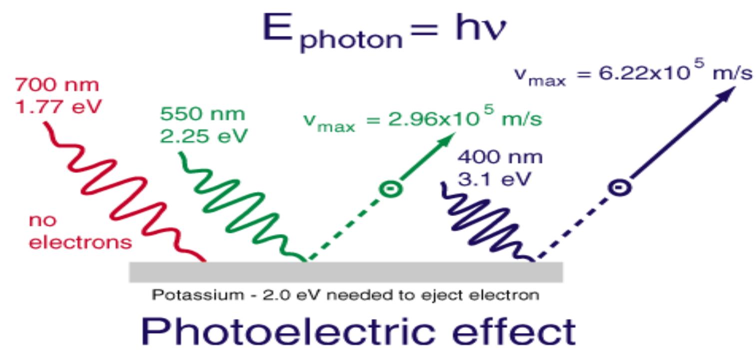


Figure 4

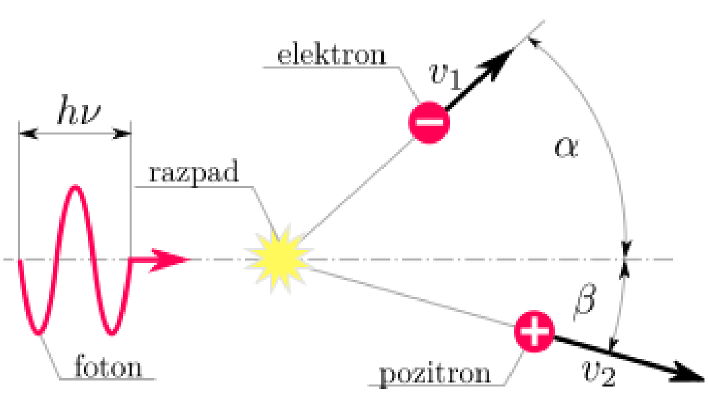
Photoelectric effect is a phenomenon in which electrically charged particles are released from or within a material when it absorbs electromagnetic radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it figure 4. High-energy radiation Desirable, X-ray photon completely absorbed, Excellent contrast bone/tissue at low energy.

Pair production can only occur if the incident photon energy is at least 1.022 MeV. As the photon interacts with the strong electric field around the nucleus it undergoes a change of state and is transformed into two particles: one electron and one positron, figure 5.

Attenuation of X-rays:

Is the intensity reduces with distance figure6 ; $I = I_0 e^{-\mu x}$

I is the photon intensity of x-rays at depth x from the surface, I_o is the initial intensity of x-ray, x is the depth of x-rays from the surface, μ is the absorption coefficient. Intensity: [W\m^2].



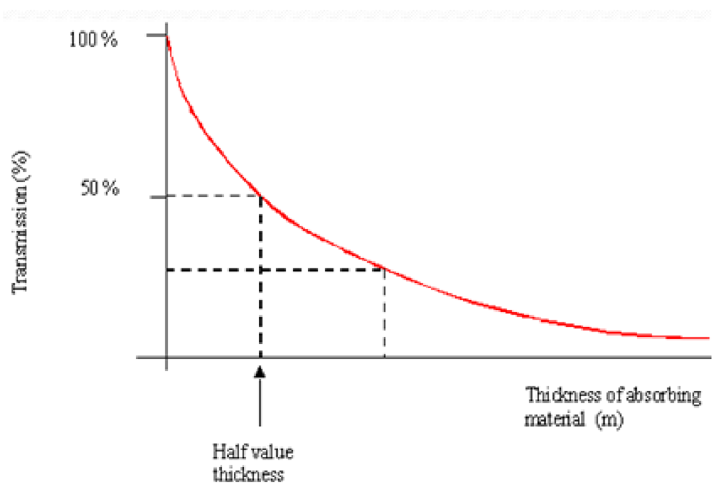


Figure 5 Pair production **Figure 6**: attenuation of x- rays.

μ — linear attenuation coefficient

Half-value layer $\approx 0.693/\mu$

The Half-Value Layer (HVL) for Muscle and Bone as a Function of the Energy of the Incident X-Rays

X-ray energy (keV)	HVL, muscle (cm)	HVL, bone (cm)
30	1.8	0.4
50	3.0	1.2
100	3.9	2.3
150	4.5	2.8

X ray source

15 - 150 kV, rectified AC
50 - 400mA anode current
Tungsten wire (200 _m) cathode, heated to _ 2200_C
Anode rotates at 3000 rpm
Molybdenum or thungsten-rhenium anode
Thermoionic emission
Focal spot size 0:3mm _ 1:2mm
Spectrum: (150 kV)

Uses of X-rays:

1- Diagnosis
2- Treatment of cancers (radiotherapy) with high energy X-rays.

X-ray workers

1) Wear a film badge to check the amount of radiation they get.
2) Wear lead aprons while the machine is in use.
3) Verify that the machine is in an enclosed room and the controls are in a separate room.
4) Ensure that that there is no entry into the X-ray room while the machine is in use.

Dangers of X-rays:

1- Water ionises to produce free radicals which produce H_2O_2
2- Enzymes & DNA are damaged
3- Parts of cells are damaged
4- Tissue & organ damage
5- Life expectancy shortens

6- Mutations cause gene alterations in populations

Question calculate the following values, For an incoming wavelength

λ_i = [ ] nm = [ ] x 10^[ ] m

scattered at angle θ=[ ] degrees

the change in wavelength is

$\Delta\lambda$ = [ ] nm = [ ] x 10^[ ] m

and the final wavelength is

λ_f = [ ] nm = [ ] x 10^[ ] m

Expressed in terms of photon energies, the incoming photon energy is

$E_i = hc/\lambda_i$ = [ ] x 10^[ ] eV = [ ] x 10^[ ] joules

= [ ] eV = [ ] keV = [ ] MeV

and the scattered photon energy is

$E_f = hc/\lambda_f$ = [ ] x 10^[ ] eV = [ ] x 10^[ ] joules

= [ ] eV = [ ] keV = [ ] MeV

This implies that the energy transferred to the electron is

$KE_{electron}$ = [ ] x 10^[ ] eV = [ ] x 10^[ ] joules

= [ ] eV = [ ] keV = [ ] MeV .

This exploration is designed to accept values for the input wavelength or energy and the angle of scattering. Unspecified parameters will default to the case of molybdenum K-alpha xrays scattering at 90 degrees, one of Compton's historical results. Any of these input values can be changed.

Radiation Protection

Exposure from discrete sources of radiation in three basic ways. They work much the same way as protection against overexposure to the sun.

Time: The concept of time works in two ways. Limiting or minimizing the amount of exposure time will reduce the dose from the radiation source. Also, allowing radioactive material as much time as possible to decay before exposure will minimize radiation exposure when that material needs to be handled.

Distance: Increasing the distance from the radiation source will sharply decrease exposure. The intensity of radiation decreases the further you are from the source in the same way that the heat from a fire is less intense the further away you are from it.

Shielding: Inserting a solid material or shield between person and a radiation source will greatly reduce the radiation dose. Barriers of lead, concrete or water provide protection from radiation from gamma rays and neutrons. This is why certain radioactive materials are stored under water or in concrete or lead lined rooms, and why dentists place a lead blanket on patients receiving x-rays of their teeth.