Lecture (one , two) : forces on and in the body

Forces

Forces in the body
1- Gravitational force
2-Electrical force
3-Nuclear force

Forces on the body
1- Static force
2-Dynamic force
3-Frictional force

The force controls all motion in the world, the important force in the body is the muscular forces that cause the blood to circulate and the lungs to take in air and other. Physicists recognize four fundamental forces. In order of their relative strength from weakest to strongest . They are :

1- Gravitational force

2- Electrical force

3- Weak nuclear force

4- Strong nuclear force

1- Gravitational force :-

From Newton law: There is a force of attraction between any two objects. (F=mg) . Where: g = acceleration due to gravity (cm/sec^2 or m/sec^2) , m= the mass (g , kg) , f = the force (N, dyne) .

Our weight is due to the attraction between the earth and our bodies. **The medical effects of gravitational force is the formation of varicose veins in the legs as the venous blood travels against the force of gravity on its way to the heart.** Varicose veins are veins that have become enlarged and twisted. When veins become varicose, the leaflets of the valves no longer meet properly (as illustrated in figure-1), and the valves do not work. This allows blood to flow backwards and they enlarge even more. Varicose veins are most common in the superficial veins of the legs, which are subject to high pressure when standing. Besides being a cosmetic problem, varicose veins can be painful, especially when standing. **Another medical effects of gravitational force is on the skeleton (on the bones) , in some way contributes to healthy bones , if a person becomes weightless , such as in an orbiting satellite . he may lose some bone mineral.**

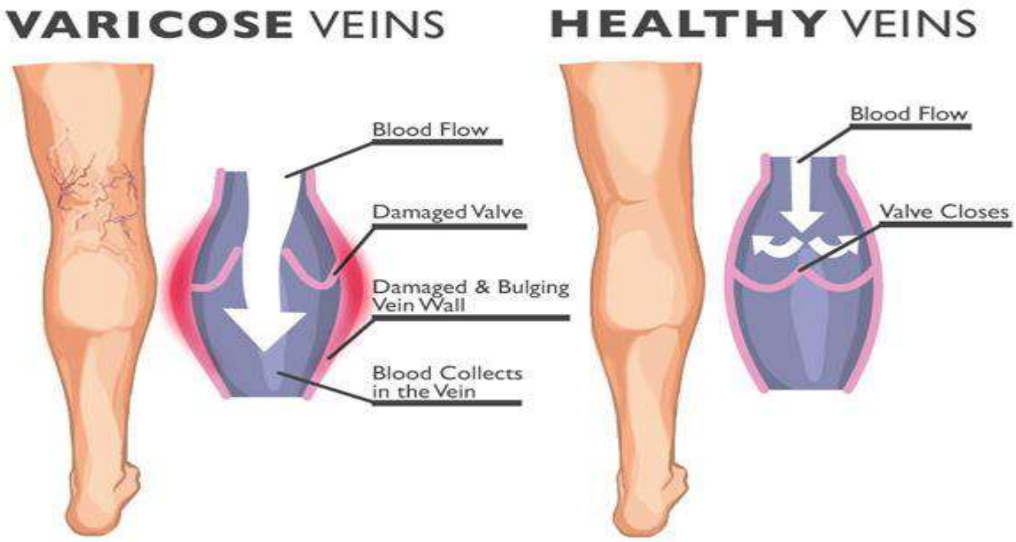

Fig.(1) shows the cause of varicose veins

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). The electrical forces are immense compared to gravitational force, for example 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 , as shows in figure (2).

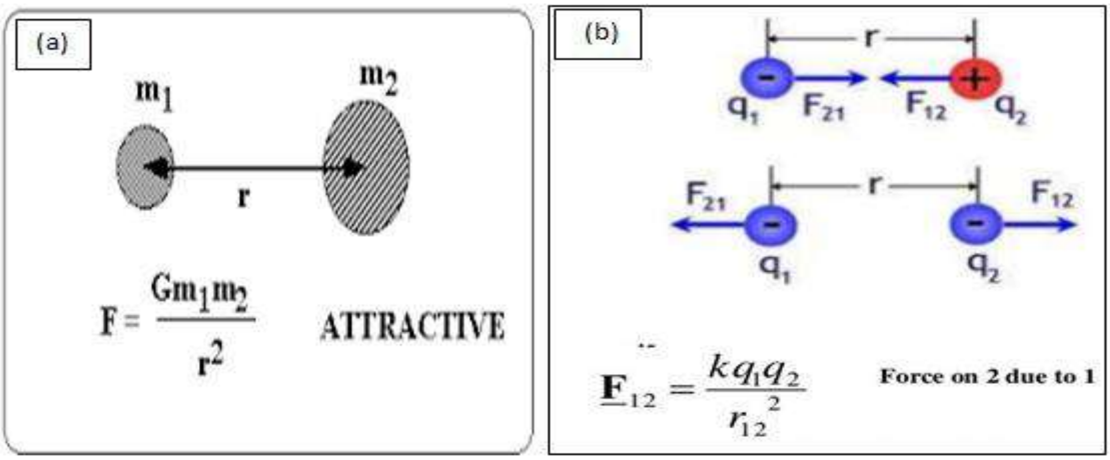

Fig.(2) Represents (a) Gravitational force, and (b) Electrical force.

One life process that appears to be electrically controlled is bone growth.

Bone contain collagen which behave like n-type semiconductor (i.e. conduct current by negative charge), while mineral crystal of the bone (apatite) close to the collagen (as illustrated in figure-3) behave as

p-type(i.e. conduct current by positive charge), at this junction the current flows easily from p-type to n-type that induced and control bone growth.

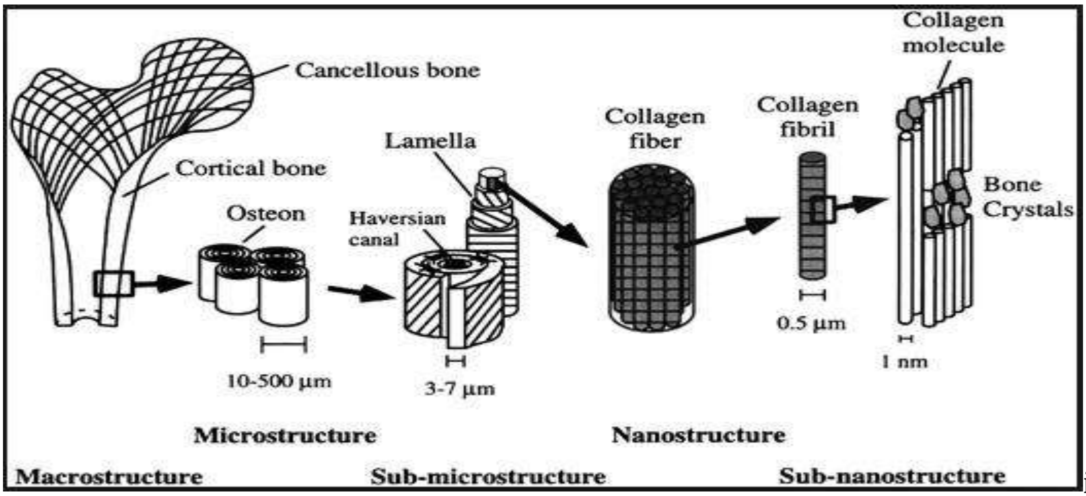

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Fig.3 shows bone structure in verious length scale

3- The nuclear force :-

A- strong nuclear force : is much larger then the other it acts as the " glue " to hold the nucleus together against the repulsive

force produced by the protons on each other .

B- weaker nuclear force : is involved with electron (beta) decay from the nucleus .

There are two types of problems involving forces on body, the first is statics (where the body in equilibrium) and the second is dynamics (when the body is accelerated). While the friction is involved in both (statics and dynamics) .

a-Statics force

Objects are stationary (static) they are in a state of equilibrium when:-

1- Translational equilibrium: (the sum of force in any direction is zero) (First condition of equilibrium), as illustrated in figure (4-a).

$$\sum_i \vec{F_i} = 0$$

2- Rotational equilibrium: The sum of the torques about any axis is zero(Second condition of equilibrium), as illustrated in figure (4-b).

$$\sum \vec{\tau} = 0$$

$\tau = F \cdot L$

Where : τ: The torque (N.m), F: The force (N), and L: The vertical distance from the fulcrum (pivot)point to the line action of the force (m, cm).

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

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

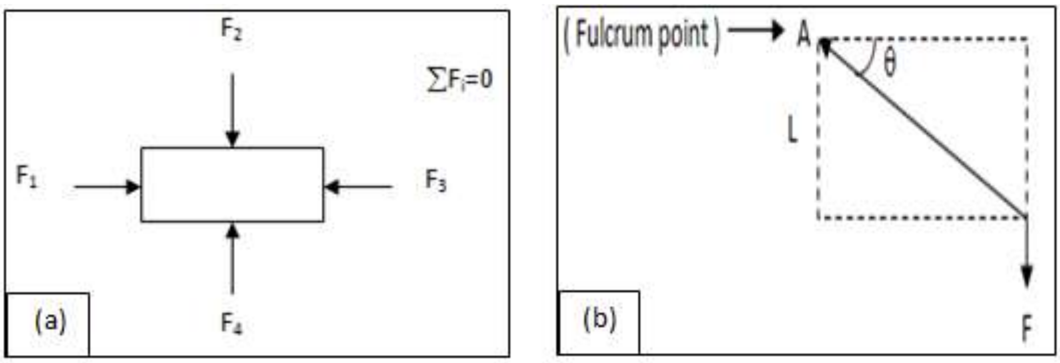


Fig.(4) Shows (a) Translational equilibrium , and (b) Rotational equilibrium

Many of the muscle and the bone system of the body acts as levers. Levers are classified according to the positions of the fulcrum, effort and load or resistance. There are three classes of levers, identified as **first**, **second**, and **third class** levers. We can tell the classes of levers apart by:

1. The **force** you apply (or the effort you make)… M.

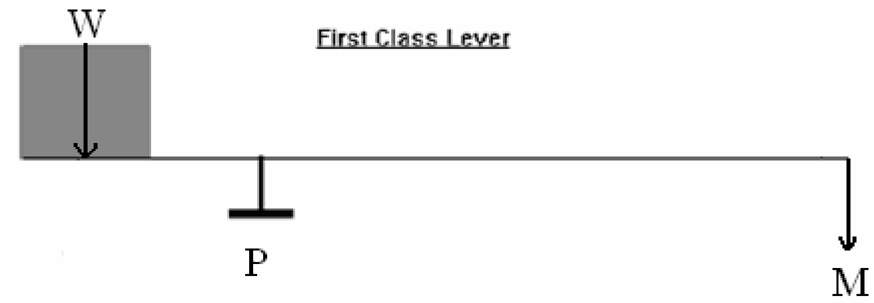
2. An **opposing force** such as a weight, which is usually called the load… W.

3. The pivot point, or **fulcrum** of the action.

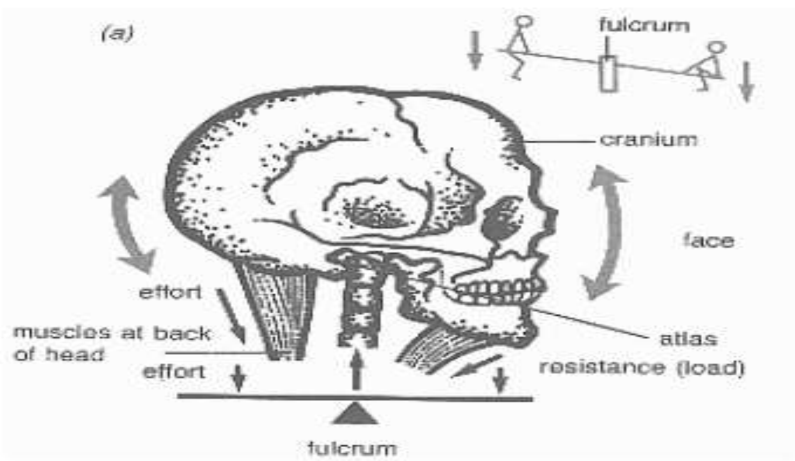
Bones as Levers :

Each of the three types of levers can be found in the human body. In each type of lever, notice where the fulcrum is located compared to the effort and the load. In your body, the **effort** is the **force** that your muscles apply to the lever. The **load** is the weight that resists the pull of your muscles.

1- First Class Lever

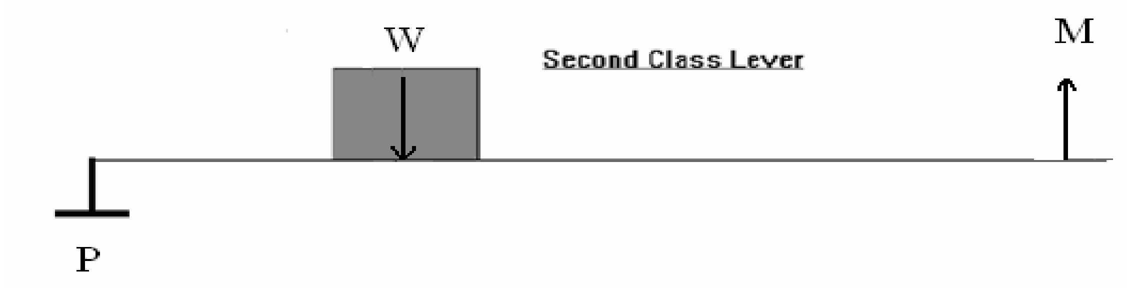


In a first class lever, the weight and force are on opposite sides of the fulcrum: An Examples of a **first-class lever** is the joint between the **skull and the atlas vertebrae** of the spine: the spine is the fulcrum across which muscles lift the head.

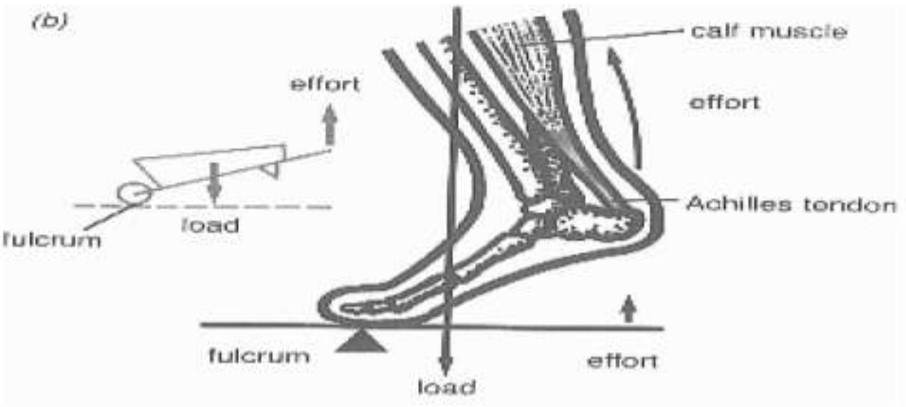


2- Second Class Lever

In the second class lever, the load is between the fulcrum and the force:

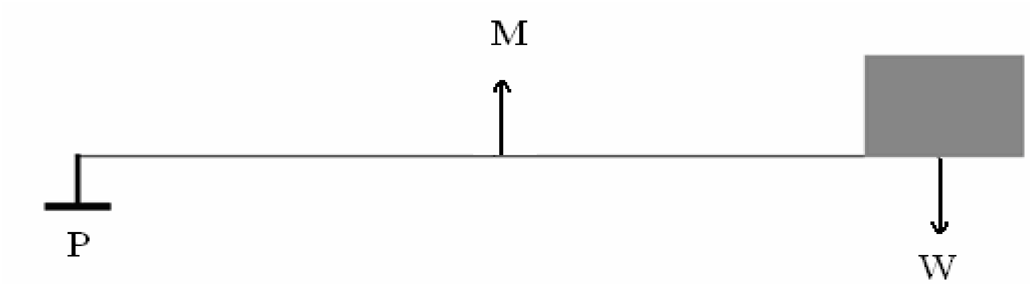


An example in the human body of a **second-class lever** is the **Achilles tendon**, pushing or pulling across the heel of the foot.

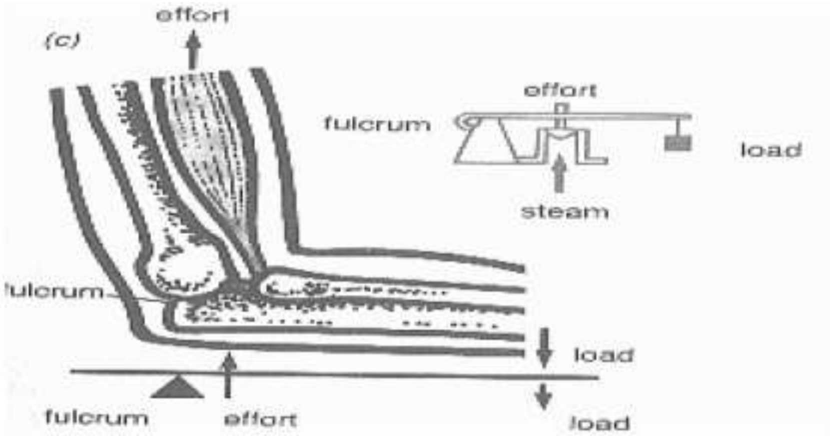


3- Third Class Lever

In the third class lever, the force is between the fulcrum and load :



An example of a **third-class** lever in the human body is the **elbow joint**: when lifting a book , the elbow joint is the fulcrum across which the biceps muscle performs the work.

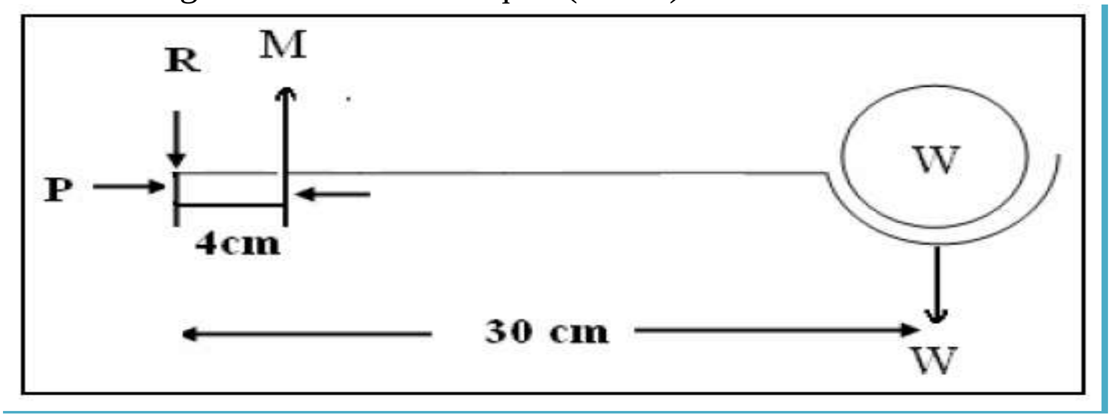


Example:- The lever system in the body is the case of the biceps muscle and the radius bone acting to support a weight in the hand.

R:- The reaction force of the humerus on the ulna.

M:- The Muscle force supplies by the biceps.

W:- the weight in the hand and equal (100 N).



Sol:

$$\tau_{CW} = \tau_{CCW}$$

$$\tau_{W} = \tau_{M}$$

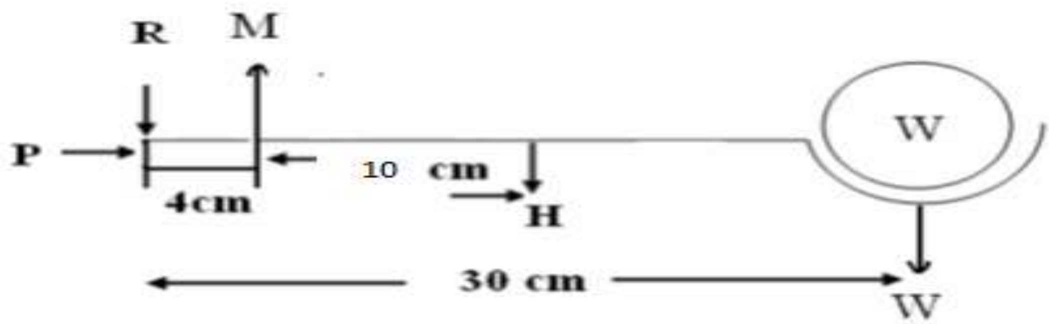
$$\tau = r \times F$$

$$30 \times 10^{-2} \times 100 = 4 \times 10^{-2} \times M$$

$$\therefore M = 750N$$

M=750N [If neglected the weight of the forearm and hand]

The force and dimension where the weight of the tissue and bones of the hand and arm (H) at their center of gravity. From this example find value of (M) when H=15N and W=5N??



Sol:

Tow torques:

1. due to the weight W
2. due to muscle M

$\tau_{CW} = \tau_{CCW}$

$\tau_W = \tau_M$

$\tau = r \times F$

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

$$150 + 210 = 4M$$

$$\therefore M = 90N$$

The effect of the arm angle on the muscle force:-

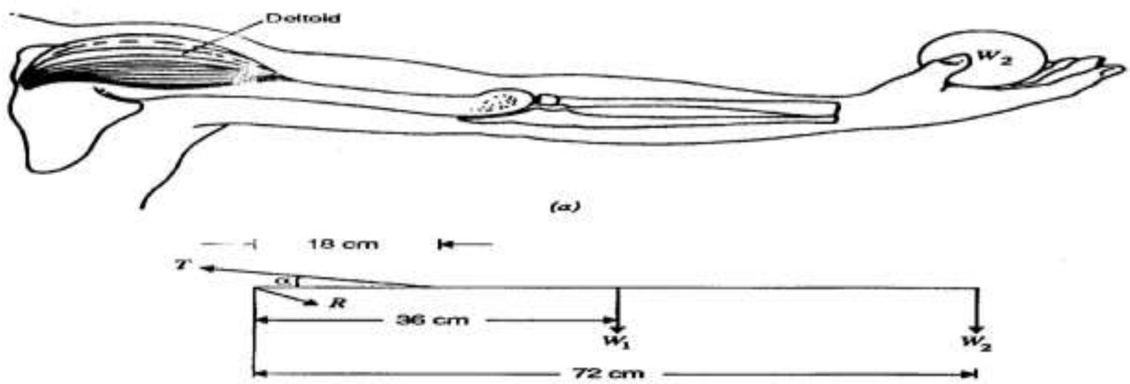


Figure. Raising the arm**.(a)** The deltoid muscle and bone structure involved**.(b)**The forces on the arm. **T** is the tension in the deltoid muscle fixed at the angle , **R** is the reaction force on the shoulder joint,**W1** is the weight of the arm located at its center of gravity, and **W2** is the weight in the hand.

If the biceps pulls vertically, the angle of the forearm(الساعد) does not affect the force required but it does affect the length of the biceps muscle which affects the ability of the muscle to provide the needed force.

The arm can be raised and held out horizontally from the shoulder by the deltoid muscle (عضلة الكتف) (figure a); we can show the forces schematically (figure b). By taking the sum of the torques about the shoulder joint ,the tension **T** can be calculate from

$$\mathbf{T} = \frac{2W1 + 4W2}{sin\alpha}$$

W1(the weight of the arm),and **W2**(the weight in the hand).(Figure).

If alpha =16 deg.

W1(The weight of the arm)=68N.

W2 (the weight in the hand)=100N.

Then T=1985.2 N.

I.e., the force needed to hold up the arm is surprisingly large.

Example:- What is the forces needed to held up the arm under the state of raising the arm (**α**=16°,**W1**=68N,**W2**=45N)?

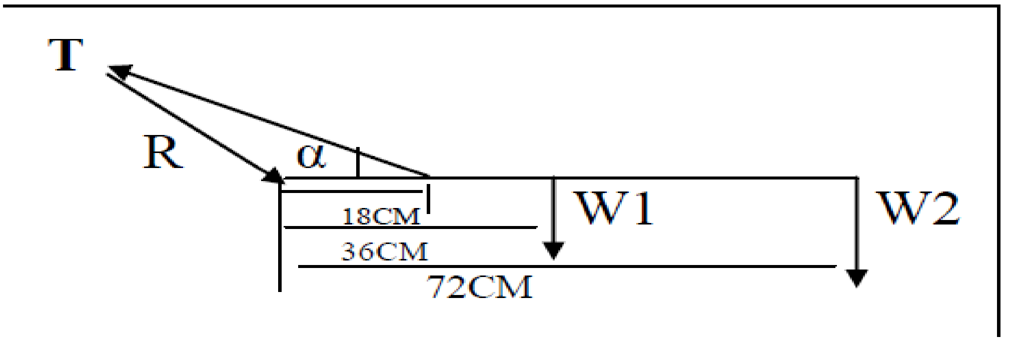
Sol-:.

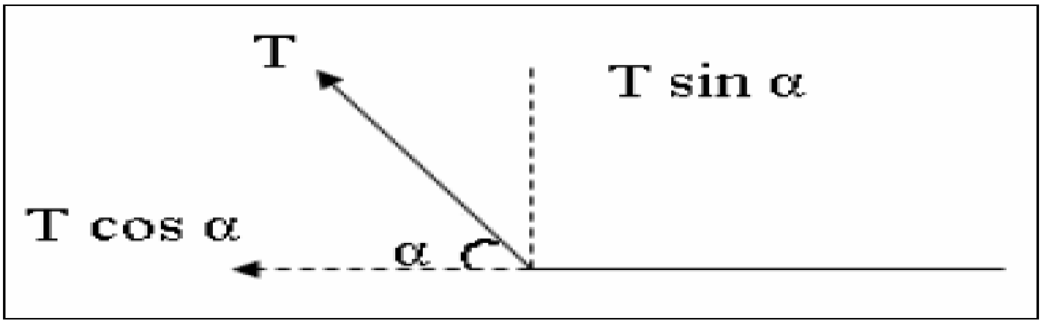
T (tension) at angle **α** resolved into tow components. **Tsinα**, **Tcosα** and taking the sum of the torques about the shoulder joint.

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

$$36\times10^{-2}\times68+72\times10^{-2}\times45=18\times10^{-2}\ T\ \sin\alpha$$

T=1145N the force needed to hold up the arm is large.





b-Frictional force

A force which resists the motion between two surface (in contact) depended on the nature of the surface and is independent on the area of the surface. Friction force is always opposite to the direction of motion and tends to decrease net force. All materials have their own friction constant in other words friction force depends on the type of materials. Another factor affecting friction force is the normal force. When you apply a force to an object, then friction force becomes active and resists with the force of having opposite direction to your net force. Generally frictional force is divided to:

1- Static friction (F_s):

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

$$F_s = \mu_s N$$

Where:-

μ_s= coefficient of static friction (used to find the max. resistance force on an object can exert before it starters to move).

N= normal force.

2- Kinetic (sliding) friction (F_k):-

The effective force between surfaces that are in relative motion.

$$F_k = \mu_k N$$

Where:-

$F_k \propto N$

μ_k= coefficient of kinetic friction, the greater the coefficient values and the greater the friction force.

$\mu_s > \mu_k$ = (Force to start the motion is a greater than needed to keep it moving).

Friction in the body

The Walking:-

As the heel of the foot touch the ground a force is transmitted from the foot to the ground Fig (a), we can resolve this force into horizontal (F_h) and vertical components. The max. Force of friction (F) is:

$F_h = \mu N$

F_h= the horizontal reaction component supplied by frictional forces.

N= normal force supplied by the forces.

When the foot touch the ground F_h between the heel and surface prevent the foot from slipping forward fig(a).while when it leaves the ground , F_h prevents the toe from slipping backward fig (b).

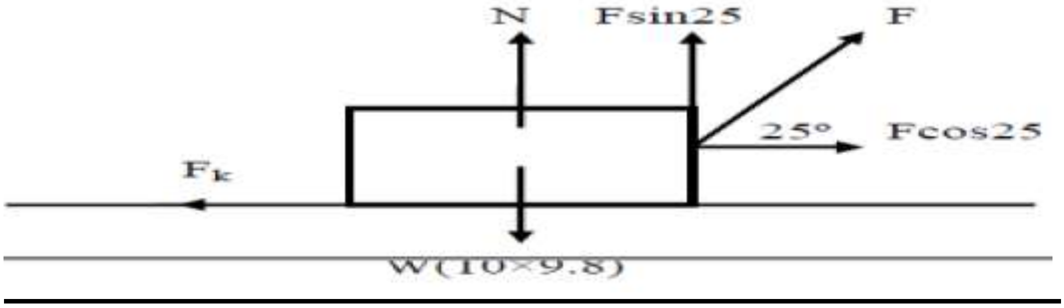
Measurement of F_h:-

The value of the horizontal force component (F_h) of the heel as it strikes the ground when a person is walking is given by: $F_h \approx 0.15W$

W=mg (persons weight). When μ less than 0.15, his foot slips.

- The coefficient of friction in the boon joints is usually much lower than in engineering type material. If a disease of the joint exists the friction may become large, the synovial fluid in the joint involved in the lubrication.

Example :- The mass of (10 kg)is pulled along a horizontal surface at constant velocity by a force 50N and which make an angle of 25° with horizontal what is the coefficient of μ_k between block (mass) and the plane ?



Solution:-

$F_k = \mu_k N$

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

$F_k = F\cos 25 = 50 * 0.92 = 46.2N$

$N = (10\times 9.8) - F\sin 25 = 98 - (50\times 0.38) = 79N$

$\therefore \mu_k = \frac{46.2N}{79N} = 0.58$

Dynamic

The force on the body under the constant acceleration or deceleration of one dimensional motion. The Newton's second law, force equal mass times acceleration, can be written without vector notation as:-

F=ma where: F= The force (N, dyne) , m= The mass (Kg, g) , a= acceleration (cm /sec^2 or m/ sec^2)

Also F = The change of momentum (p) over a short interval of time (t).

$$\therefore F = \frac{\Delta p}{\Delta t}$$

Δp= change of momentum =Δ(mυ) , m=mass, υ= velocity of this mass

Δt = interval of time

Example:-

A 60 Kg person walking at 1 m/sec bumps into a wall and stops in a distance of 2.5 cm in about 0.05sec what is the force developed on impact?

Solution:-

$\Delta(m\upsilon)$= momentum before impact- momentum after impact

$$\Delta(m\upsilon) = 60Kg \times 1m/sec - 0 = 60\ Kg\ m/sec$$

$$\Delta F = \frac{\Delta(mv)}{\Delta t} = \frac{60kg.\,m/sec}{0.05sec} = 1200kg.\frac{m}{sec^2}$$
$$= 1200N$$

Example : 60 gm of blood is given upward of about 0.1 sec in a velocity nearly 1m / sec , the force is equal to :

$$F = \frac{m\Delta v}{\Delta t} = \frac{(60\times10^{-3})kgm\times1m/sec}{0.1} = 0.6\,N$$

Accelerations can produce a number of effects such as

1- An apparent increase or decrease in body weight

2- Changes in internal hydrostatic pressure

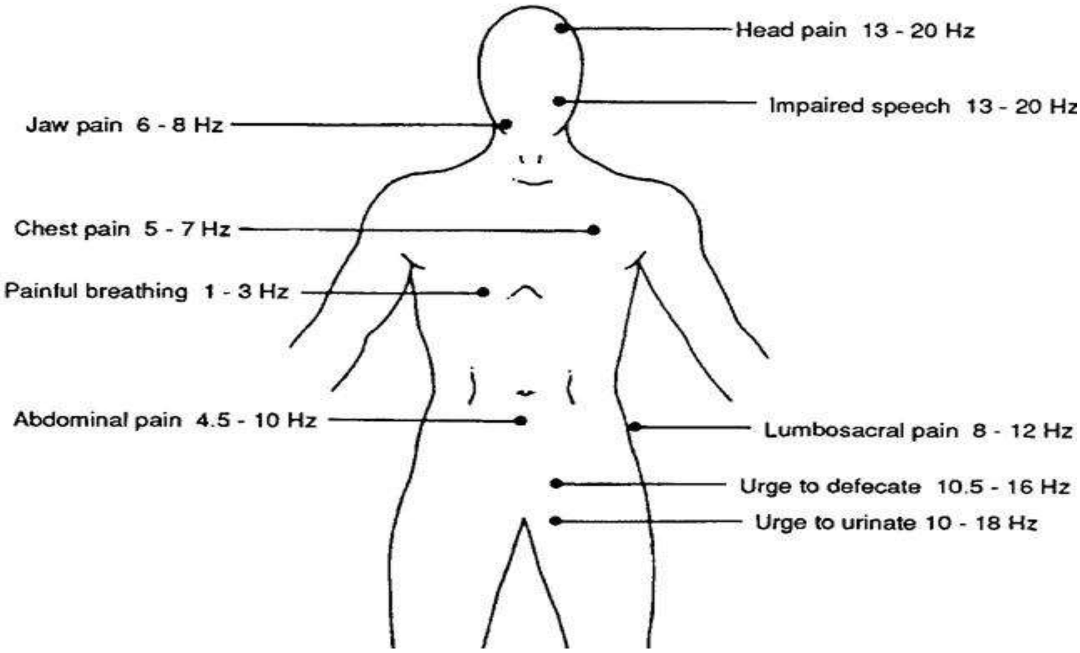
3- Distortion of the elastic tissues of the body

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

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

Pain symptoms of human subjected to vibrations from 1 to 20Hz

Each of our major organs has its own resonant frequency (or natural period) which depends on its mass and elastic forces that act on it. Pain or discomfort occurs if particular organ is vibrated strongly and its resonant frequency



Example:-

A 60 Kg person walking at 1 m/sec bumps into a wall and stops in a distance of 2.5 cm in about 0.05sec what is he force developed on impact?

Example:-

A person walking at 1 m/sec hits his head on a steel beam . Assume his head stops in 0.5 cm in about 0.01 sec . If the mass of his head is 4kg, what is the force developed **?**

The centrifuge way:-

Is way to increase apparent weight, it is especially useful for separating in a liquid, the centrifuge works using **the sedimentation principle**. It speed up the sedimentation that occur at a slow rate under the force of gravity. In a laboratory centrifuge that uses sample tubes, the radial acceleration causes denser particles to settle to the bottom of the tube, while low-density substances rise to the top

Stock law

Let us consider sedimentation of small spherical objects of density **P** in a solution of density $\mathbf{P_o}$ in a gravitational field(g). We know that falling objects reach a maximum terminal velocity due to viscosity effects. Stock has shown that for a spherical object of radius(a), the retarding force F_d and terminal velocity (υ) are related by :-

$$F_d = 6\pi a\eta v \text{ ....} Stock\ law$$

Where:-

F_d= retarding force..

υ= terminal velocity.

η= dynamic viscosity of liquid

Stokes' law makes the following assumptions for the behavior of a particle in a fluid:

- Spherical particles
- Homogeneous (uniform in composition) material
- Smooth surfaces
- Particles do not interfere with each other.

when the particle is moving at a constant speed, the F_d is an equilibrium with the difference between the downward (F_g)and the upward buoyant force (F_B) :

$F_d = F_g - F_B$

F_g=force of gravity$= \frac{4}{3}\pi a^3 \rho g$

F_B=the buoyant force $= \frac{4}{3}\pi a^3 \rho_0 g$

H.W : calculate the terminal velocity ?

- The force of the gravity ⟶ $F_g = 4/3\ \pi\ a^3\ \rho g$
- The buoyant force ⟶ $F_B = 4/3\ \pi\ a^3\ \rho_\circ g$
- The retarding force ⟶ $F_d = 6\pi a v \eta$

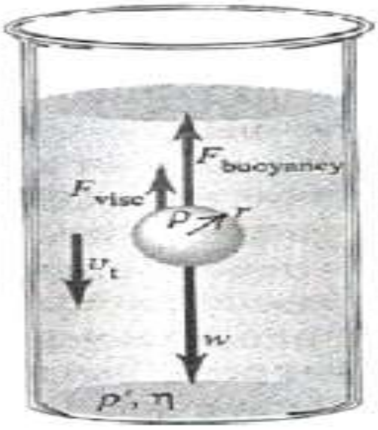
F_g acts downward and F_B acts upward, and the difference is equal to F_d

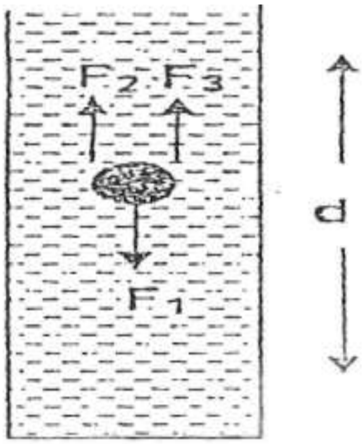
$F_d + F_B = F_g$

$F_d = F_g - F_B$

We obtain the expression for the terminal velocity (sedimentation velocity),

$$v = \frac{2a^2}{9\eta} g(\rho - \rho_0)$$

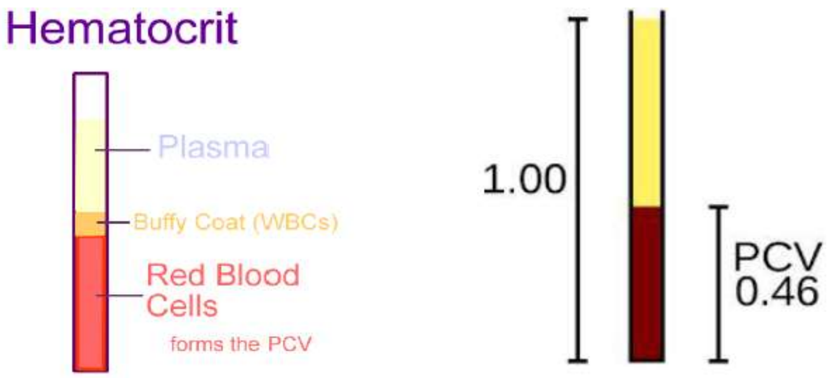




In some forms of disease such as rheumatic fever, rheumatic heart disease, and gout, the red blood cells clump together and the effective radius increases; thus an increased sedimentation velocity occurs.

In other diseases such as sickle cell anemia, the red blood cells change shape or break. The radius decrease; thus the rate of sedimentation of these cells is slower than normal.

Hematocrit (packed cell volume PCV) is the percent of red blood cells in the blood.



Since the sedimentation velocity is proportional to the gravitational acceleration, it can be greatly enhanced if the acceleration is increased. We can increase **g** by means of a centrifuge, which provides an effective acceleration $\mathbf{g_{eff}}$

$$g_{eff} = 4\pi^2 f^2 r$$

Where **f** is the rotation rate in revolution per second and **r** is the position on the radius of the centrifuge where the solution is located.

Hematocrit depends upon:

.□ Radius of centrifuge

.□ Speed of centrifuge

□ Duration of centrifuge.

The medical use of terminal velocity:-

* In some forms of disease such as :

1 - rheumatic fever

2 - rheumatic heart disease

3 - gout

the RBCs clump together and the effective radius increase ; thus an increased sedimentation velocity occurs

In other disease such as :

1 - hemolytic jaundice .

2 - skill cell anemia

the RBCs change or break , the radius decrease , then the rate of sedimentation is slower than normal

NOTE :

A related medical test that also depend on the $\nu = \frac{2a^2}{9\eta} g(\rho - \rho_0)$ equation indetermination of the hematocrit (the present of RBCs in blood). Since v increase with g it can be greatly enhanced if g increase. We can increase by means of a centrifuge :

$g_{eff} = 4 \pi^2 f^2 r$

where f = in the rotation rate of revolutions per second (rbm)

r = in the position on the radius of centrifuge

A normal hematocrit is 40 - 60 .

a lower value than 40 indicates animia .

a high value than 60 indicates poly cythemia

Polycthmia ⇒ (high number of RBCs in the blood)

Prove the terminal velocity (sedimentation velocity) is equal to :

$\nu = \frac{2a^2}{9\eta} g(\rho - \rho_0)$?

Find the effective acceleration at radius r = (22) cm for a centrifuge rotating at (3000) rpm ?

The application of a dynamic force in the body (للاطلاع فقط)

1- The work done by the heart beats (systole) 60g of blood is given a velocity of 1m/sec upward in about 0.1sec. The upward momentum is 0.06 kg × 1 m/sec and due to third Newton's law producing downward reaction force on the rest of the body is (0.06 kg sec-1/0.1sec or 0.6 N).

2- The deceleration of the body take place through compression of the padding of the feet when the person jumps from a height of 1m, under these condition , the body is traveling at 4.5m/sec just prior to hitting ,and if the padding collapses by 1cm the body stops in 0.005 sec.

∴F (foot)= 100of body's weight(W), force in the leg= 100N.

3-The large velocity of modern cars the riders have a larger momentum than when walking, in accident the car stops in a short time, producing very large forces the result of these forces on the passenger can be broken bones, injuries,… death,.

4-Consider the case of "whiplash" a person sitting in an auto that is struck from behind will often suffer a whiplash injury of the neck (Cervical region of the spin) when the car is struck, forces act through the seat forcing the trunk of the body a head while the inertia of the head causes it to stay in place, leading to severe stretching of the neck.