

# Forces on and in the Body



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 •

Only the gravitational and electrical forces are importance in our study of the forces affecting the human body.

The electrical force important at molecular and cellular levels, e.g. affecting the binding together of our bones and controlling the contraction of our muscles.

Gravitational force, though very much weaker than the electrical force by a factor 1039.

# 1. How Forces Affect the Body

- \_The muscular forces that cause the blood to circulate and lungs to take in air.
- -In the bones there are many crystals of bone mineral that require calcium. A calcium atom will become part of crystal if it gets close to a natural place for calcium and electrical forces are great enough to trap it. It will stay in that place until local conditions have changed and electrical forces can no longer hold it in place. This might happen if the bone crystals destroyed by cancer.

# 1-1. Some Effects of Gravity on the Body

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- One of the important medical effects of gravity is the formation of varicose veins in the legs as the venous blood travels against the force gravity on its way to the heart.

# 1-2. Electrical Forces in the Body

- The forces produced by muscles are caused by electrical charges attracting opposite electrical charges.
- Cells in the body has an electrical potential difference across the cell membrane.

# 1-3. Frictional forces

- Friction and energy loss resulting from friction appear everywhere in our everyday life.
- Some diseases of the body, such as arthritis, increase the friction in bone joint.
- Force of friction  $F_f$  is described by

$$F_f = \mu N$$

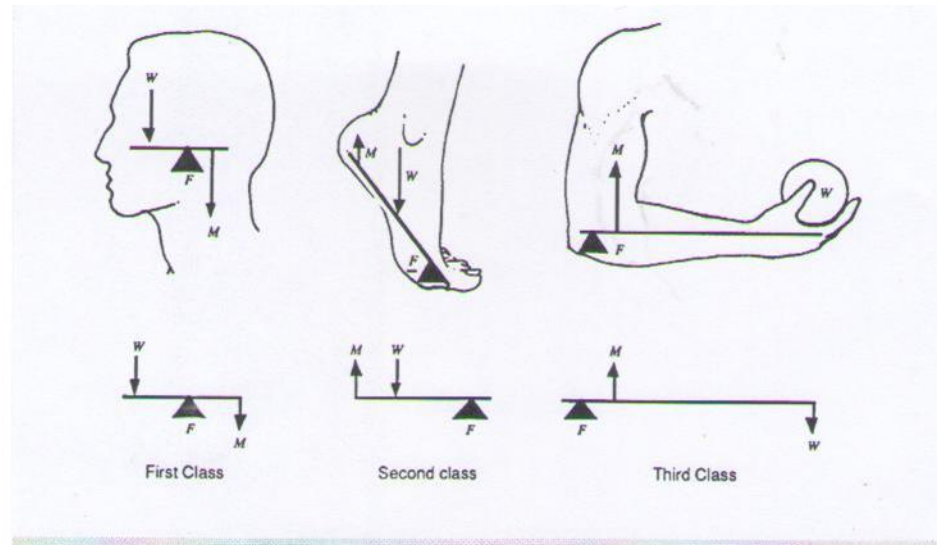
- $N$  : is normal force
- $\mu$  is coefficient of friction between two surfaces
- - Friction must be overcome when joints move, but for normal joints it is very small. If a disease of the joint exists, the friction may become large.
- Synovial fluid in the joint is involved in lubrication.
- The saliva we add when we chew food acts as lubricant.



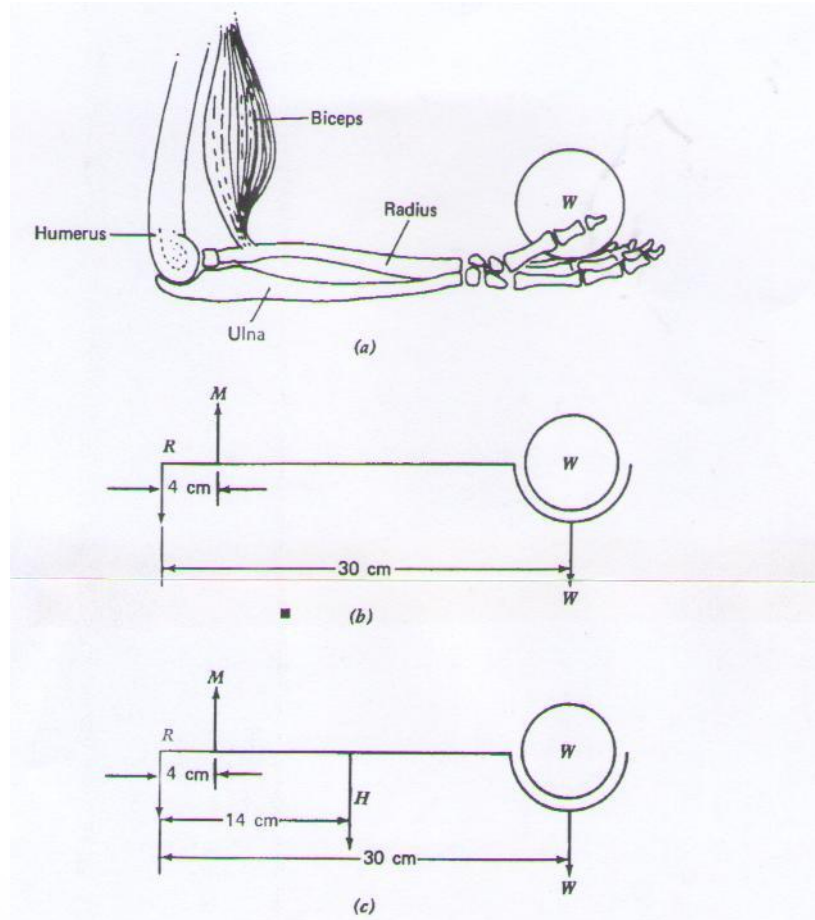
# 1-4. Forces, Muscles, and joints

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

# second, and third class systems



# Third class levers are most common in the body



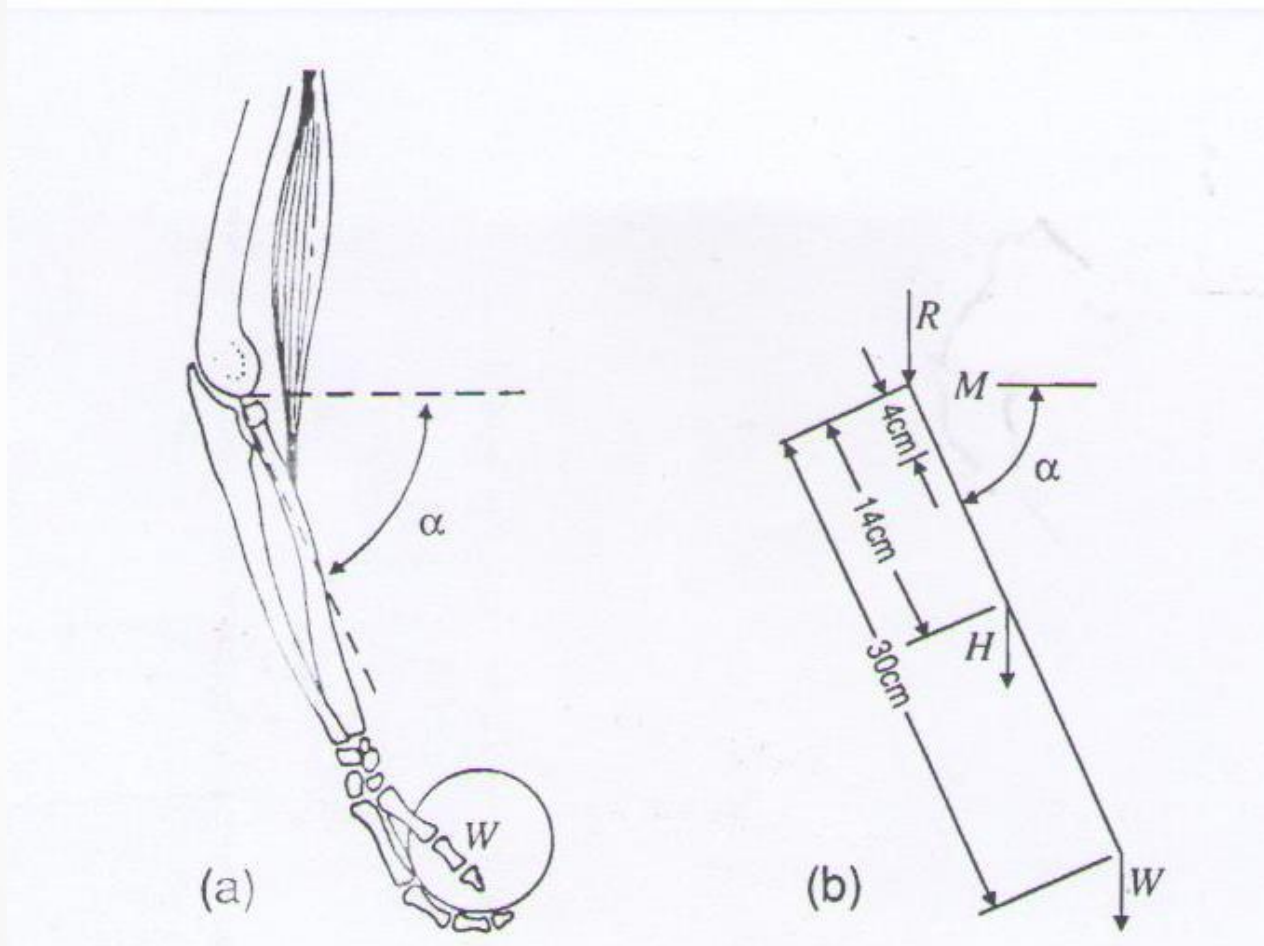
A simple example is in the case of biceps muscle and radius bone acting to support a weight  $W$  in the hand (Fig 2a),(Fig 2b) shows the forces and dimensions of a typical arm. There are only two torques: that due to the weight  $W$ , which is equal to  $30W$  acting clockwise and that produced by the muscle force  $M$ , which is counterclockwise and of magnitude  $4M$ , with the arm in equilibrium we find that

We can find the force supplied by the biceps if we sum the torques about the pivot point at the joint .

$$4M - 30W = 0 \quad \text{and} \quad M = 7.5W$$

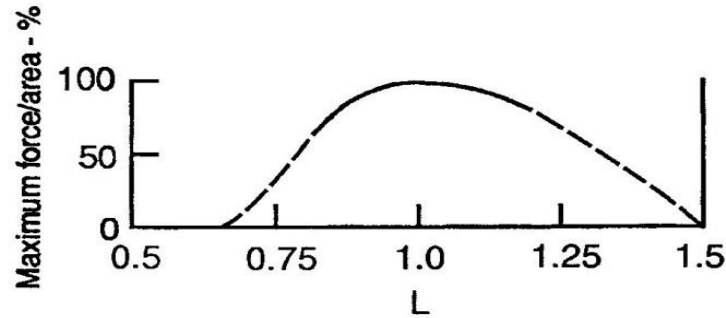
A muscle force 7.5 times the weight, we neglected the weight of the forearm and hand.

(Fig.3)The forearm at the angle  $\alpha$  to the horizontal. (a) The muscle and the bone system. (b) The forces and dimensions



the torques about the joint we find that  $M$  remains constant  
as  $\alpha$  change

- length of the biceps muscle changes with the angle. In general, each muscle has a minimum length to which it can be contracted and maximum length to which it stretched and still function. At these two extremes the force the muscle can exert is essentially zero. At some point in between, the muscle can produce its maximum force



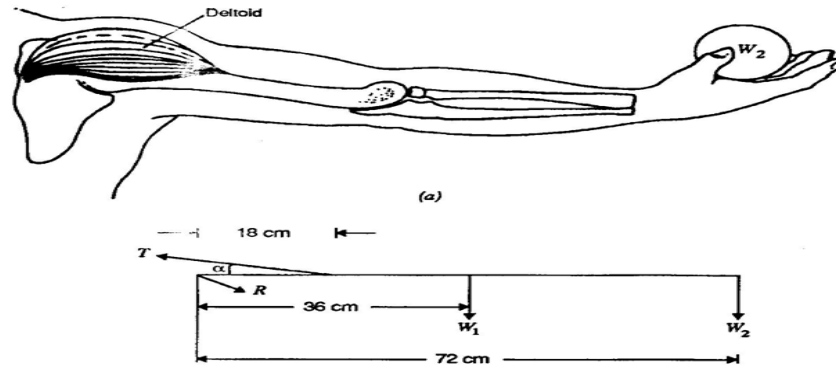
(Fig.4) At its resting length  $L$  a muscle is close to its optimum length for producing force. At about 80% of this length it cannot shorten much more and the force it can produce drops significantly. The same is true for stretching of the muscle about 20% greater than its natural length. A very large stretch of about  $2L$  produces irreversible tearing of the muscle.

-The arm can be raised and held out horizontally from the shoulder by the deltoid muscle

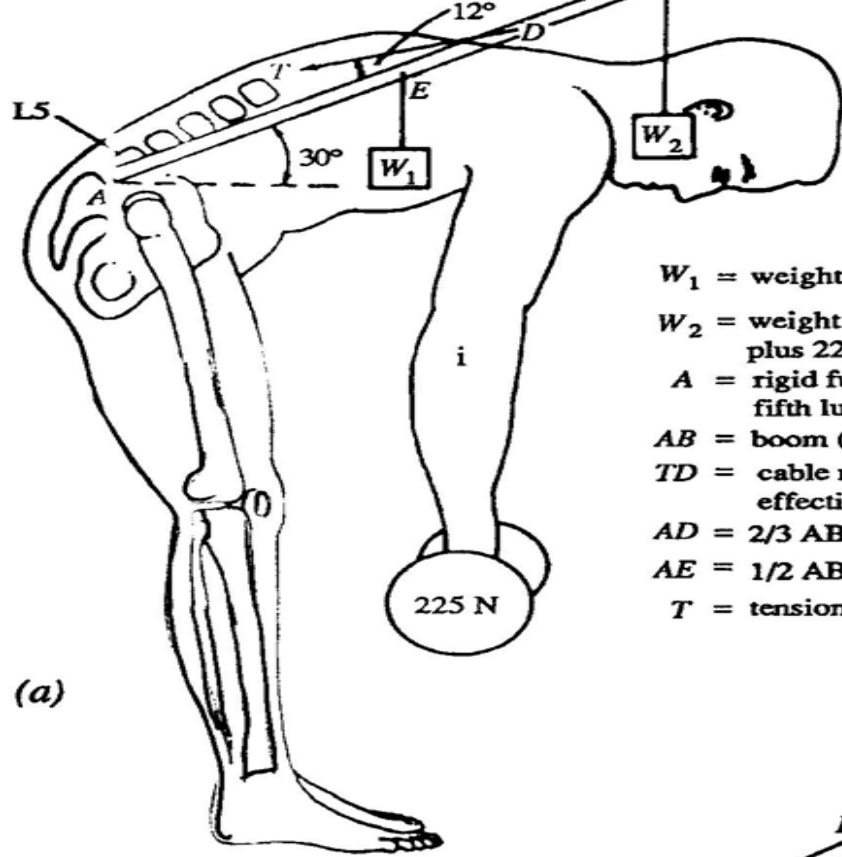
By taking the sum of the torques about shoulder joint, the tension T can be calculated.

$$T = (2W_1 + 4W_2) / \sin \alpha$$





Raising the right arm. (a) The deltoid muscle and bones involved. (b) The forces on the arm.  $T$  is the tension in the deltoid muscle fixed at the angle  $\alpha$ ,  $R$  is the reaction force on the shoulder joint,  $W$  is the weight of the arm located at its center of gravity, and  $W$  is the weight in the hand.



$W_1$  = weight of body trunk (320 N)

$W_2$  = weight of arms and head plus 225 N (382 N)

A = rigid fulcrum at about fifth lumbar vertebra

AB = boom (body trunk)

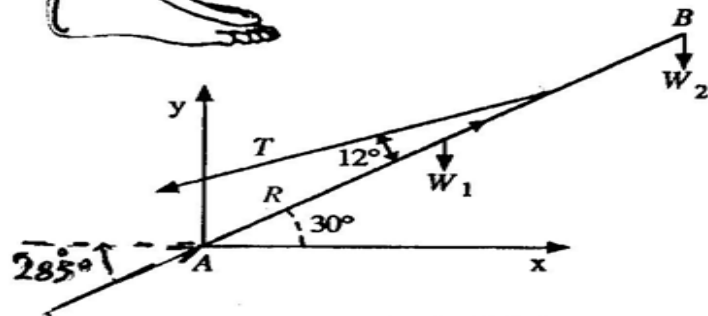
TD = cable representing effective muscle

AD =  $\frac{2}{3}$  AB

AE =  $\frac{1}{2}$  AB

T = tension in the muscle

(a)



(b)

$$R \approx 3800 \text{ N}$$

$$T \approx 3400 \text{ N}$$

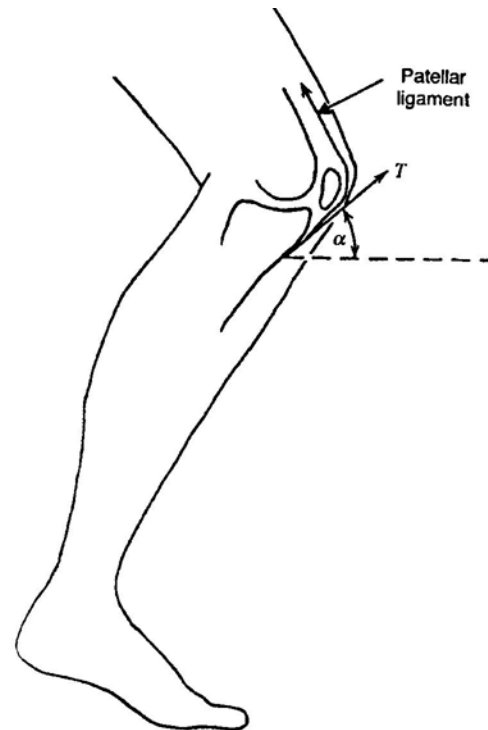
) Lifting a weight. (a) Schematic of forces used. (b) The forces where T is an approximation for all of the muscle forces and R is the resultant force on the fifth lumbar vertebra (L5).

An often abused part of the body is the lumbar (lower back) region. The calculated force at the fifth lumbar vertebra (L5) with the body tipped forward at  $60^\circ$  to the vertical and with weight of 225N in the hands can approach 3800N, lifting heavy objects from this incorrect position cause of low back pain.

Some times vertebral bone collapse rather than disc damage occurs. This often happens in elderly women who suffer from weakened bones.

hand but with your knee flexed cannot; the patella is held rigidly in place by the

force from the tendon



# 2- DYNAMICS

- Forces on the body where acceleration, the Newton's second law, force equals mass times acceleration .
- $F = ma$
- The force equals the change of momentum  $\Delta(mv)$  over a short interval of time  $\Delta t$  or
- 
- $F = (\Delta(mv) )/\Delta t$
- 
-

# Accelerations can produce a number of effects such as

- 1-An apparent increase or decrease in body weight
- 2-Changes in internal hydrostatic pressure
- 3-Distortion of the elastic tissues of the body
- 4-the tendency of the solids with different densities suspended in a liquid to separate.

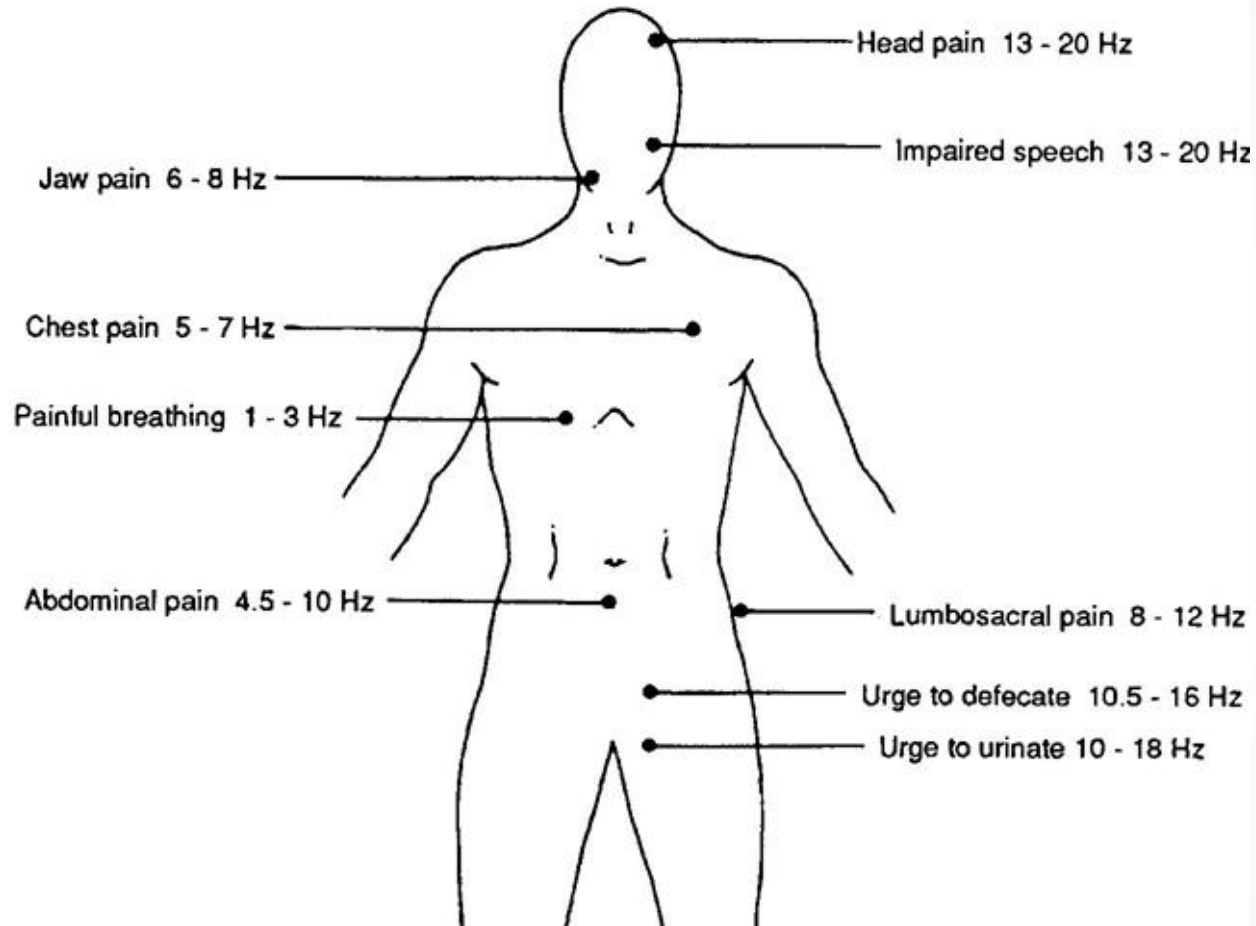
-If the acceleration become large may pool in various regions of the body, the location of the pooling depends upon the direction of acceleration. If a person is accelerated head first the lack of blood flow to the brain can cause blackout.

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

- Where  $g$  is the acceleration gravity,  $L$  is the length, and  $T$  is the period of oscillation.
- -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 vigorously and its resonant frequency



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



# tendency of the suspended solids of different

## densities to separate when accelerated

- The speed at which small objects fall through a liquid depends on their size, viscosity, acceleration due to gravity  $g$ , we can artificially increase  $g$  by centrifuge. Let us consider sedimentation of the small spherical objects of density  $\rho$  in the solution of the density  $\rho_0$  in the gravitational field  $g$ . Stokes has shown that for a spherical object of radius  $a$ , the retarding force  $F_d$  and terminal velocity  $V$  are related by  $F_d = 6\pi\eta aV$

$$F_d = 6\pi\eta aV$$

$\eta$ : is viscosity of the liquid

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

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

The retarding force  $F_d = 6\eta\pi aV$

In equilibrium  $F_g - F_B = F_d$

We obtain the sedimentation velocity

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

In some forms of disease such as rheumatic heart disease, the red blood cells clump together and the effective radius increases; thus an increased sedimentation velocity occurs. In other disease such as hemolytic jaundice and sickle cell anemia , the red blood cells changes shape and break. The radius decreases; thus the rate of sedimentation of these cells is slower than normal

Where  $f$  is rotation rate in revolution per second and  $r$  is the position on the radius of the centrifuge

A related medical test that also depends on the equation of sedimentation velocity, is the determination of the hematocrit, the percent of red blood cells, 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  $\mathbf{g}_{\text{eff}} = 4\pi^2 f^2 r$

Since the packing of the red blood cells takes place in the centrifuge, the hematocrit obviously depends upon the radius of the centrifuge and the speed and duration of centrifugation. The increase of any these leads to more dense packing of the red blood cells or a smaller hematocrit. One standard method utilizes centrifugation for 30 min at 3000rpm with  $r = 22\text{cm}$ .

A normal hematocrit is 40 – 60; a value lower than 40 indicates anemia, and a high value may indicate polycythemia vera .