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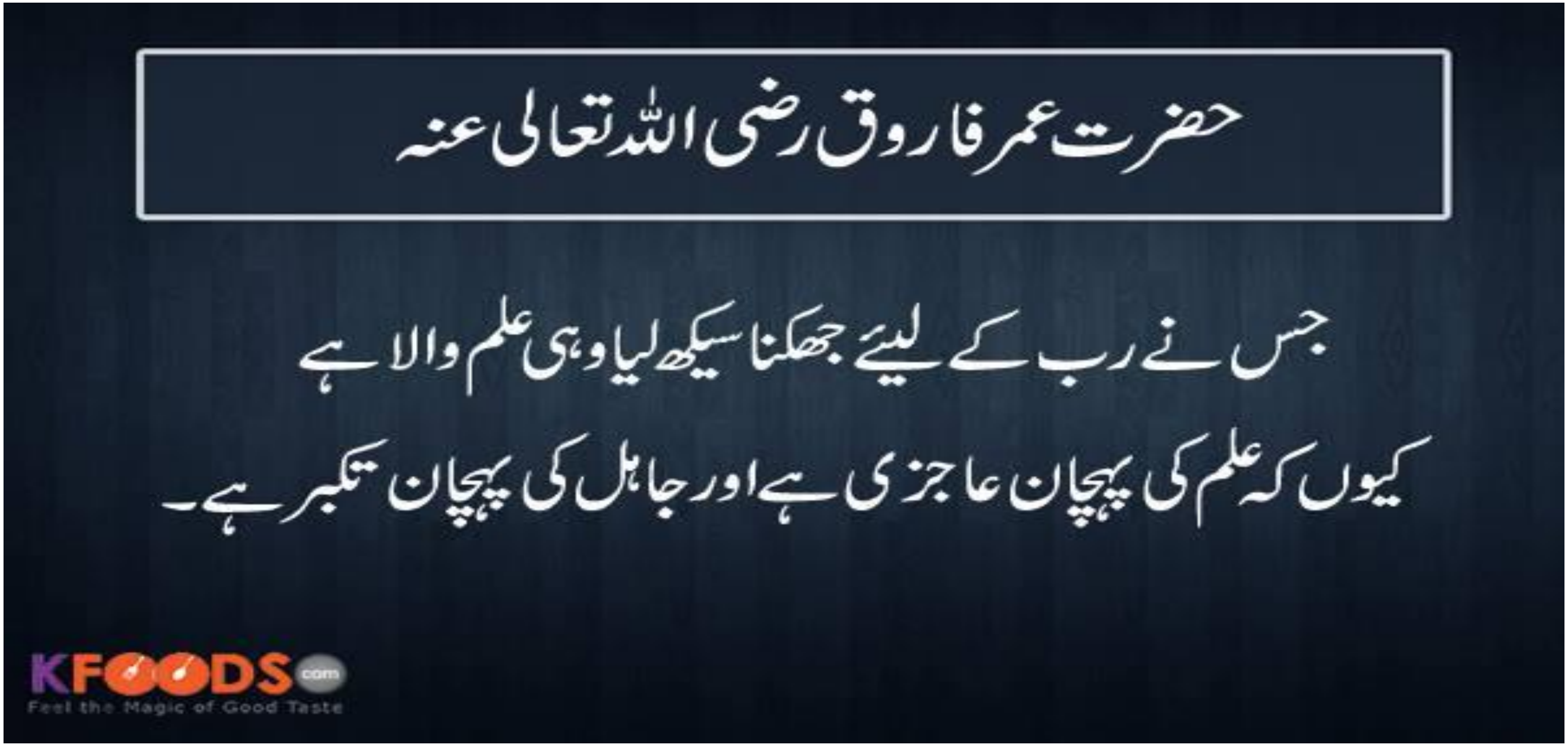



DR.AYESHA BASHARAT

BSPT(K.E.MU), PPDPT (RIU). M.Phill (Gold Medalist)

**credits:**

Research publications:

Poster award, HEC 1million & international funded project

Workshops on research, member of sports, admission and anti-fooling community

# BIOMECHANICS & ERGONOMICS
100+100=200

***Basic biomechanics of musculoskeletal system* By: Nordin & Frankel, 3rd edition.**

- Basic terminologies
- Kinetics & kinematics' concept and application
- Biomechanics of tissues and structures of the musculoskeletal system
- Biomechanics of upper & lower extremities
- Biomechanics of spine
- Applied biomechanics
- **angular kinetics of human movement**
- **angular kinametics of human movement**

# UNIT 1:

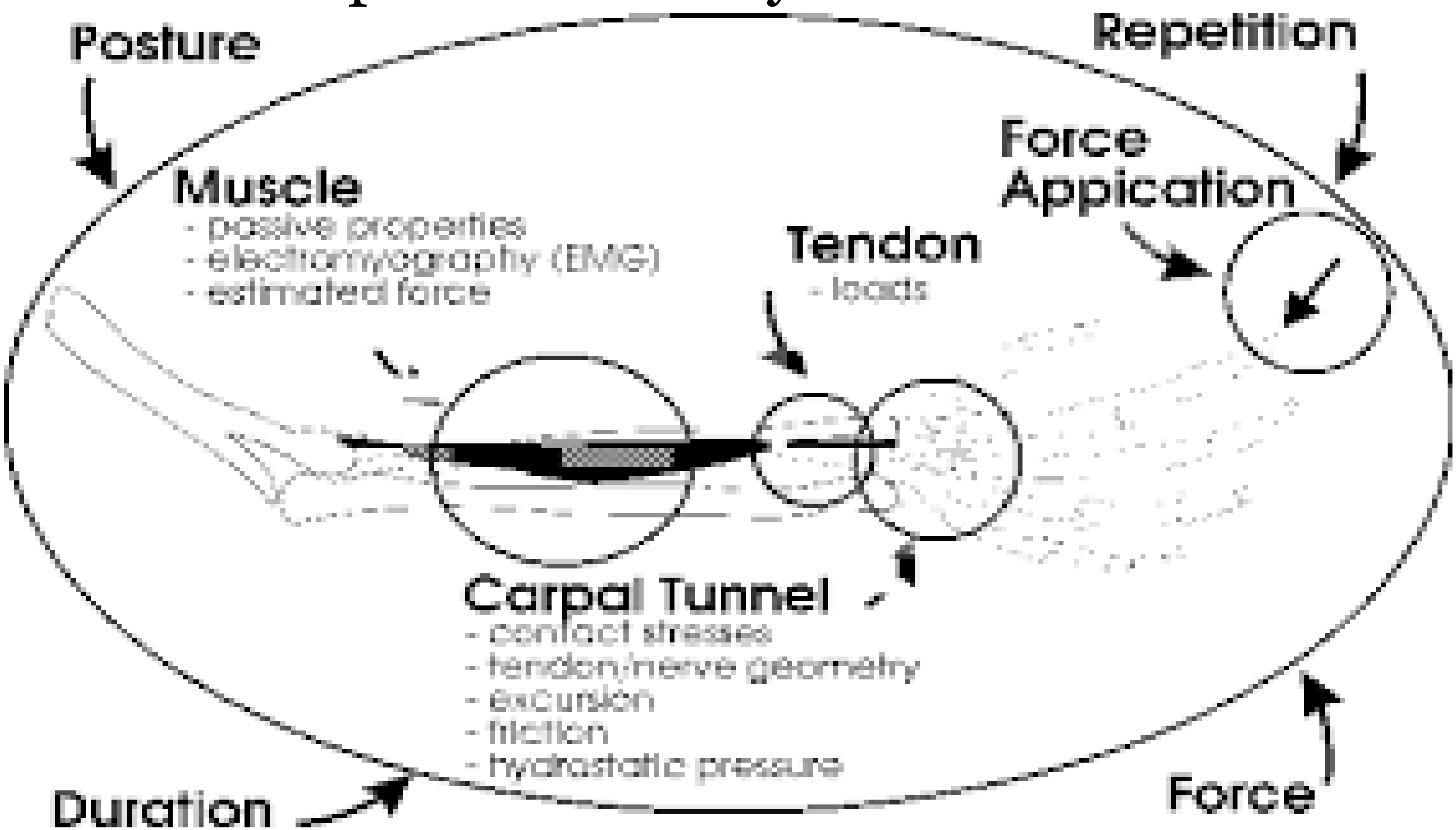
# Introduction to Biomechanics

# Biomechanics

- Study of the structure and function of biological systems such as humans, animals, plants, organs, and cells by means of methods of mechanics.
- The word "biomechanics" (1899), that related "biomechanical" (1856) from the Ancient Greek βίος *bios* "life" and, *mēchanikē* "mechanics", refer to the study of the **mechanical principles of living organisms, particularly their movement and structure**

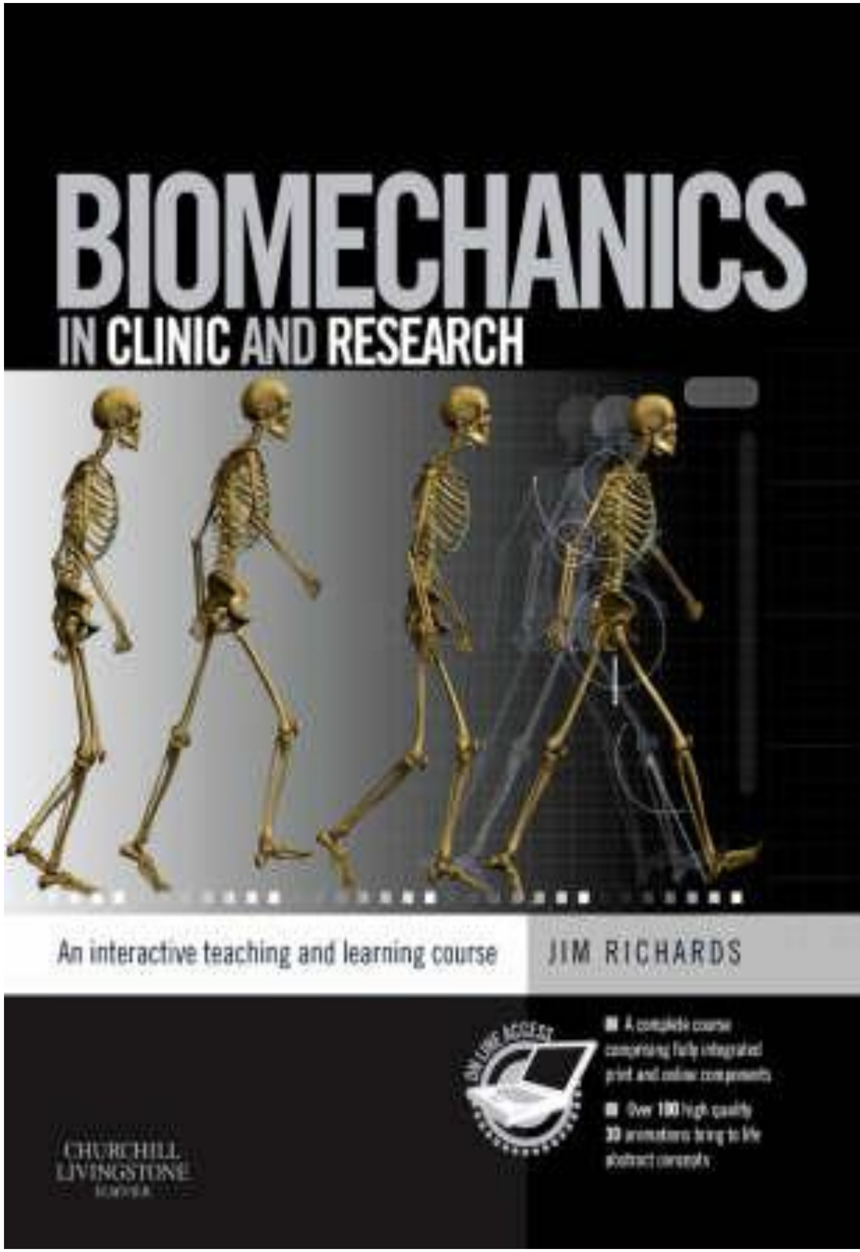
# Mechanics

- Branch of physics that analyzes the actions of forces on particles and systems



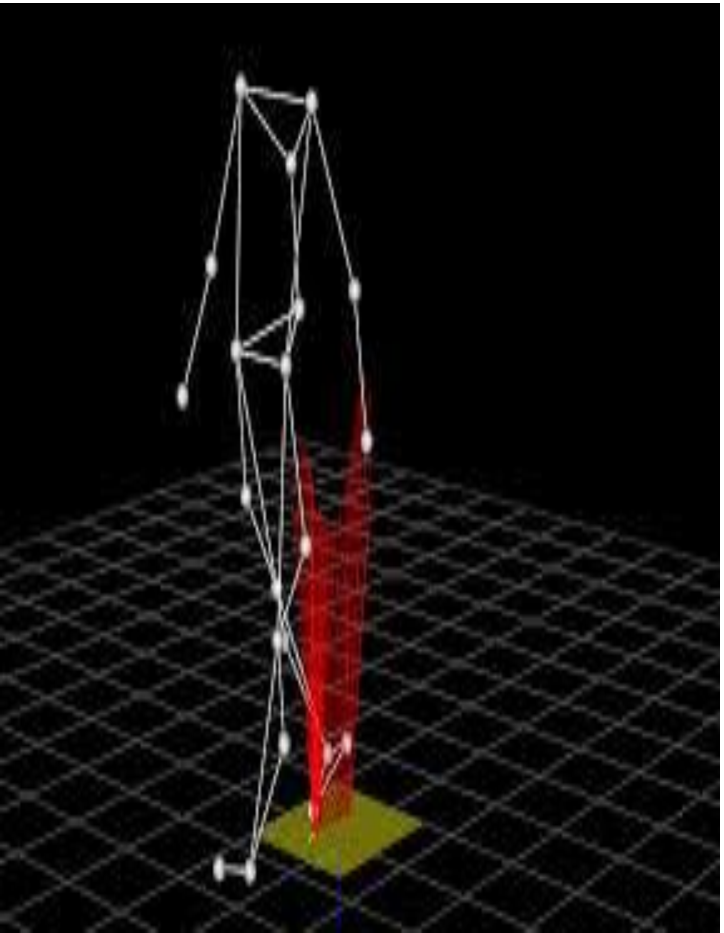
# Biomechanics

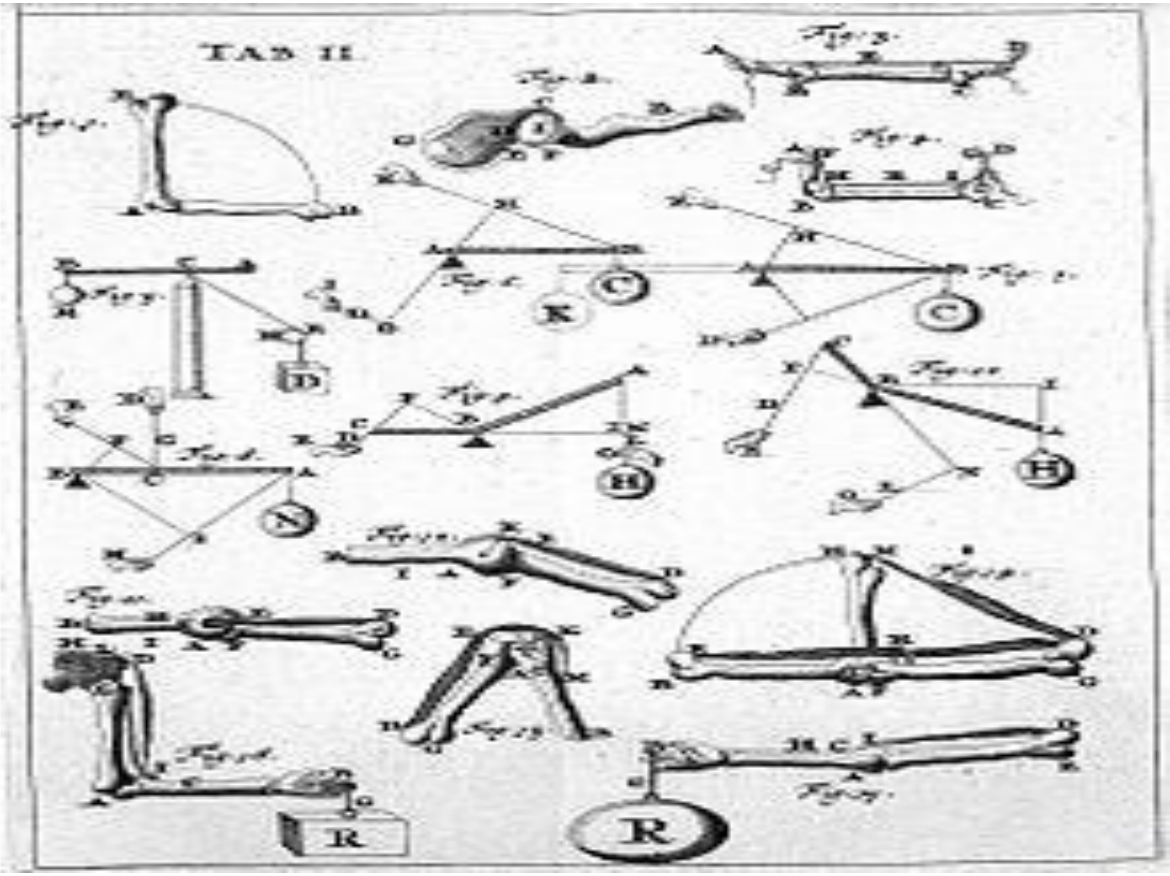
- Application of mechanical principles in the study of living organisms
- **It is the application of engineering approach to biological systems.**
- **Application of Newton's laws**
- Forces, moments, energy, work, power
- Movements de-/accelerations
- Muscle activity



# Statics

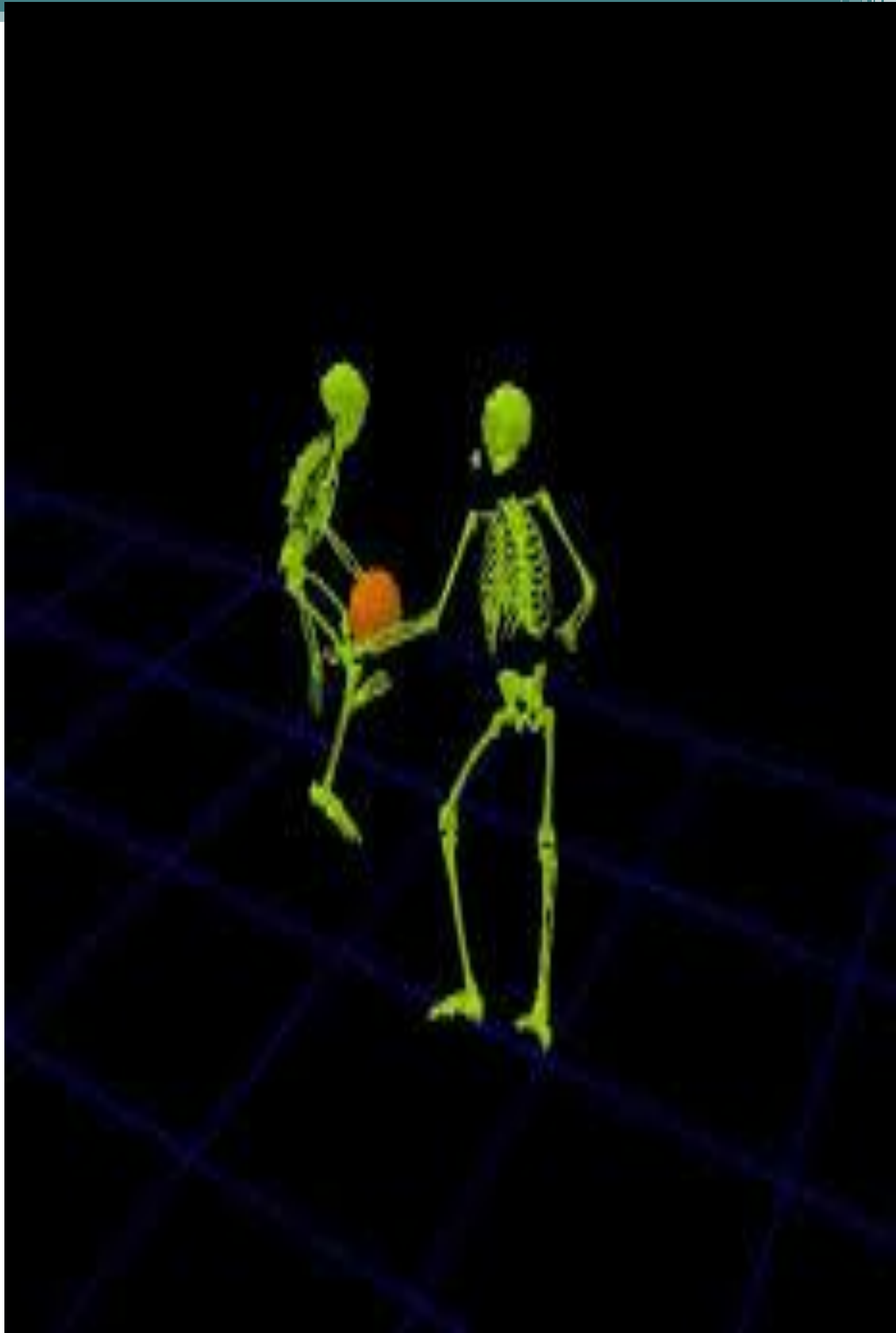
- Branch of mechanics dealing with systems in a **constant state** of motion.(steady state)





# Dynamics

- Branch of mechanics dealing with systems to acceleration/ without constant movement



# Kinematics

- Study of the description of motion, including considerations of space and time
- Area of biomechanics includes description of motion without regard for forces producing the motion.
- (**time, displacement, velocity**

# Kinematic example:

- **i. Types of motion. ii. Location of motion. iii. Direction of motion. iv. Magnitude of motion.**
- **(i) Types of motion:** four types of motion are there.
- **a. Rotatory motion:** It is the movement of an object around **a fixed axis in a curved path.**
- Each point on the object or segment moves through the same angle at same distance in a curved path.
- In human the goal of most muscles appear to rotate bony lever around fixed axis.

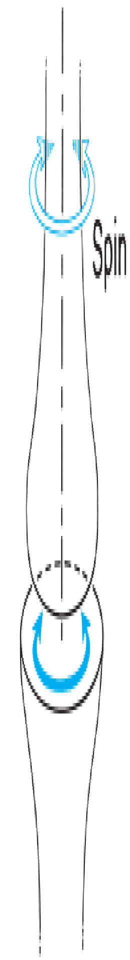
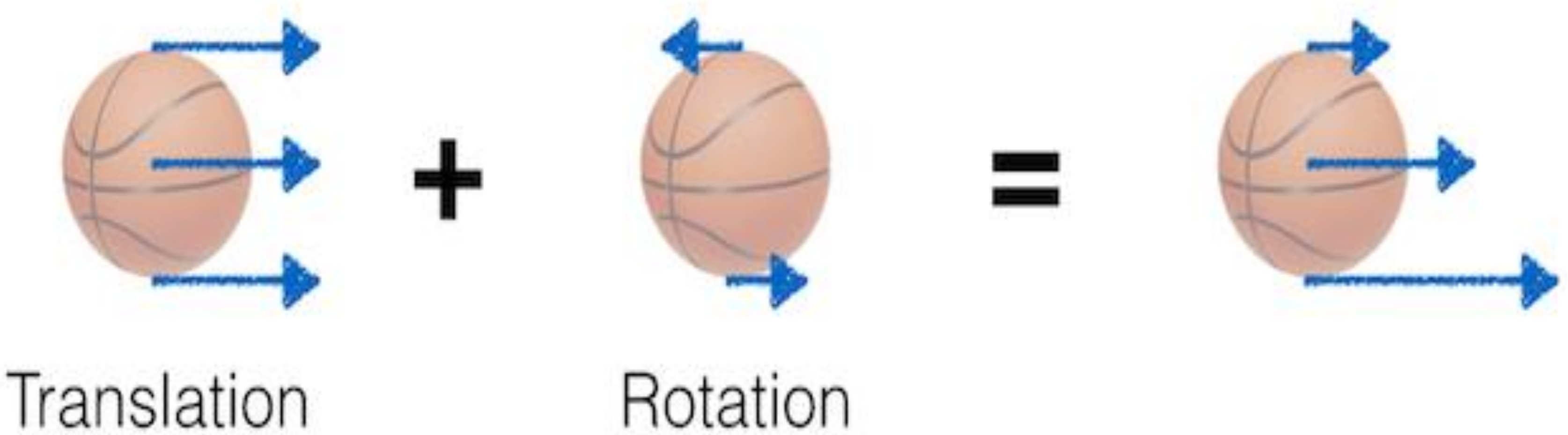



FIGURE 5.6 Representation of spinning. There is rotation of a segment about a stationary mechanical axis.

- **b. Translatory/ linear motion:** It is the movement of an object in a straight line.
- Each point of an object moves through the **same distance, same speed, at the same time,** in parallel paths.



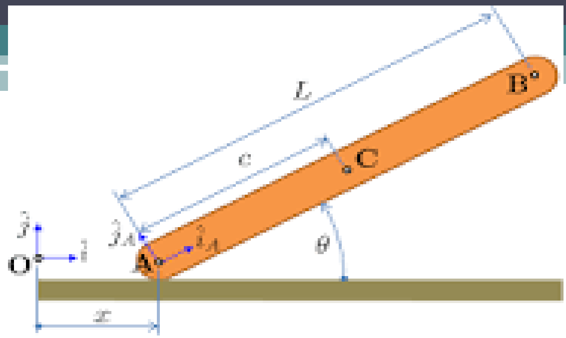
- **c. Curvilinear motion:** Both rotatory and translatory motions combine to produce this motion. It is the most common form of motion produced in human joints
- **Ex** : thrown ball, where the ball moves through space and rotates on its own axis.

- **d. General plane motion:** Here the object is segmented and free to move

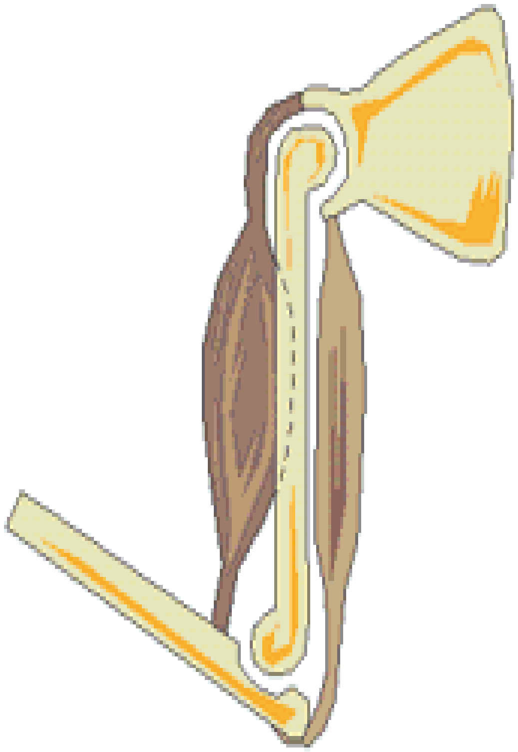
# (ii) Location of motion:

- Motion at a joint may occur in transverse, frontal or sagittal planes……..
- **(iii) Direction of Motion:** Movement may occur either in clockwise or anticlockwise direction.
- **iv) Magnitude of Motion** can be given either in degrees or radians.
- Goniometer is most widely used measure for joint range in degrees.

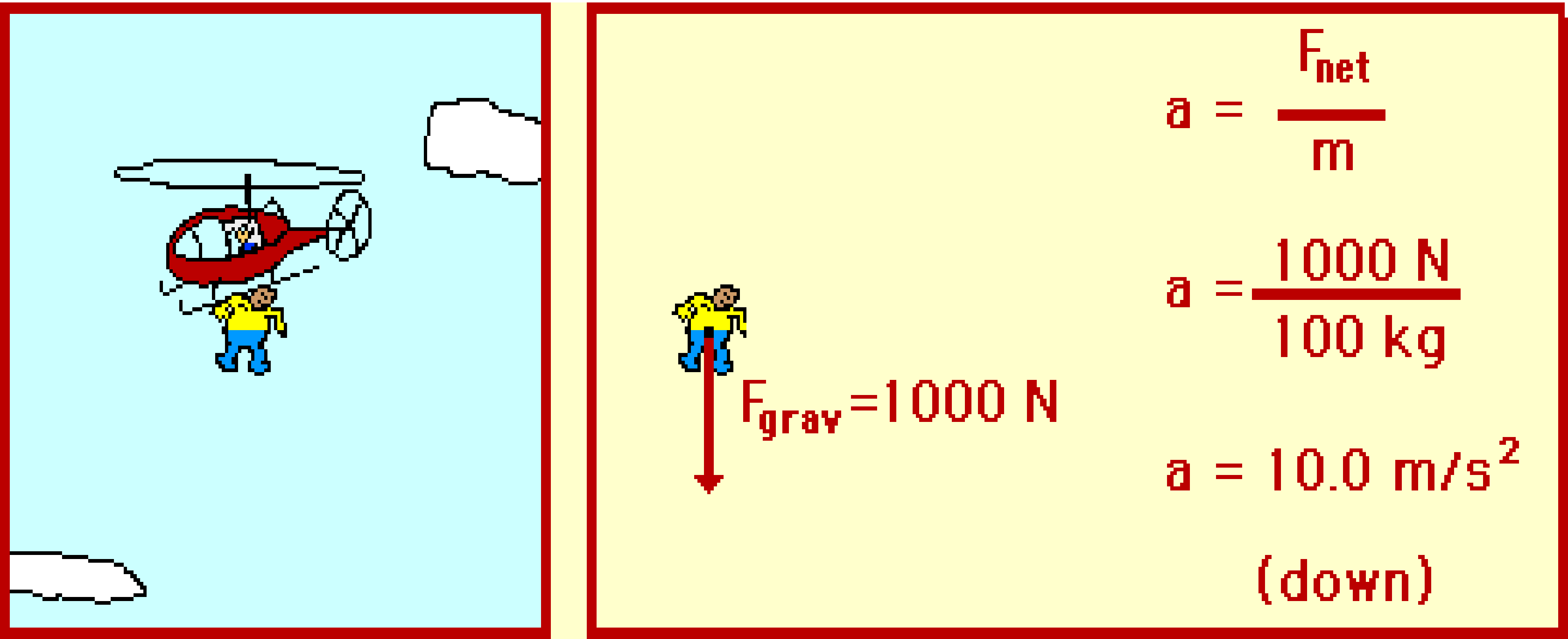
# Kinetics



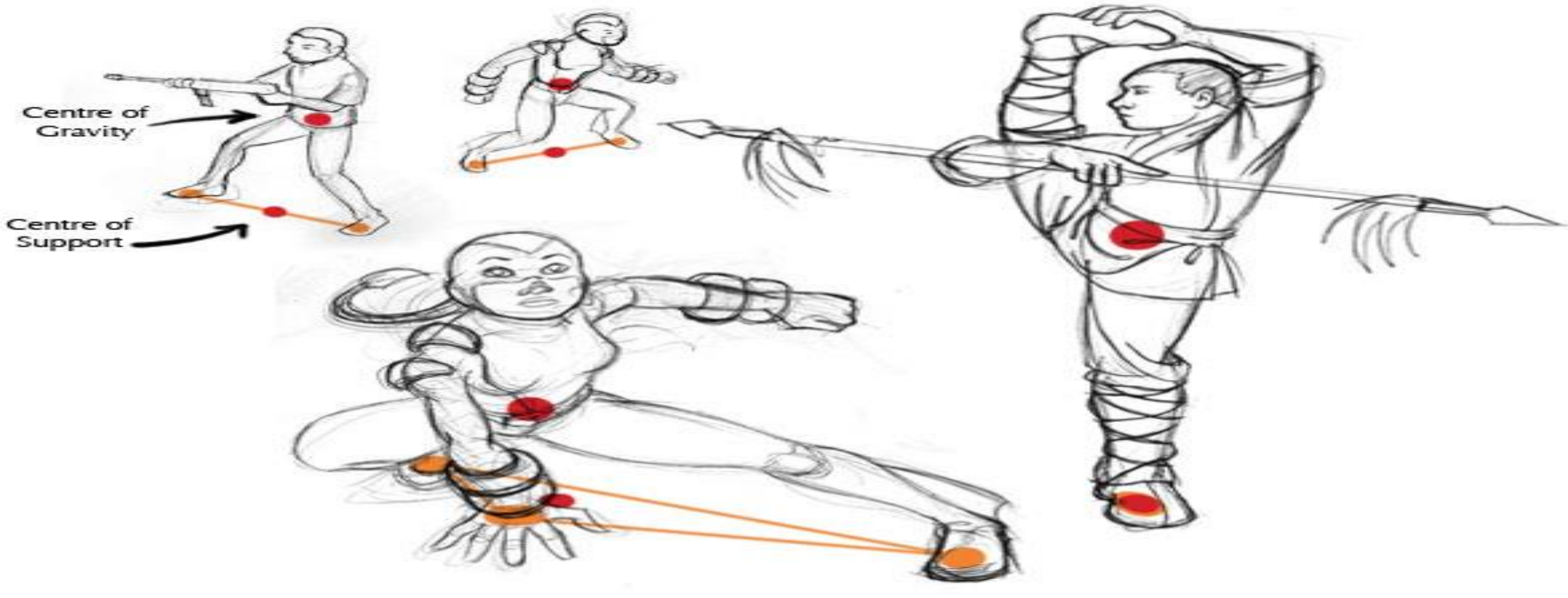

- Study of the action of forces
- *Kinetics* is an area of biomechanics concerned with forces producing motion or maintaining equilibrium. All forces are described as either **External forces** are pushes or pulls on the body arise from sources outside the body. Ex: Gravity.
- **Internal forces** are forces act on the body arise from sources within human body Ex: Muscles, bones etc,



- **Gravity:**
- It is force by which all the bodies are attracted to earth. It is the most consistent force encountered by human body and behaves in a predictable manner.



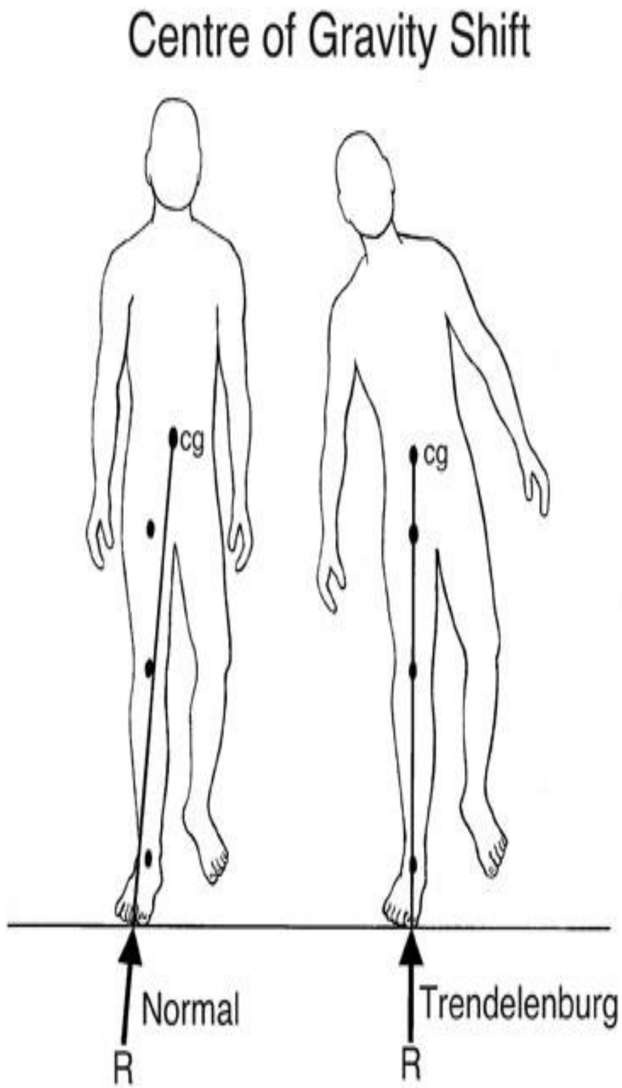
- **CENTER OF GRAVITY (COG):**
- It is the point through which the earth's attraction effectively acts regardless of position of body. The center of gravity (COG) of human body lies approximately at S2, anterior to sacrum.



# Center of Gravity

- The point around which a body's weight is equally balanced, no matter how the body is positioned
- Position of COG in human body

The gymnast can balance because the centre of gravity of the body is located directly over the hands (base of support).


Centre of Gravity Shift
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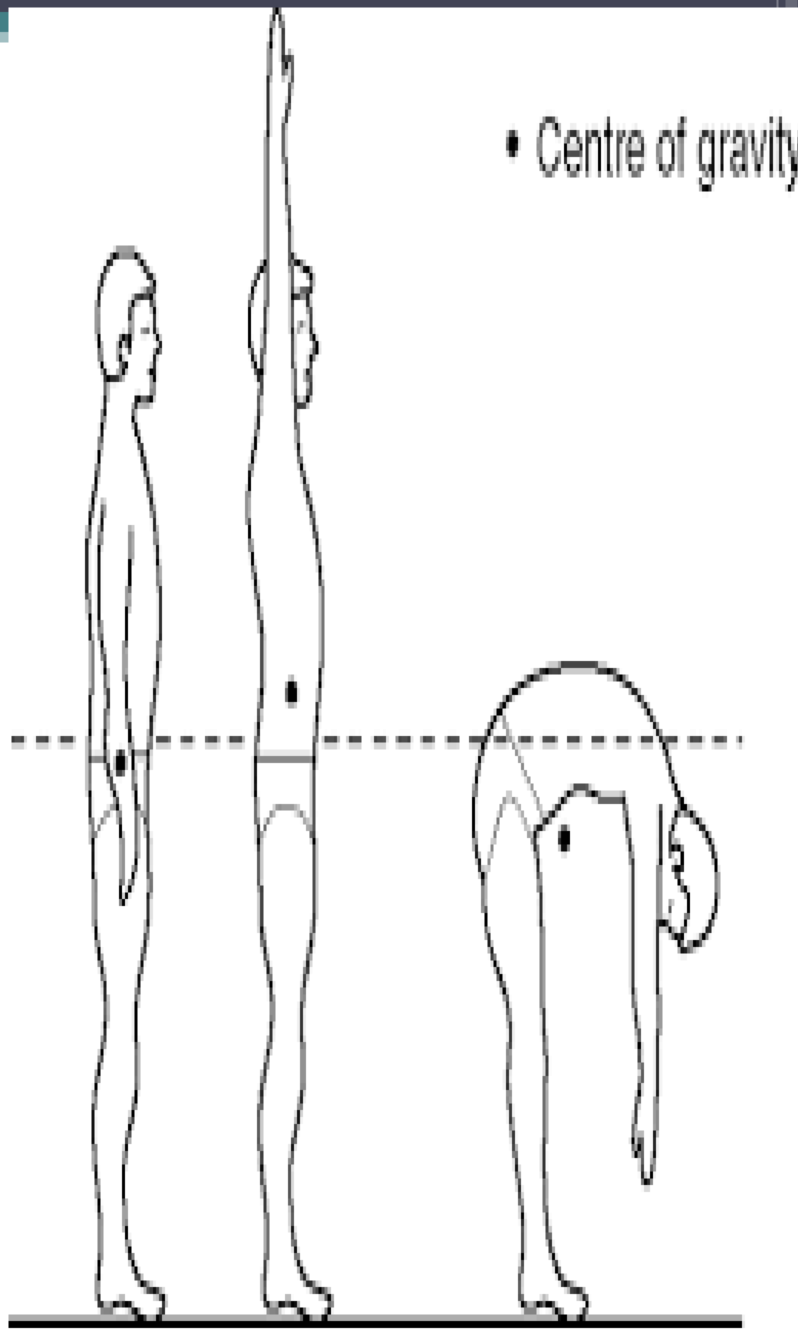
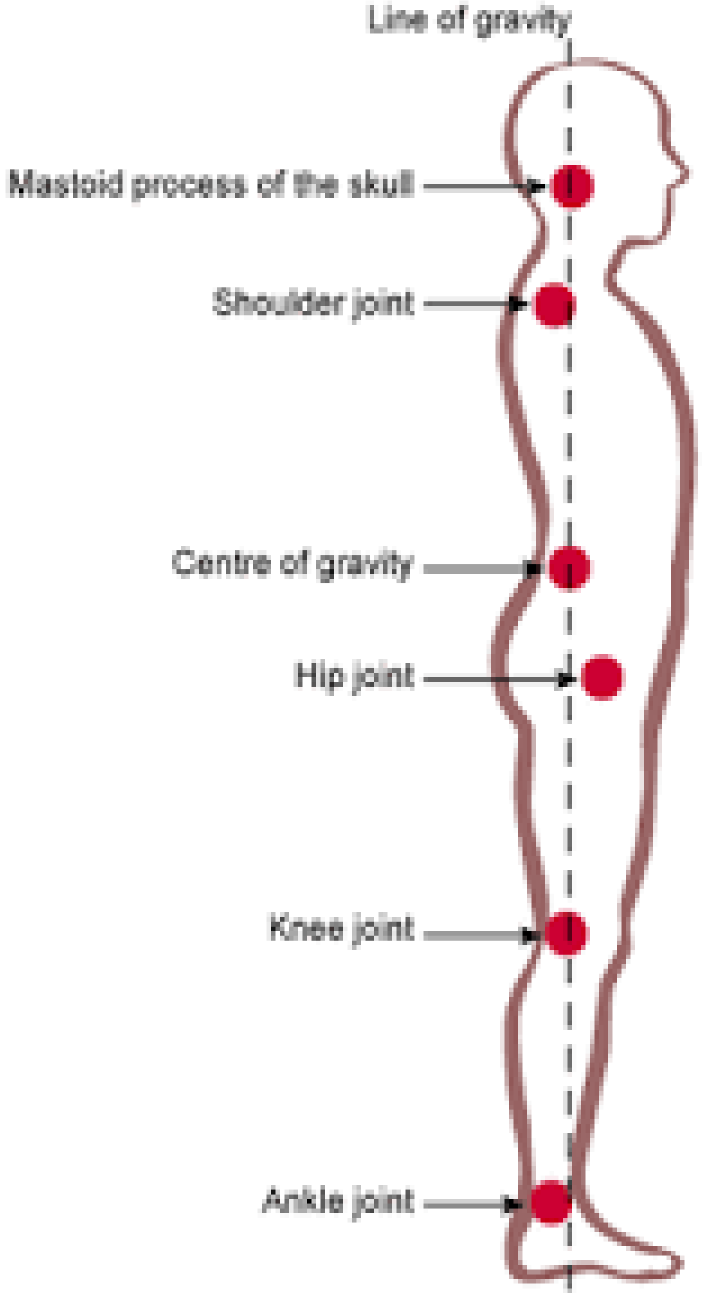
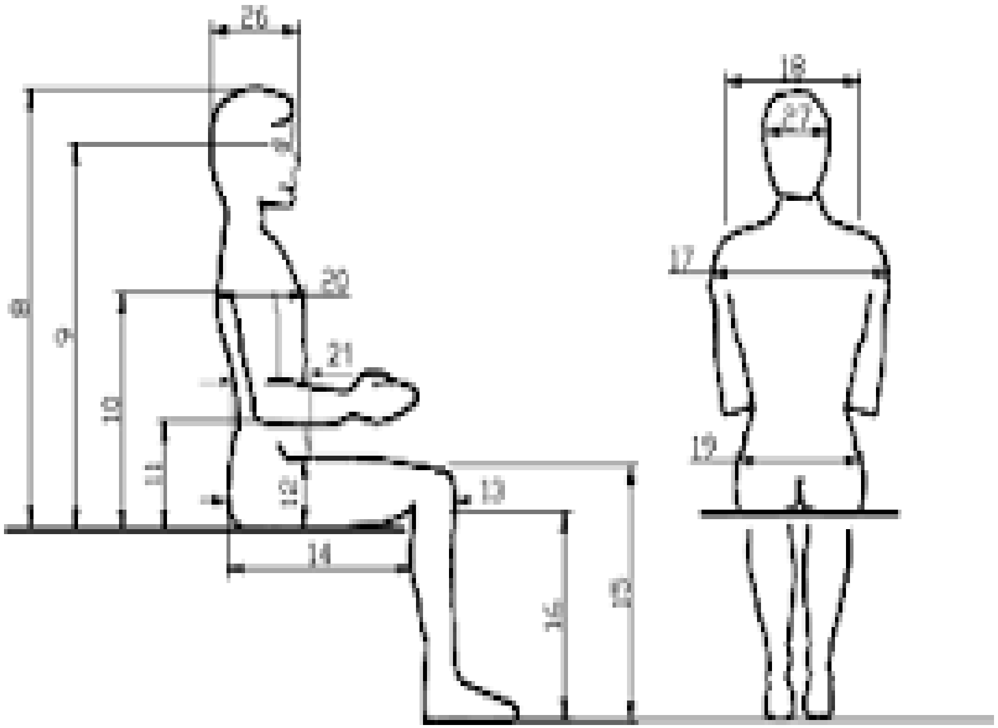

• Centre of gravity

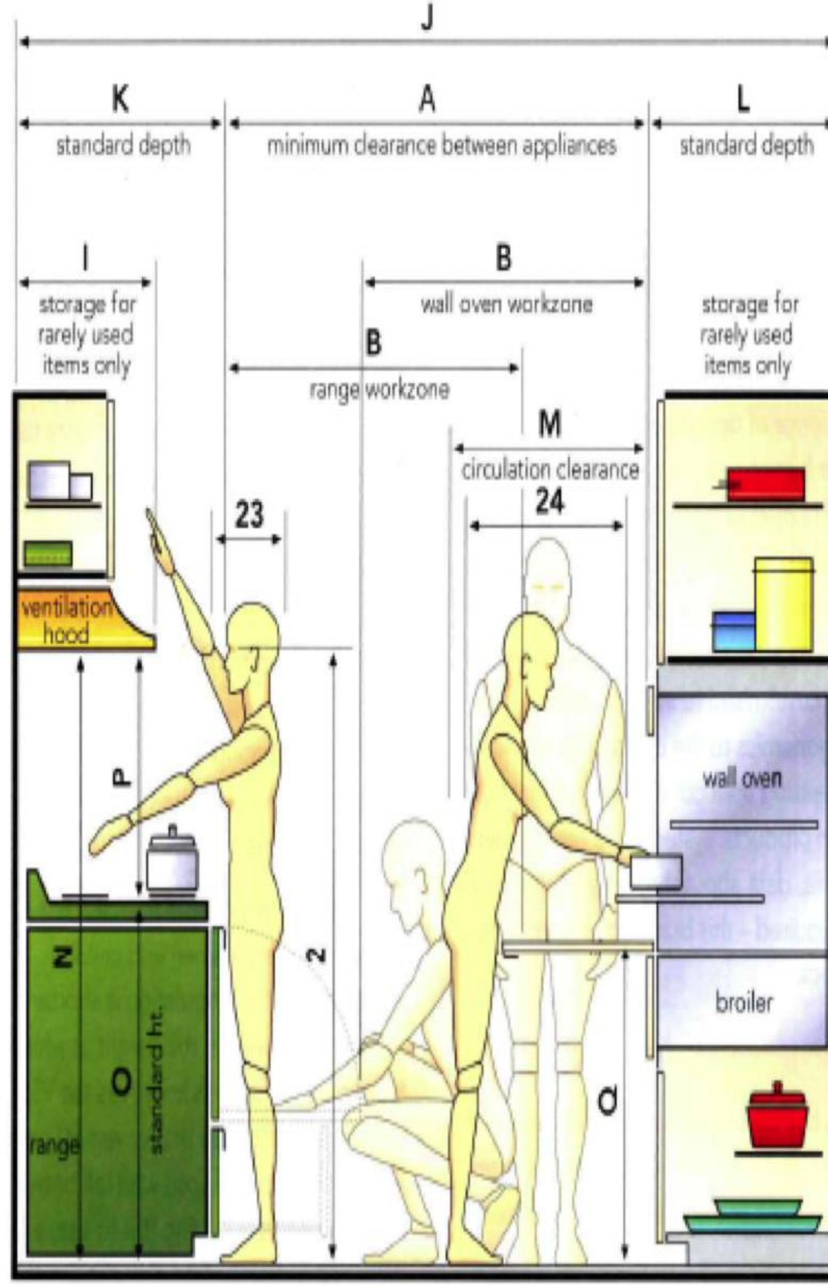
- **LINE OF GRAVITY (LOG):-**
- It is the vertical line through centre of gravity. When the human body is in fundamental standing position, the line of gravity (LOG) pass through vertex and a point between the feet, level with transverse tarsal joints.



# Anthropometrics

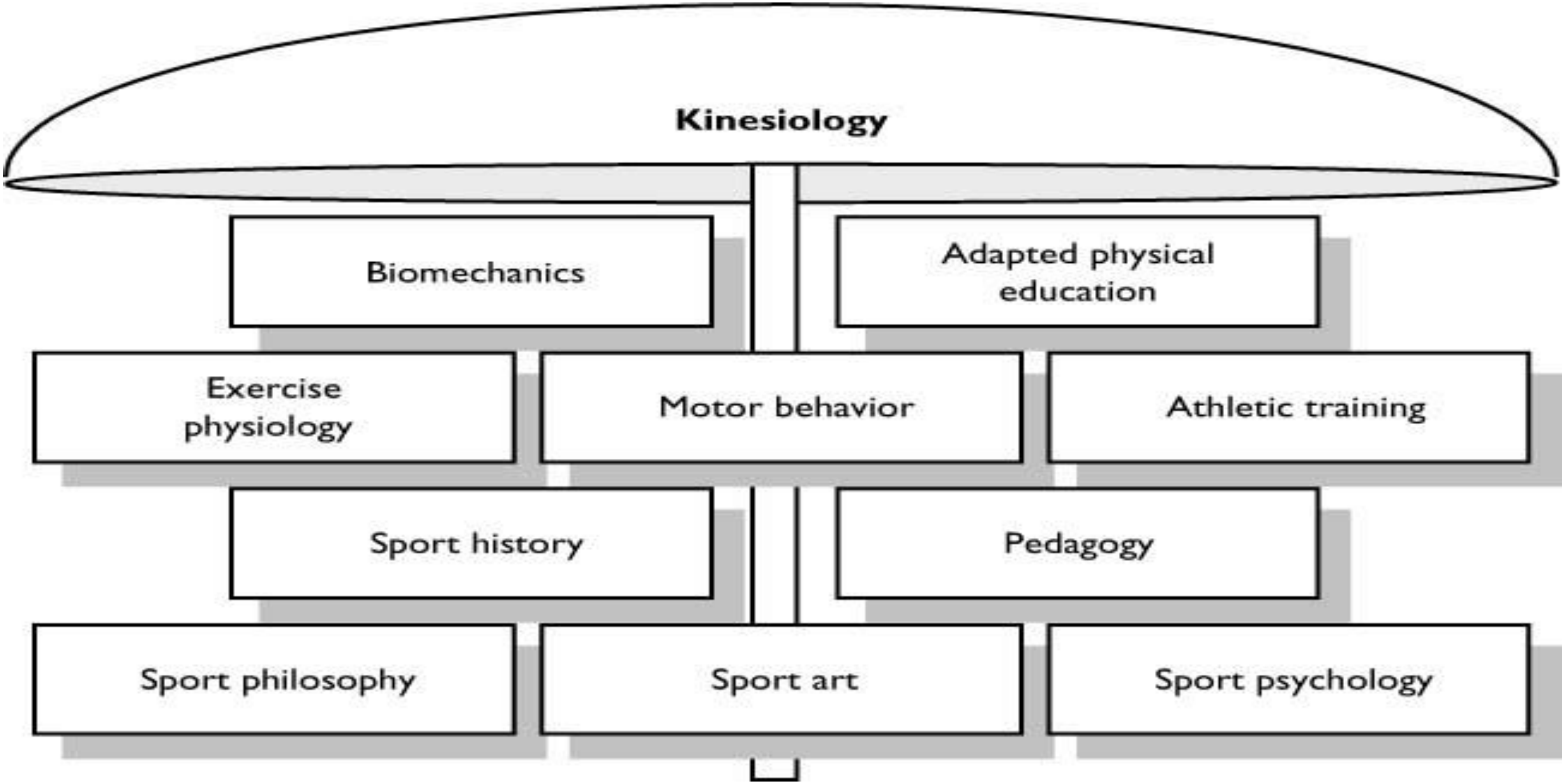
- Related to the dimensions and weights of body segments(ex: size, shape, weight)



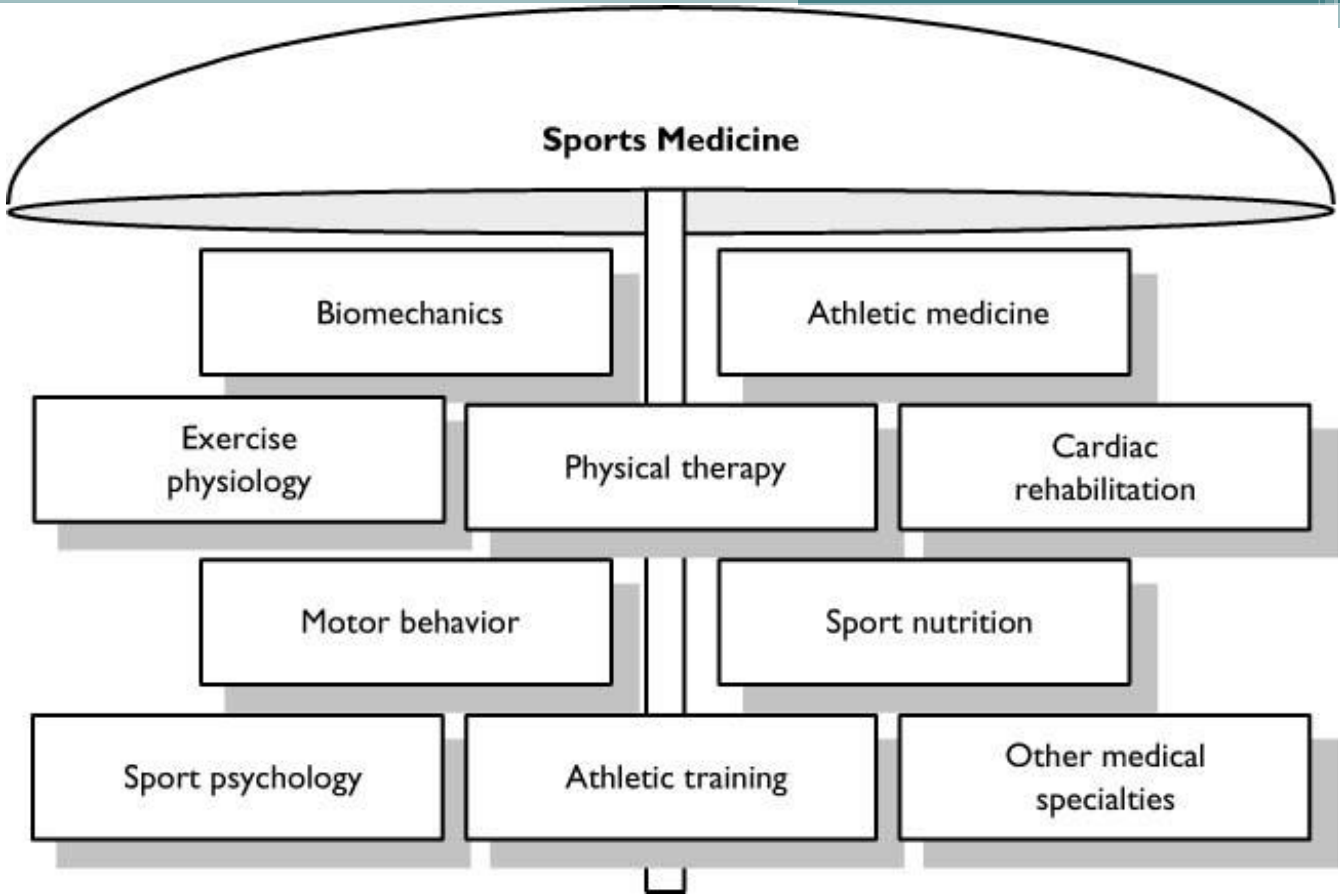
# Kinesiology

- Study of human movement



# Sports Medicine

- Clinical and scientific aspects of sports and exercise.
- In sports biomechanics, the laws of mechanics are applied to human movement **in order to** gain a greater understanding of athletic performance and to reduce **sports injures** as well.
- Also to understand **movements of action of human bodies** and sports implements such as cricket bat, hockey stick.


Sports Medicine
Biomechanics
Athletic medicine
Exercise physiology
Physical therapy
Cardiac rehabilitation
Motor behavior
Sport nutrition
Sport psychology
Athletic training
Other medical specialties

# Studied Problems

- **Locomotion patterns:** biped vs. quadruped
- **Energy cost with specific movements :** what is **energetically** optimal?(energy systems)
- **Transitional changes:** (for example) energetics of walking in human children as their bodies undergo developmental changes in body proportions and motor skills with growth

# Problems Continued…

**NASA:** microgravity and musculoskeletal system: few days in space can elicit reduced bone density, mineralization and strength, especially in lower extremities.

- **Osteoporosis:** 90% of all fractures in men and women are osteoporosis related after the age of 60.
- **Mobility Impairment:** **age related** as decreased balance and increased risk of fall. **Studied:** **factors** that help to avoid future falls, safe landing characteristics, protective and preventative clothing/flooring surfaces.

# Problems Continued…

- **Mechanical Analysis of Specific Movements:** breakdown of a movement (i.e. discus throw) and related factors, where the idea is to find the optimal force, velocity, form to enhance the positive and reduce the negative for best performance results.
- **Safety and Injury Reduction e.g**: Sport shoe design and specific to sport, conditions etc.

# Problems Continued…

- **Clinical Research:** Gait normalization for children with cerebral palsy, improved gait for amputees, prosthesis research
- **Occupational Research:** prevention of work-related injuries and improvement of work conditions and worker performance (both physical and mental preparation)
- **Sport Performance Enhancement:** in equipment -. Cycling Ex: aerodynamic helmets, clothing, cycle designs.
- Uni-suits in swimming, track, skating, .

# Why Study Biomechanics?

- To address problems related to human health and performance.
- Useful for
  - **Phys Ed Teachers**
  - **Physical Therapists**
  - **Physicians**
  - **Coaches**
  - **Personal Trainers**
  - **Exercise Instructors**


Thank You

# بسم اللہ الرحمٰن الرحیم

سیدنا ابو خدری رضی اللہ عنہ سے روایت ہے، کہ حضور نبی کریم ﷺ نے ارشاد فرمایا:

شیطان نے اللہ سے کہا تھا کہ اے میرے رب! مجھے تیری عزت کی قسم! میں تیرے بندوں کو گمراہ کرتا رہوں گا جب تک ان کی روحیں انکے جسموں میں رہیں گی تو رب تعالیٰ نے جواباً فرمایا:

مجھے میری عزت اور میرے جلال کی قسم! وہ (میرے بندے) جب تک استغفار کرتے رہیں گے مجھ سے مغفرت طلب کرتے رہیں گے میں ان کی مغفرت و بخشش فرماتا رہوں گا۔

(جواھر الحدیث جلد ۱، صفحہ ۵۳)
(مشکاۃ المصابیح جلد ۲، صفحہ ۴۴۹)

# Biomechanics

*Lecture : 2*

# Problem-Solving Approach

- Analysis of human movement can be either
  - Quantitative or
    - Involving the use of numbers
    - Six Meters, Three Seconds, Fifty Turns, Two Players, Ten Dollars, etc.
  - Qualitative
  - Involving nonnumeric description of quality
  - Good, Poor, Long, Heavy, Flexed, Rotated, spiffy, etc.

# Types of questions 1:General Question Examples

- Is the movement being performed with adequate (or optimal) force?
- Is the movement being performed through an appropriate range of motion?
- Is the sequencing of body movements appropriate (or optimal) for execution of the skill?

# 2:specific Question Examples

- Is there excessive Pronation taking place during the stance phase of gait?
- Is release of the ball taking place at the instant of full elbow extension?
- Does selective strengthening of the quadriceps muscles improve mobility level

# Formal Problems:3 components

- **1) A set of given information**
- **2) A particular goal, answer, or desired finding**
- **3) A set of operations or processes that can be used to arrive at the answer from the given information**

# Solving Formal Quantitative Problems

1) Read the problem carefully.
2) List the given information.
3) List the desired (unknown) information for which you are to solve.
4) Draw a diagram of the problem situation showing the known and unknown information.
5) Write down formulas that may be of use.
6) Identify the formula to use.

# Solving Formal Quantitative Problems

- 7) If necessary, reread the problem statement to determine whether any additional needed information can be inferred
- 8) Carefully substitute the given information into the formula.
- 9) Solve the equation to identify the unknown variable (the desired information).

# Solving Formal Quantitative Problems

- 10) Check that the answer is both reasonable and complete
- 11) Clearly box the answer.
- *Note: Be sure to provide the correct unit of measurement with the answer.

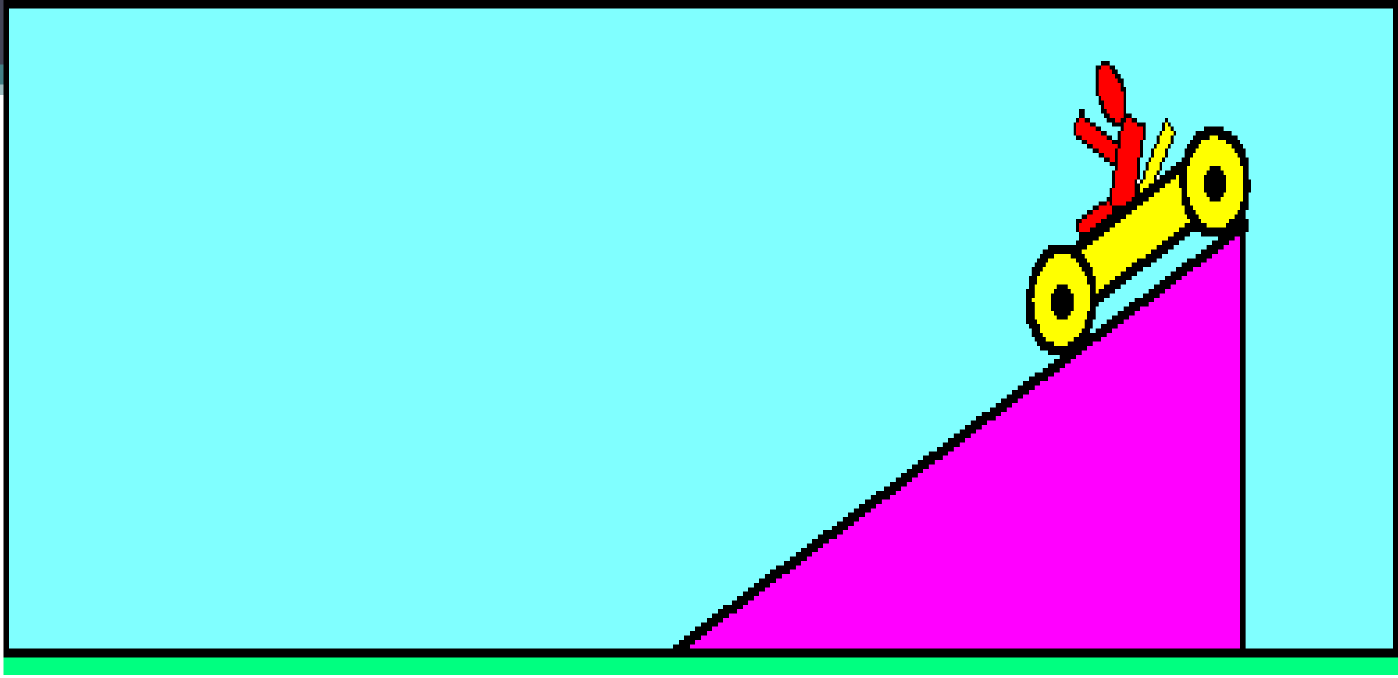
# *Kinetic Concepts for Analyzing Human Motion*

# Basic Concepts Related to Kinetics

- Inertia
- Mass
- Force
- Free body diagram
- Center of Gravity
- Weight

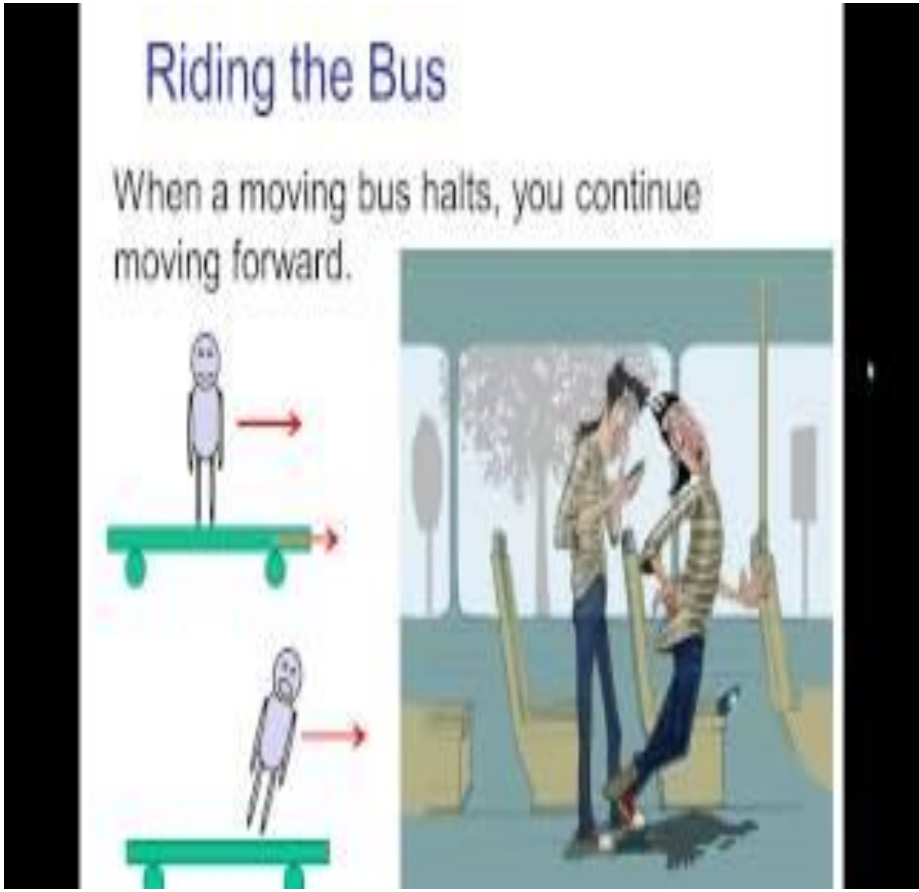
- Pressure
- Volume
- Density
- Specific weight
- Torque
- Impulse

# Inertia



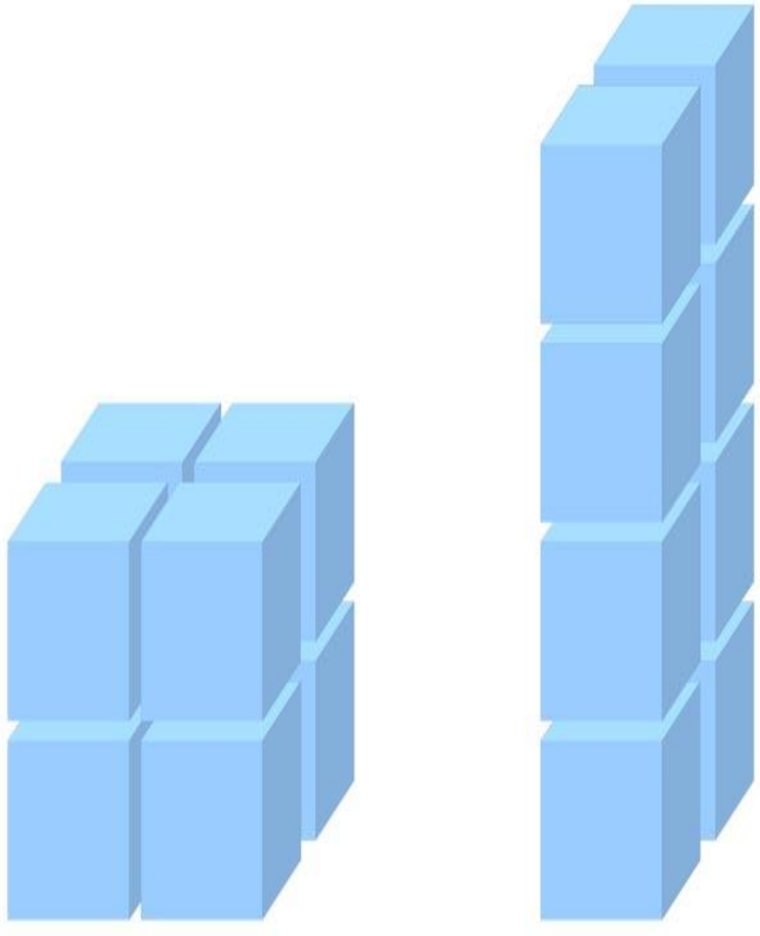
- Tendency for a body to resist a change in its state of motion
- No unit of measurement
- It is dependent upon mass of the body
- More heavy → more inertia

- Body can be either motionless or in a state of constant velocity.
- Implication in human body
- Exercise implication



# Mass

- Quantity of matter contained in an object
- **Common unit for measurement in metric system is kg**
- In English system- Slug which is larger than kg



# Momentum

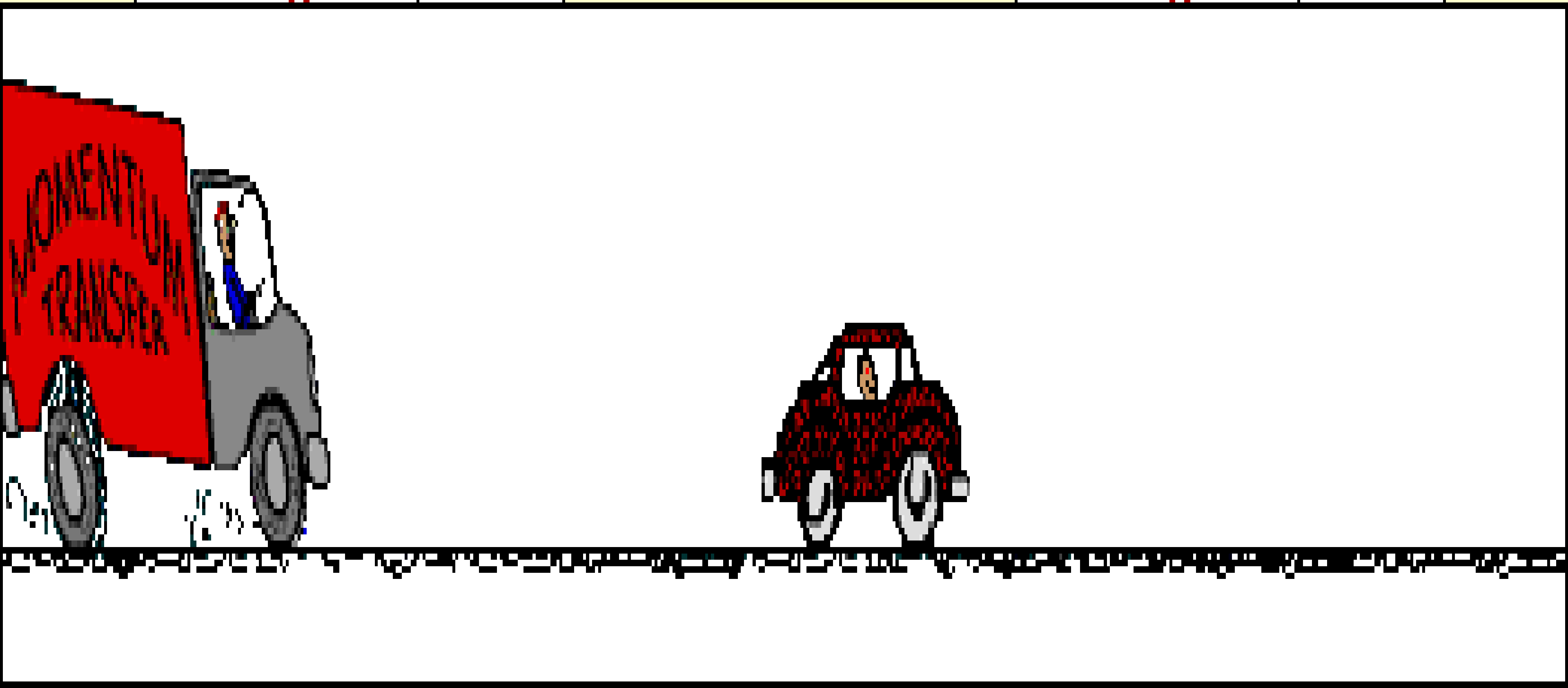
- In classical mechanics, linear **momentum** or translational **momentum**(SI unit kg m/s, or equivalently, N s) **is the product of the mass and velocity of an object.**
- **Example**, a heavy truck moving rapidly has a large momentum—it takes a large or prolonged force to get the truck up to this speed, and it takes a large or prolonged force to bring it to a stop afterwards.
- If the truck were lighter, or moving more slowly, then it would have less momentum.

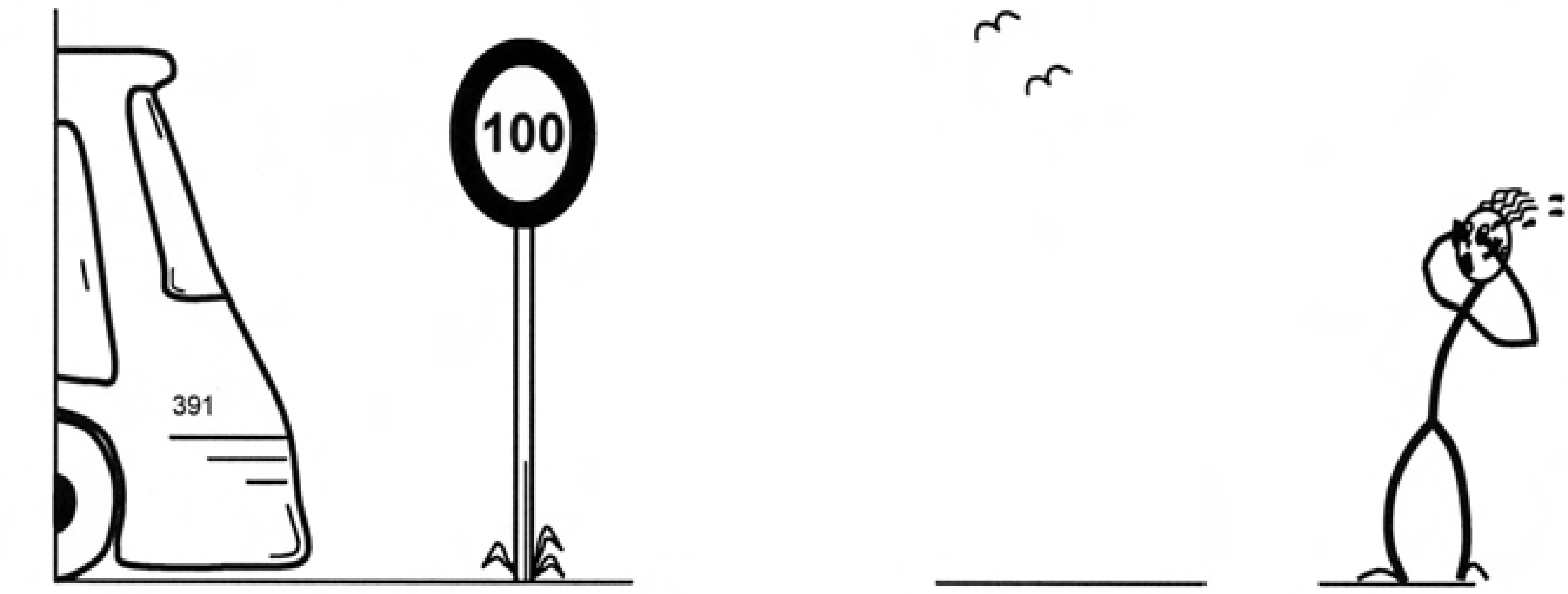
**Truck**

| | |
|---|---|
| mass (kg) | 3000 |
| vel. (m/s) | 20.0 |
| mom. (kg m/s) | 60 000 |

**Car**

| | |
|---|---|
| mass (kg) | 1000 |
| vel. (m/s) | 0.0 |
| mom. (kg m/s) | 0 |






***A large bus moving quickly has a large momentum. It would take a large force produced over a significant time period to stop it.***

The mass of the big fish is 4X the mass of the little fish.

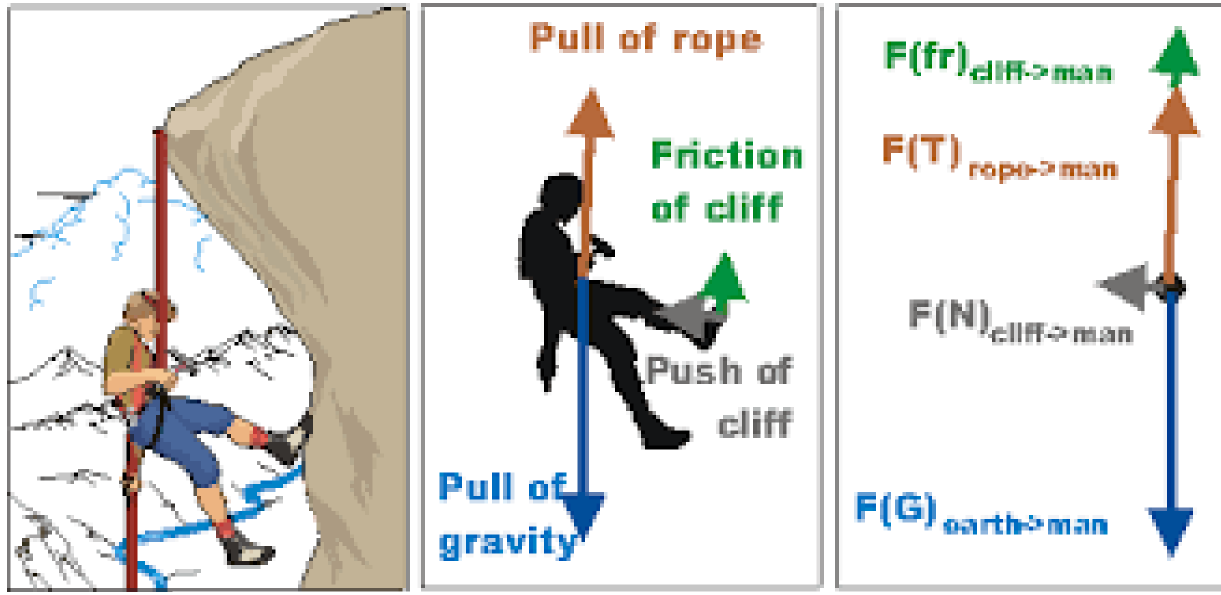
Speed of Big Fish = 5 km/hr

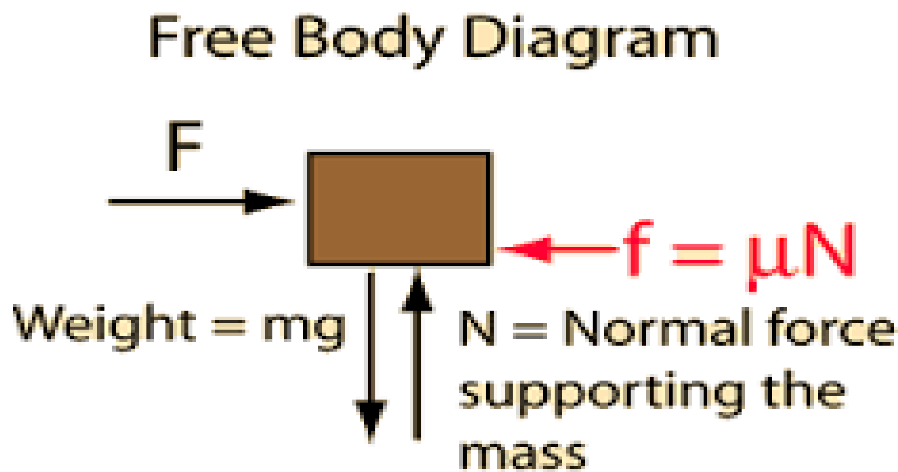
# Force


- Push or pull
- the product of mass and acceleration
- Its effects can be described by Magnitude, direction and point of application
- Common forces acting on human body????
- F=ma
- 1Newton= N : 1 kg mass * 1 m/S2
- 1Pound: lb: 1 slug*1 ft/S2

# Free body diagram

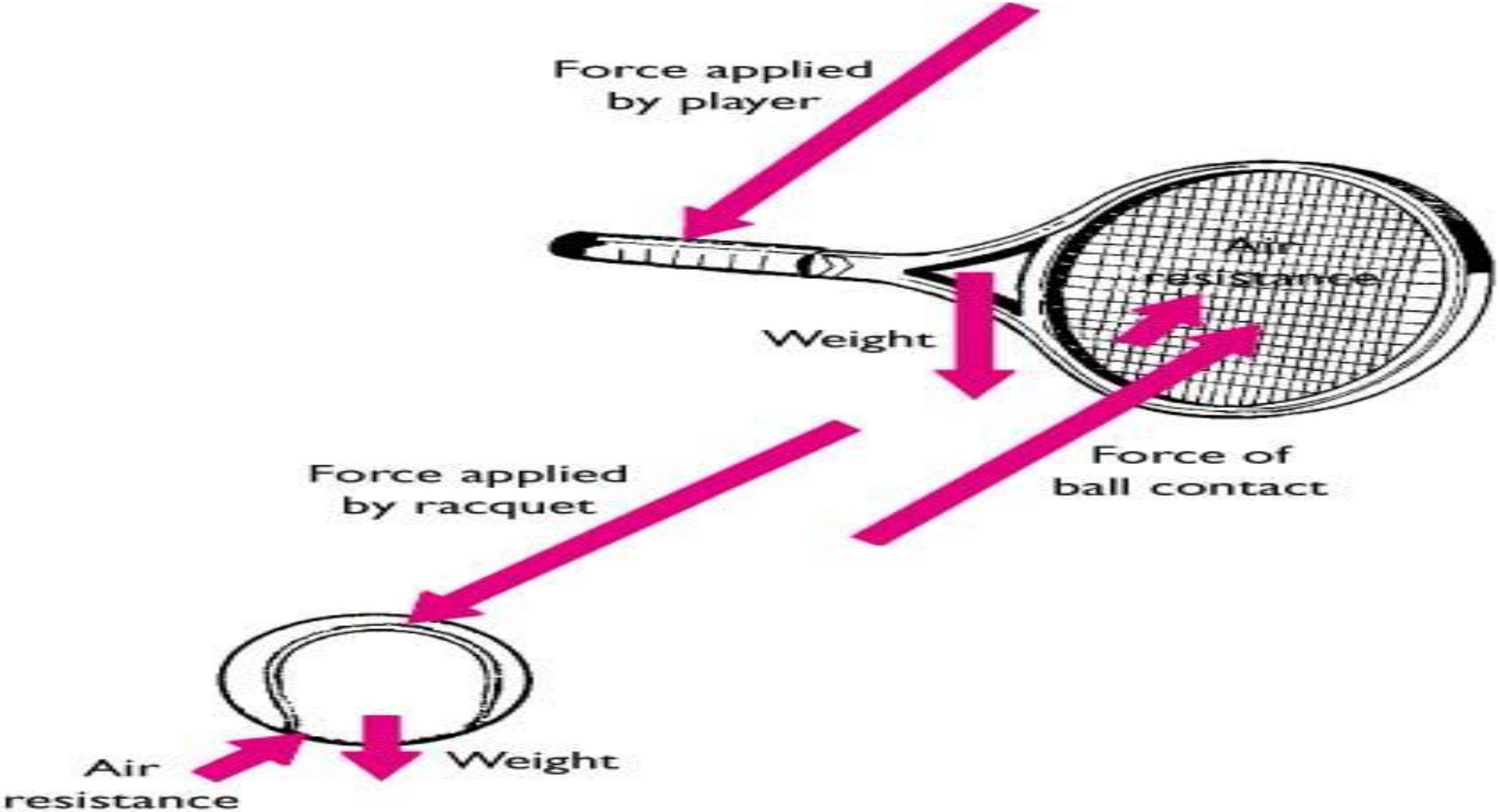
- A sketch that shows a defined system in isolation with all of the force vectors acting on the system
- Number of forces act on the body simultaneously in many situations



Free body diagram is the first step in analysis of effect of forces

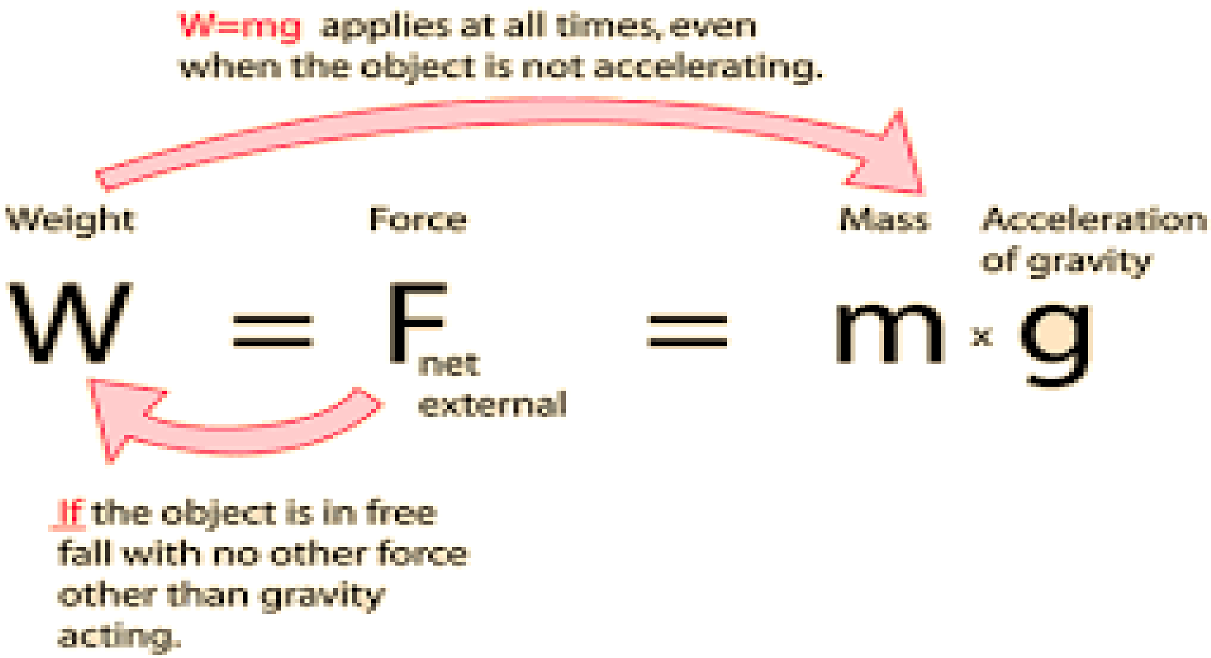
Free body: any body, object or body part which is being focused upon for analysis.

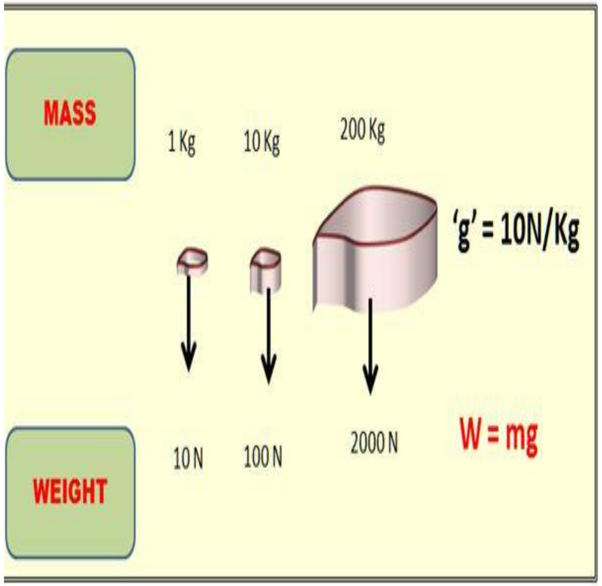


- The overall effect of the many forces acting upon the body is the function of net force= vector sum of all forces
- **When all forces** acting on the body are **balanced or cancel** each other, the net force is zero and body **remains motionless or continue with constant velocity**
- **When net force is present** , then movement takes place in the direction of the net force

# Weight

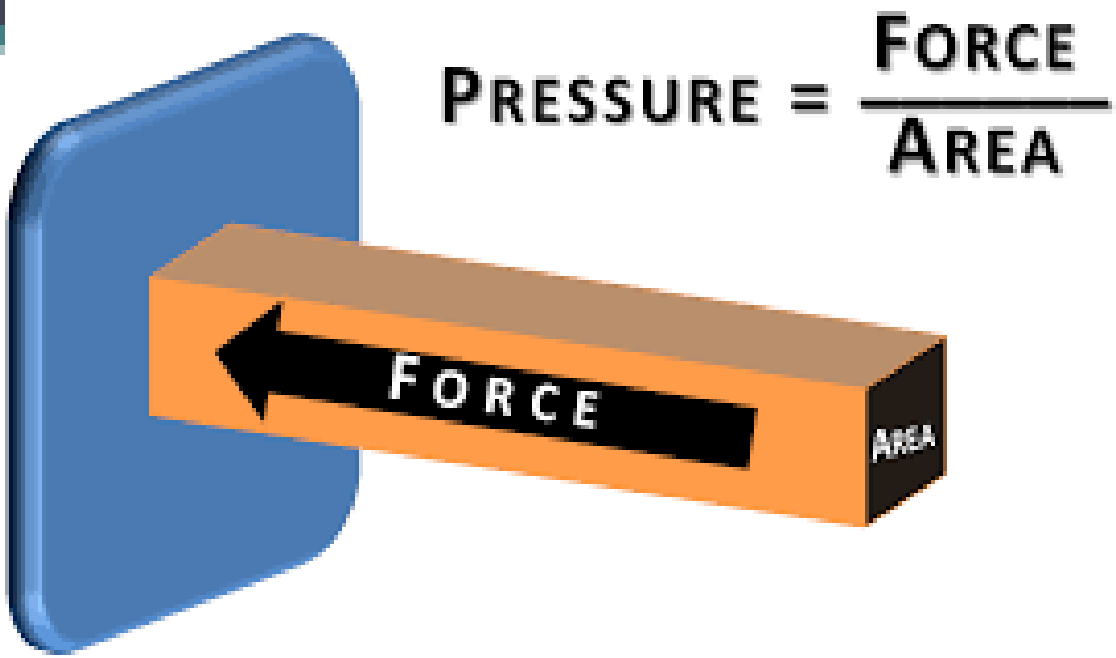
- Attractive force that the earth exerts on a body or it’s a mass along with forces acting on it
- W= m.g
- As the mass increases the weight increases
- Effect of gravity????

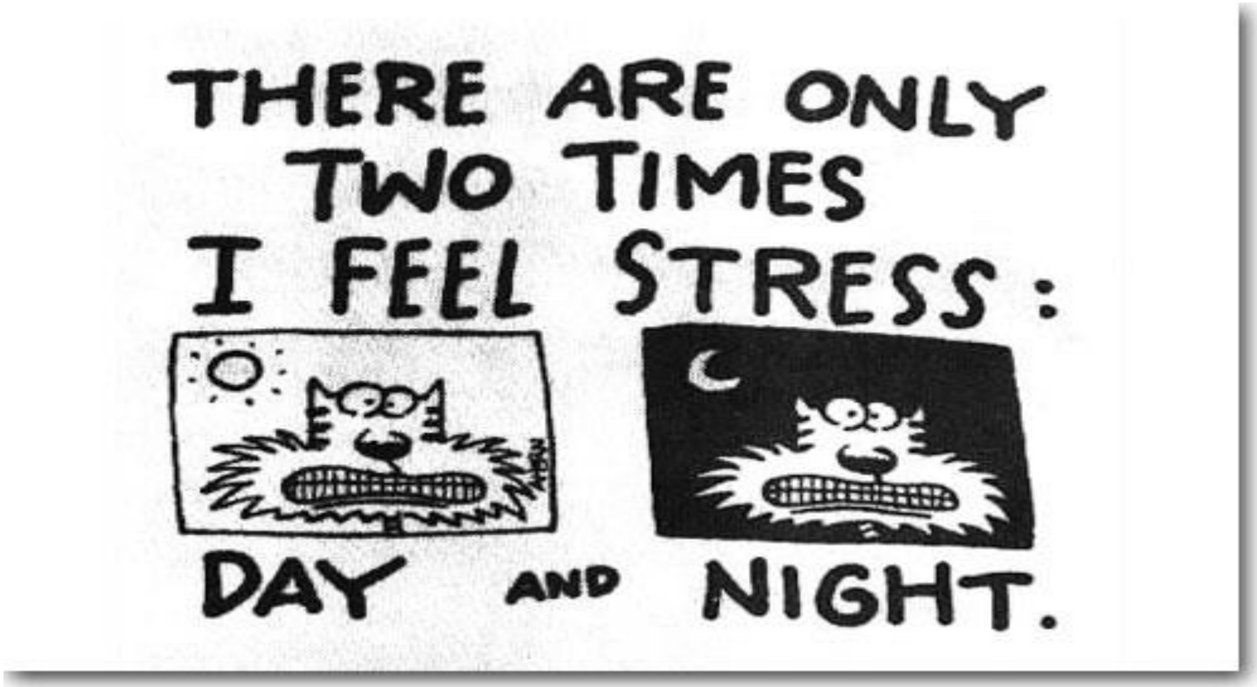


# Pressure

- Force per unit of area over which the force acts
- P=F/A
- Unit= Pascal
- Pa= N/m2



# Sample Problem

what is better to be stepped on by a women. A) wearing a spike or b) a court shoe?

Known: wt = 556 N $A_s$ = 4 $cm^2$ $A_c$ = 175 $cm^2$

Solution

Wanted: Answer

Pressure exerted by the spike heel p = 139N/$cm^2$

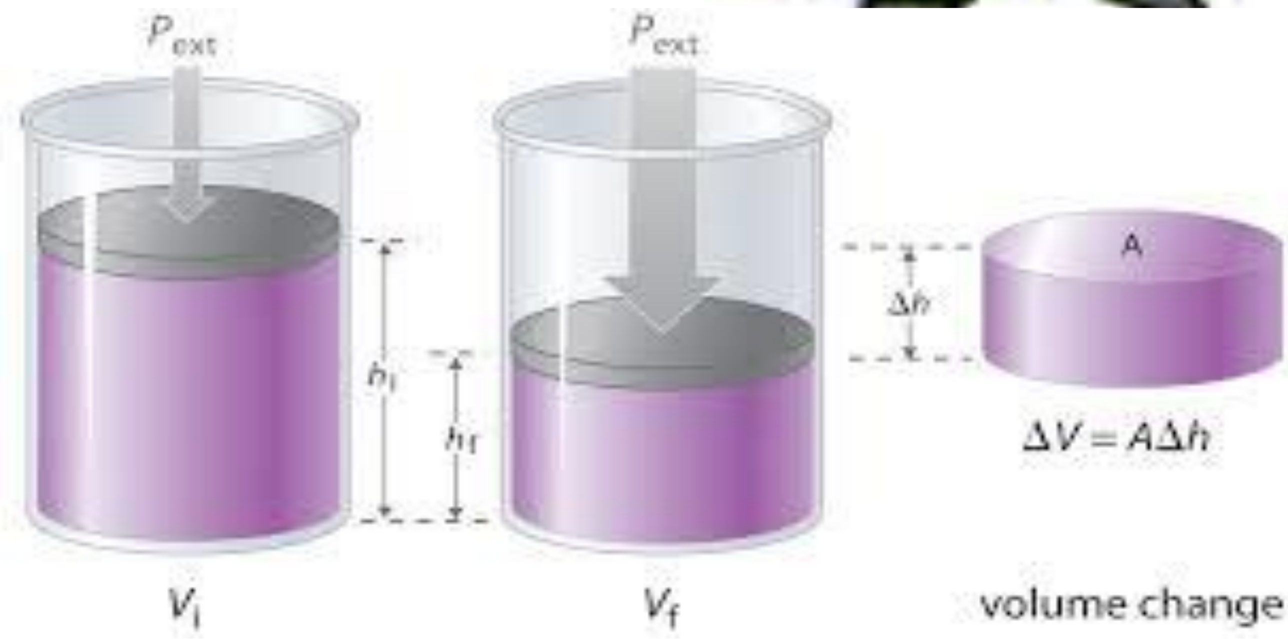
Pressure exerted by the court shoe p = 3.8 N/$Cm^2$

135.2 times more pressure by spike heel or by using formula below

Formulas: p = F/A 43.75 times more pressure

# Volume

- Space occupied by a body
- Space is considered to have three dimensions(Width, Height, Depth)
- Unit in cubed
- In metric system: cm3, m3 or litre
- 1 L= 1000cm3

# What is Density?

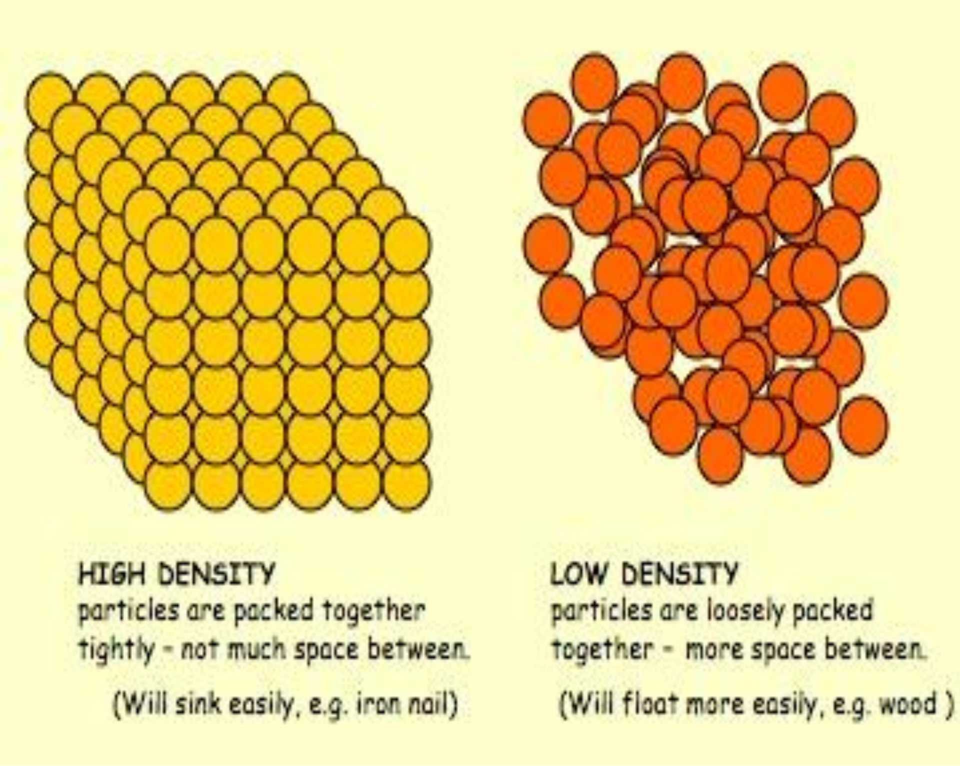
## Density is....

- "Mass per unit volume"
- How closely packed the "stuff" is within an object.
- If something is *more dense* that means more *stuff* is taking up that objects space, and is more closely packed.

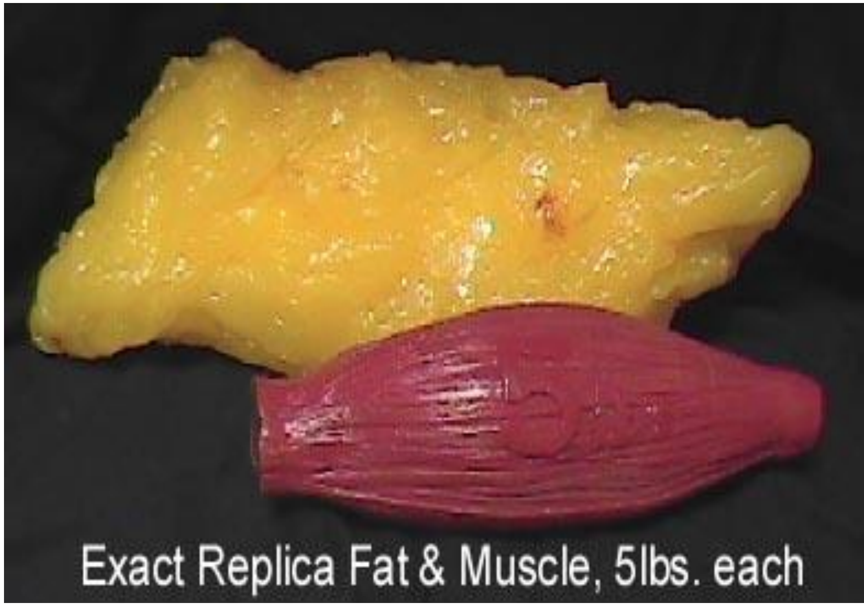
## Which is denser?

# Density

- Mass per units of volume
- ρ rho
- Density= mass/volume
- Kg/m3



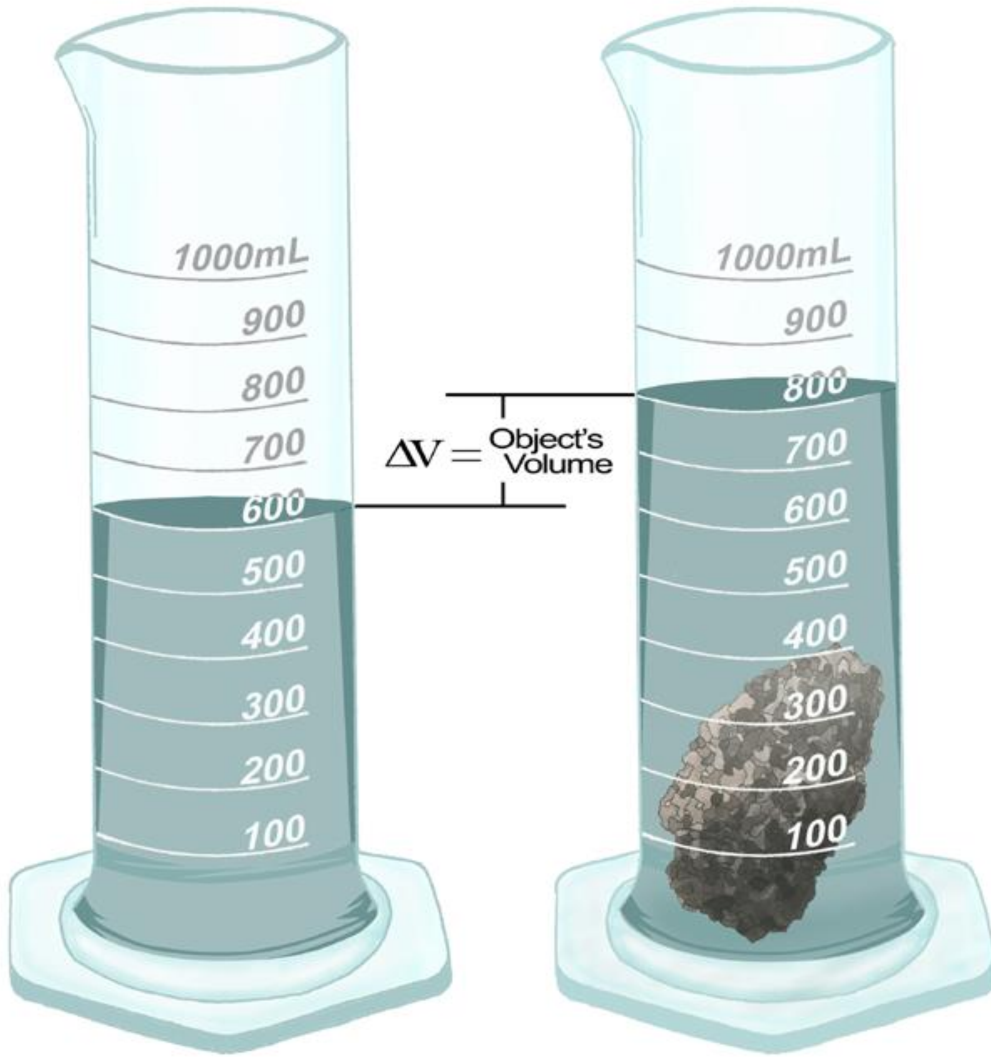

- A muscular person of the same body volume as compared to the obese person with same body volume...which one has more density? Or **Fat is denser or muscle????**



# DETERMINATION OF UNKNOWN DENSITY

$$\text{DENSITY} = \frac{\text{MASS}}{\text{VOLUME}}$$

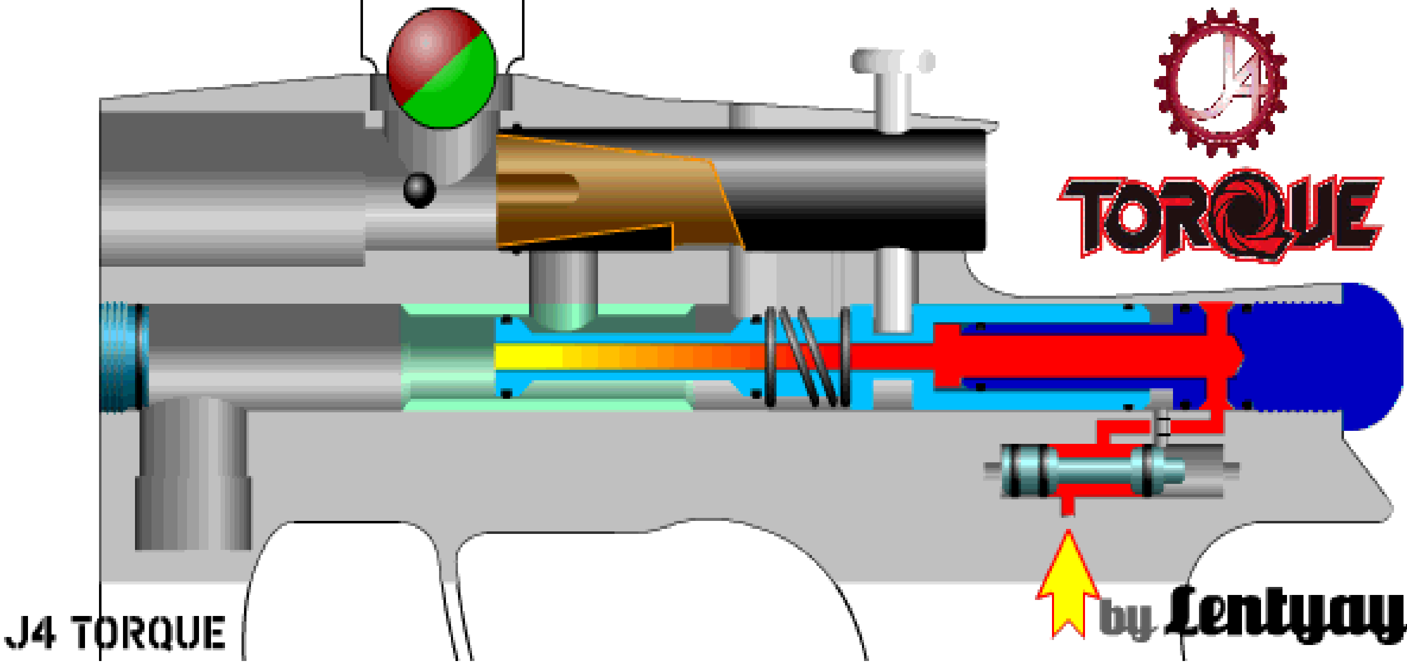
$$\rho\ (\text{g/cm}^3) = \frac{m\ (\text{g})}{\Delta V\ (\text{cm}^3 = \text{mL})}$$

# Specific Weight

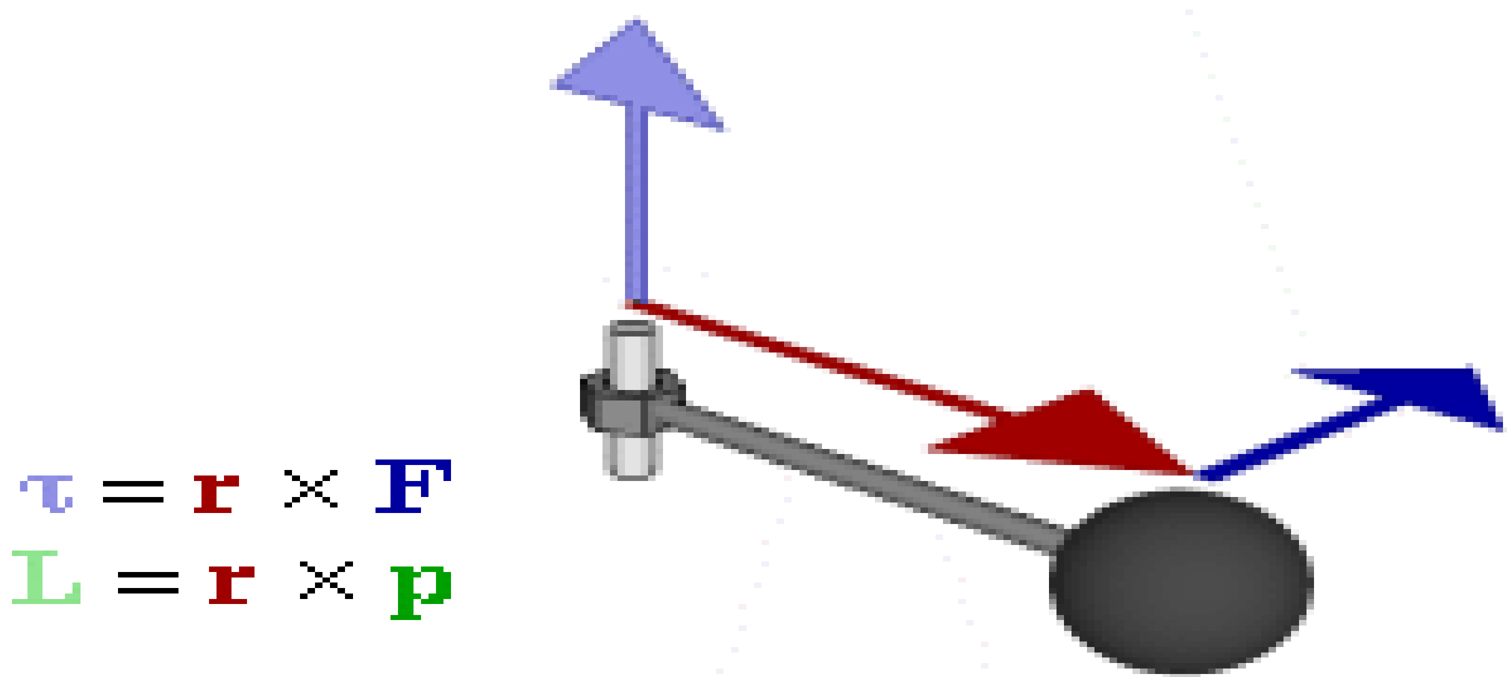
- Weight per unit of volume
- N/m3

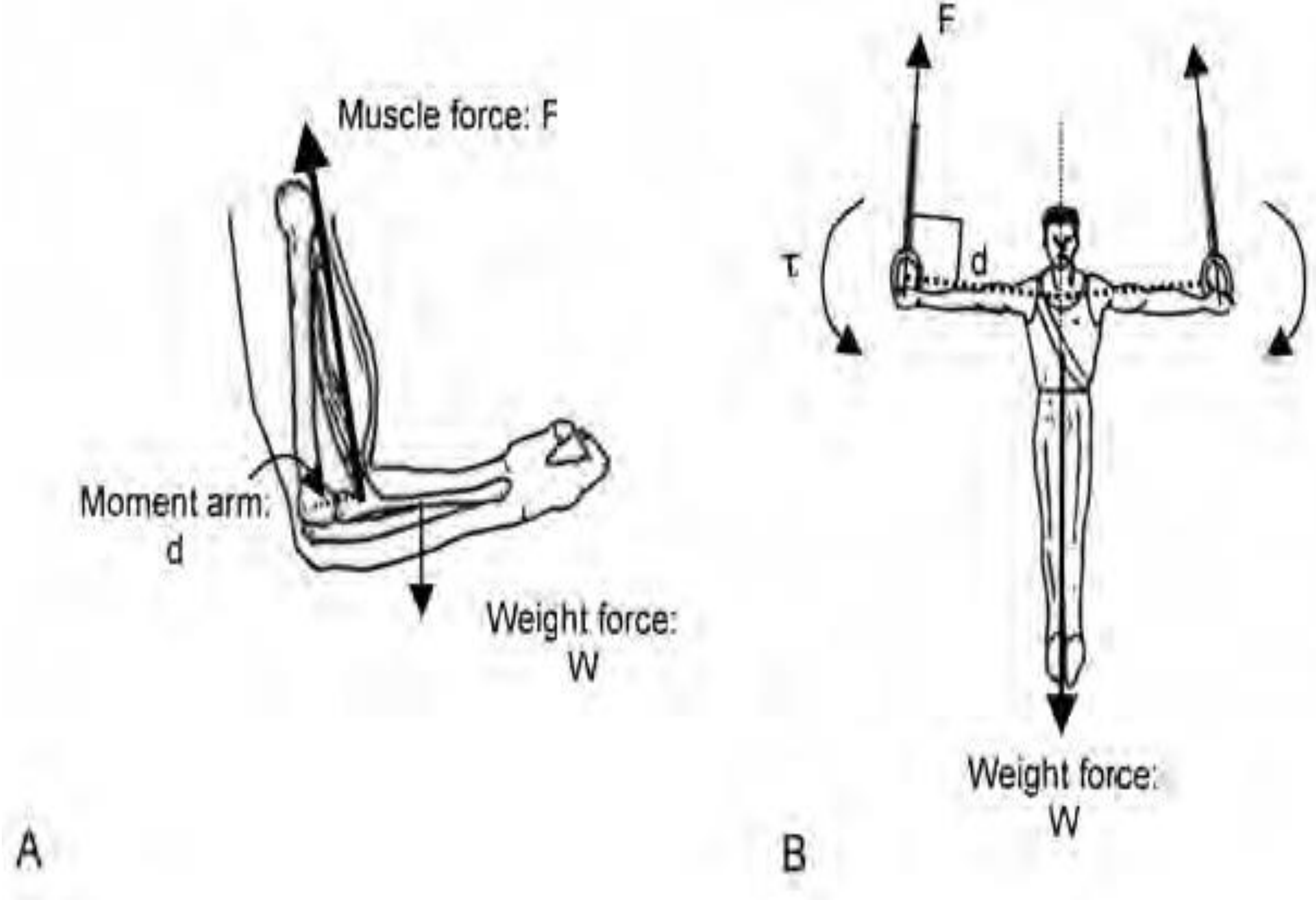
# Torque




- Rotary effect of a force
- Concentric force applied in the middle results in translation in direction of the force
- Eccentric force ( applied other than at centre) results in translation as well as rotation.
- T=F. d ( Perpendicular distance from axis of rotation
- N. m

torque is a measure of the turning force on an object such as a bolt or a flywheel. For example, pushing or pulling the handle of a wrench connected to a nut or bolt produces a torque (turning force) that loosens or tightens the nut or bolt.




Muscle force: F
Moment arm:
d
Weight force:
W
A
F
τ
d
Weight force:
W
B

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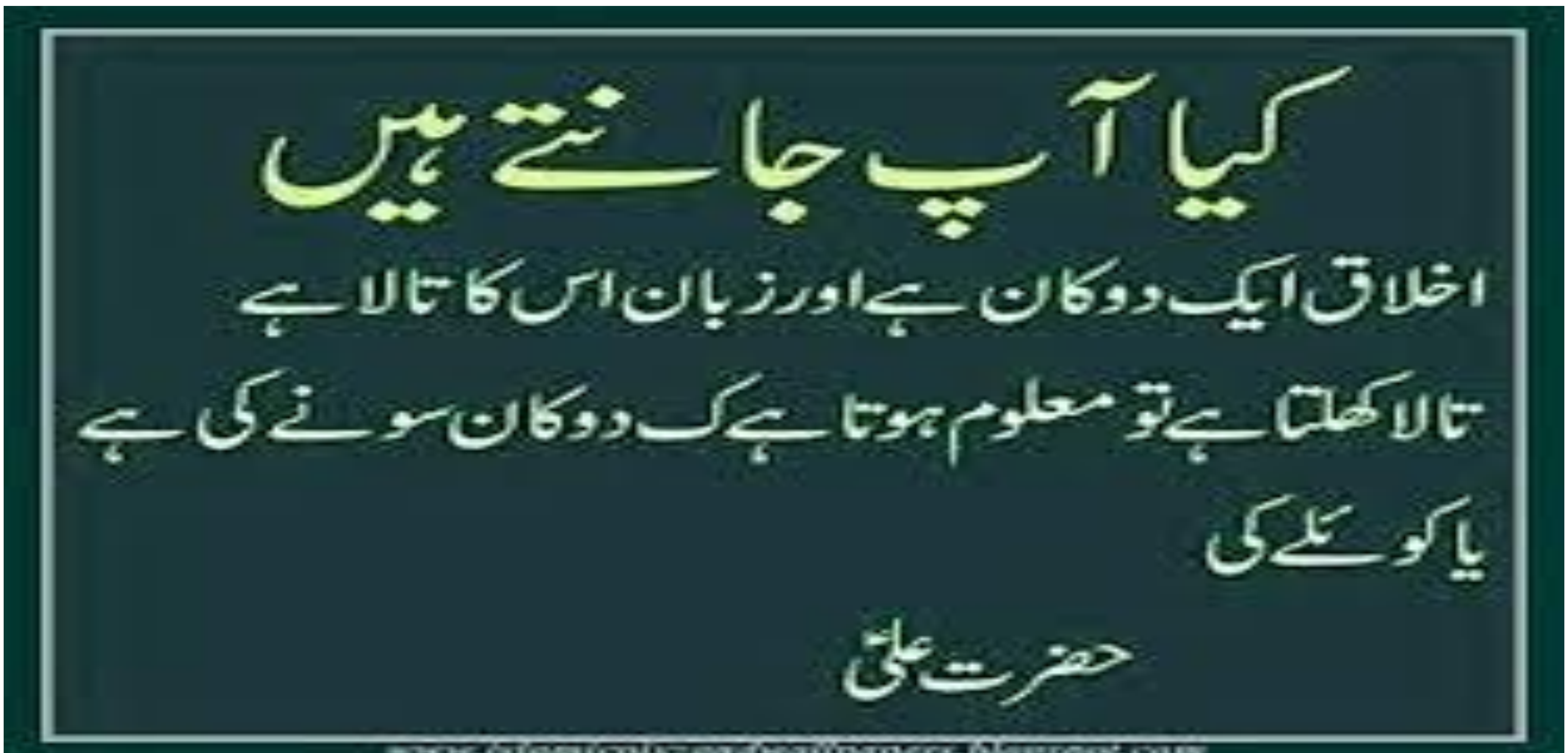


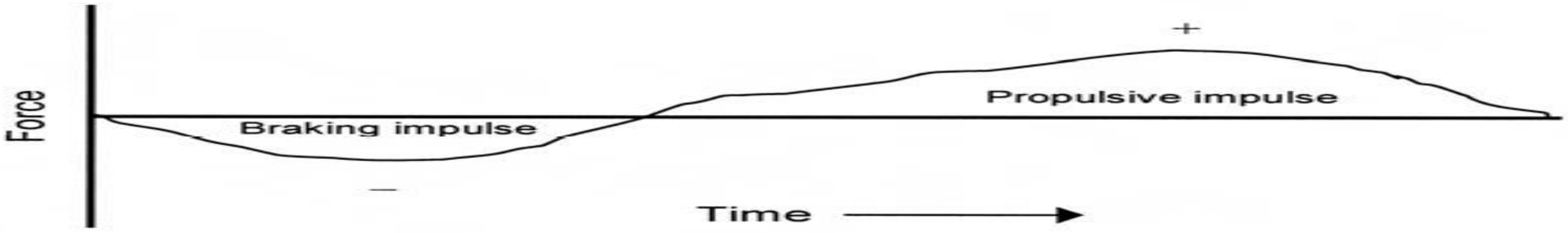
# Impulse

- Product of force and the time over which the force acts

- In classical mechanics, **impulse** (symbolized by **J** or **Imp**) is the **integral** of a **force**, **F**, over the **time** interval, **t,** for which it acts.

- Since force is a vector quantity, impulse is also a vector in the same direction.

- ***impulse produce during walking or running***
- **Effect on speed of individual**

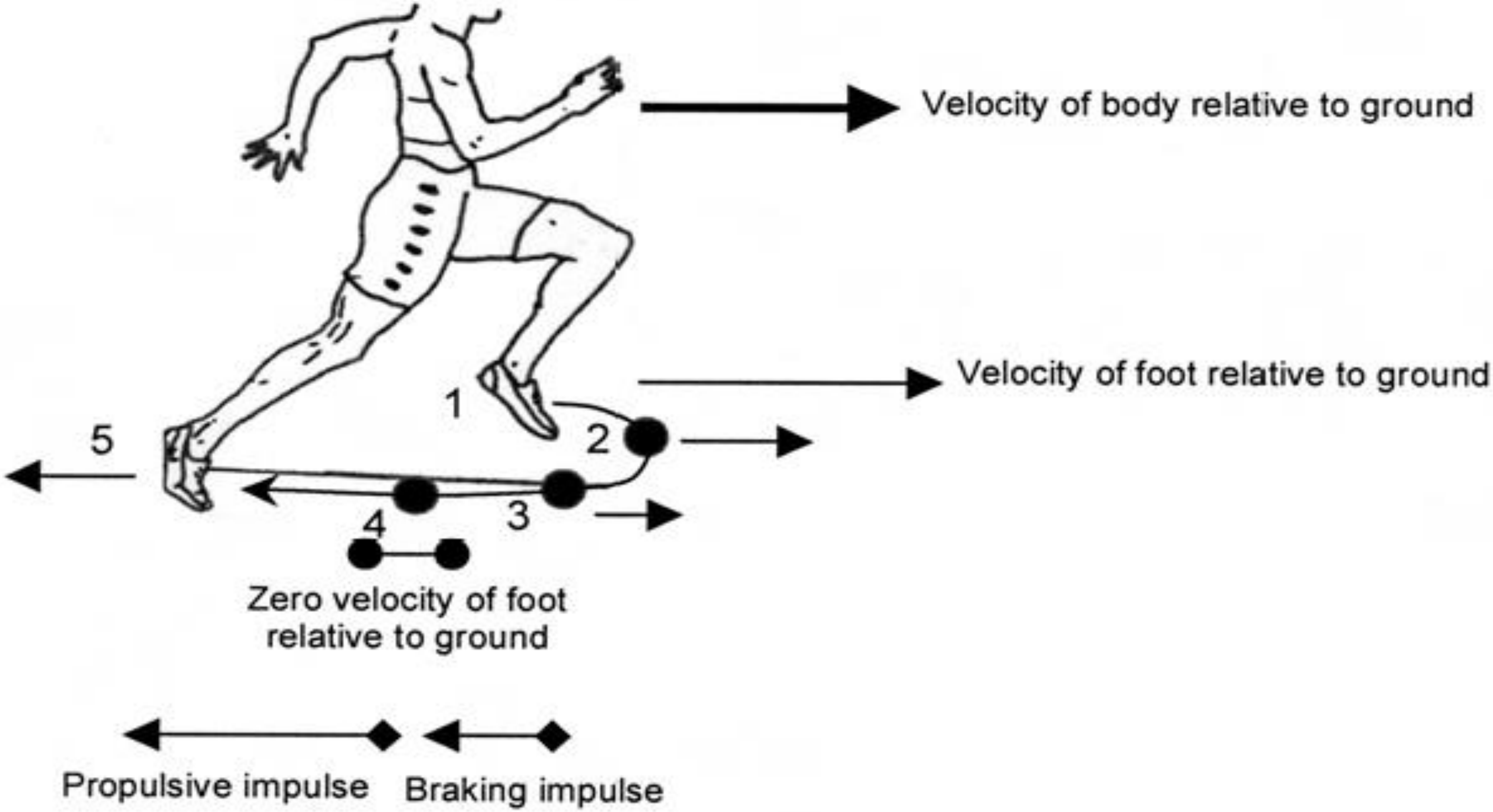



*Horizontal ground reaction force trace or impulse for a runner.*

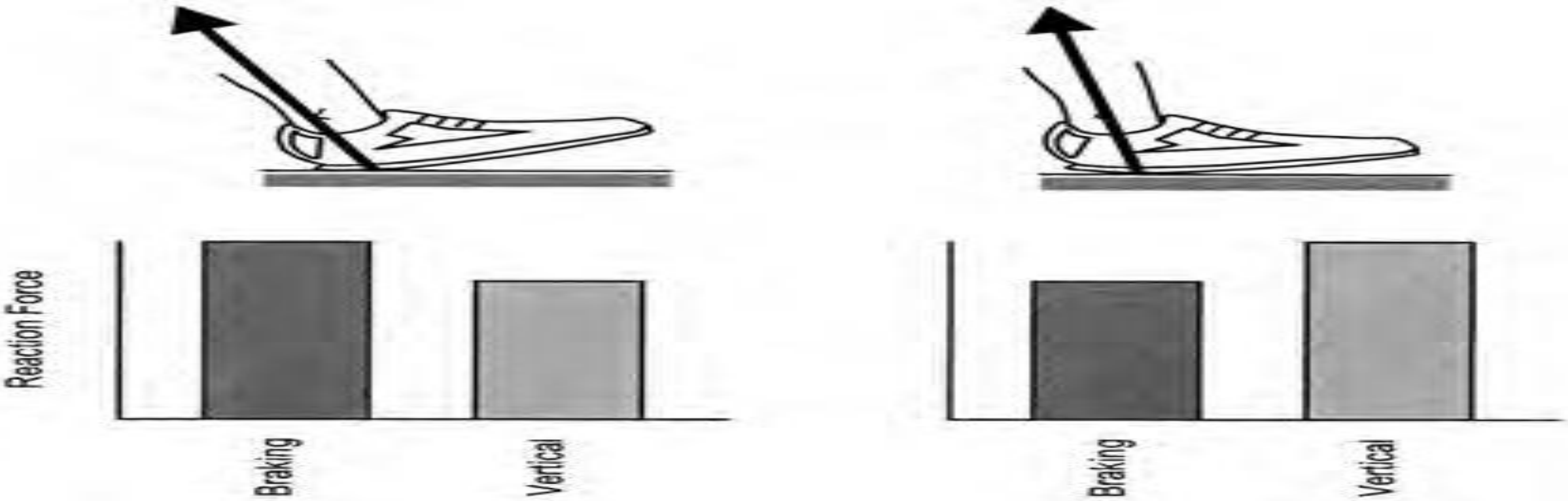
*A forward force exerted by the runner* ***elicits*** *a backward or braking reaction force ;…*

*Since the force is applied over time, the area under the curve (force × time) is the braking impulse. As the foot passes under the body, the runner pushes backwards to elicit a forward or propulsive reaction force .*

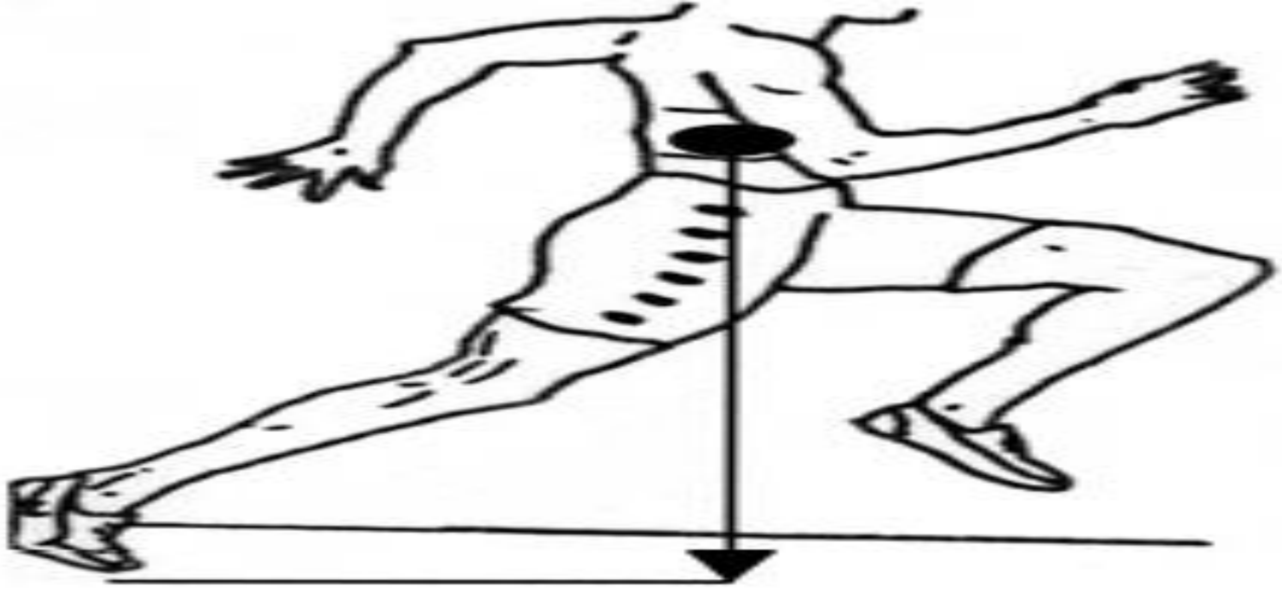
*Since the force is also applied over time, there is a propulsive impulse.*




**NOTE**: More propulsive impulse more speed




*When the foot lands at a greater **angle** in front of the body (left diagram) the braking impulse is large. The total positive impulse  is therefore smaller so acceleration is lesser.*
*When the foot lands at a smaller angle and further under the body (right diagram) the braking impulse is smaller, although the vertical (purpulsive) impulse might be bigger. The total positive impulse is larger. (more speed)*
***Elite sprinters** land with their foot about 6 cm in front of the body whereas novice sprinters might land with their foot about twice that distance in front.*




*Tracing of foot–ground contact phase of Marion Jones (USA). Her significant hip extension allows the foot to travel far past the body. This provides a* ***greater time for force application****, which results in a greater propulsive impulse.*

***Her short contact times (~0.11 s)*** *result from the high speed of her body over the foot and the placement of her foot only slightly in front of her body at foot–ground contact.(small braking impulse)*

# Common Units for Kinetic Quantities

| Quantity | Symbol | Metric Unit | English Unit |
|---|---|---|---|
| Mass | m | kg | slug |
| Force | F | N | lb |
| Pressure | P | Pa | psi |
| Volume (solids) | V | $m^3$ | $ft^3$ |
| (liquids) | | liter | gallon |
| Density | ρ | $kg/m^3$ | |
| Specific weight | γ | $N/m^3$ | $lb/ft^3$ |
| Torque | T | N-m | ft-lb |
| Impulse | | N • s | lb • s |

# Mechanical Loads/stresses on the Human Body

**Stress** – distribution of force within a body, or *is force per unit area.* .....*internal* reaction or resistance to an external load. **quantified** as force divided by the area over which the force acts

**1:Compression –** pressing or squeezing force directed axially through a body OR

*force perpendicular to the cross sectional* area of the tissue in a direction toward the tissue.

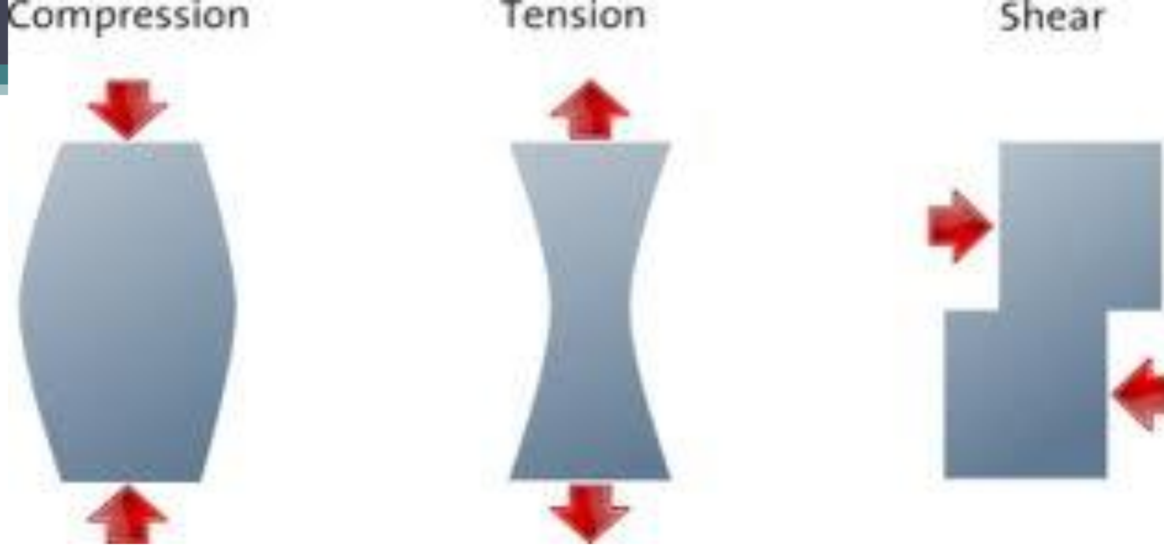
**(Muscle contraction and joint loading**)

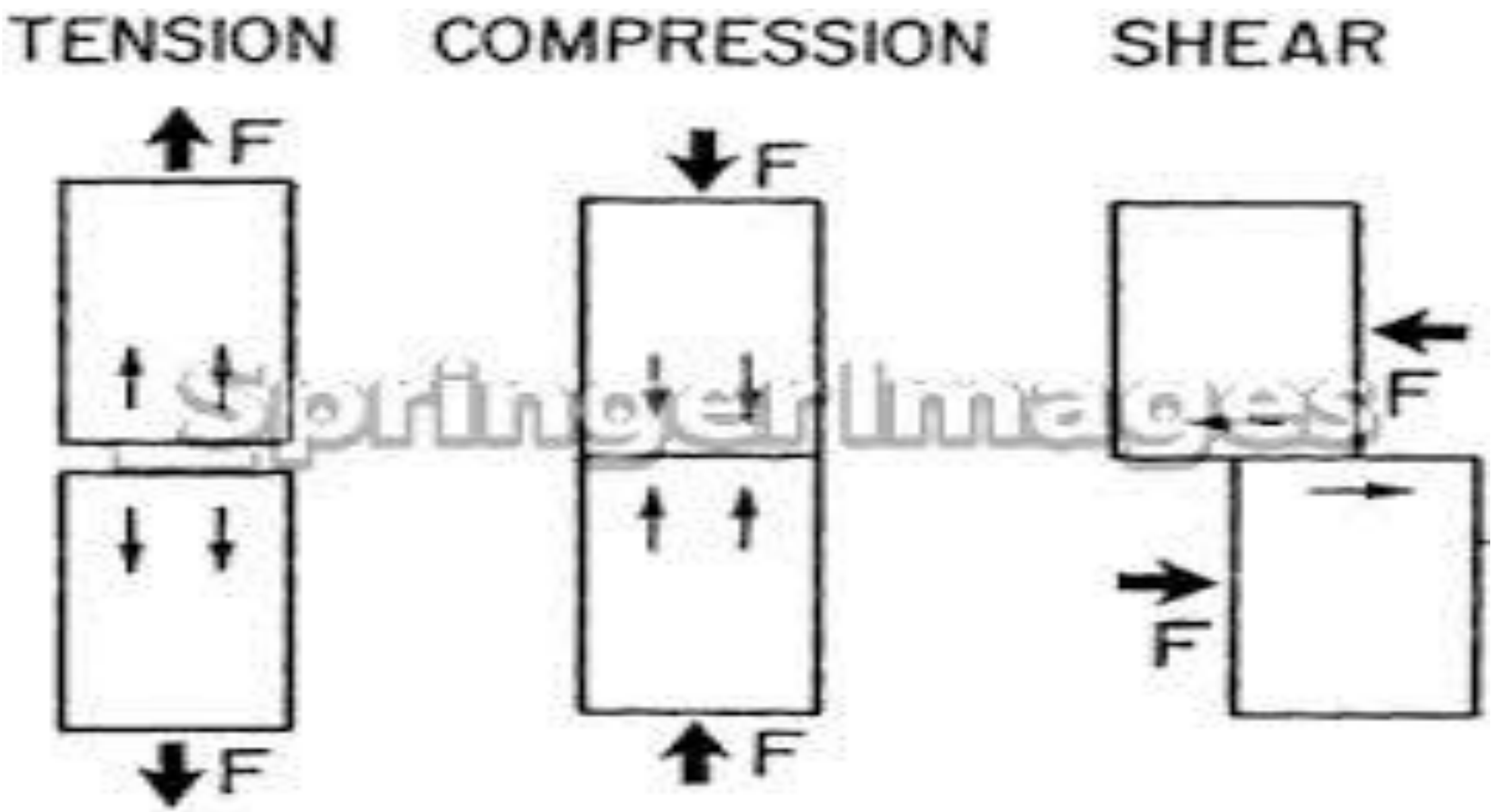
***2: Tension:*** pulling or stretching force directed axially through a body

*force perpendicular to the cross sectional* area in a direction away from the tissue. E.G **stretching**

- ***Shear:*** *force parallel to the cross-sectional area* of the tissue.

- ***Strain: change or deformation produced as a result of stress***


Compression
Tension
Shear


TENSION
COMPRESSION
SHEAR
F
F
F
F
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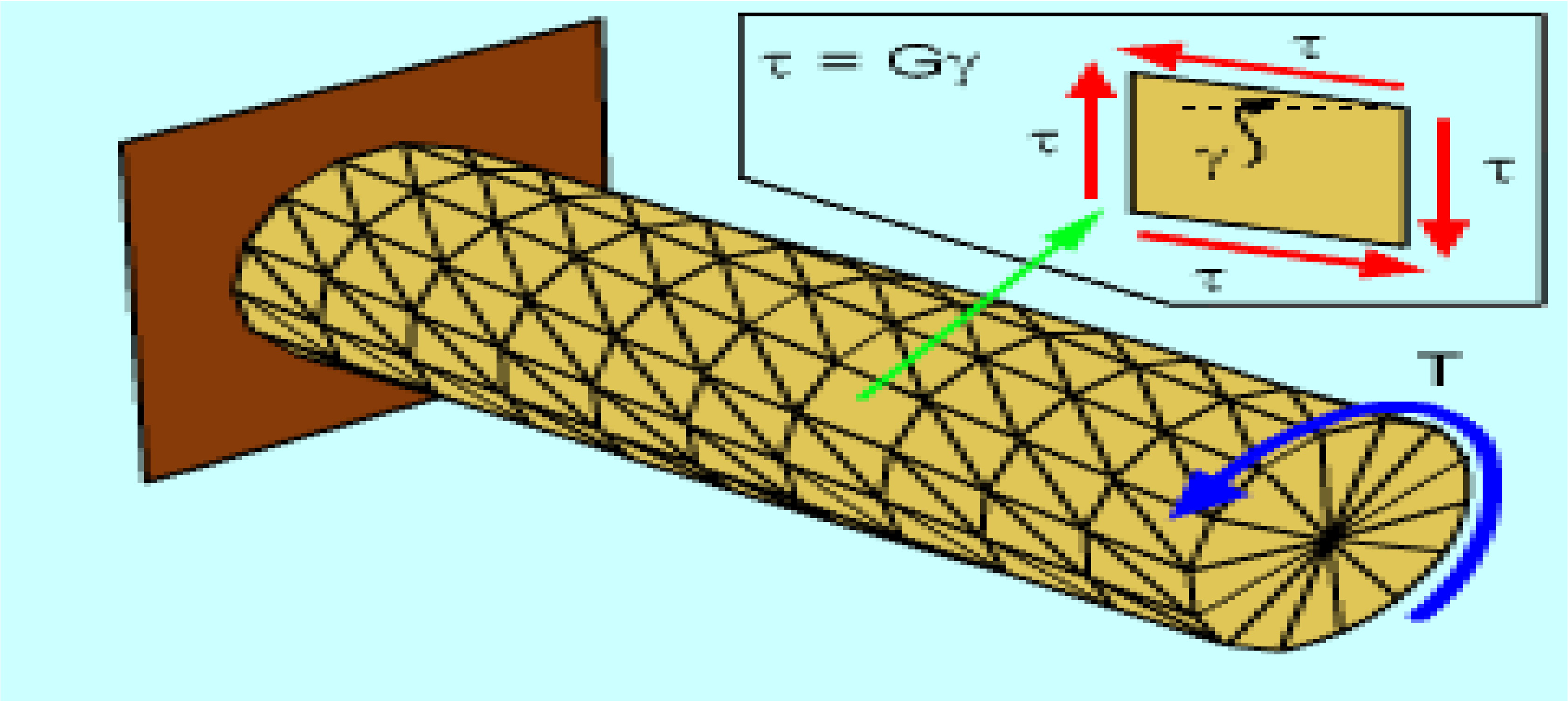
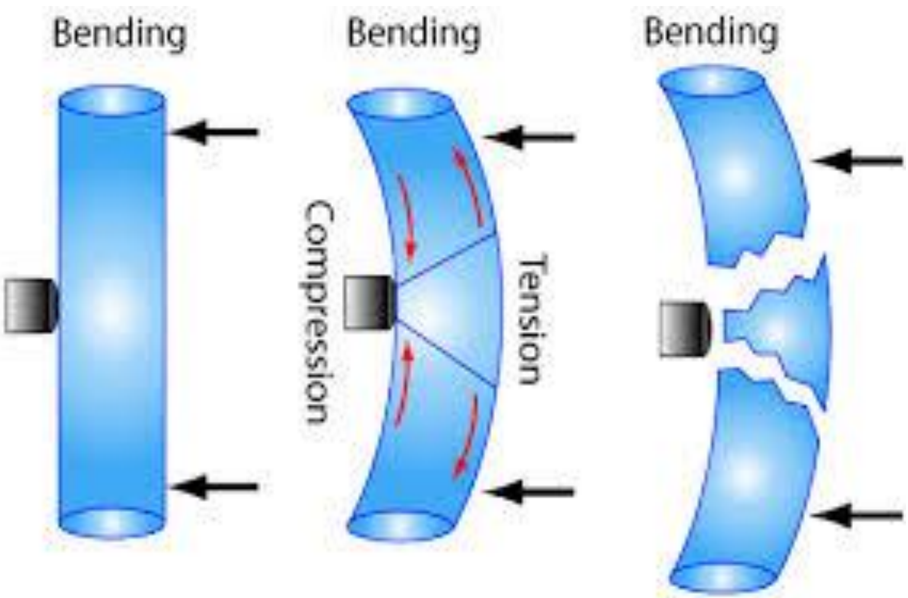
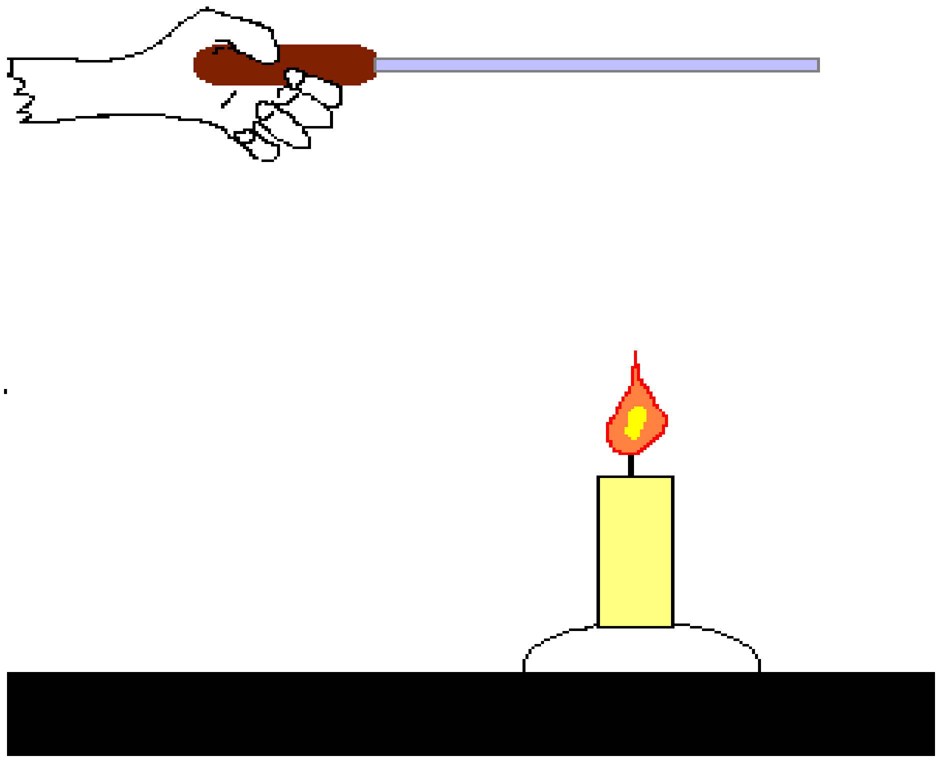
F
SpringerImages

# **4:Torsion** – force producing twisting of a body around its longitudinal axis.



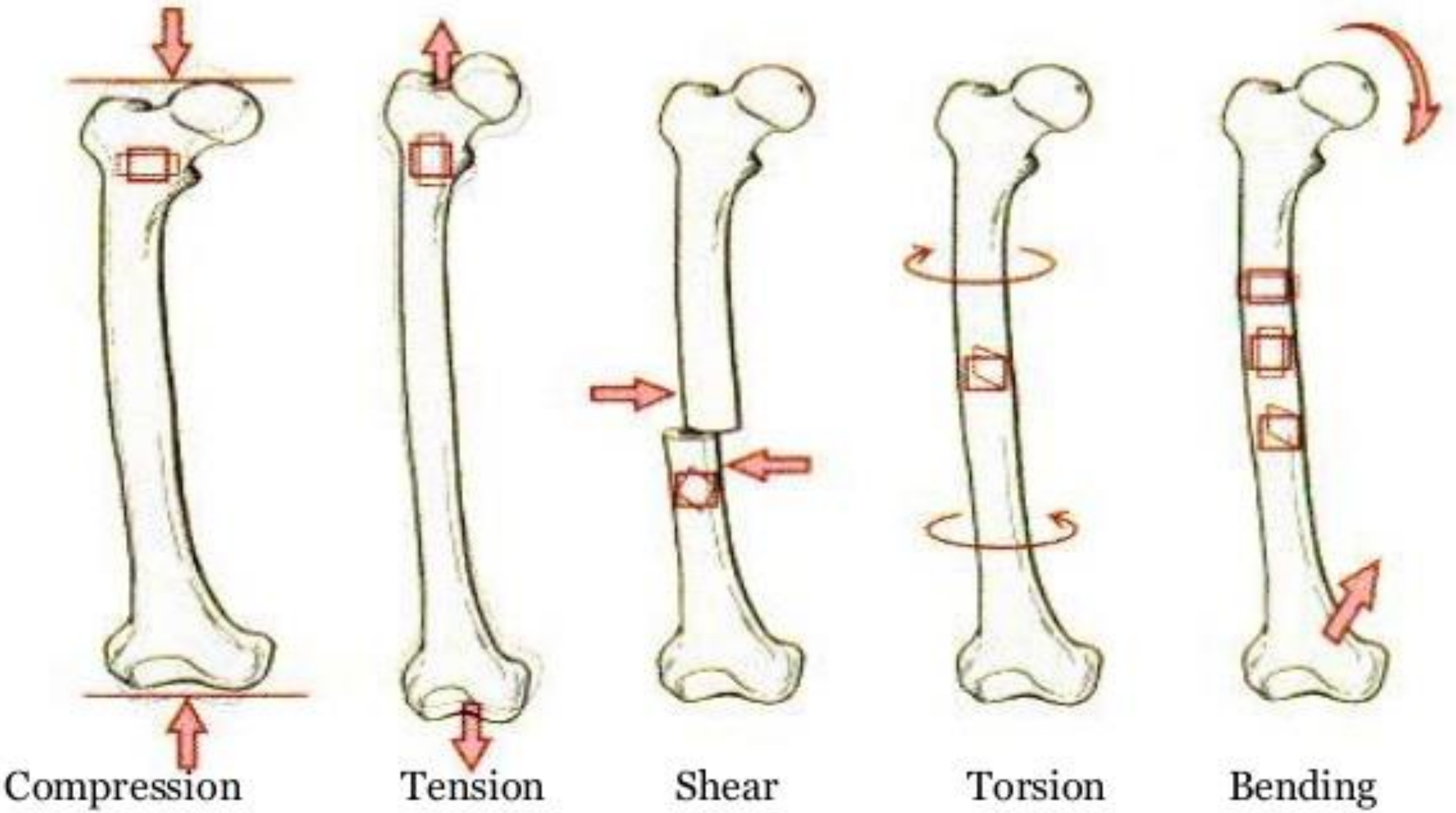
**5:Bending** – asymmetric loading that produces tension on one side of a body's longitudinal axis and compression on the other side



- **6:Combined loading** – simultaneous action of more than one of the pure forms of loading/forces

# Mechanical Loading of Bone



# Sample Problem

How much compressive stress is present on the L1, L2 vertebral disk of a 625 N woman, given that approximately 45% of body weight is supported by the disk

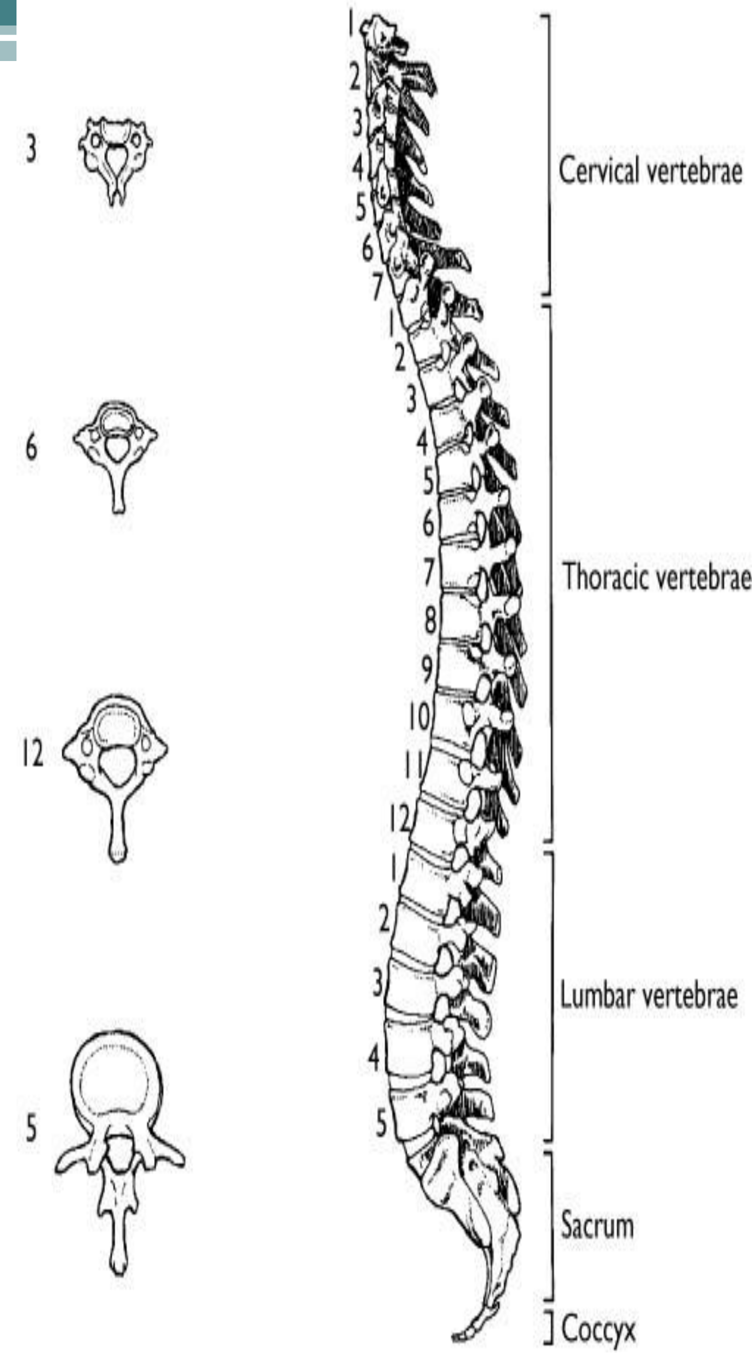
a) When she stands in anatomical positions?

Given: F = (625 N) (0.45) A = 20 cm²

Formula: Stress = F/A

Stress = (625 N) (0.45) / 20 cm²

Stress = 14 N / cm²



b) When she stands erect holding a 222 N suitcase?

Given: $F = (625\ N)(0.45) + 222\ N$  $A = 20\ cm^2$

Formula: $Stress = F/A$

$Stress = [(625\ N)(0.45) + 222\ N]\ /\ 20\ cm^2$

$Stress = 25.2\ N\ /\ cm^2$

# The Effects of Loading

- Deformation/strain

When an external force is applied to the human body, several factors influence whether an injury occurs

1. Magnitude and direction of force
2. Area over which force is distributed
3. Load-deformation curve
4. Yield point (elastic limit)
5. Failure

# Deformation - A change in shape of a material or tissue under a load.

**$Df = (L_f - L_i) = \Delta L$**

where L --> length, width, etc.

$L_i$ = initial length or size

$L_f$ = final length or size

| UNITS: | English | metric |
| --- | --- | --- |
| | **ft** | **m** |
| | in | cm, mm, µm |

# Deformation - A change in shape of a material or tissue under a load.

- **$Df = (L_f - L_i) = \Delta L$**
- **ex.** stretch a rubber band from an initial length of 2 in to a length of 6 in. What is the deformation?

Given: $L_i = 2$ in. $L_f = 6$ in

Find: $\Delta L$

Formula: $\Delta L = (L_f - L_i)$

Solution: $\Delta L = (6 \text{ in} - 2 \text{ in})$

$\Delta L = 4$ in

# Mechanical Strain

- Strain (ε): A measure of the change in shape of a tissue or material under mechanical stress.
- Expressed as a fraction of % of material length or width
- **$\varepsilon$ = Deformation/original size = $\Delta L / L_i$**

$\varepsilon = (L_f - L_i)/L_i$

UNITS: English metric

ft/ft, in/in m/m, cm/cm

**% or strain** **% or strain**

$\varepsilon = |L_f - L_i|/Li \cdot 100 = \%$

# Strain

- A medial collateral ligament (MCL) of the knee is 53 mm long when relaxed at full knee flexion. At full knee extension the measure length (by MRI) is 57 mm. What is the strain?

Given: $L_i = 53$ mm $L_f = 57$ mm

Formula: **$\varepsilon = |L_f - L_i| / L_i \bullet 100$**

Solution: $\varepsilon = |57 \text{ mm} - 53 \text{ mm}| / 53 \text{ mm} \bullet 100$

$\varepsilon = 4 \text{ mm}| / 53 \text{ mm} \bullet 100\%$

$\varepsilon = 0.0755 \text{ mm/mm} \bullet 100\%$

**$\varepsilon = 7.55\ \%$**

# Load, Stress, Deformation, Strain and Material Properties

- **Strength** – the maximal load or maximal stress that can be withstood before injury or failure
  - Ex. Bone stronger in young adults than in children
  - The opposite of strong is **weak**
- **Elasticity** - the ability of a material to return to its original shape once deformed

  **Ex. Rubber band, healthy tendons, muscles**

  - **The opposite of elastic is Plastic**

# Stress-Strain Curve – Relates change in stress to the change in shape it produces

**Stress-Strain or load-deformation curves are the keys to measuring material properties of connective tissues:**

- They tell us about:
  - **Strength**
  - **Stiffness**
  - **Brittleness**
  - **Energy absorbed**
  - **Where injuries occur and the severity of the injury**

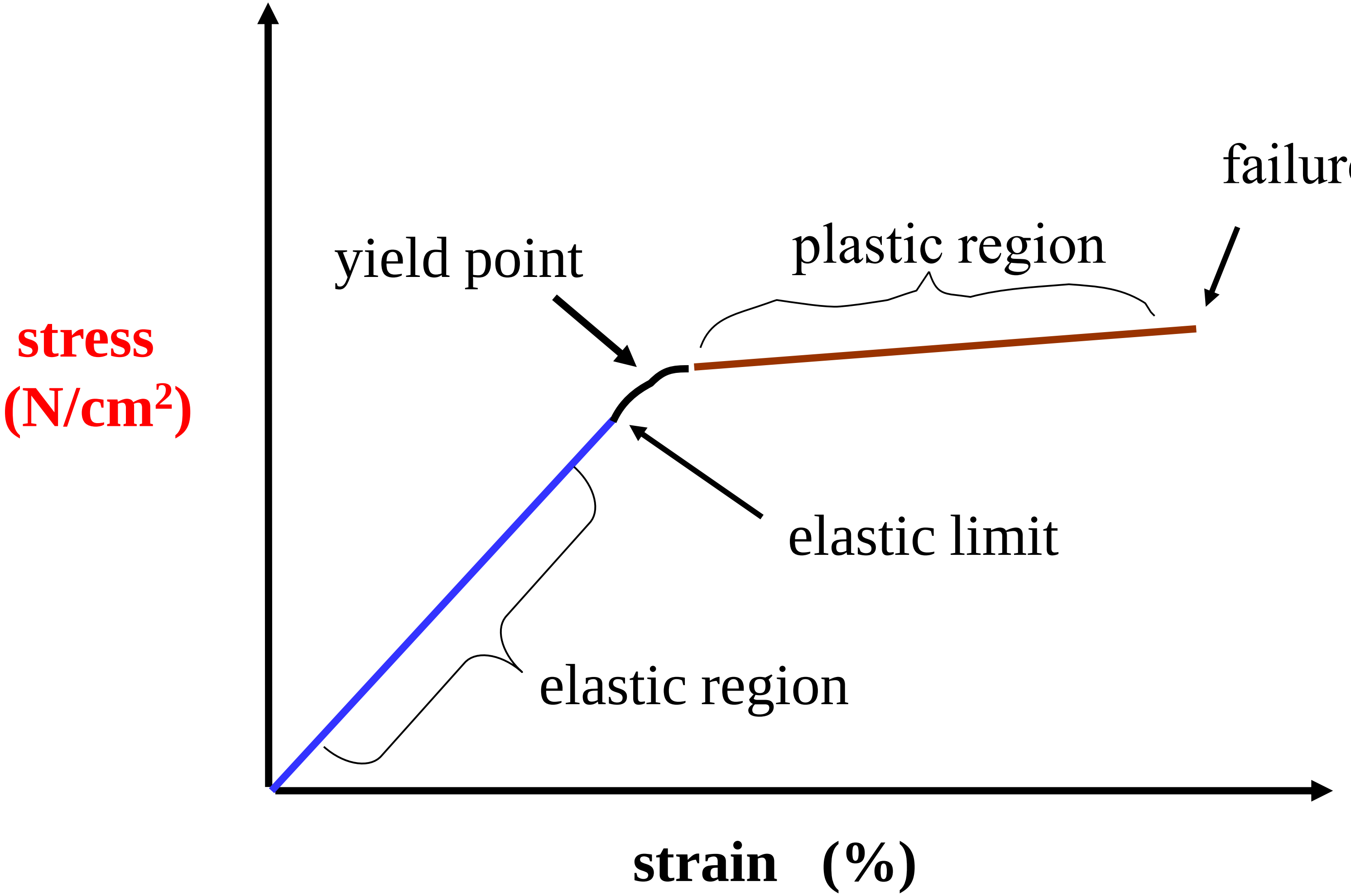
- **Allow us to look at the effects of:**
  - **aging, injury, rehabilitation, immobilization, Exercise**

# Stress-Strain Curve – Relates change in stress to the change in shape it produces

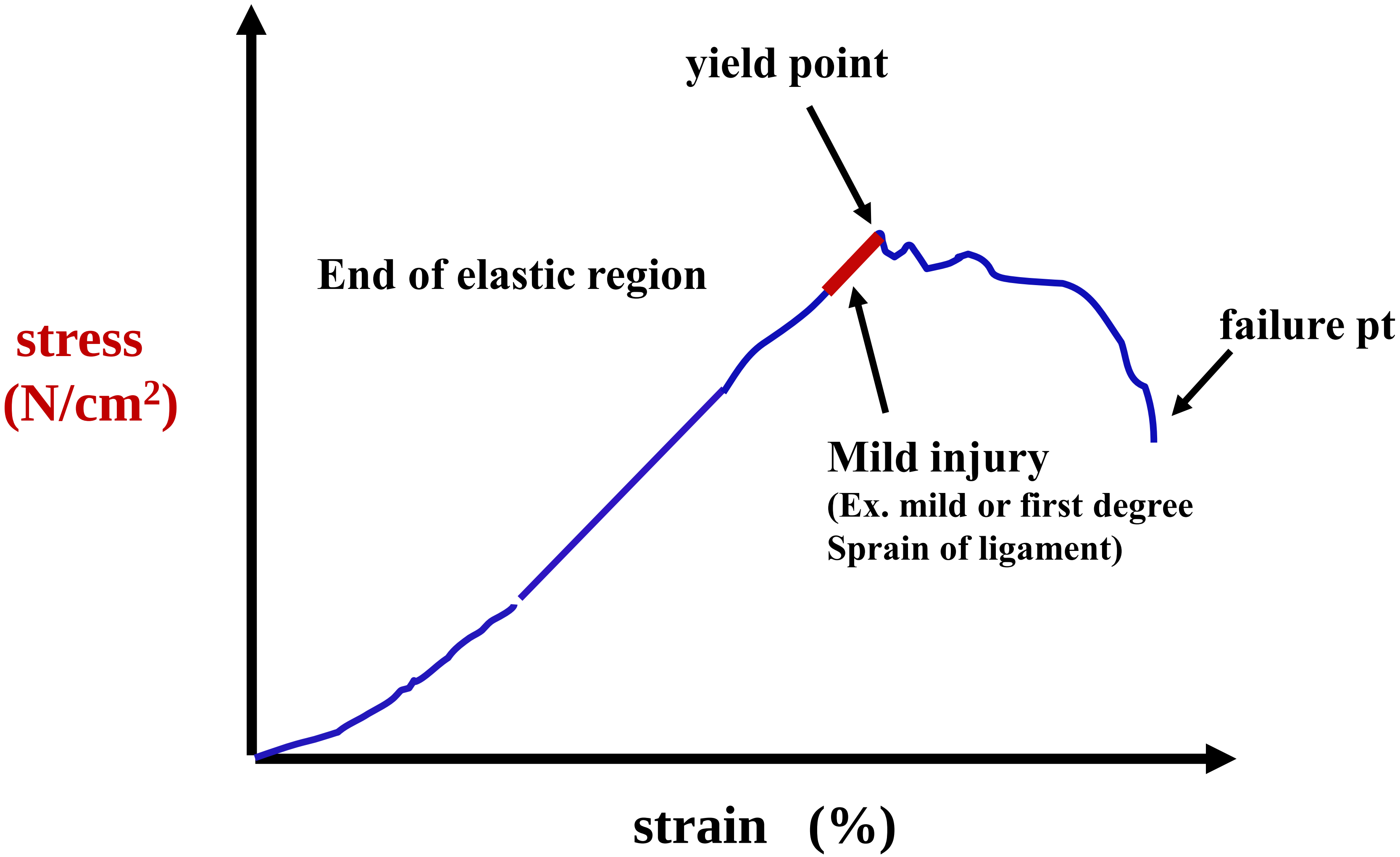
Contains the following regions:

- **elastic region** – The material will return to its original shape when the stress is removed
- **yield point** – The material starts to be permanently deformed (injuries occur just before and beyond this point). Starts at the **elastic limit.**
- **plastic region** – Material shape is permanently changed. Curve flattens out
- **failure** – The material breaks completely or separates.

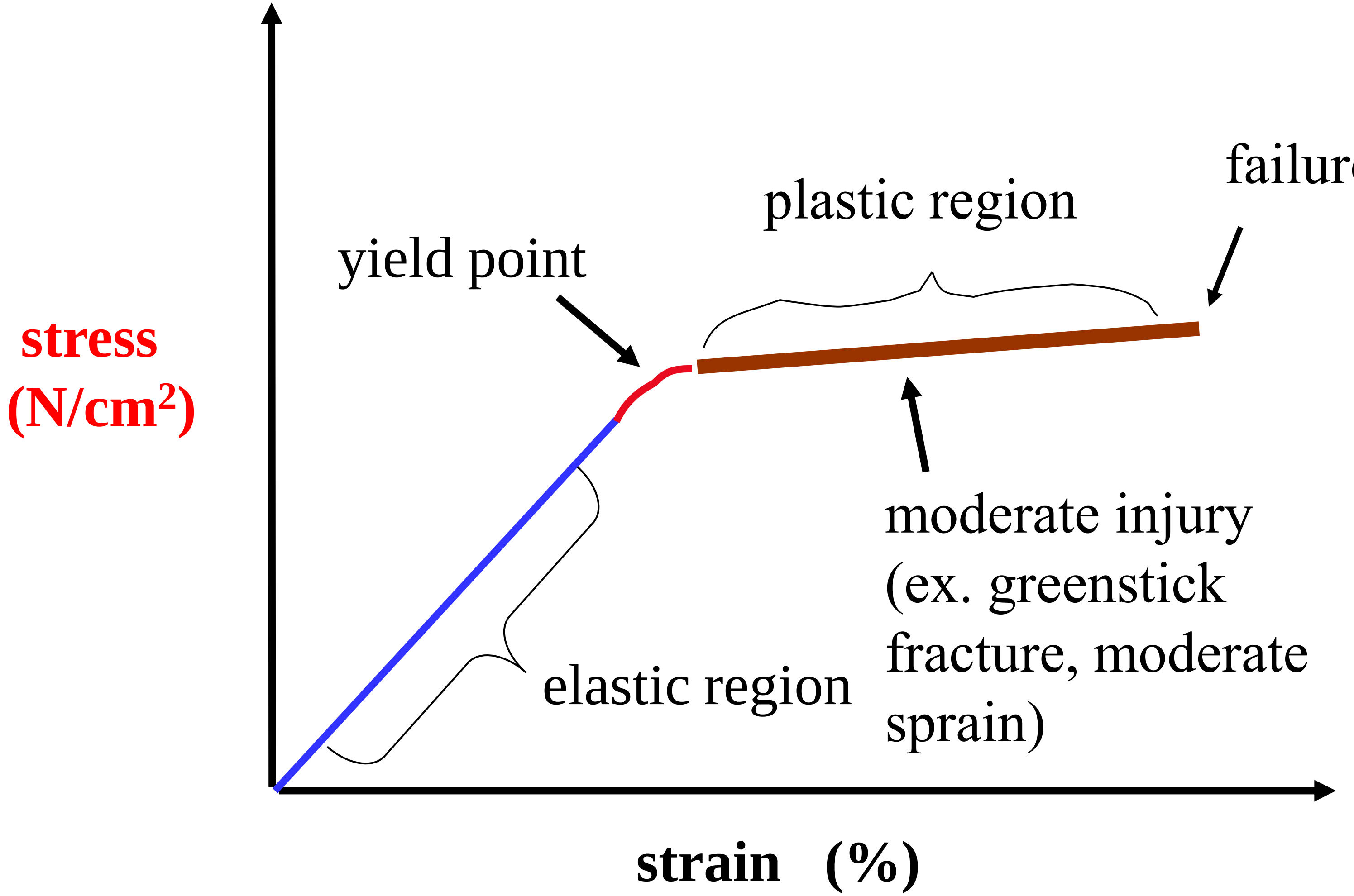
# Stress-strain curves



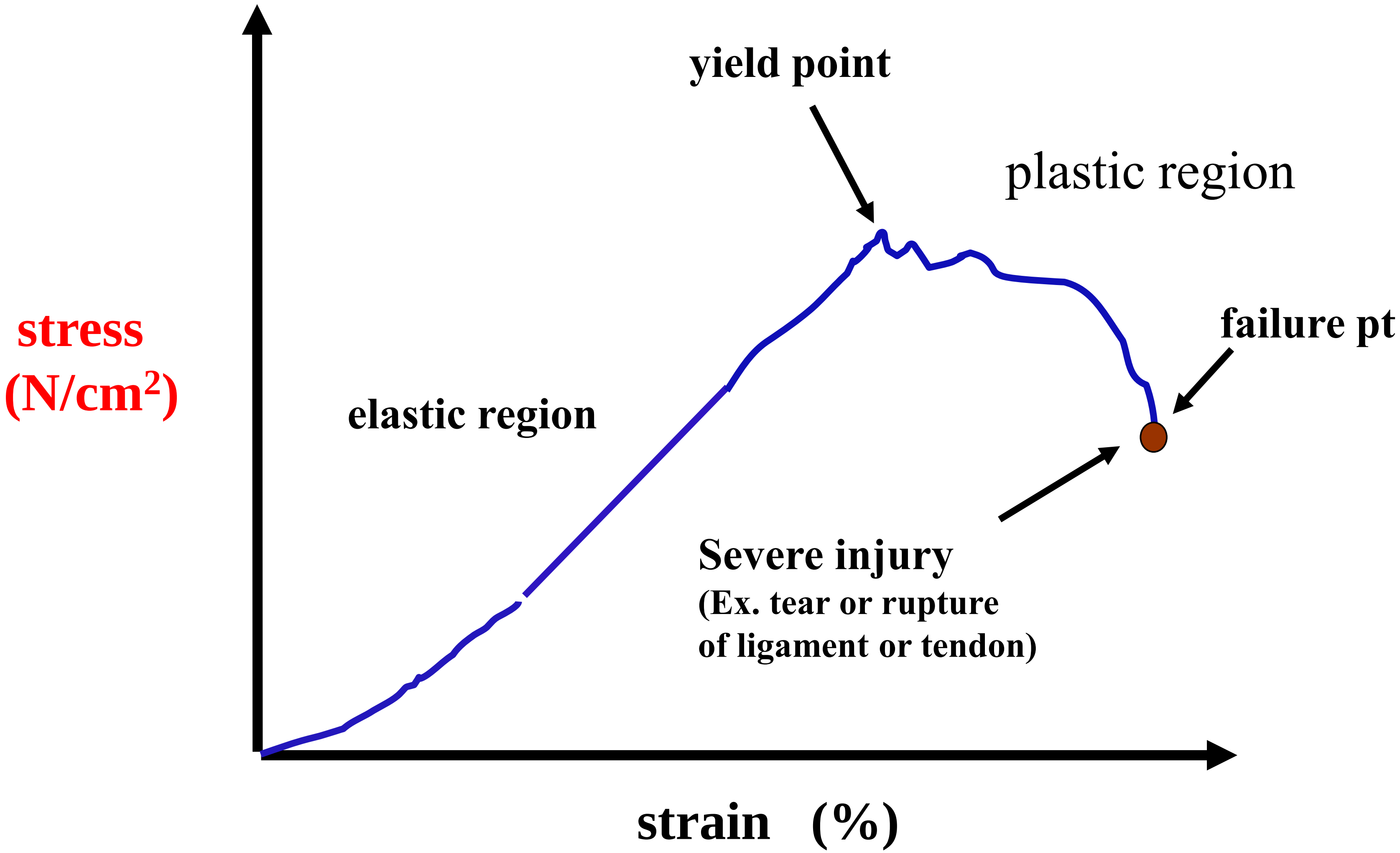
# Stress-Strain Curves



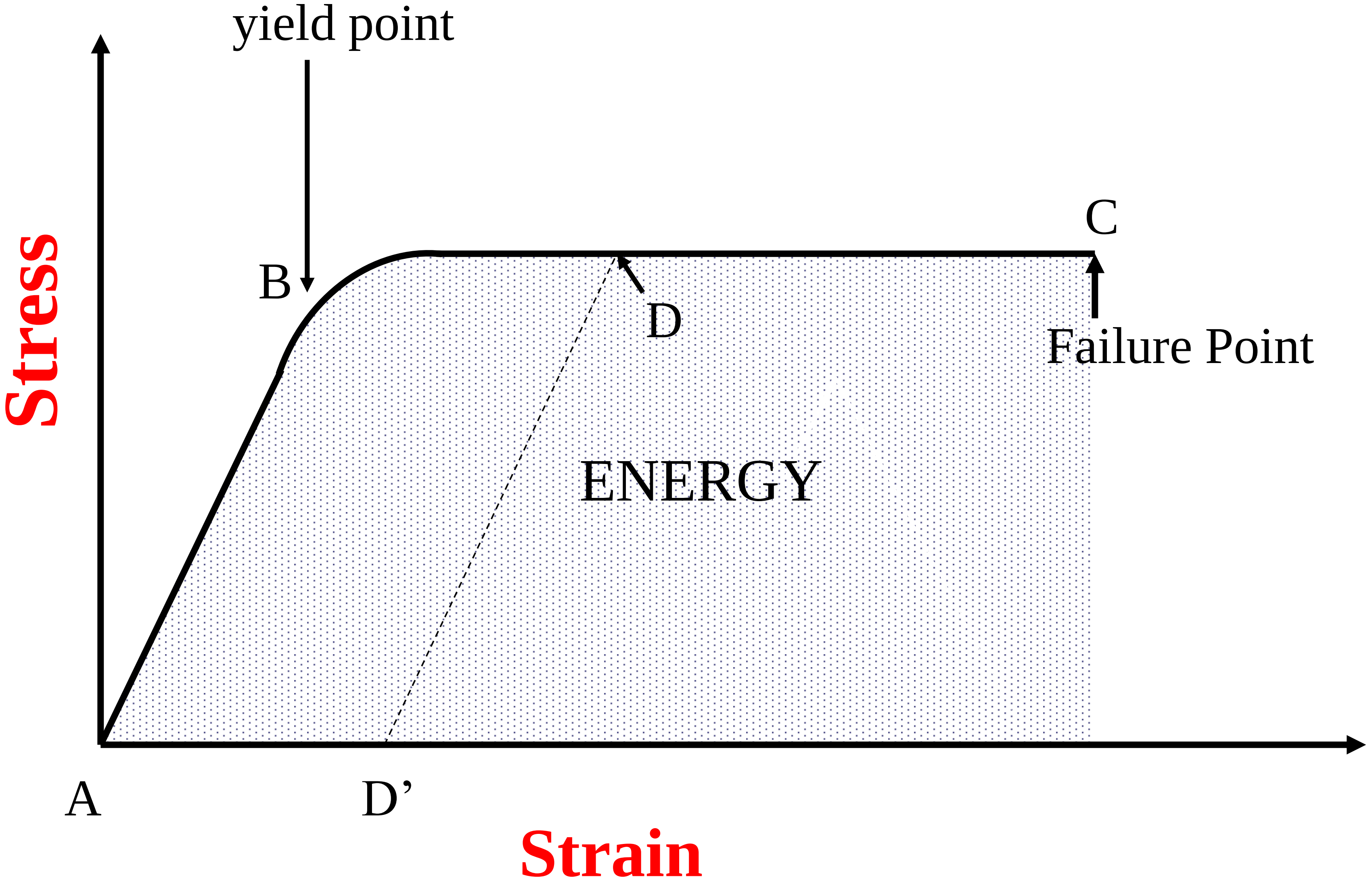
# Stress-strain curves



# Stress-Strain Curves



# Energy Absorption



# Principal stresses

- Maximum and minimum normal stresses are called principal stresses.
- The planes whose normals are in the direction of maximum and minimum stresses are called principal planes.
- Fractures or material failures occur along the planes of maximum stresses.
- Kept in consideration during Structure design .


Thank You
Thank You
Thank You!!!!
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