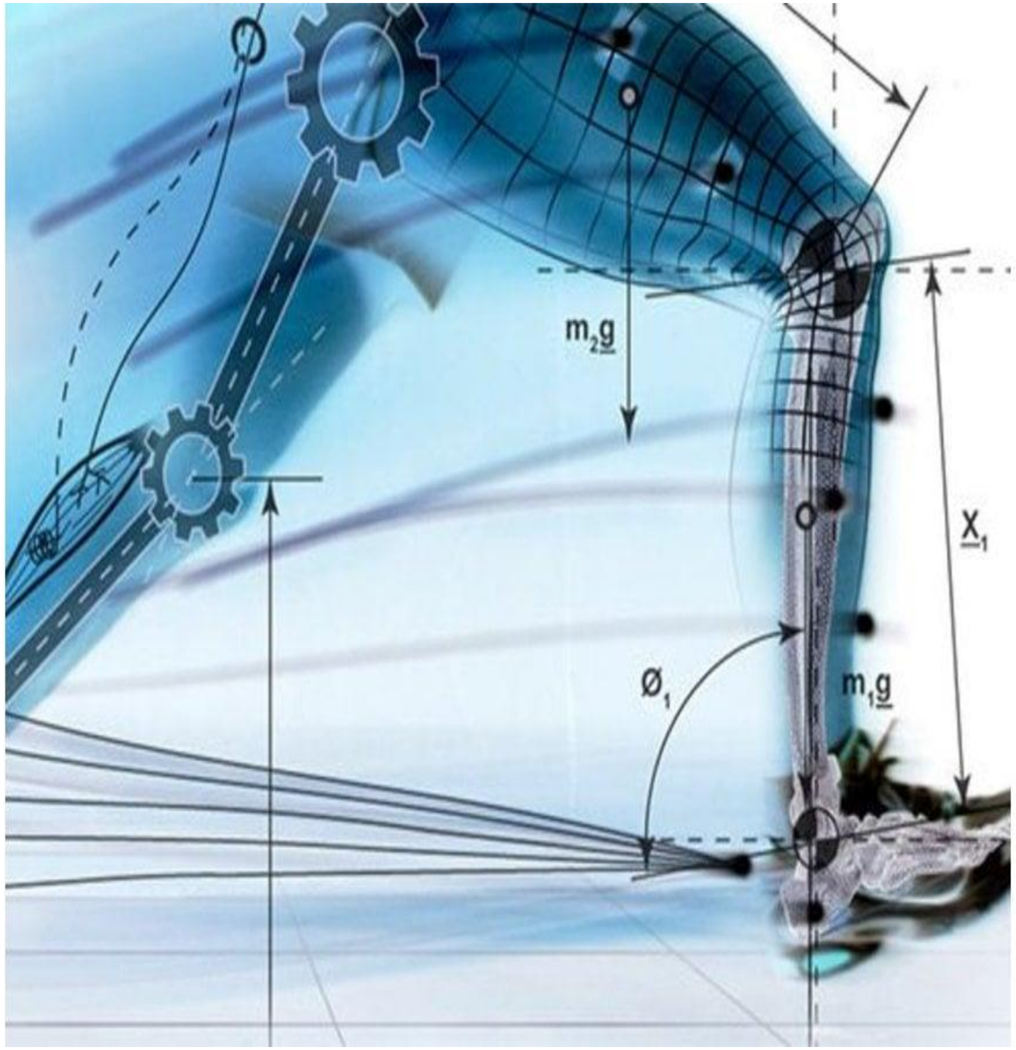
Lecture – 06

Introduction to Biomechanics

Textbook: Fundamentals of Biomechanics Equilibrium, Motion, and Deformation by Nihat Özkaya, Dr. Sci. Margareta Nordin



Biomechanics

- Bios = life.
- Mechanics = study the effect of forces on bodies during static and dynamic situations.
- Mechanics = It is the branch of physics which deals with the interrelations between force, matter and motion.
- Biomechanics is the application of mechanical principles to living structures either animals or human being at rest and during movement.

Biomechanics is the science concerned with the internal & external forces acting on the human body and the effects produced by these forces.

External forces

-environmental forces

-air

-water

-friction

-gravity

Internal forces

-muscular forces

Classification of Biomechanics

Mechanical kinesiology

Study of mechanical factors affecting human body at rest or in motion

Kinematics

Descriptive analysis of mechanical components of a motion without consideration of balanced and unbalanced forces causing motion. It includes- Distance, displacement, speed, velocity, Acceleration, gravitational acceleration.

Qualitative analysis

Naming and evaluating moment components (Non numerical)

Quantitative analysis

Counting and measuring of moment components (Numerical)

Kinetics

Casual analysis of motion with consideration of interacting forces that causes motion. It includes- Force, Inertia, Mass, Weight, Pressure, Moment

Statics

Study of body in a state of equilibrium caused by balanced forces

Dynamics

Study of body in a state of motion change caused by unbalanced forces

Biomechanics deals with the locomotion system which is the musculoskeletal system.

Musculoskeletal system

- The combination of bones, joints, muscles and related connective tissues are known as the musculoskeletal system.

- **Joints:** Where the bones come together (and with the power of the muscles) give a variety and range of motion. Consist of 360 joints.
- **Bones:** The framework of the body is the skeleton (Bones). Bones of the skeletal system consist of 206 bones.
- **Muscles:** The bodies motive power (muscular system). Consist of 640 muscles.

Subfields of Biomechanics

1. Biofluid Mechanics:

- ❖ Fluid mechanics is the application of the laws of force and motion to fluids.
- ❖ There are two branches of fluid mechanics:
  - Fluid Statics or hydrostatics is the study of fluids at rest.
  - Fluid Dynamics is the study of fluids in motion.

- ❖ Biofluid mechanics is focused on how biological systems interact with and/or use liquids/gases.
- ❖ Example includes-blood flow in the human cardiovascular system

2. Biotribology:

- ❖ Tribology comes from the Greek word “tribos,” which means “to rub.”
- ❖ Tribology is generally defined as the study of three areas — friction, lubrication and wear.
- ❖ Biotribology is the study of friction, wear and lubrication of biological systems especially human joints such as hips and knees

3. Comparative Biomechanics:

- ❖ Application of biomechanics to non-human organisms, whether used to gain greater insights into humans or into the functions, ecology and adaptations of the organisms themselves.
- ❖ Common areas of investigation are Animal locomotion and feeding, as these have strong connections to the organism's fitness and impose high mechanical demands.

4. Sports Biomechanics:

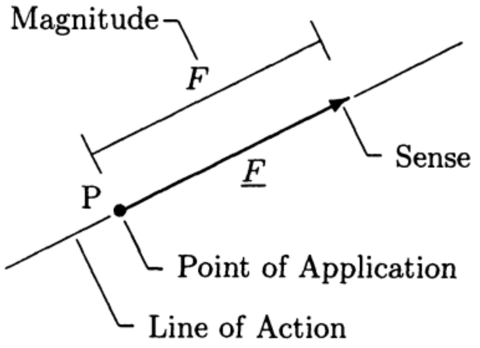
- ❖ In sports biomechanics, the laws of mechanics are applied to human movement in order to gain a greater understanding of athletic performance and to reduce sport injuries as well.
- ❖ Biomechanics in sports can be stated as the muscular, joint and skeletal actions of the body during the execution of a given task, skill and/or technique.

Generalized Procedure

The general method of solving problems in biomechanics may be outlined as follows:

1. Select the system of interest.
2. Postulate the characteristics of the system.
3. Simplify the system by making proper approximations. Explicitly state important assumptions.
4. Form an analogy between the human body parts and basic mechanical elements.
5. Construct a mechanical model of the system.
6. Apply principles of mechanics to formulate the problem.
7. Solve the problem for the unknowns.
8. Compare the results with the behavior of the actual system. This may involve tests and experiments.
9. If satisfactory agreement is not achieved, steps 3 through 7 must be repeated by considering different assumptions and a new model of the system.

Force



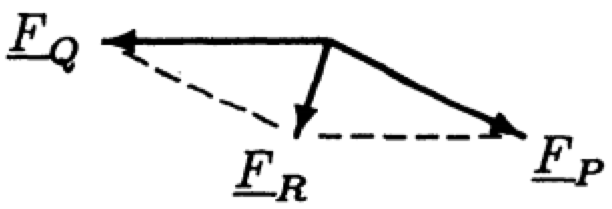
- *Force* may be defined as mechanical disturbance or load.
- A force acting on an object can
  - ✓ deform the object,
  - ✓ change its state of motion, or both.
- Although forces cause motion, it does not necessarily follow that force is always associated with motion. For example, a person sitting on a chair applies his/her weight on the chair, and yet the chair remains stationary.

Properties of force as vector:

- To describe a force fully, its magnitude and direction must be specified.
- As illustrated in Figure 1, a force vector can be illustrated graphically with an arrow such that
  - ➢ the orientation of the arrow indicates the line of action of the force vector,
  - ➢ the arrowhead identifies the direction and sense along which the force is acting, and
  - ➢ the base of the arrow represents the point of application of the force vector.
- Like other vector quantities, forces may be added by utilizing graphical and trigonometric methods.

$$\underline{F}_R = \underline{F}_Q + \underline{F}_P$$

$$F_R = \sqrt{F_Q^{\,2} + F_P^{\,2}}$$



Force

System	Units of Force	Special Name
SI	kilogram-meter/second^2	Newton (N)
c-g-s	gram-centimeter/second^2	dyne (dyn)
British	slug-foot/second^2	pound (lb)

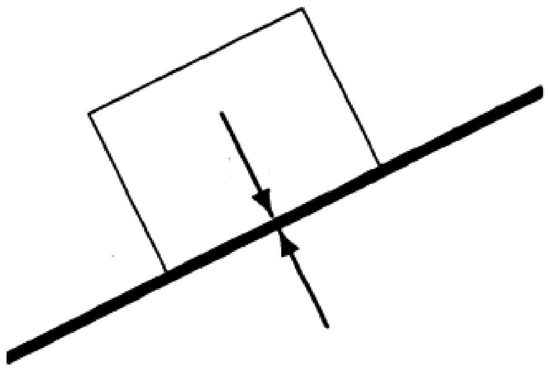
Force Systems:

- Any two or more forces acting on a single body form a *force system.*
- Forces may be classified according to
  - their effect on the bodies upon which they are applied or
  - according to their orientation as compared to one another.

Force

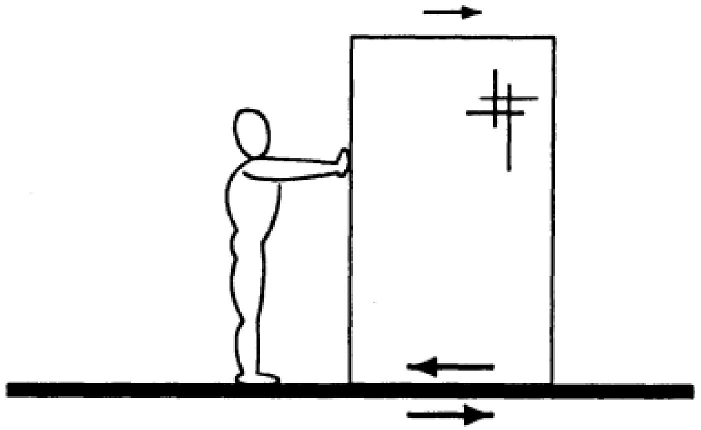
External and Internal forces:

- Force may be broadly classified as *external* or *internal.*
- Almost all commonly known forces are external forces. For example, when you push a cart, hammer a nail, sit on a chair, kick a football, or shoot a basketball, you apply an external force on the cart, nail, chair, football, or basketball.
- Internal forces, on the other hand, are the ones that hold a body together when the body is under the effect of externally applied forces. What holds any material together under externally applied forces is the internal forces generated within that material. If we consider the human body as a whole, then the forces generated by muscle contractions are also internal forces.



Normal and Tangential forces:

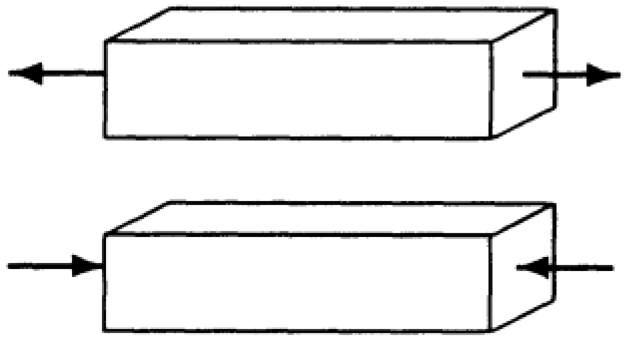
- In mechanics, the word "normal" implies perpendicular. If a force acting on a surface is applied in a direction perpendicular to that surface, then the force is called a *normal force.*
- A *tangential force* is that applied on a surface in the direction parallel to the surface. A good example of a tangential force is the frictional force.



Force

Tensile and Compressive forces:

- A *tensile force* applied on a body will tend to stretch or elongate the body, whereas a *compressive force* will tend to shrink the body in the direction of the applied force
- It must be noted that there are certain materials upon which only tensile forces can be applied. For example, a rope, a cable, or a string cannot withstand compressive forces. The shapes of these materials will be completely distorted under compressive forces. Similarly, muscles contract to produce tensile forces that pull together the bones to which they are attached. Muscles can neither produce compressive forces nor exert a push.



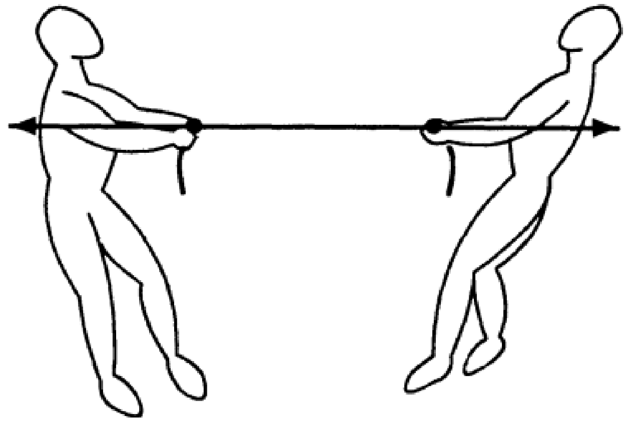
Coplanar forces:

- A system of forces is said to be *coplanar* if all the forces are acting on a two-dimensional (plane) surface. Forces forming a coplanar system have at most two non-zero components. Therefore, with respect to the Cartesian (rectangular) coordinate frame, it is sufficient to analyze coplanar force systems by considering the x and y components of the forces involved.

Force

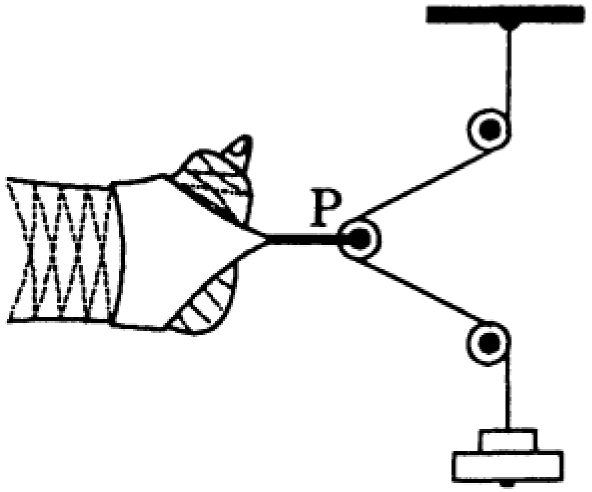
Collinear forces:

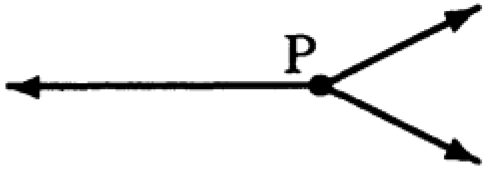
- A system of forces is *collinear* if all the forces have a common line of action. For example, the forces applied on a rope in a rope-pulling contest form a collinear force system



Concurrent forces:

- A system of forces is *concurrent* if the lines of action of the forces have a common point of intersection. Examples of concurrent force systems can be seen in various traction devices. Owing to the weight in the weight pan, the cables stretch and forces are applied on the pulleys and the leg. The force applied on the leg holds the leg in place.

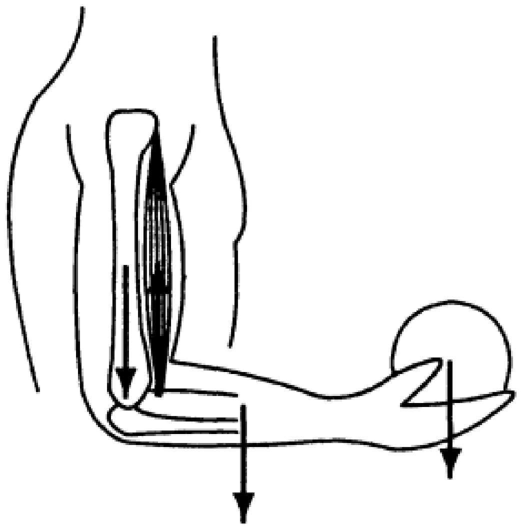




Force

Parallel forces:

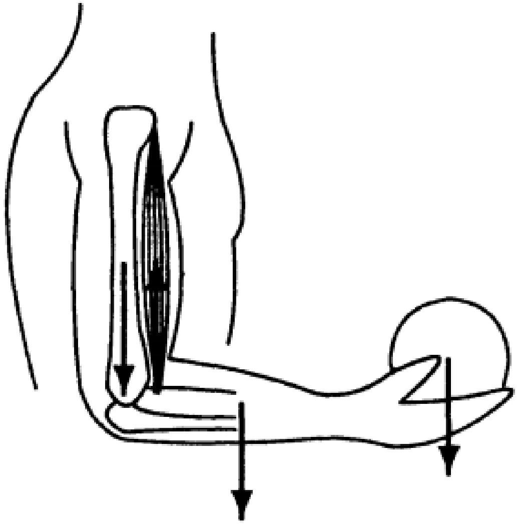
- A set of forces form a *parallel* force system if the lines of action of the forces are parallel to each other.
- An example of a parallel force system is illustrated in Figure by a human arm flexed at a right angle and holding an object. The forces on the forearm are the weight of the object, the weight of the arm itself, the tension in the biceps muscle, and the joint reaction force at the elbow.



Force

Gravitational force:

The force exerted by Earth on an object is called the *gravitational force* or *weight* of the object. The magnitude of weight of an object is equal to the mass of the object times the magnitude of gravitational acceleration.



System	Gravitational Acceleration
SI	9.81 m/s^2
c-g-s	981 cm/s^2
British	32.2 ft/s^2

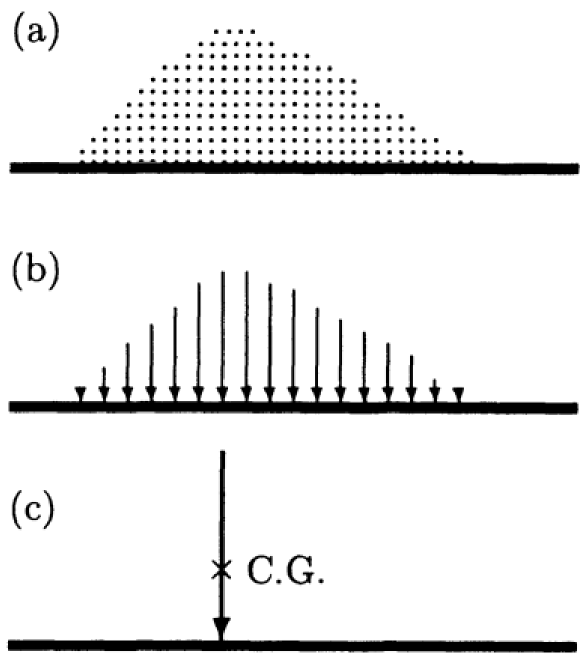
Force

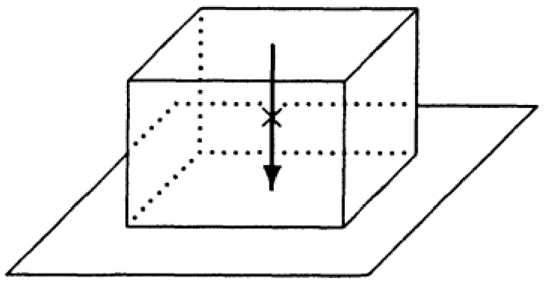
Distributed force system:

- Consider a pile of sand lying on a flat horizontal surface, as illustrated in Figure. The sand exerts force or load on the surface, which is distributed over the area under the sand. The load is not uniformly distributed over this area. The marginal regions under the pile are loaded less as compared to the central regions.
- For practical purposes, the distributed load applied by the sand may be represented by a single force, called the *equivalent force* or *concentrated load.* The magnitude of the equivalent force would be equal to the total weight of the sand. The line of action of this force would pass through a point called the *center of gravity.*
- *Average pressure* is equal to total applied force divided by the area of the surface over which the force is applied in a direction perpendicular to the surface. It is also known as *load intensity.*

$$p = \frac{W}{A}$$

SYSTEM	UNITS OF PRESSURE	SPECIAL NAME
SI	$kg/m\text{-}s^2$ or N/m^2	Pascal (Pa)
c-g-s	$gm/cm\text{-}s^2$ or dyn/cm^2	
British	lb/ft^2 or lb/in^2	psf or psi

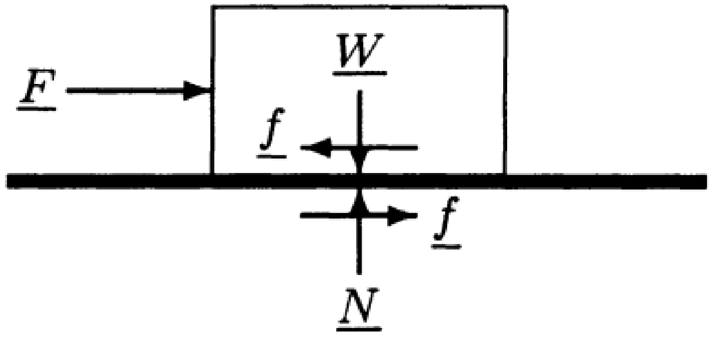




Force

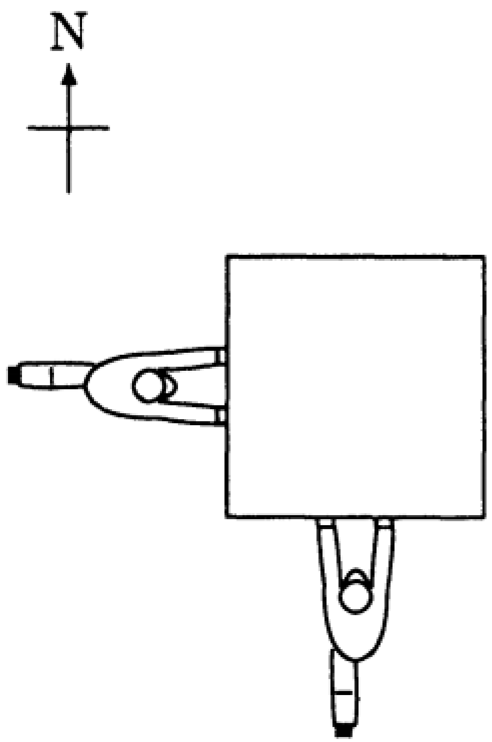
Frictional force:

- *Frictional forces* occur between two surfaces in contact when one surface slides or tends to slide over the other.
- When a body is in motion on a rough surface or when an object moves in a fluid (a viscous medium such as water), there is resistance to motion because of the interaction of the body with its surroundings.
- In some applications friction may be desirable, while in others it may have to be reduced to a minimum. For example, it would be impossible to start walking in the absence of frictional forces. Automobile, bicycle, and wheelchair brakes utilize the principles of friction.
- On the other hand, friction can cause heat to be generated between the surfaces in contact. Excess heat can cause early, unexpected failure of machine parts. Friction may also cause wear.
- Friction depends on the nature of the two sliding surfaces.
- For example, if all other conditions are the same, the friction between two metal surfaces would be different than the friction between two wood surfaces in contact.
- Friction is larger for materials that strongly interact.
- Friction depends on the surface quality and surface finish. A good surface finish can reduce frictional effects. The frictional force does not depend on the total surface area of contact.



Force

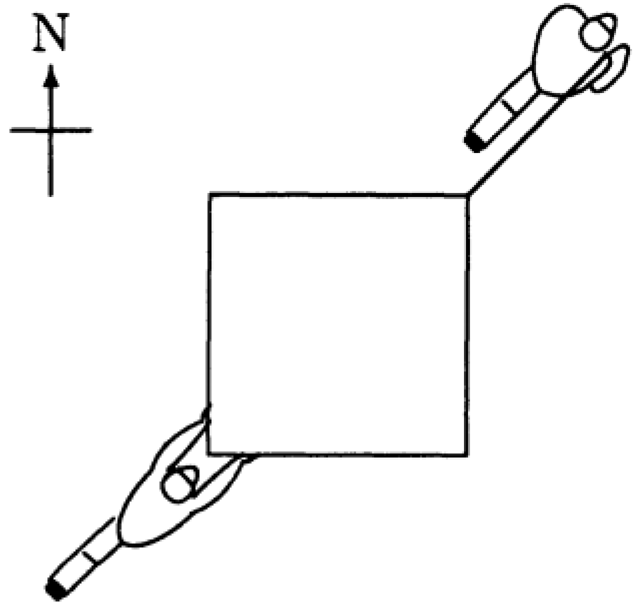
- As illustrated in Figure, consider two workers who are trying to move a block. Assume that both workers are applying equal magnitude forces of 200 N. One of the workers is pushing the block toward the north and the other worker is pushing it toward the east. Determine the magnitude and direction of the net force applied by the workers on the block.



Answer: 283 N, northeast.

Force

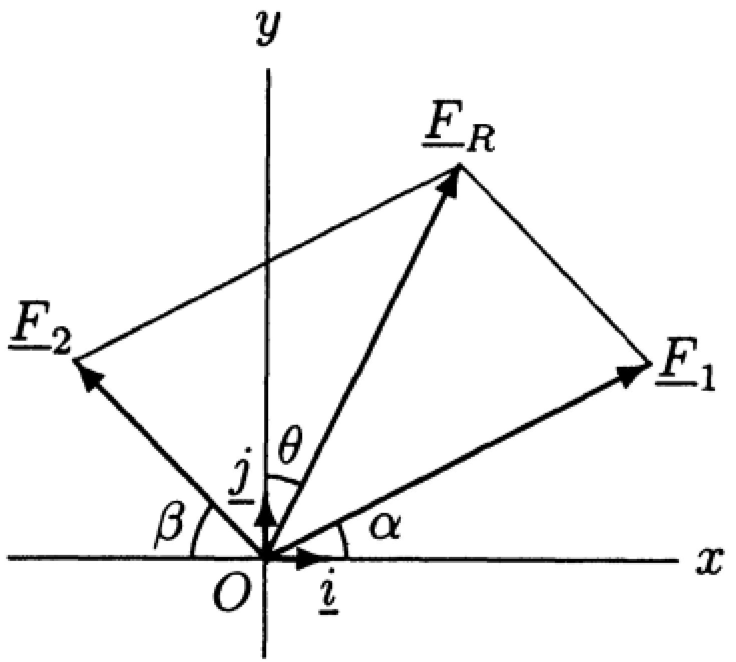
- As illustrated in Figure, consider two workers who are trying to move a block. Assume that both workers are applying equal magnitude forces of 200 N. One of the workers is pushing the block toward the northeast, while the other is pulling it in the same direction. Determine the magnitude and direction of the net force applied by the workers on the block.



Answer: 400 N, northeast.

Force

Consider the two forces, *F1* and *F2* shown in Figure. Assume that these forces are applied on an object in the xy-plane. The first force has a magnitude *F1* = 15 N and is applied in a direction that makes an angle $\alpha = 30°$ with the positive *x* axis, and the second force has a magnitude *F2* = 10 N and is applied in a direction that makes an angle $\beta = 45°$ with the negative *x* axis.

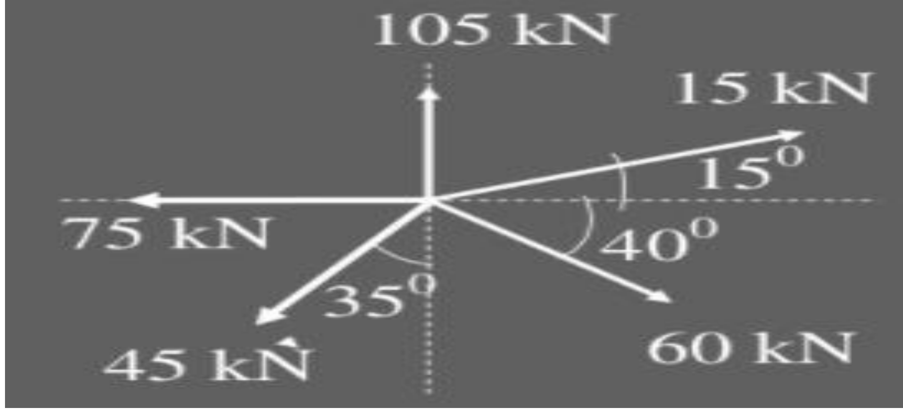


(a) Calculate the scalar components of *F*1 and *F*2 along the *x* and *y* directions.
(b) Express *F*1 and *F*2 in terms of their components.
(c) Determine an expression for the resultant force vector, F_R
(d) Calculate the magnitude of the resultant force vector.
(e) Calculate angle (θ) that F_R makes with the positive *y axis*.

(a) $F_{1x} = 13.0$ N, $F_{1y} = 7.5$ N, $F_{2x} = 7.1$ N, $F_{2y} = 7.1$ N
(b) $\underline{F}_1 = 13.0\underline{i} + 7.5\underline{j}$ and $\underline{F}_2 = -7.1\underline{i} + 7.1\underline{j}$
(c) $\underline{F}_R = 5.9\underline{i} + 14.6\underline{j}$
(d) $F_R = 15.7$ N
(e) $\theta = 22°$

Resultant of Forces

❖ Obtain the resultant of the concurrent coplanar forces acting as shown in figure-



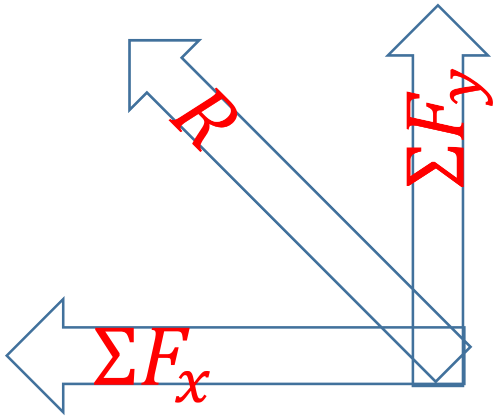
Answer:

$+\rightarrow \Sigma F_x = 15\cos 15° + 0 - 75 - 45\,sin\,35° + 60cos40°$ = -40.359 KN

$+\uparrow \Sigma F_y = 15\sin 15° + 105 - 0 - 45\cos 35° - 60sin40°$ = +33.453 KN

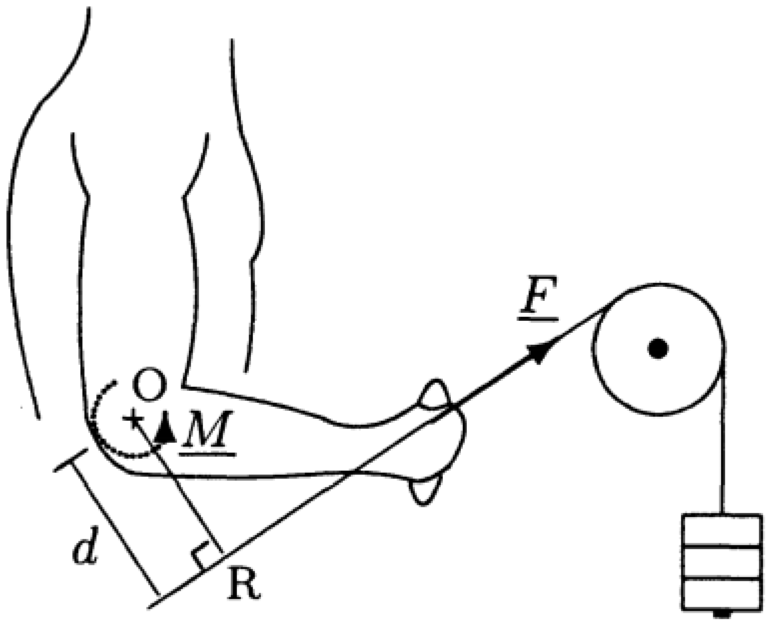
R=$\sqrt{(33.453)^2+(40.359)^2}$ =52.42 KN

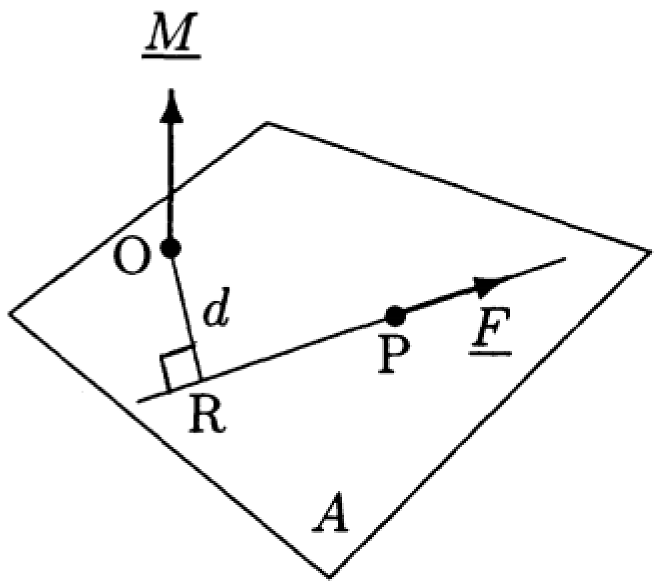
$\theta = \tan^{-1}$(33.453/ 40.359) =39.65°



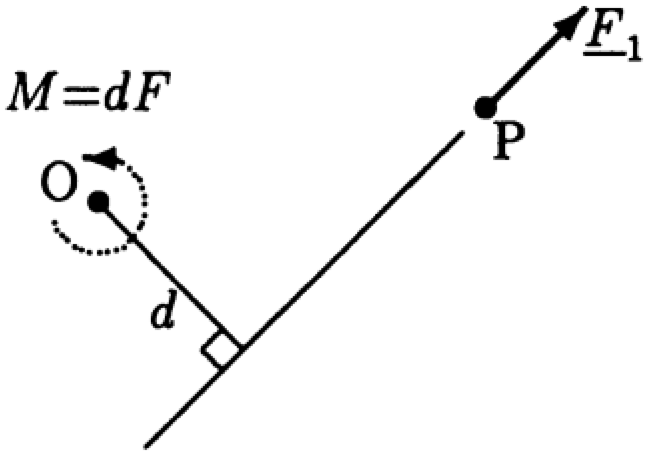
Moment of a force about an axis

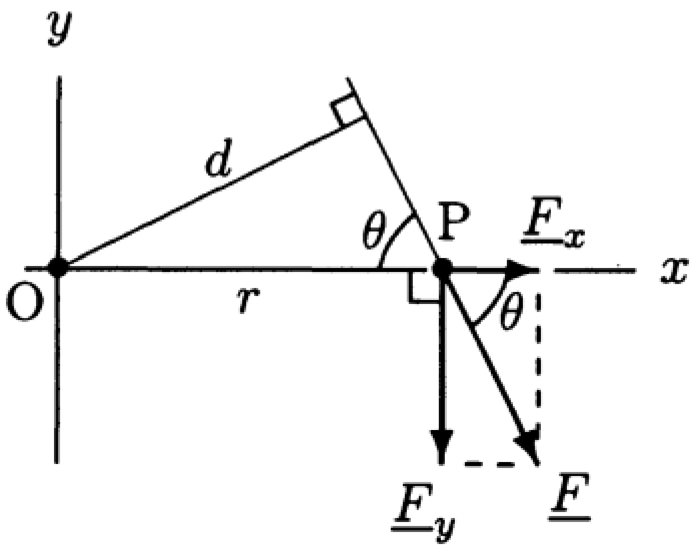
- The applied force can also tend to rotate the body about an axis in addition to motion. This rotational tendency is known as moment.
- Moment is the tendency of a force to make a rigid body to rotate about an axis.
- This is a vector quantity having both magnitude and direction.
- The magnitude of the moment of a force about a point is equal to the magnitude of the force times the length of the shortest distance between the point and the line of action of the force, which is known as the *lever* or *moment arm.*

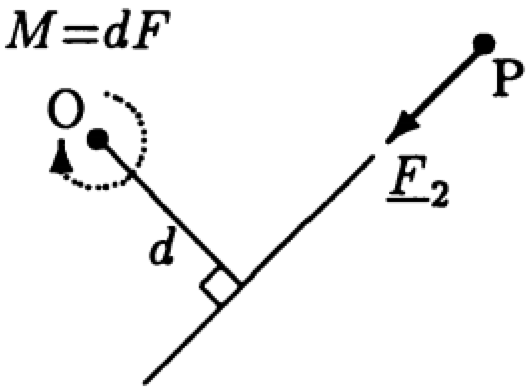


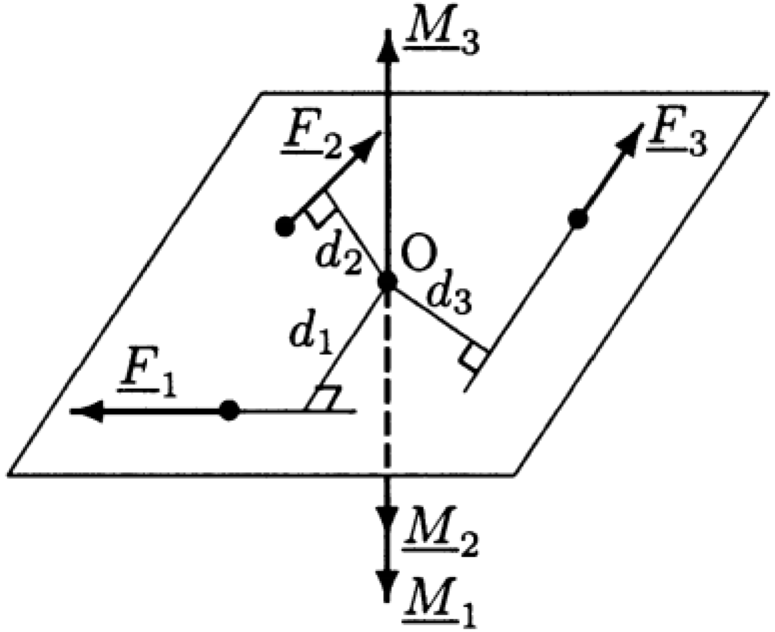


Moment of a force about an axis









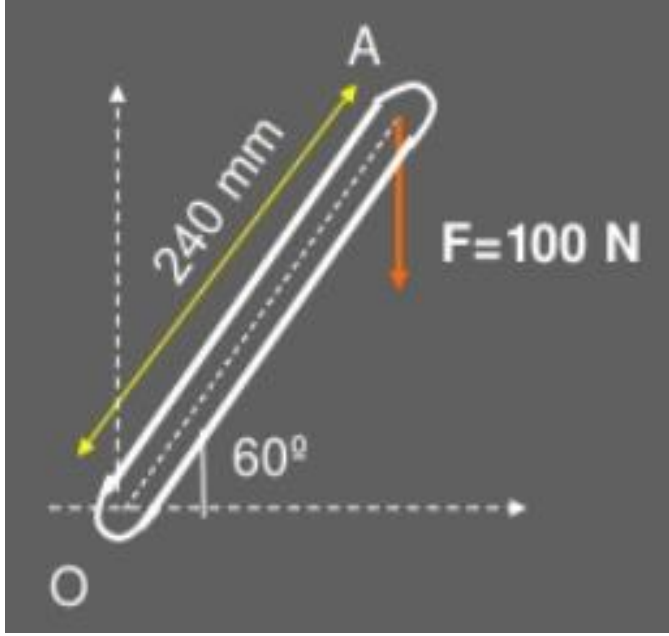
❖ A 100N vertical force is applied to the end of a lever at ‘A’, which is attached to the shaft at ‘O’ as shown in the figure. Determine-

1.The moment of 100N force about ‘O’.

2.Magnitude of the horizontal force applied at ‘A’, which develops same moment about ‘O’.

3.The smallest force at ‘A’, which develops same effect about ‘O’.

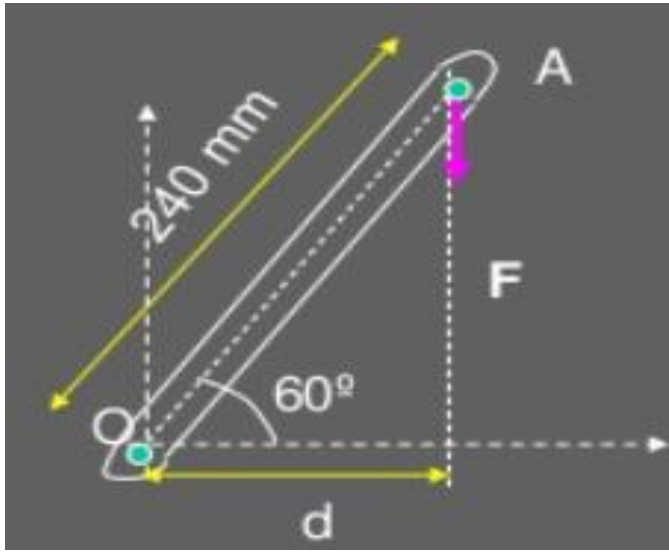
4.How far from the shaft a 240N vertical force must act to develop the same effect?



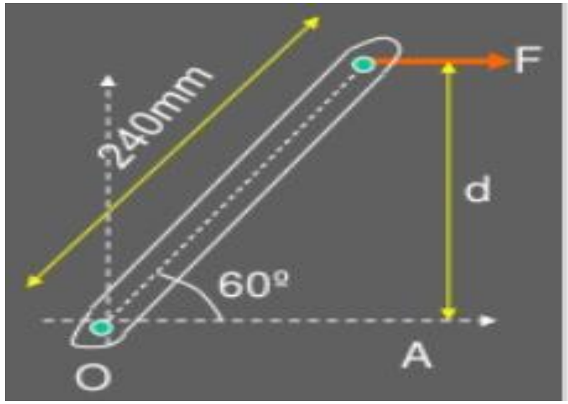
<u>Solution:</u> 1)Perpendicular distance from the line of action of force F to the moment center ‘O’ =d =240cos60° $= 120\ mm$

Moment about ‘O’= F*d=100*120

=12,000 N-mm (clockwise)



2. Magnitude of the horizontal force applied at ‘A’, which develops same moment about ‘O’.

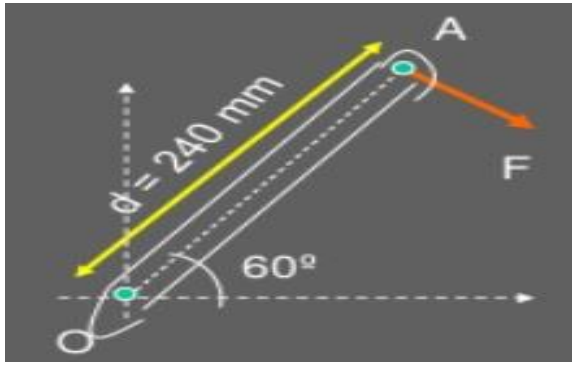


If force F is acting horizontally then the perpendicular distance between the line of action of horizontal force F at A, to moment center ‘O’-

$$=d=240\sin60° = 207.85\ mm$$

Therefore, 12,000=F*207.85 $\therefore F = \frac{12,000}{207.85} = 57.73\ N$

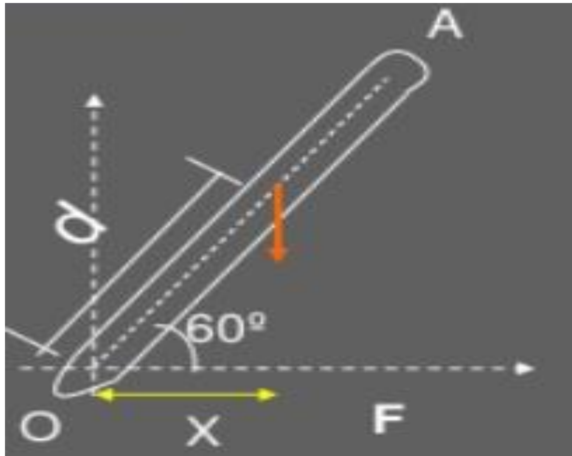
3.The smallest force at ‘A’, which develops same effect about ‘O’.



Force is minimum when the perpendicular distance is maximum so as to produce same moment (12,000 N-mm). $\therefore d = 240\ mm$

Therefore, $F_{min} = \frac{12,000}{240} = 50$ N

4.How far from the shaft a 240N vertical force must act to develop the same effect?

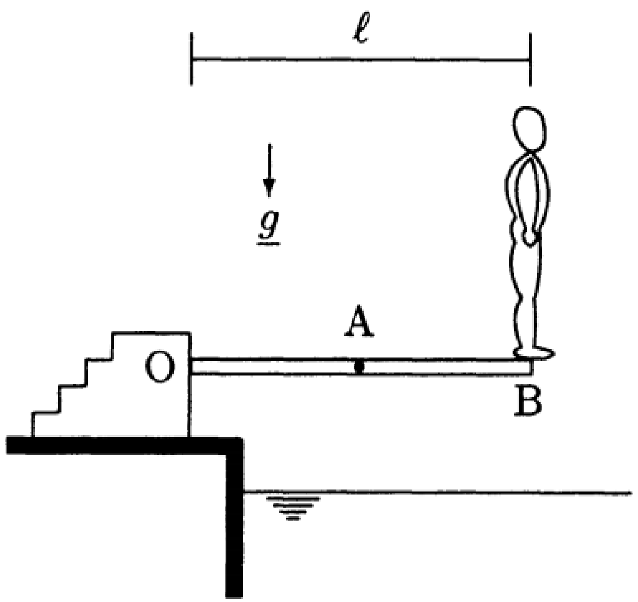


If the distance along the shaft axis is d

Therefore, $12,000 = 240 * d\cos60°$

$$\therefore d = \frac{12,000}{240\cos60}° = 100\ mm$$

- A person preparing to dive into a pool. The horizontal diving board has a uniform thickness, mounted to the ground at 0, has a mass of 120 kg, and is l= 4 m in length. The person has a mass of 90 kg and stands at B which is the free-end of the board. Point A indicates the location of the center of gravity of the board. Point A is equidistant from points o and B.



- Determine the moments generated about point 0 by the weights of the person and the board. Calculate the net moment about point O.

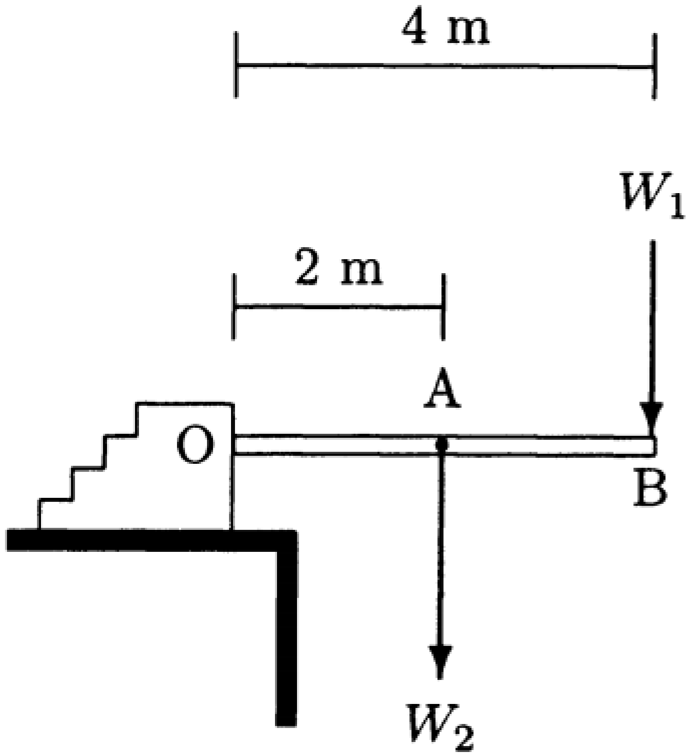
$$W_1 = m_1 g = (90\ \text{kg})(9.8\ \text{m/s}^2) = 882\ \text{N}$$

$$W_2 = m_2 g = (120\ \text{kg})(9.8\ \text{m/s}^2) = 1176\ \text{N}$$

$$M_1 = \ell W_1 = (4\ \text{m})(882\ \text{N}) = 3528\ \text{N-m} \qquad \text{(cw)}$$

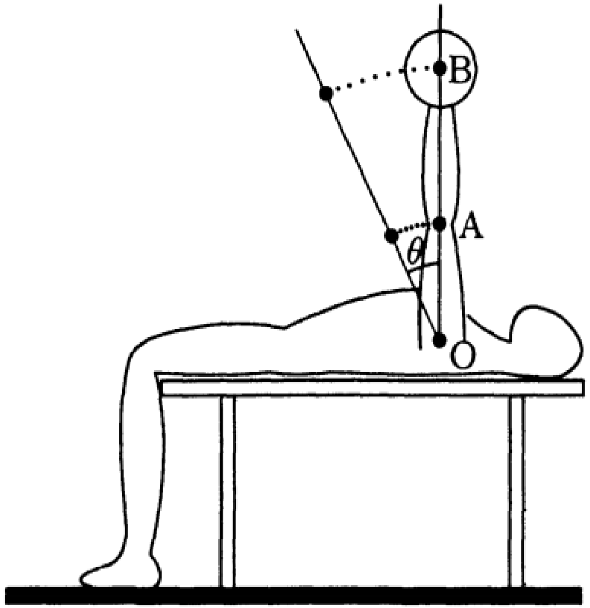
$$M_2 = \frac{\ell}{2} W_2 = (2\ \text{m})(1176\ \text{N}) = 2352\ \text{N-m} \qquad \text{(cw)}$$

$$M_{net} = M_1 + M_2 = 5880\ \text{N-m}$$



- An athlete doing shoulder muscle strengthening exercises by lowering and raising a barbell with straight arms. 0 represents the shoulder joint, A is the center of gravity of one arm, and B is a point of intersection of the centerline of the barbell and the extension of line OA. The distance between 0 and A is a = 24 cm and the distance between 0 and B is b = 60 cm. Each arm weighs W1 = 50 N and the total weight of the barbell is W2 = 300N.

- Determine the net moment due to W1 and W2 about the shoulder joint as a function of θ, which is the angle the arm makes with the vertical. Calculate the moments for θ = 0°, 15°, 30° , 45°, and 60°.



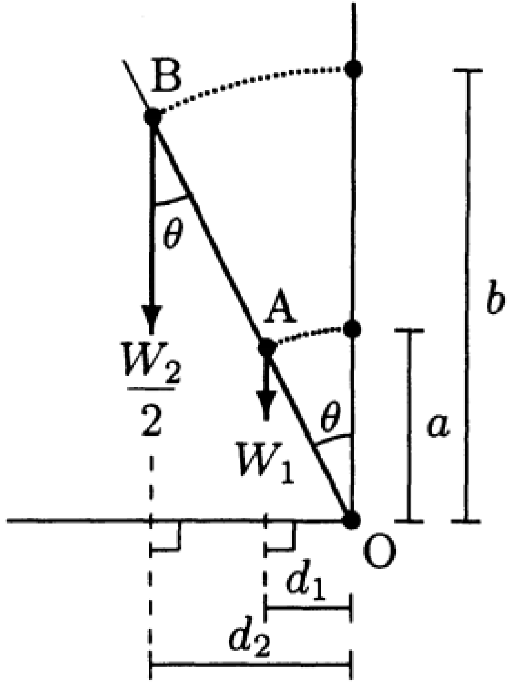
$$d_1 = a \sin\theta$$

$$d_2 = b \sin\theta$$

$$M_1 = d_1 W_1 = a W_1 \sin\theta = (0.24)(50)\sin\theta = 12 \sin\theta$$

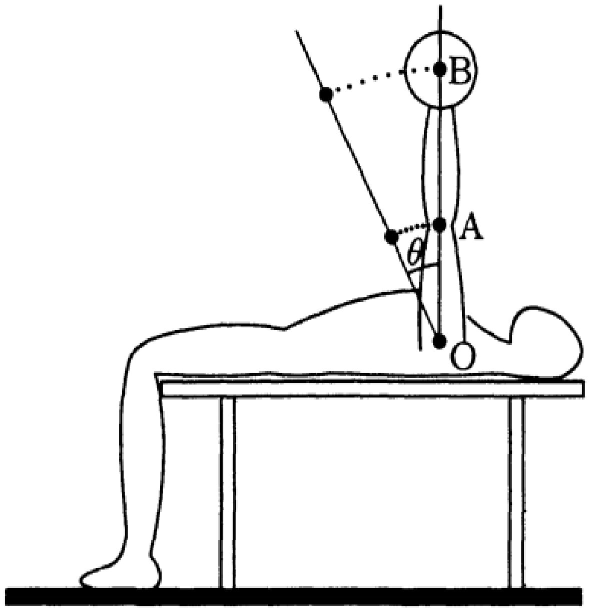
$$M_2 = d_2 \frac{W_2}{2} = b \frac{W_2}{2} \sin\theta = (0.60)\left(\frac{300}{2}\right)\sin\theta = 90 \sin\theta$$

$$M_O = M_1 + M_2 = 12 \sin\theta + 90 \sin\theta = 102 \sin\theta \quad \text{N-m} \quad \text{(ccw)}$$

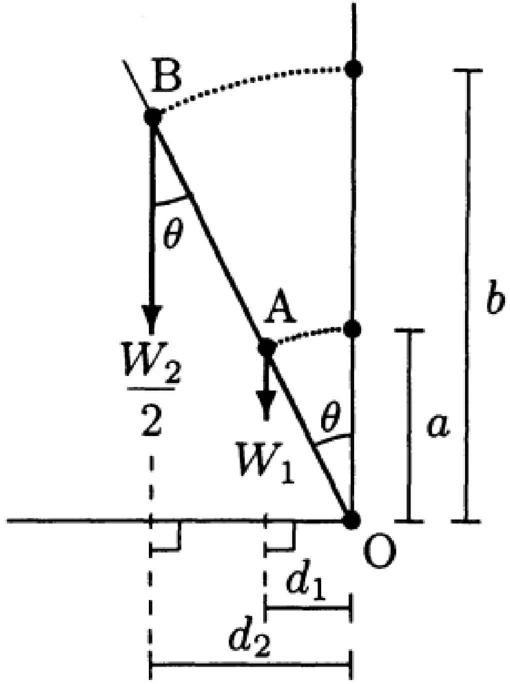


- An athlete doing shoulder muscle strengthening exercises by lowering and raising a barbell with straight arms. 0 represents the shoulder joint, A is the center of gravity of one arm, and B is a point of intersection of the centerline of the barbell and the extension of line OA. The distance between 0 and A is a = 24 cm and the distance between 0 and B is b = 60 cm. Each arm arm weighs WI = 50 N and the total weight of the barbell is W2 = 300N.

- Determine the net moment due to WI and W2 about the shoulder joint as a function of 0, which is the angle the arm makes with the vertical. Calculate the moments for θ = 0°, 15°, 30° , 45°, and 60°.



θ	$\sin\theta$	M_O (N-m)
0°	0.000	0.0
15°	0.259	26.4
30°	0.500	51.0
45°	0.707	72.1
60°	0.866	88.3

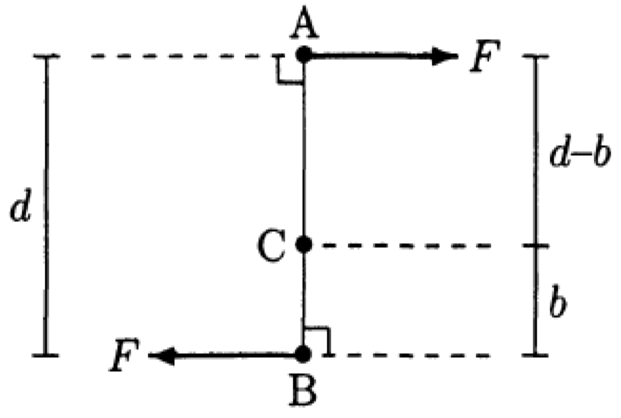


Couple and Couple-moment

- A special arrangement of forces that is of importance is called *couple*, which is formed by two parallel forces with equal magnitude and opposite directions.
- On a rigid body, the couple has a pure rotational effect. The rotational effect of a couple is quantified with *couple-moment.*
- The net moment about point A is M = $d\ F$ (cw), which is due to the force applied at B.
- The net moment about point B is also $M=dF$ (cw), which is due to the force applied at A.
- The net moment about C is,

$$M = (d - b)\,F + b\,F = d\,F$$

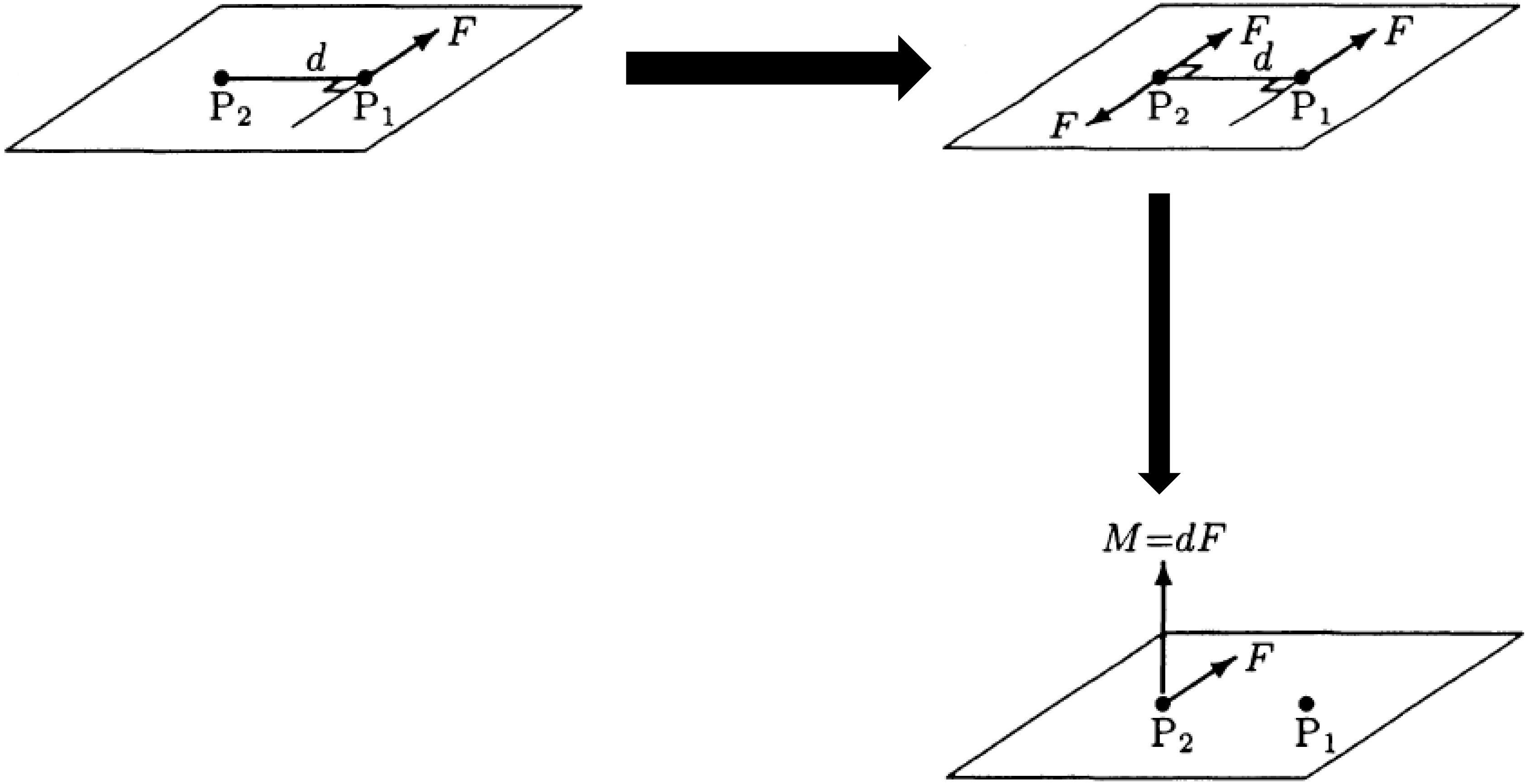
- It can be concluded without further proof that the couple has the same moment about every point in space.
- The direction of the couple-moment can be determined by the right-hand-rule.



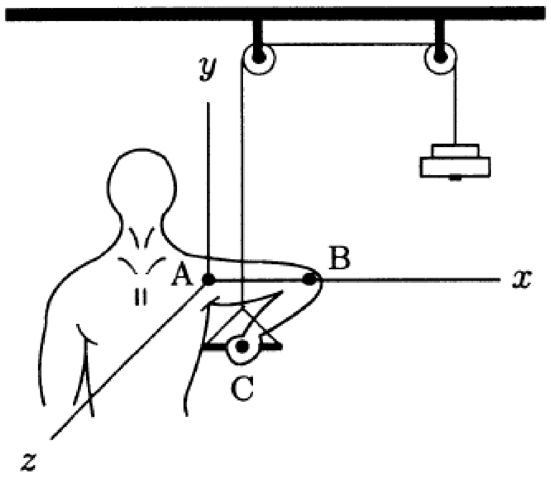
A couple.

Couple and Couple-moment

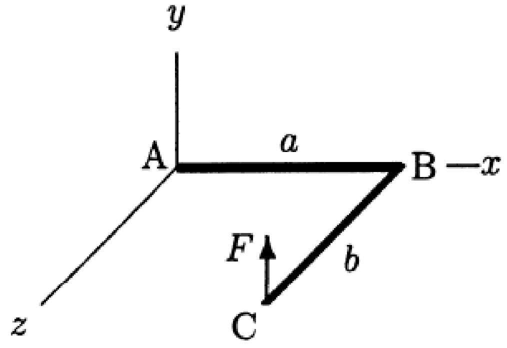
Translation of forces (scalar method):



A person using an exercise machine. The *"L"* shaped beam shown in Figure represents the left arm of the person. Points A and B correspond to the shoulder and elbow joints, respectively. Relative to the person, the upper arm (AB) is extended toward the left *(x* direction) and the lower arm (BC) is extended forward (z direction). At this instant the person is holding a handle that is connected by a cable to a suspending weight. The weight applies an upward (in the *y* direction) force with magnitude F on the arm at point C. The lengths of the upper arm and lower arm are a = 25 cm and b = 30 cm, respectively, and the magnitude of the applied force is F =200N.



- Explain how force F can be translated to the shoulder joint at A, and determine the magnitudes and directions of moments developed at the lower and upper arms by F.



Vector method:

$$\underline{r} = a\,\underline{i} + b\,\underline{k}$$

$$\underline{F} = F\,\underline{j}$$

$$\begin{aligned}\underline{M} &= \underline{r} \times \underline{F} \\ &= (a\,\underline{i} + b\,\underline{k}) \times (F\,\underline{j}) \\ &= a\,F\,(\underline{i} \times \underline{j}) + b\,F\,(\underline{k} \times \underline{j}) \\ &= a\,F\,\underline{k} - b\,F\,\underline{i} \\ &= (0.25)(200)\,\underline{k} - (0.30)(200)\,\underline{i} \\ &= 50\,\underline{k} - 60\,\underline{i}\end{aligned}$$

$$\begin{aligned}M_x &= 60\text{ N-m} \qquad (-x \text{ direction}) \\ M_y &= 0 \\ M_z &= 50\text{ N-m} \qquad (+z \text{ direction})\end{aligned}$$