Mechanics
UES009

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Review of Newton’s Laws of Motion and Particle Equilibrium

UES009 Mechanics

- Mechanics: Oldest of the Physical Sciences
- Archimedes (287-212 BC): Principles of Lever and Buoyancy!
- Mechanics is a branch of the physical sciences that is concerned with the state of **rest or motion** of **bodies** subjected to the action of **forces**.

Rigid-body Mechanics

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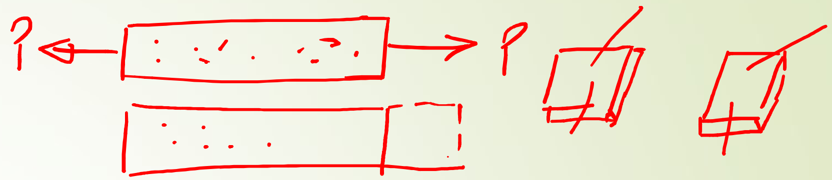
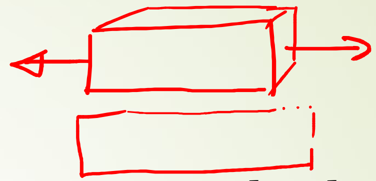
- Rigid-body Mechanics
- Deformable body mechanics
- Fluid mechanics



- **Rigid Body:** A combination of large number of particles in which all particles remain at a fixed distance from one another before and after applying a load.

Material properties of a rigid body are not required to be considered when analyzing the forces acting on the body.

In most cases, actual deformations that occur in structures, machines, mechanisms, etc. are relatively small, and rigid body assumption is suitable for analysis.



Deformable Bodies: The bodies in which particle to particle distance does not remain the same and it can go in the plastic zone in which it can completely change or deform.

Statics: deals with equilibrium of bodies under action of forces (bodies may be either at rest or move with a constant velocity).

Dynamics: deals with motion of bodies under acceleration.

Mechanics: Fundamental Concepts

Force: Force represents the action of one body on another. A force tends to move the body in the direction of its action. The action of force is characterized by its magnitude, direction of its action, and its points of application.

- **Force is a Vector quantity**

Scalar quantities: These are the quantities characterized by only magnitude, such as mass, temperature.

Vector quantities: These are the quantities characterized by magnitude and direction, such as velocity, force.

Mechanics: Idealizations

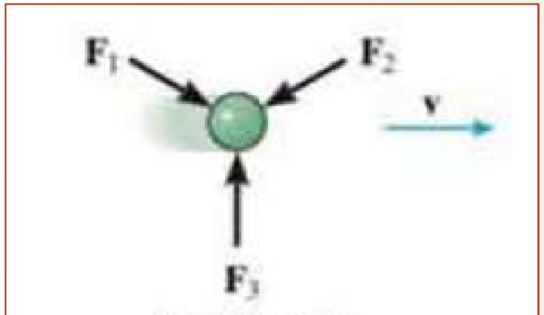
Particle: A particle is a body with negligible dimensions.

Size of the Earth is insignificant compared to the size of its orbit. Earth can be modeled as a particle when studying its orbital motion.

Mechanics: Newton's Three Laws of Motion

Basis of formulation of rigid body mechanics.

First Law: A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is not subjected to an unbalanced force.



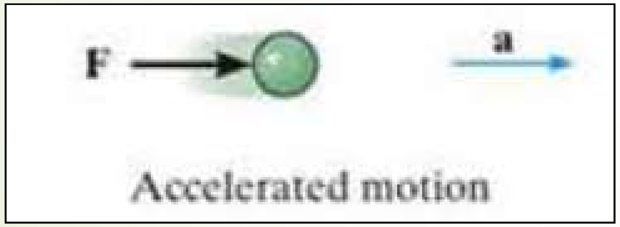
Equilibrium

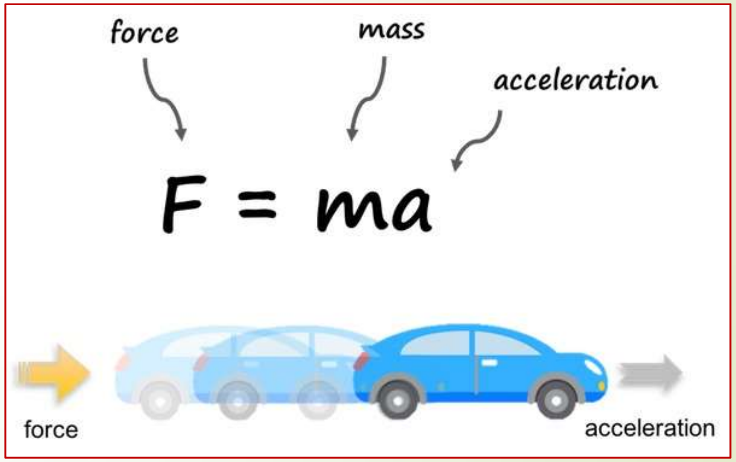
First law contains the principal of the equilibrium of forces-main topic of concern in statics.

Mechanics: Newton's Three Laws of Motion

Second Law: A particle of mass '*m*' acted upon by an unbalanced force '*F*' experiences an acceleration '*a*' that has the same direction as the force and a magnitude that is directly proportional to the force.

Mathematically, this law is stated as : ***F=ma***

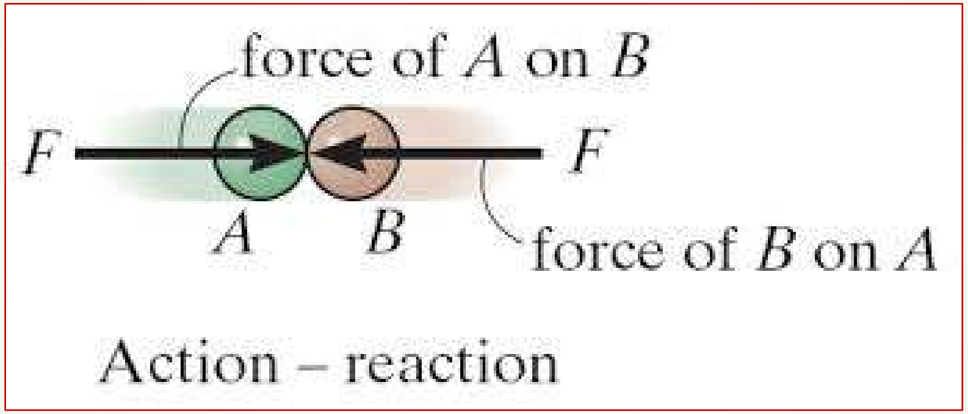




Second Law forms the basis for most of the analysis in Dynamics.

Mechanics: Newton's Three Laws of Motion

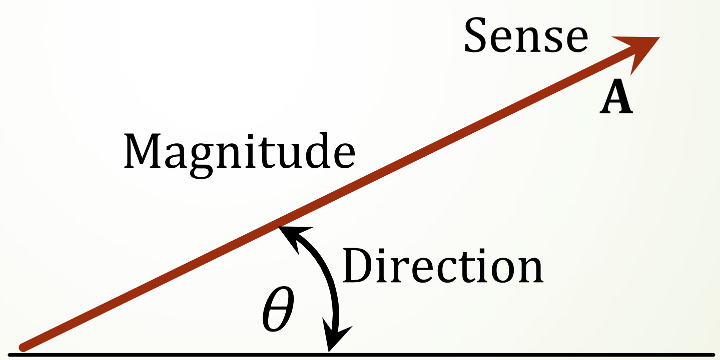
Third Law: For every action, there is an equal and opposite reaction.



Forces

- Concentrated Force: When effect of loading is assumed to act at a point(CG)on a body.

Provided the area over which the load is applied is very small compared to the overall size of the body.

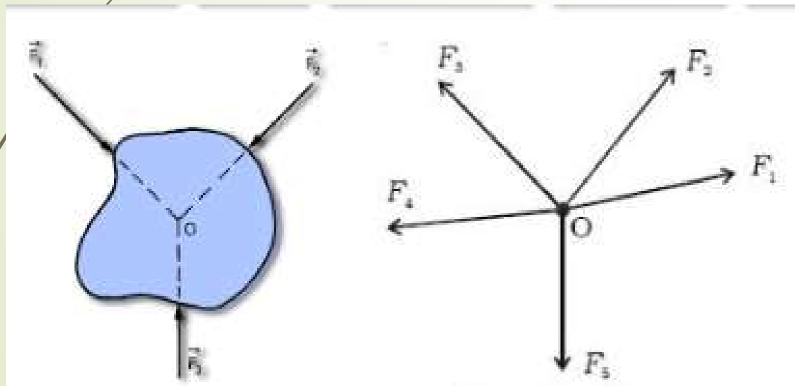


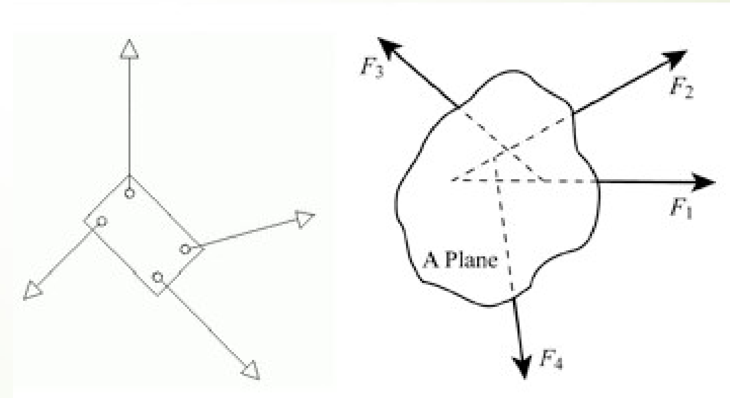
Representation of a Force

System of forces

Concurrent and non-concurrent system of forces

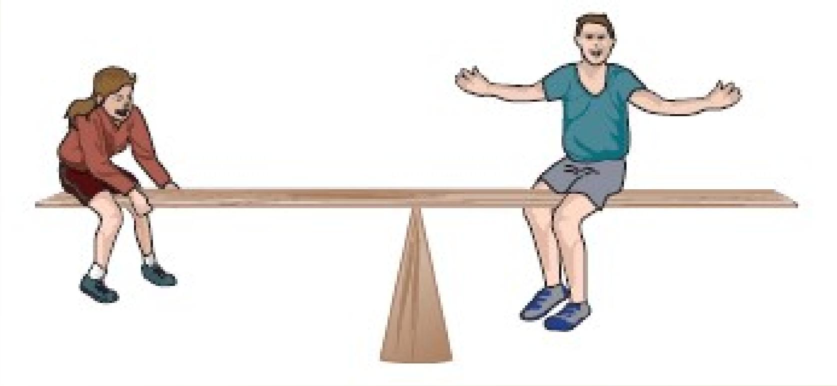
- When line of action of all forces pass through a single point then it is concurrent system of forces.
- When line of action of all forces does not pass through a single point then it is non concurrent system of forces





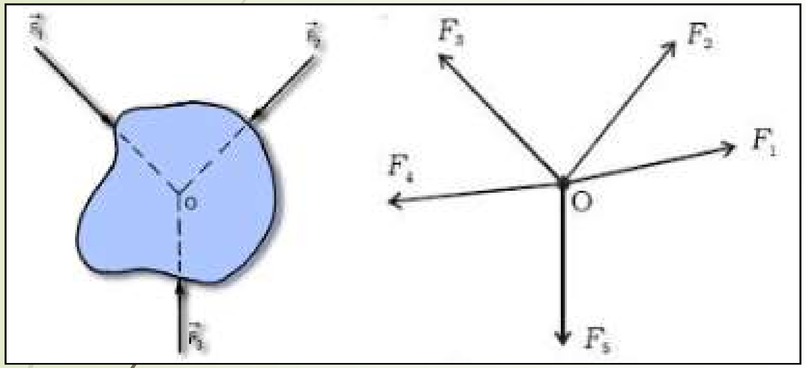
Equilibrium of forces

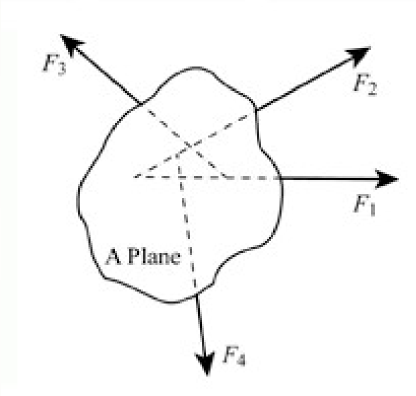
A body is said to be in equilibrium if it is at rest or moving with a constant velocity



- Unchanging state i.e. the state of balance
- At equilibrium, the vector sum of all the external forces acting on a body is zero
- In the solution of a problem, first of all a free body diagram (FBD) of the body is drawn to identify the external forces
- Equilibrium equations are used to determine unknown forces acting on a body

Equilibrium-Governing equations





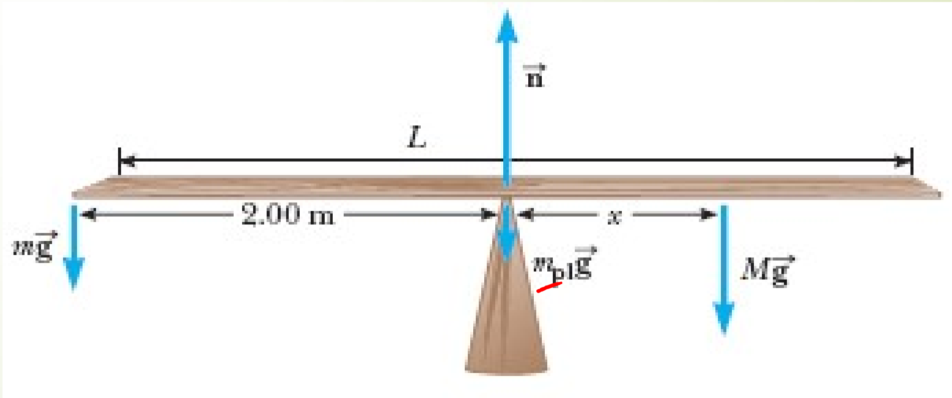
$$R_x = \Sigma F_x = 0;$$
$$R_y = \Sigma F_y = 0;$$

$$\Sigma F_x = 0; \qquad \Sigma F_y = 0; \qquad \Sigma M = 0;$$

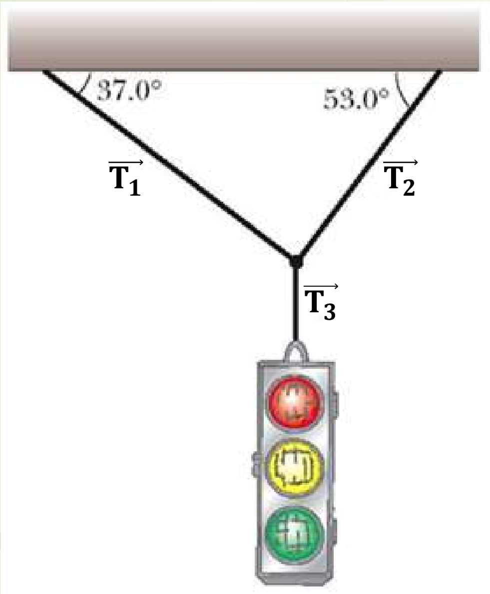
Free body diagram (FBD)

A free body diagram (FBD) is a diagram of a body or system of bodies or a portion of a body which depicts all the applied forces, constraints or reactions acting on the body.

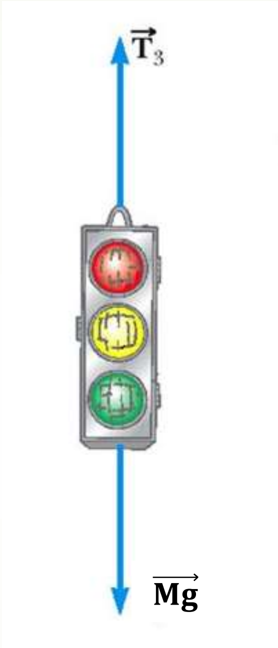
- First of all a FBD of the body is drawn and reactions are determined
- The complete system of applied forces and reactive forces acting on the body makes it in the state of static equilibrium



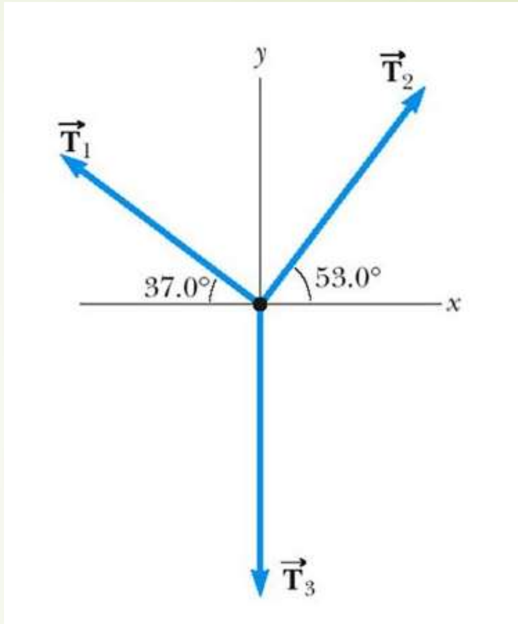
Free body diagram (FBD)



Colour light signals

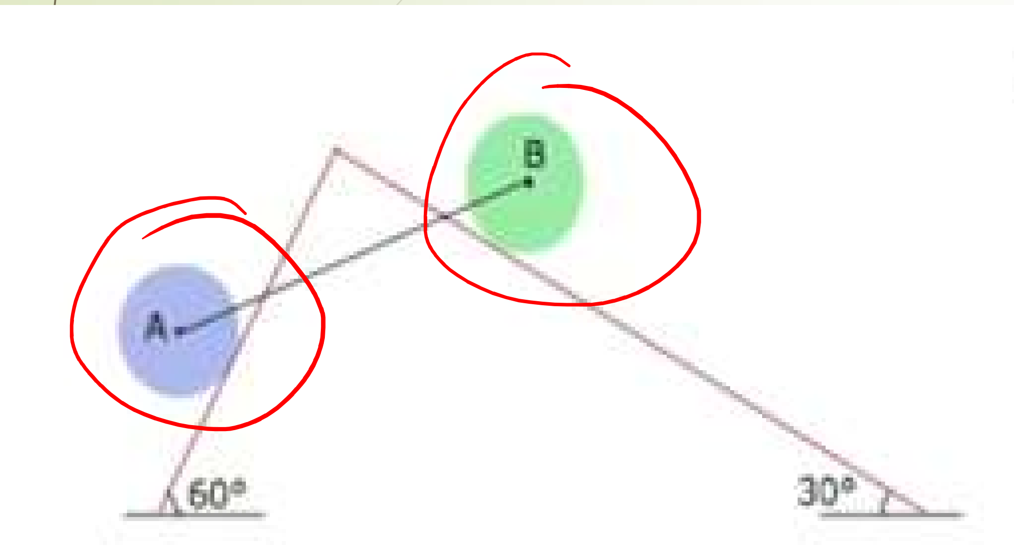


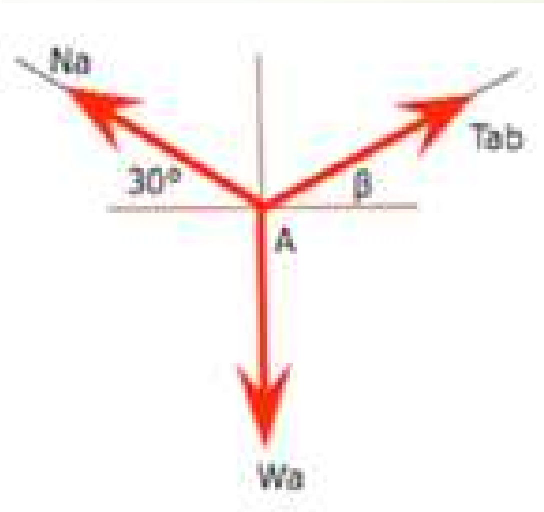
FBD of the lights block



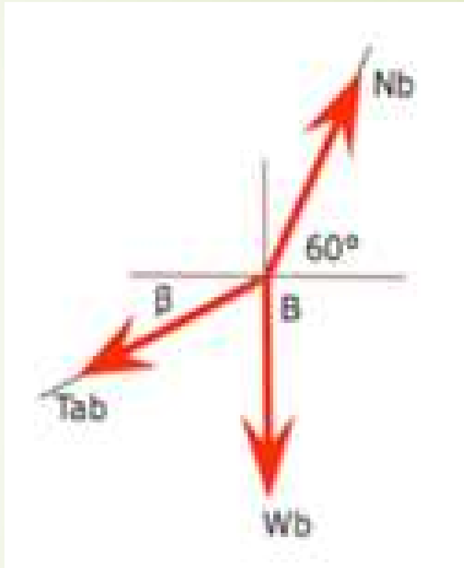
FBD at the joint of cables

Free body diagram-Examples



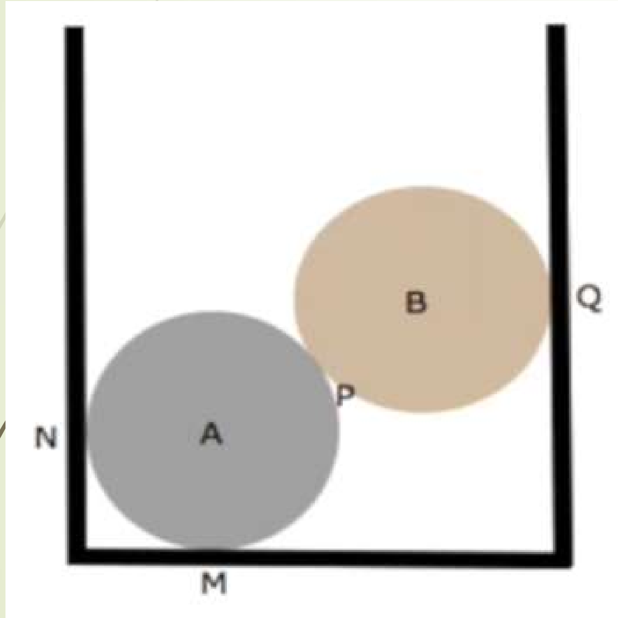


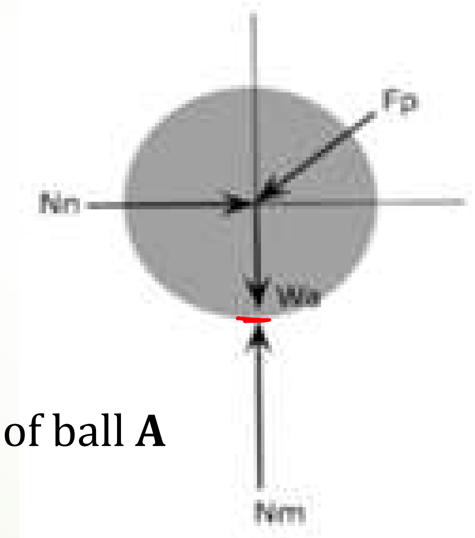
FBD at **A**



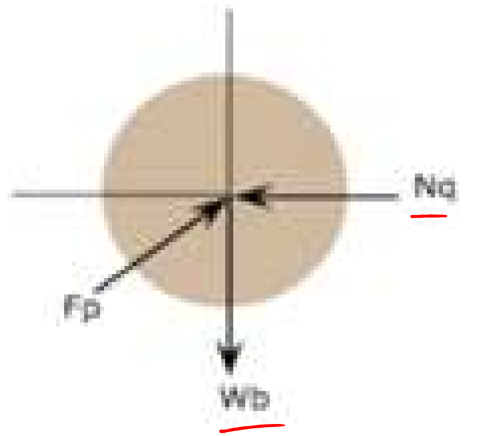
FBD at **B**

Free body diagram-Examples



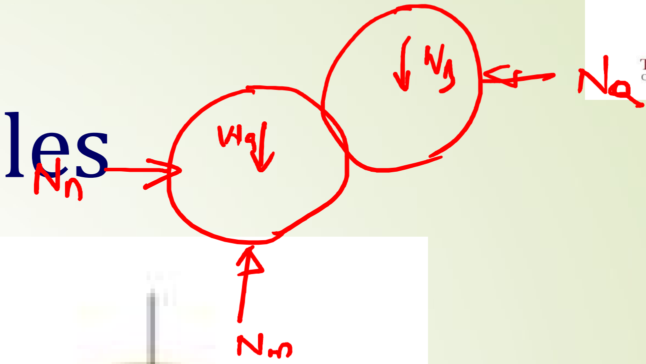


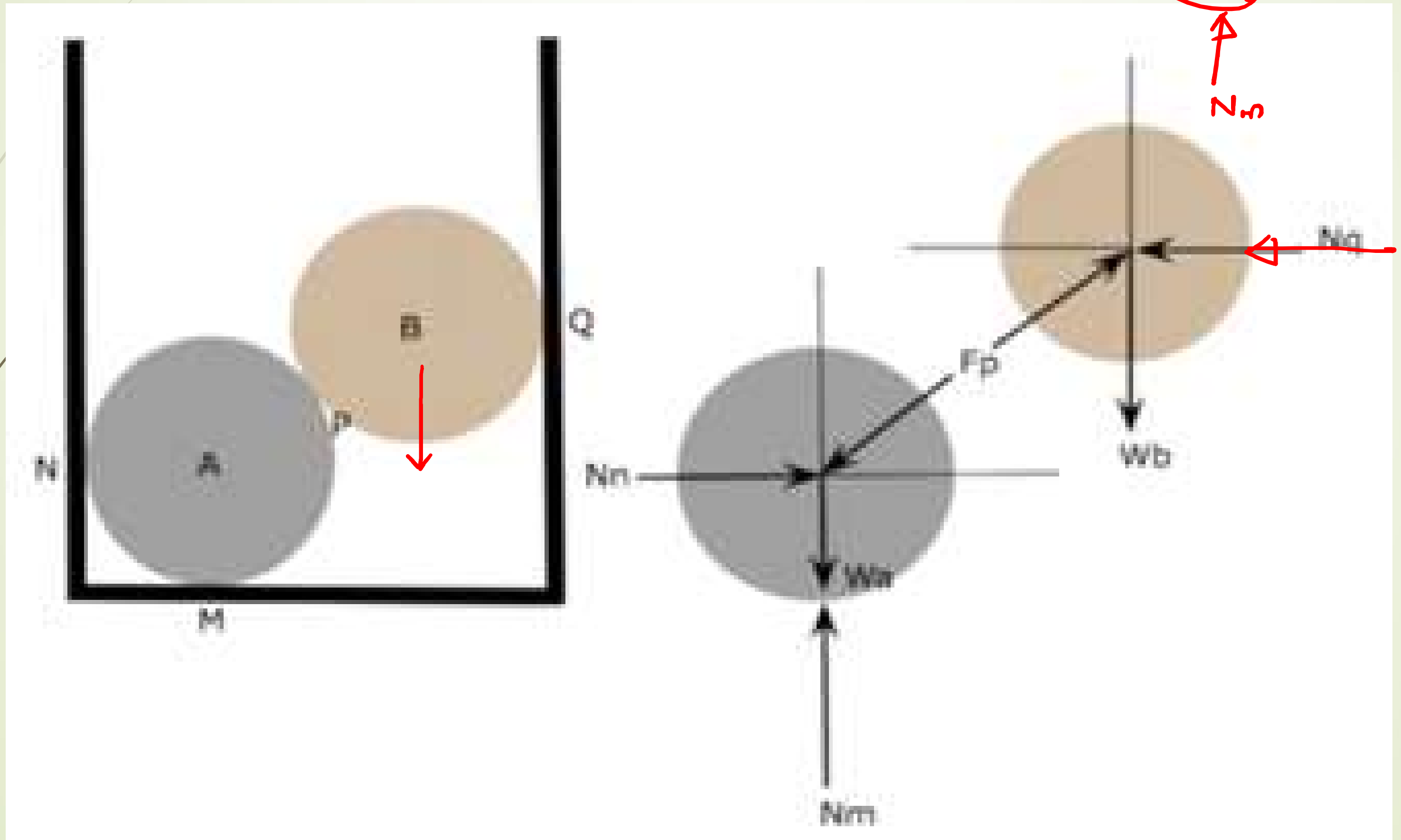
FBD of ball **A**



FBD of ball **B**

Free body diagram-Examples



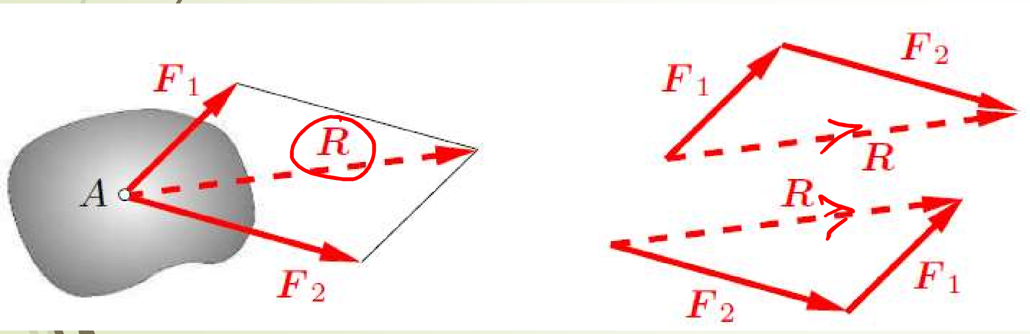


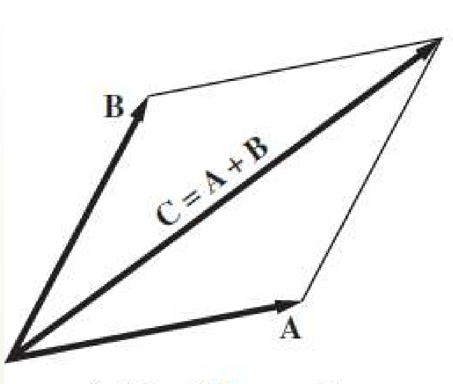
Mechanics: Fundamental Properties of Vectors

A scalar is a quantity that has magnitude only.

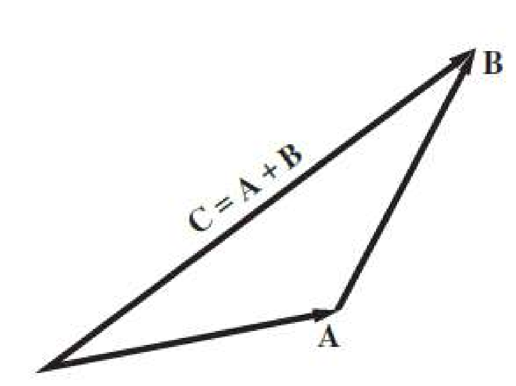
A vector is a quantity that possesses magnitude and direction and obeys the parallelogram law for addition.

The Parallelogram Law and the Triangle Law





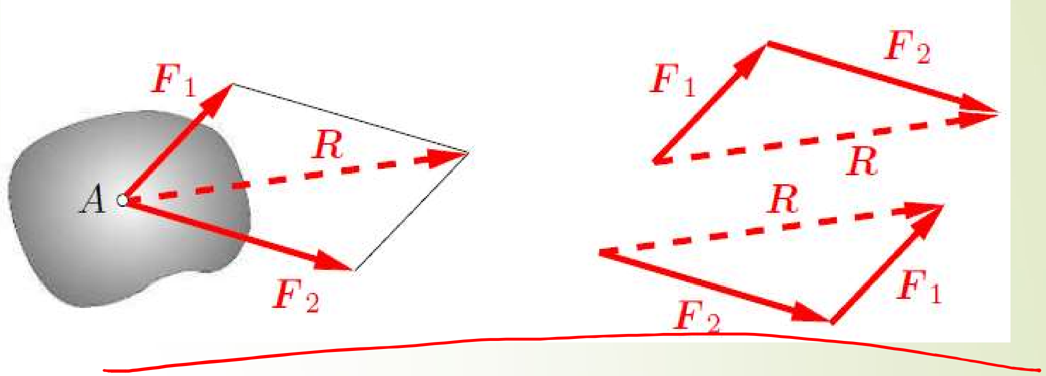
(a) Parallelogram law

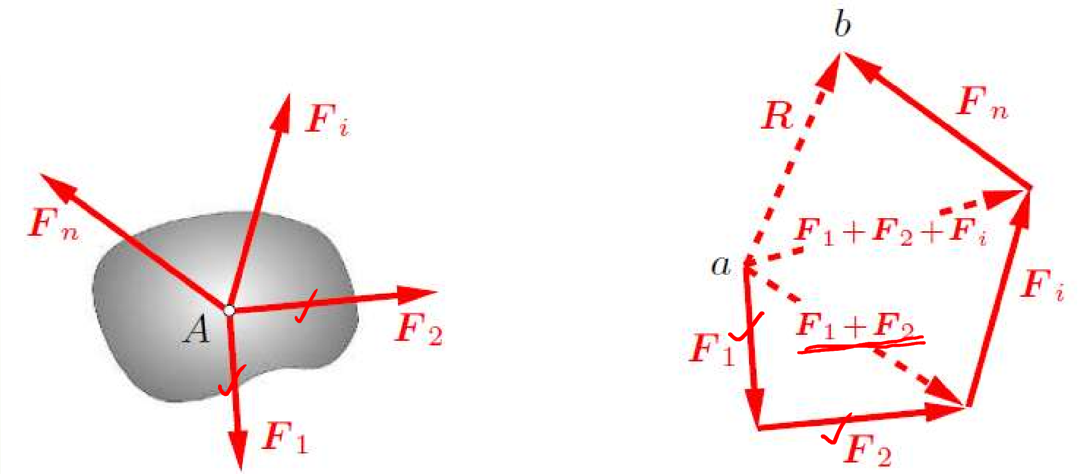


(b) Triangle law

Addition of Forces in a Plane

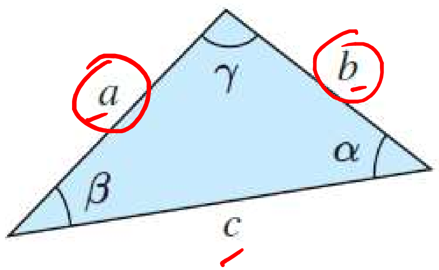
The effect of two non-parallel forces $\mathbf{F_1}$ and $\mathbf{F_2}$ acting at a point **A** of a body is same as the effect of the single force **R** acting at the same point and obtained as diagonal of the parallelogram formed by $\mathbf{F_1}$ and $\mathbf{F_2}$.





Mechanics: Fundamental Properties of Vectors

Law of sines and cosines



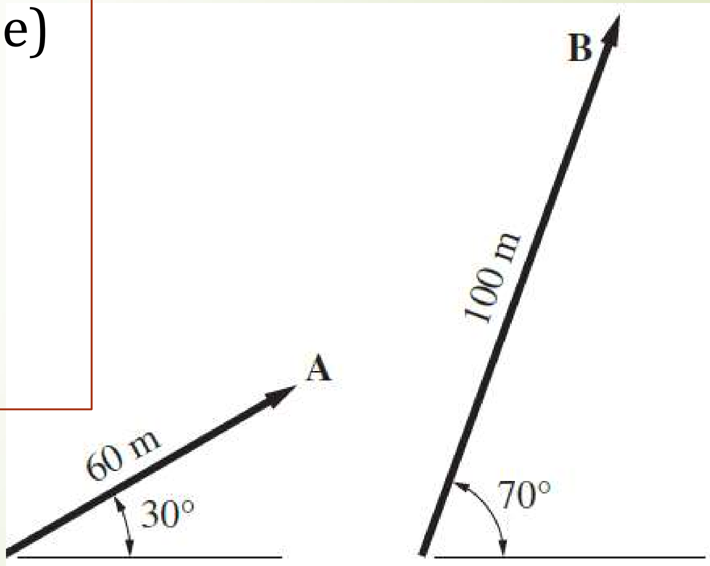
Law of sines	$\dfrac{a}{\sin\alpha} = \dfrac{b}{\sin\beta} = \dfrac{c}{\sin\gamma}$
Law of cosines	$a^2 = b^2 + c^2 - 2bc\cos\alpha$ $b^2 = c^2 + a^2 - 2ca\cos\beta$ $c^2 = a^2 + b^2 - 2ab\cos\gamma$

Mechanics: Fundamental Properties of Vectors

Illustration: Figure below shows two position vectors of magnitudes A=60 m and B =100 m. Determine the resultant.

Plan the Solution:

- ✓ The first step is to draw a sketch (approximately to scale) of the triangle law.
- ✓ The magnitude and direction of the resultant are then found by applying the laws of sines and cosines to the triangle.



Mechanics: Fundamental Properties of Vectors

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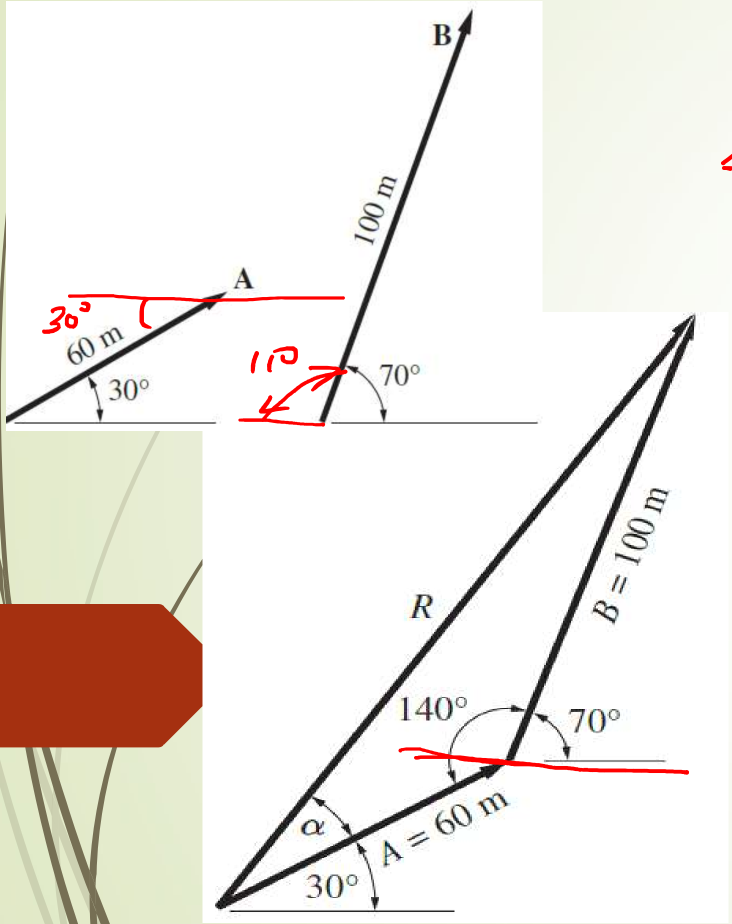
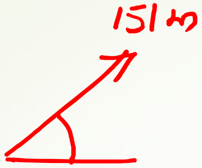




Solution:
The magnitude R of the resultant and the angle α are the unknowns to be determined. Applying the law of cosines, we obtain

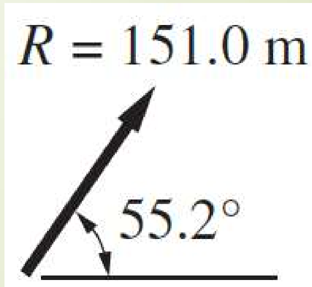
$$R^2 = 60^2 + 100^2 - 2(60)(100)\cos 140^\circ$$

$$\boxed{R = 151.0 \text{ m}}$$

Applying the law of sines, we obtain

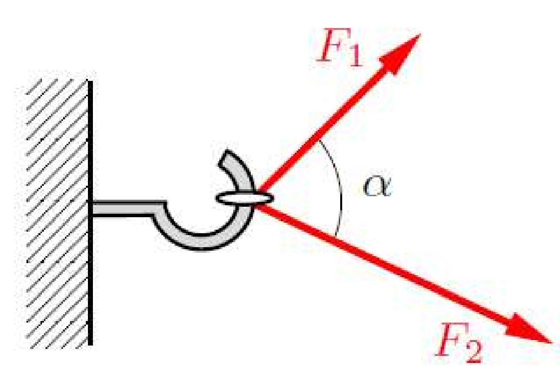
$$\frac{100}{\sin\alpha} = \frac{R}{\sin 140^\circ}$$

$$\alpha = 25.2^\circ$$



Mechanics: Fundamental Properties of Vectors

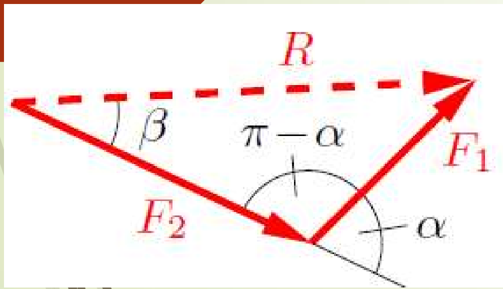
Illustration: A hook carries two forces F_1 and F_2, which define the angle α. Determine the magnitude and direction of the resultant.



$$R^2 = F_1^2 + F_2^2 - 2\,F_1\,F_2 \cos(\pi - \alpha)$$

or

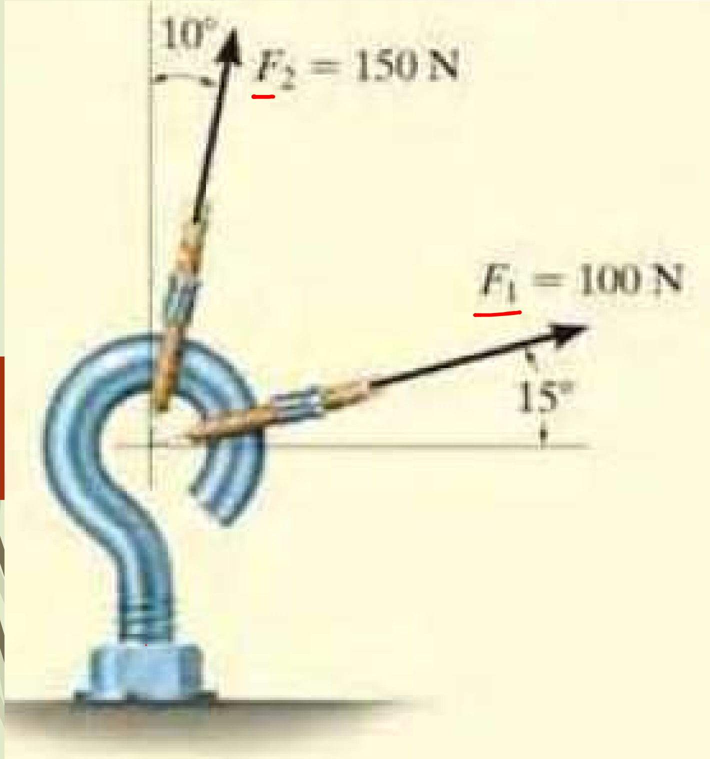
$$R = \sqrt{F_1^2 + F_2^2 + 2\,F_1\,F_2 \cos\alpha}\,.$$

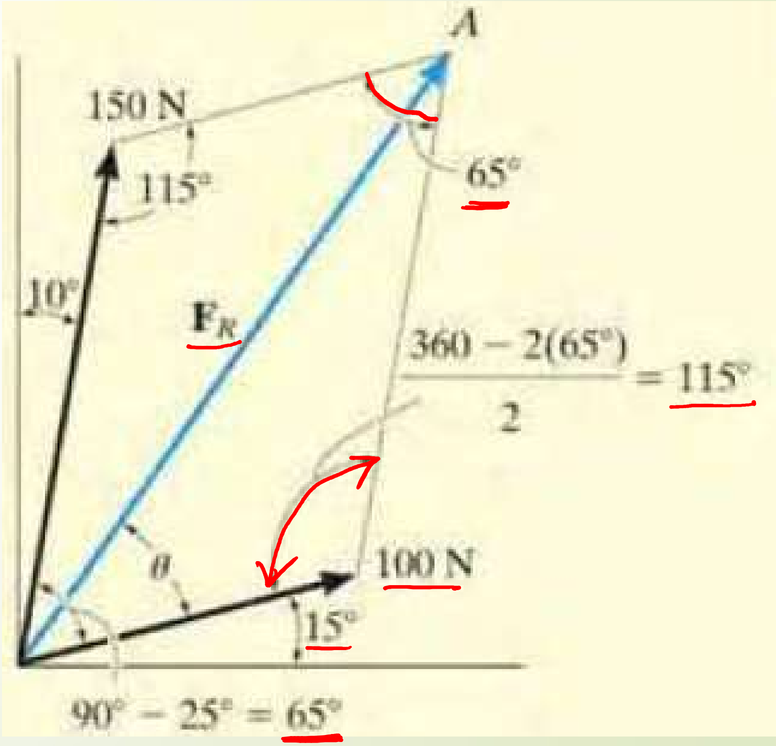


$$\frac{\sin\beta}{\sin(\pi - \alpha)} = \frac{F_1}{R}\,.$$

Mechanics: Fundamental Properties of Vectors

Illustration: The screw eye in the figure is subjected to two forces F1 and F2. Determine the magnitude and direction of the resultant force.





Mechanics: Fundamental Properties of Vectors

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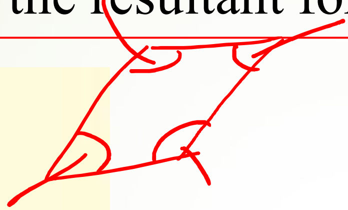

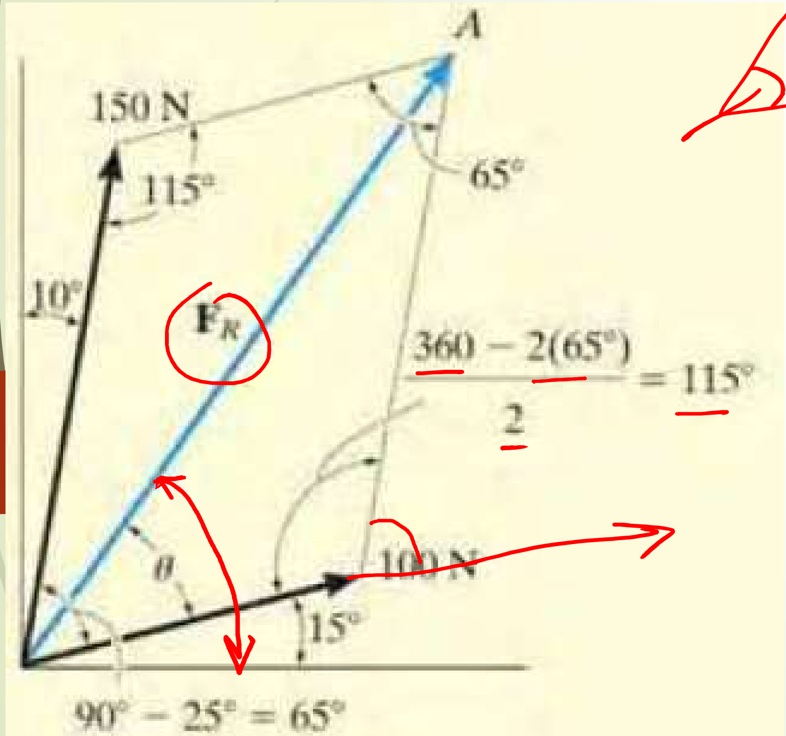

$A = 100$
$B = 150$

$$F_R = \sqrt{(100\text{ N})^2 + (150\text{ N})^2 - 2(100\text{ N})(150\text{ N})\cos 115°}$$
$$= \sqrt{10\,000 + 22\,500 - 30\,000(-0.4226)} = 212.6\text{ N}$$

Applying the law of sines to determine θ,

$$\frac{150\text{ N}}{\sin\theta} = \frac{212.6\text{ N}}{\sin 115°} \qquad \sin\theta = \frac{150\text{ N}}{212.6\text{ N}}(\sin 115°)$$

$$\theta = 39.8°$$

$= 39.8 + 15 = 54.8°$

Mechanics: Fundamental Properties of Vectors

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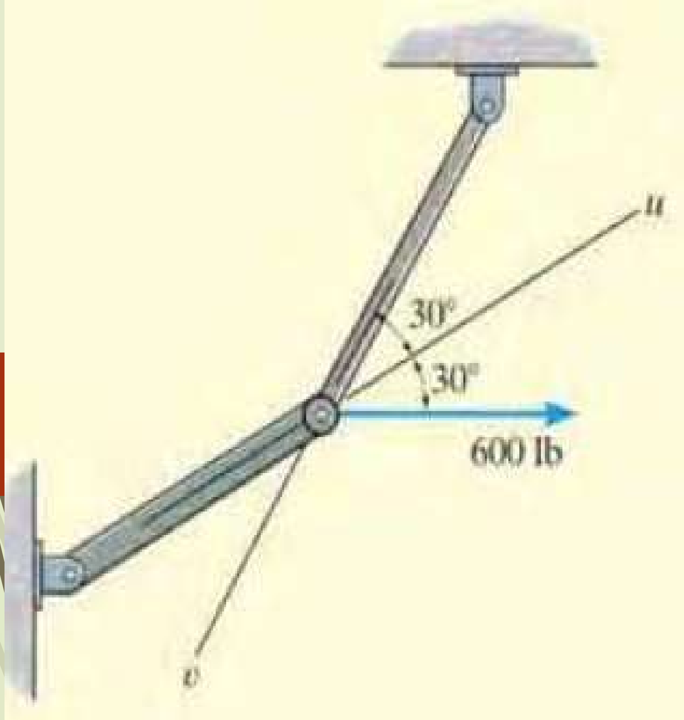
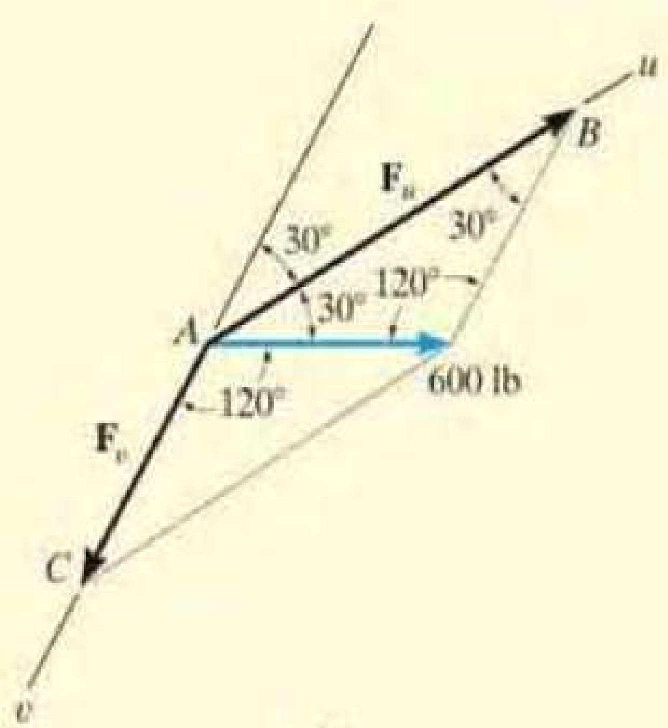
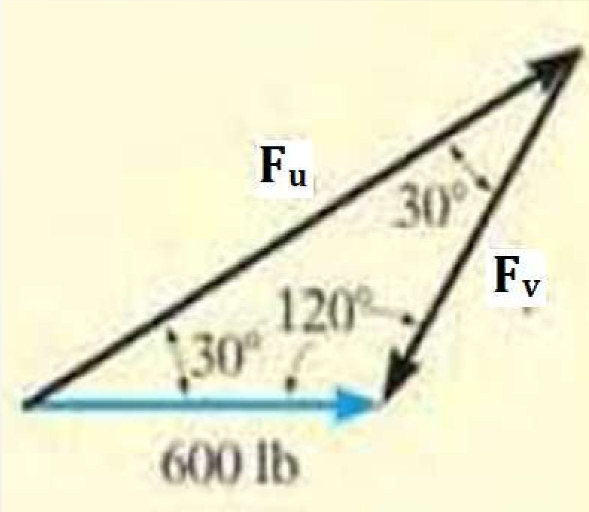
Illustration: Resolve the horizontal 600 lb force in the figure into components along the u and v axes and determine the magnitudes of these components.

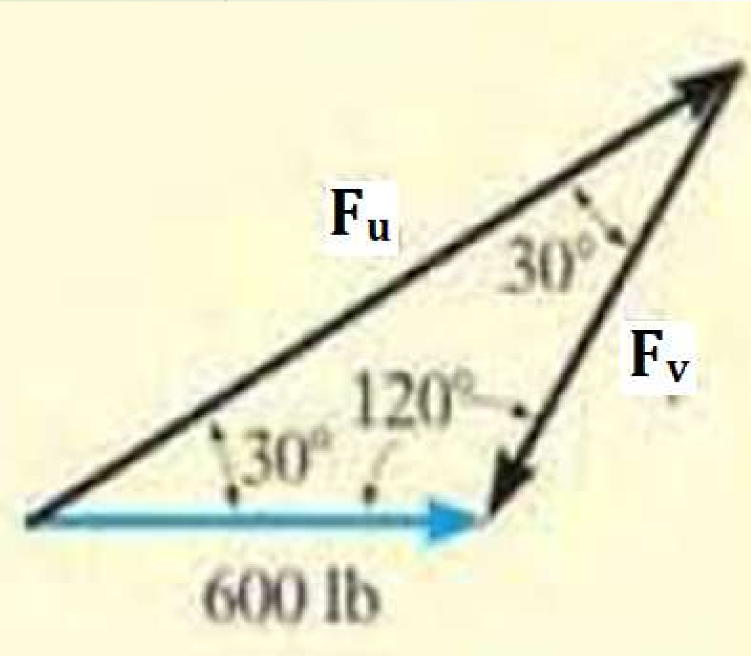






Mechanics: Fundamental Properties of Vectors

Illustration: Resolve the horizontal 600 lb force in the figure into components along the u and v axes and determine the magnitudes of these components.



$$\frac{F_u}{\sin 120^\circ} = \frac{600\text{ lb}}{\sin 30^\circ}$$

$$F_u = 1039\text{ lb}$$

$$\frac{F_v}{\sin 30^\circ} = \frac{600\text{ lb}}{\sin 30^\circ}$$

$$F_v = 600\text{ lb}$$

THANK YOU