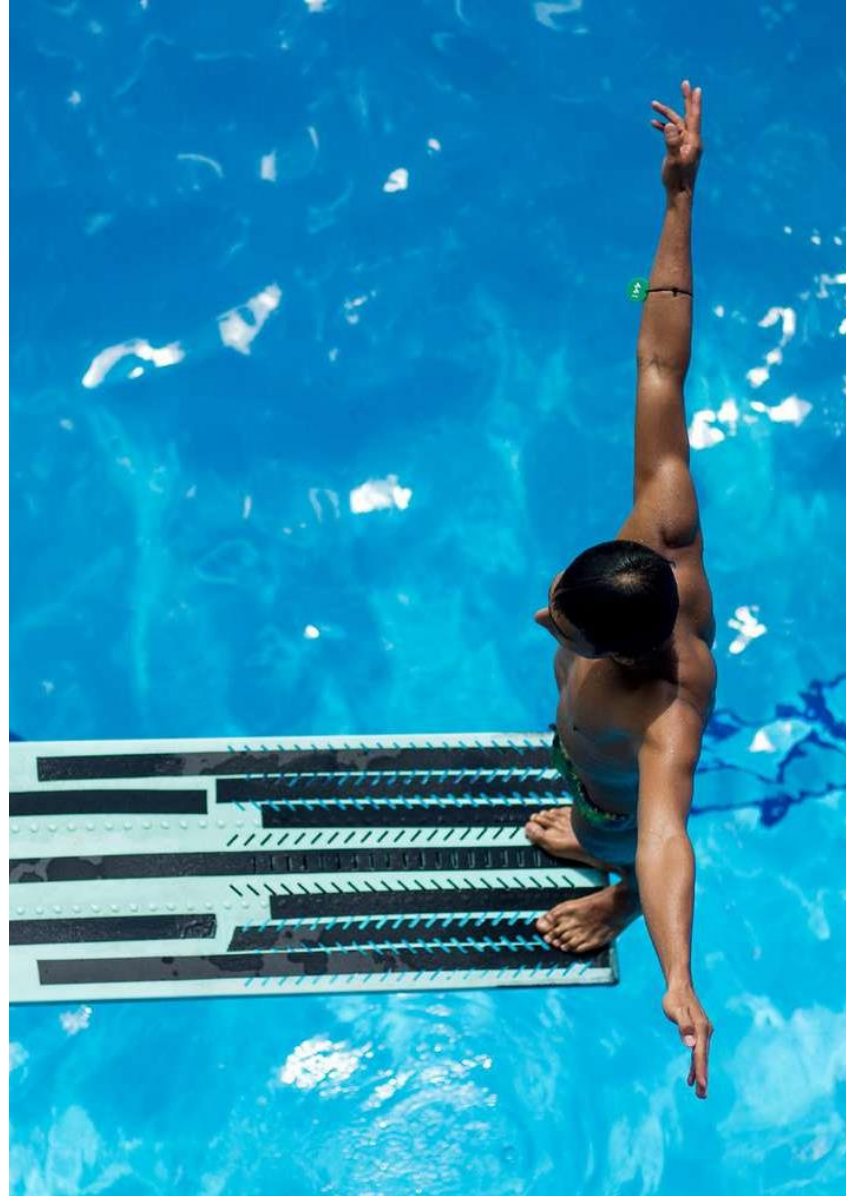


CHAPTER 1

Forces: Maintaining Equilibrium or Changing Motion



Objectives

- **Define force**
- **Classify forces**
- **Define friction force**
- **Define weight**
- **Determine the resultant of two or more forces**

(continued)

Objectives *(continued)*

- **Resolve a force into component forces acting at right angles to each other**
- **Determine whether an object is in static equilibrium, if the forces acting on the object are known**
- **Determine an unknown force acting on an object, if all the other forces acting on the object are known and the object is in static equilibrium**

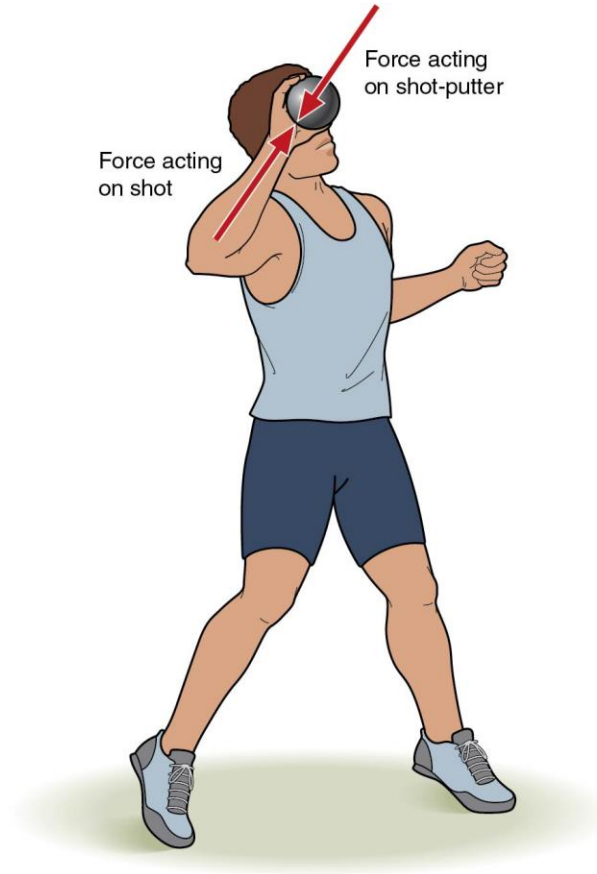
Force

- A push or pull exerted by one object on another object
- Force pairs are equal in size but act in opposite direction on each object
- Causes, or tends to cause, each object to *accelerate*
 - *Start, stop, speed up, slow down, change direction*
- English unit: pound
- SI unit: newton (N)
 - $1.0 \text{ N} = (1.0 \text{ kg})(1.0 \text{ m/s}^2)$

Characteristics of a Force

- **Magnitude:** the size of the push or pull
- **Direction:** line of action
Sense: which way a force is pushing or pulling
- **Point of application**
Where the push or pull is applied on the object

Forces Acting on a Shot-Putter



Force Is a Vector Quantity

- **A vector quantity requires describing**
 - **Magnitude**
 - **Direction**
- **Force is represented graphically with an arrow**
 - **Length of the arrow represents force magnitude**
 - **Arrowhead indicates force sense (direction)**
 - **Shaft of the arrow indicates line of application**
 - **One end of the arrow indicates point of application on the object**

Assumptions in Rigid-Body Mechanics

- **Rigid bodies are point masses or particles**
- **All forces on the body have the same point of application**
- **The effect of the forces acting on the body are not affected by changes in the dimensions or shape**

Classifying Force

Internal force

- Pair of forces act *within* the object or system
- Each force affects object part it acts on but does not affect the motion of the body
- Hold the object together
 - Tensile force: pulling (tension)
 - Compressive force: squeezing (compression)

(continued)

Classifying Force *(continued)*

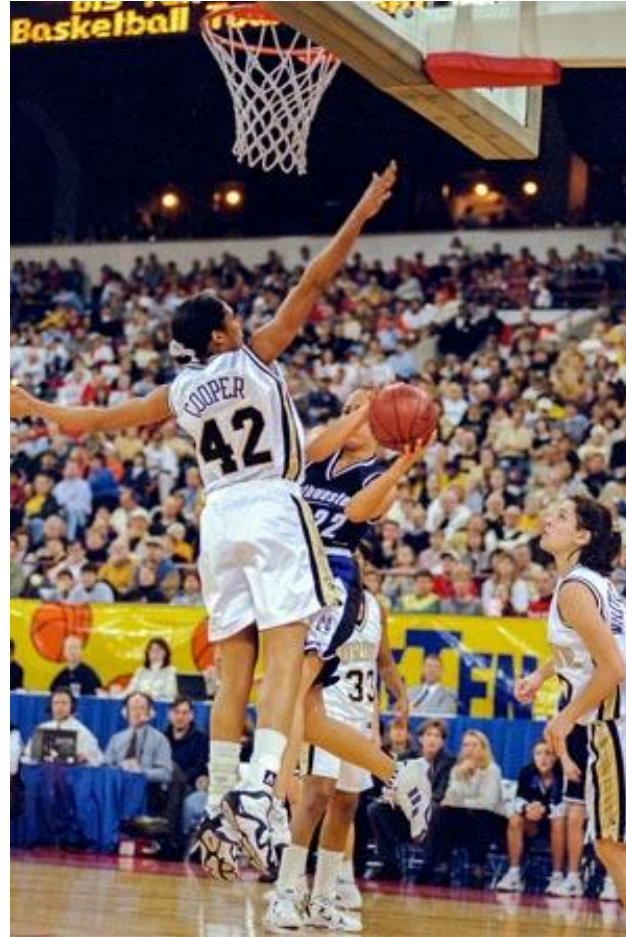
External force

- **Acts on an object or system through interaction with environment**
 - **Contact force: objects touch each other**
 - **Noncontact force: objects not touching each other**
 - **Gravitational force: weight of the object**

Noncontact Forces

- Force pair between objects *not* touching each other
- Weight: force of gravity acting on an object
- $W = mg$
 - W = weight in newtons
 - m = mass in kilograms (kg)
 - g = acceleration due to gravity = 9.81 m/s^2 downward
 - For ease of calculation: $9.81 = 10 \text{ m/s}^2$

A Basketball Player Cannot Change Her Motion Once She Has Jumped Into the Air



Contact Forces

- Forces occur between objects touching each other
- Each force acts separately on one of the objects
- Also called *reaction forces*

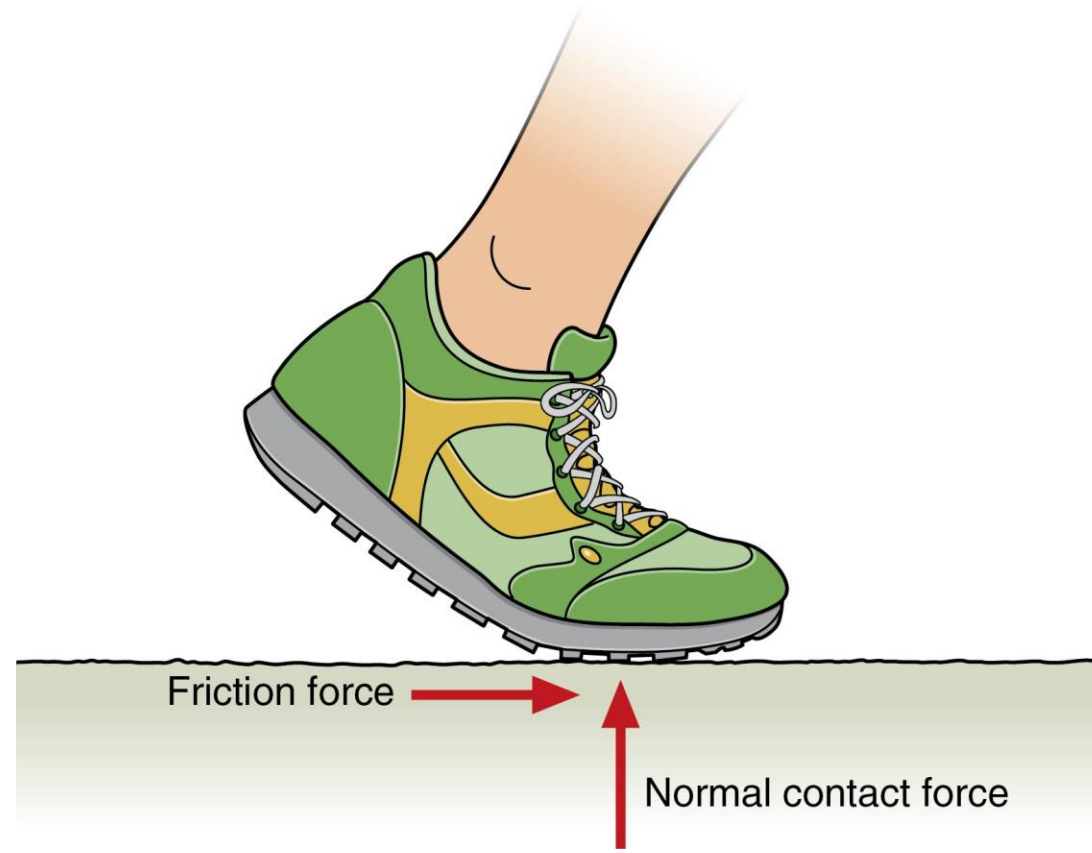
(continued)

Contact Forces *(continued)*

Contact forces can be resolved into components

- **Normal contact force: perpendicular to the two objects in contact**
- **Parallel contact force: parallel to contacting surfaces of two objects**
 - **Also known as *friction force***
 - **Opposes motion or sliding between the surfaces**

Normal Contact Force and Friction Force Acting on a Runner's Foot



Friction

- **Opposes sliding or motion between objects in contact**
- **Results from interaction between surface molecules**
- **Static friction: two surfaces not moving on each other**

Limiting friction: maximum friction before objects start to slide

- **Dynamic friction: two surfaces are moving on each other**

Also known as sliding friction or kinetic friction

(continued)

Friction *(continued)*

- **Proportional to the force pushing the two surfaces together**

Represented by R (normal reaction force)

Greater $R \rightarrow$ greater friction

- **Affected by characteristics of the two materials in contact**

Represented by μ (Greek letter mu)

Friction Is $F = \mu R$

- Equation for friction

$$F = \mu R$$

- F = friction force (acts to oppose sliding)
- μ = coefficient of friction
- R = normal contact force

Addition of Forces: Force Composition

- **Net force: sum of all external forces acting on one object**
Also called resultant force
- **Not simply summing all external force magnitudes**
Must account for the direction of each external force
- **What is the effect of two 100 N forces on an object?**
Depends on the specified direction of the two forces

Colinear Forces

- One or more external forces with the same line of action
- Identify one direction as positive (+)
- Identify opposite direction as negative (–)

Vector Summing Colinear Forces on Barbell

- **Consider a spotter helping a lifter with a barbell**
Identify up as the positive (+) direction
Identify down as the negative (–) direction
- **Barbell weight 1000 N acts down = -1000 N**
- **Lifter pushes 980 N up = $+980\text{ N}$**
- **Spotter pulls 90 N up = $+90\text{ N}$**

(continued)

Vector Summing Colinear Forces on Barbell *(continued)*

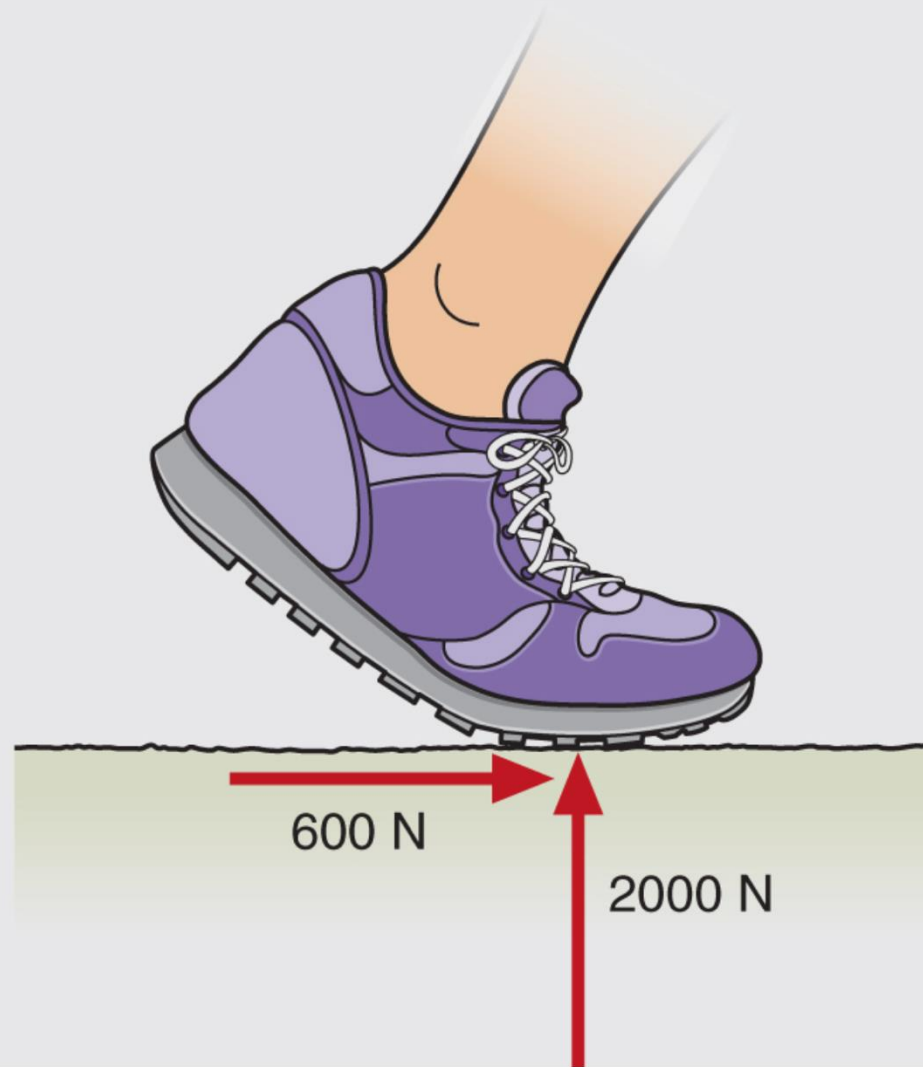
$$\text{Net Force} = \text{Lifter} + \text{Spotter} + \text{Weight}$$

$$\text{Net Force} = (+980 \text{ N}) + (+80 \text{ N}) + (-1000 \text{ N})$$

$$\text{Net Force} = +980 \text{ N} + 80 \text{ N} - 1000 \text{ N}$$

$$\text{Net Force} = +60 \text{ N}$$

Interpretation: net force on the bar is 60 N upward

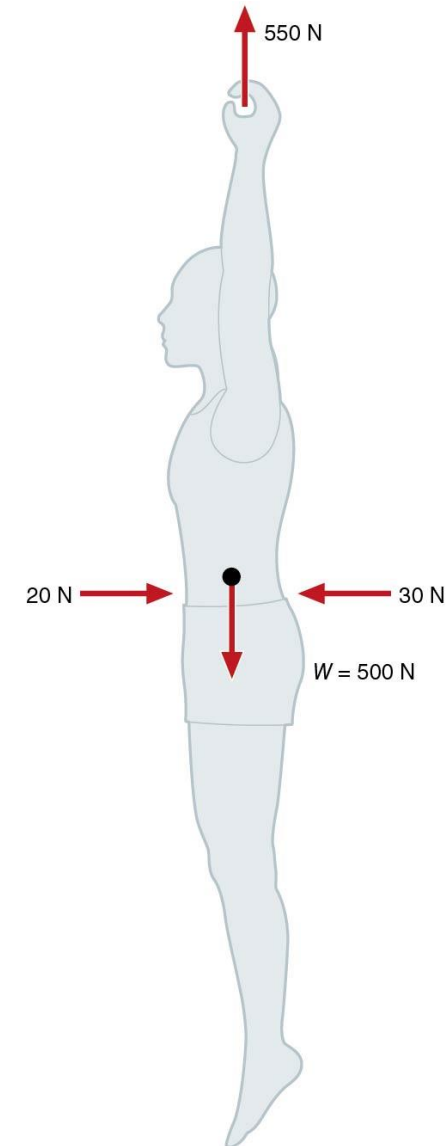


Concurrent Forces

- Forces are not colinear but act through the same point
- **Example: Gymnast hanging from grab bar; coach applies force to front and back of torso to stop swing**
 - 20 N posterior directed push on front of torso
 - 30 N anterior directed push on back of torso
 - 550 N force from bar on gymnast's hands
 - Gymnast mass 50 kg

(continued)

Free-Body Diagram Showing External Forces Acting on a Gymnast



Concurrent Forces *(continued)*

To calculate the resultant force on gymnast:

- **Solve for net vertical force**
- **Solve for net horizontal force**
- **Use Pythagorean theorem to calculate resultant force magnitude**
- **Use trigonometry to calculate resultant force angle**

(continued)

Concurrent Forces *(continued)*

- **Horizontal forces (+ direction to the right)**
 - Posterior push = -20 N
 - Anterior push = $+30\text{ N}$
- **Vertical forces (+ direction upward)**
 - Bar pull = $+550\text{ N}$
 - Gymnast weight = $mg = 50\text{ kg} \times 10\text{ m/s}^2 = -500\text{ N}$

(continued)

Concurrent Forces *(continued)*

$$\begin{aligned}\Sigma \text{ horizontal forces} &= (-20 \text{ N}) + (30 \text{ N}) \\ &= -20 + 30 = +10 \text{ N}\end{aligned}$$

Resultant horizontal force = 10 N to the right

$$\begin{aligned}\Sigma \text{ vertical forces} &= (+550 \text{ N}) + (-500 \text{ N}) \\ &= +550 - 500 \\ &= +50 \text{ N}\end{aligned}$$

Resultant vertical force = 50 N upward

(continued)

Concurrent Forces *(continued)*

- Resultant horizontal force (HF) = 10 N to the right
- Resultant vertical force (VF) = 50 N upward
- Solve resultant force (RF) using Pythagorean theorem

$$RF^2 = HF^2 + VF^2 = 10^2 + 50^2$$

$$RF^2 = 100 + 2500 = 2600$$

$$RF = \sqrt{2600} = 51 \text{ N}$$

(continued)

Concurrent Forces *(continued)*

- Resultant horizontal force = 10 N to the right
- Resultant vertical force = 50 N upward
- Solve resultant force direction using trigonometry

Select the arctangent function:

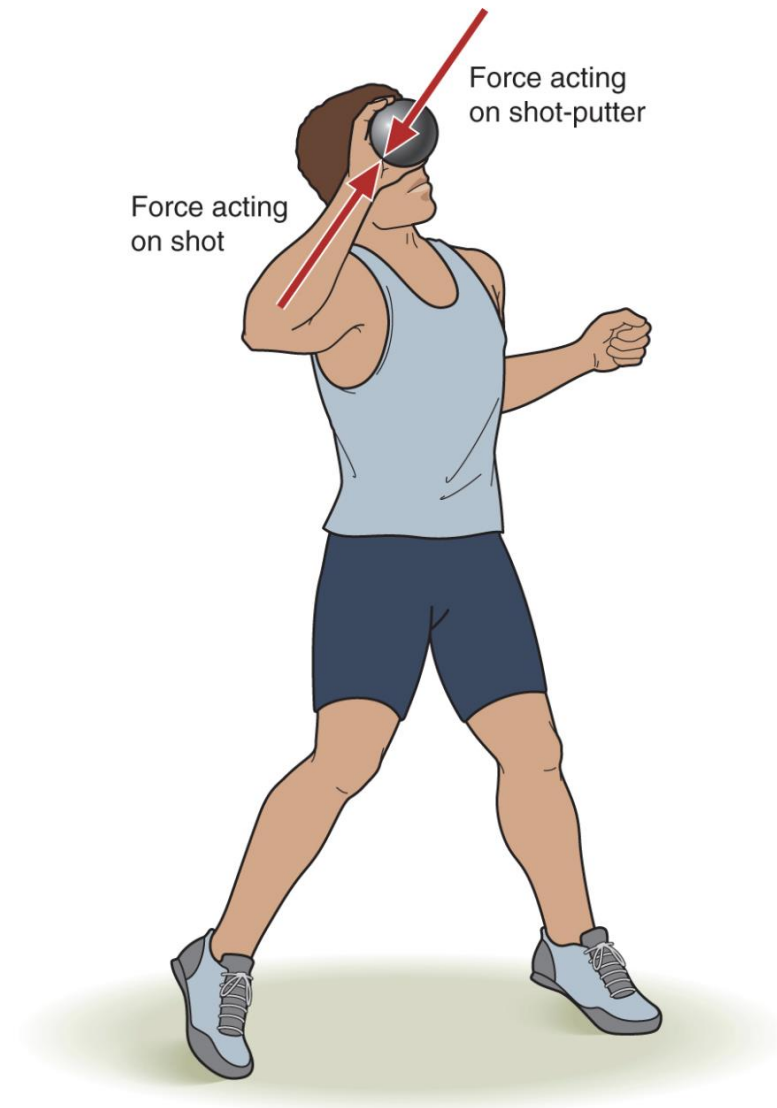
$$\theta = \arctan\left(\frac{50}{10}\right) = \arctan(5.000) = 78.7^\circ$$

The resultant force on the gymnast has a magnitude of 51 N at an angle of 78.7°.

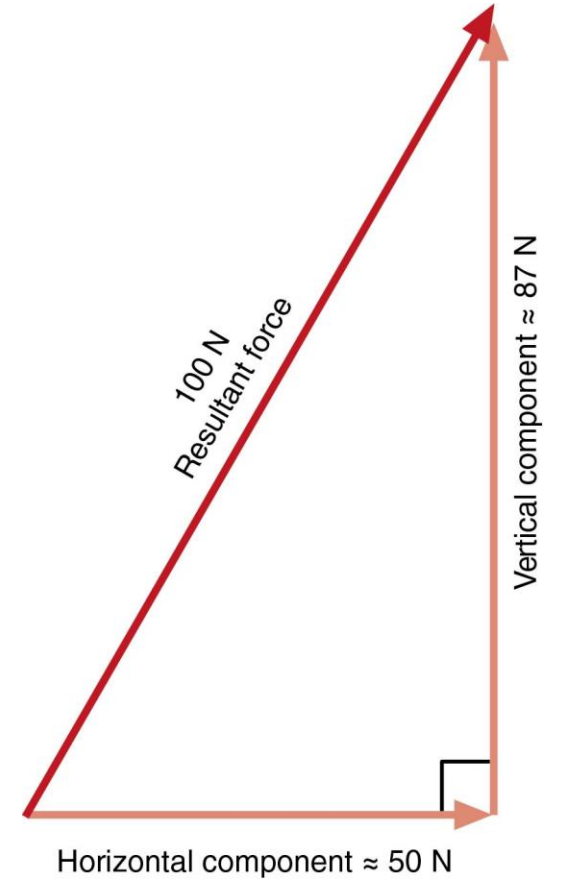
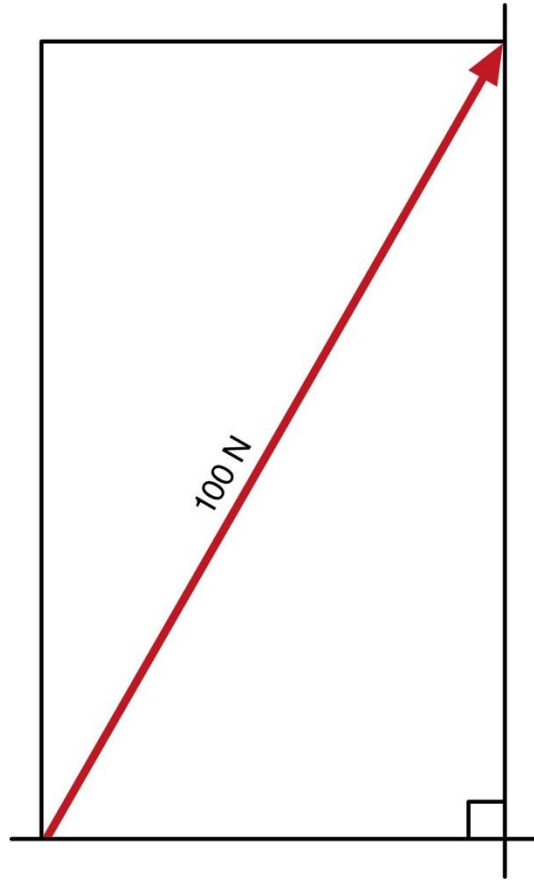
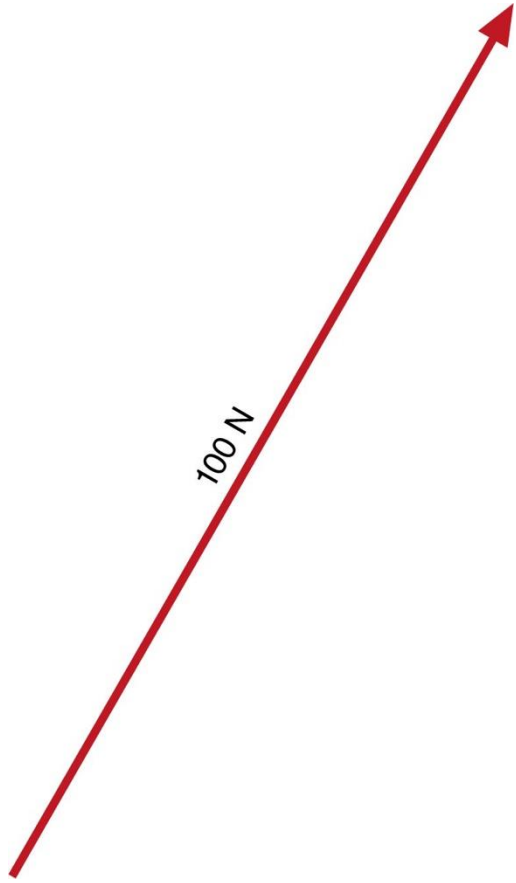
Resolution of Forces

- **Sometimes external forces are not colinear and do not act only in the horizontal and vertical directions**
- **Example: forces acting on a shot during the shot-put**
 - **100 N @ 60° from shot-putter's hand**
 - **Mass of shot = 4 kg**
- **What is the resultant force on the shot?**

(continued)



Force Components on the Shot



Resolution of Forces *(continued)*

- Resolve components (parts) of the shot-putter's force
- 100 N @ 60° from the shot-putter's hand
- Use trigonometry to calculate horizontal and vertical forces

Horizontal component

Select the cosine function

$$\cos 60^\circ = \frac{\text{adjacent side}}{100 \text{ N}}$$

$$(100 \text{ N}) (0.500) = +50 \text{ N}$$

Vertical component

Select the sine function

$$\sin 60^\circ = \frac{\text{opposite side}}{100 \text{ N}}$$

$$(100 \text{ N}) (0.866) = +86.6 \text{ N}$$

(continued)

Resolution of Forces *(continued)*

- Calculate resultant horizontal and vertical forces
- Horizontal force (only one)
 - Shot-putter force = +50 N
- Vertical forces
 - Shot-putter force = 86.6 N
 - Shot weight = $mg = 4 \text{ kg} \times 10 \text{ m/s}^2 = -40 \text{ N}$
 - Resultant vertical force = $(86.6) + (-40) = +46.6 \text{ N}$

(continued)

Resolution of Forces *(continued)*

- Calculate net force on shot-put using Pythagorean theorem
- Horizontal force = +50 N
- Vertical force = +46.6 N

$$RF^2 = HF^2 + VF^2 = 50^2 + 46.6^2$$

$$RF^2 = 2500 + 2172$$

$$RF = \sqrt{4672} = 68.4 \text{ N}$$

(continued)

Resolution of Forces *(continued)*

- Horizontal force = +50 N
- Vertical force = +46.6 N
- Calculate net force direction using trigonometry

Select the arctangent function:

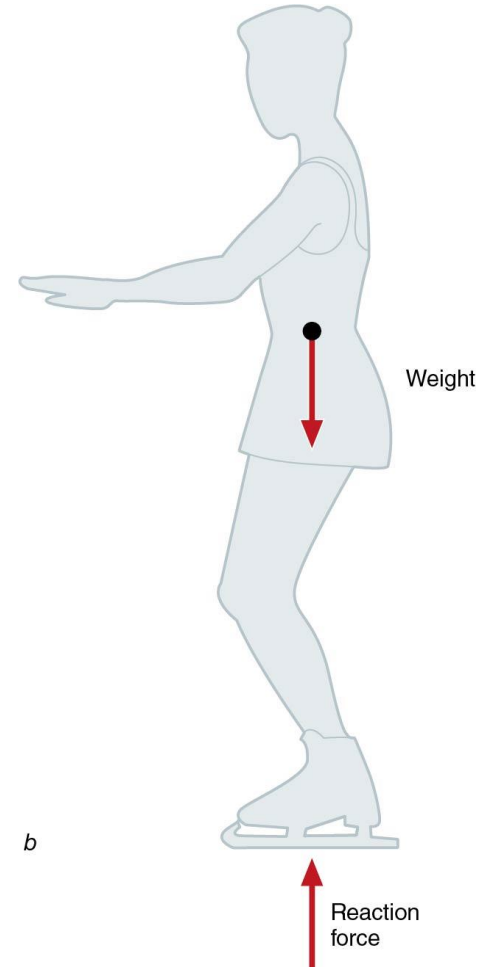
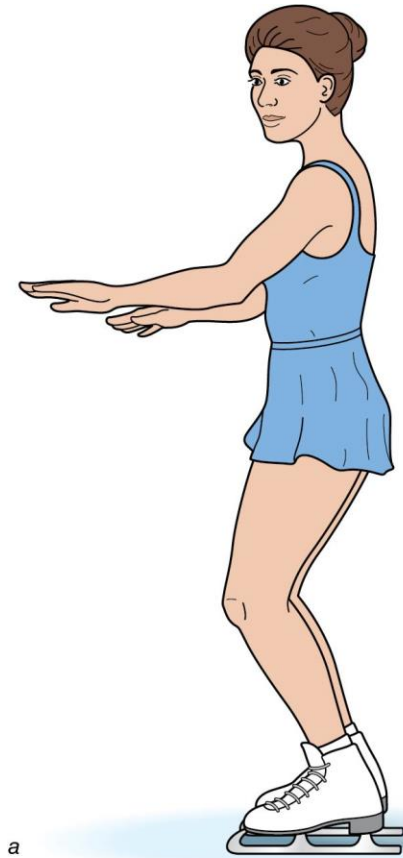
$$\theta = \arctan\left(\frac{46.6}{50}\right) = \arctan(0.932) = 43^\circ$$

The resultant force on the shotput has a magnitude of 68.4 N at an angle of 43°.

Static Equilibrium

- **Body is not accelerating (no change in motion)**
- **Forces are in equilibrium (Σ to 0 in all directions)**
- **Consider skater standing motionless on ice**
Mass = 50 kg
- **Use a free-body diagram to visualize the situation**
- **Use static analysis to solve for external force**

Free-Body Diagram of a Skater Standing on Ice



Static Analysis

- Forces on skater:
 - W (Weight) = $mg = -500 \text{ N}$
 - R (Ice) = ?
- $\Sigma F = 0$
- $W + R = 0$
- $R = -\text{Weight}$
- $R = -(-500)$
- $R = +500 \text{ N}$ (ice pushes upward on skater)

Objectives

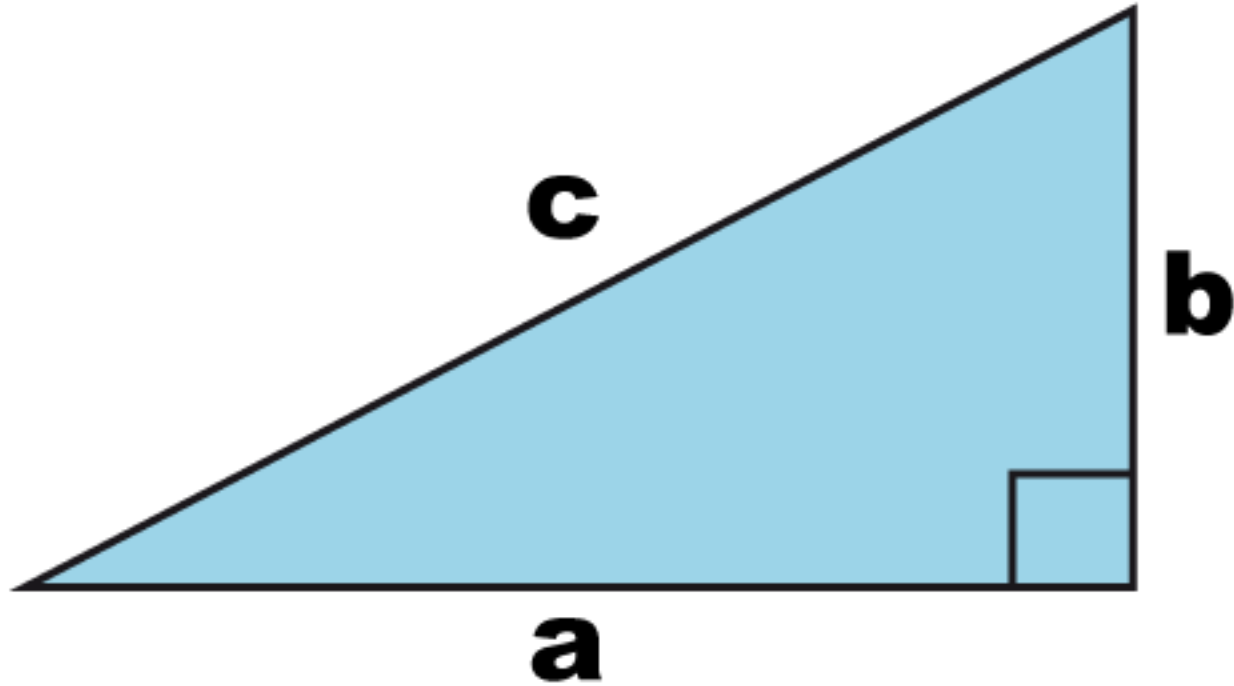
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(continued)

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Pythagorean theorem



$$a^2 + b^2 = c^2$$

Trigonometry

$$\sin \alpha = \frac{opp}{hyp} \quad = \quad \sin \alpha \times hyp = opp \quad = \quad hyp = \frac{opp}{\sin \alpha}$$

$$\cos \alpha = \frac{adj}{hyp} \quad = \quad \cos \alpha \times hyp = adj \quad = \quad hyp = \frac{adj}{\cos \alpha}$$

$$\tan \alpha = \frac{opp}{adj} \quad = \quad \tan \alpha \times adj = opp \quad = \quad adj = \frac{opp}{\tan \alpha}$$

Rearrange these equations