Honors Physics
Unit 2: Forces

Slides

Inertia and Mass

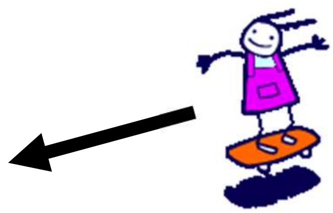
Why are large objects more difficult to move than small objects?

Inertia

Tendency of objects to resist acceleration.
Proportional to the mass of the object.

Motionless objects resist acceleration to make them move.

Moving objects resist acceleration to change their velocity.



Mass

Mass is…

- The amount of matter in an object
- A measure of an object’s resistance to changing its velocity (inertia)
- Expressed using the unit *kilograms* (kg)
- Going to remain the same no matter where the object is
- NOT the same thing as weight

For example, an astronaut’s weight will be different on the Earth and Moon, but his mass will always be the same

Lesser mass = **lesser inertia, less resistance to changing velocity**

Greater mass = **greater inertia, more resistance to changing velocity**

Force

What causes a change in velocity?

What causes acceleration?

Force

Force is…

- A push or pull
- An interaction with an object that *can* cause it to accelerate (change its velocity)
- A vector (has magnitude and direction)
- Expressed using the unit *Newtons* (N)
  - $1\ \text{N} = 1\ \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$

Forces cause changes in velocity!
Forces cause acceleration!

Forces can also cause matter to change shape or size.

Categories of Forces

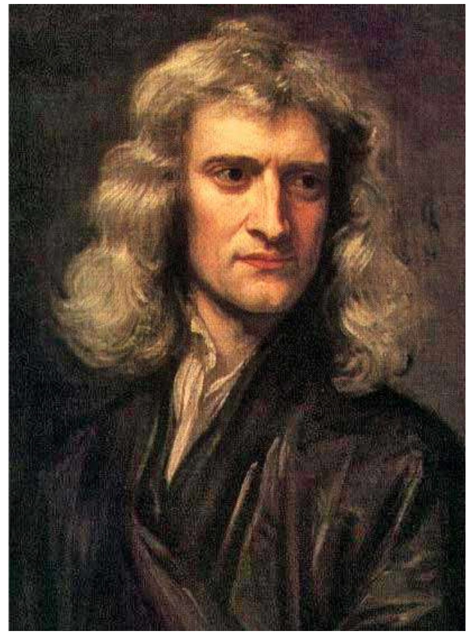
Contact Forces: forces that only act when two objects are touching each other

- Example: friction, tension, applied forces, normal force

Action-at-a-Distance (Field) Forces: forces that can act when the two objects are NOT touching

- Example: gravity, magnetic force, electric force

Newton's Three Laws of Motion

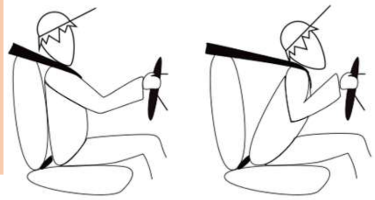


Newton's 1st Law ("Law of Inertia")

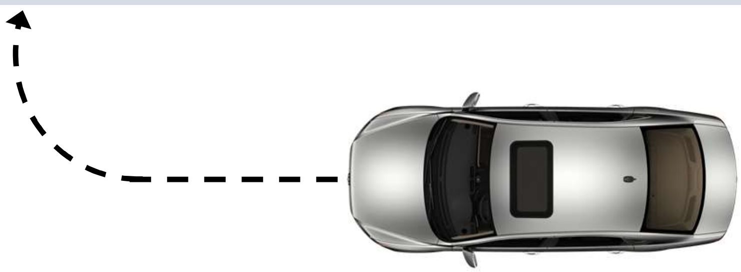
An object will have a constant velocity (constant speed and direction) **unless** acted upon by an unbalanced external force (an external net force)

- An object that is at rest and has no net force acting on it will stay at rest
- An object that is moving and has no net force acting on it will continue traveling at the same speed and in the same direction

What happens to the driver's body when the car brakes to a stop?



What happens to the driver's body when the car turns at a curve?



Newton's 2nd Law

The acceleration of an object is proportional to the net force and inversely proportional to the mass of the object

- More net force → more acceleration
- Less net force → less acceleration

- More mass → less acceleration
- Less mass → more acceleration

Newton's 2nd Law

$$\vec{F}_{net} = m \cdot \vec{a} \qquad \vec{a} = \frac{\vec{F}_{net}}{m} \qquad m = \frac{\vec{F}_{net}}{\vec{a}}$$

A boy kicks a soccer ball. The ball has a mass of 1.5 kg. The ball accelerated by 4 m/s^2. Calculate the force of the kick.

1. What information do you know?
2. Which parameter are you solving for?
3. Choose the correct equation.
4. Solve the problem.

A boy kicks a soccer ball. The ball has a mass of 1.5 kg. The ball accelerated by 4 m/s^2. Calculate the force of the kick.

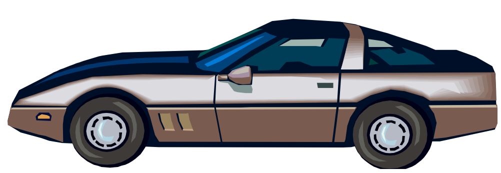
m = 1.5 kg
a = 4.0 m/s^2
F = ?

$$F = m \cdot a$$

$$F = 1.5kg \cdot 4.0 \, m/s^2 = 6.0N$$

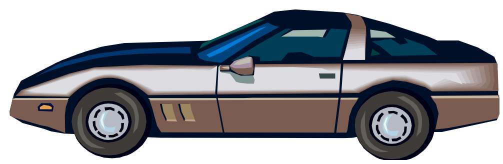
The engine of the car exerts a force of 1000 N to accelerate the car. The mass of the car is 600 kg. Calculate the acceleration of the car.

1. What information do you know?
2. Which parameter are you solving for?
3. Choose the correct equation.
4. Solve the problem.



The engine of the car exerts a force of 1000 N to accelerate the car. The mass of the car is 600 kg. Calculate the acceleration of the car.

m = 600 kg
a = ?
F = 1000 N



$$a = \frac{F}{m} = \frac{1000N}{600kg} = 1.66\, {}^{m}\!/_{s^2}$$

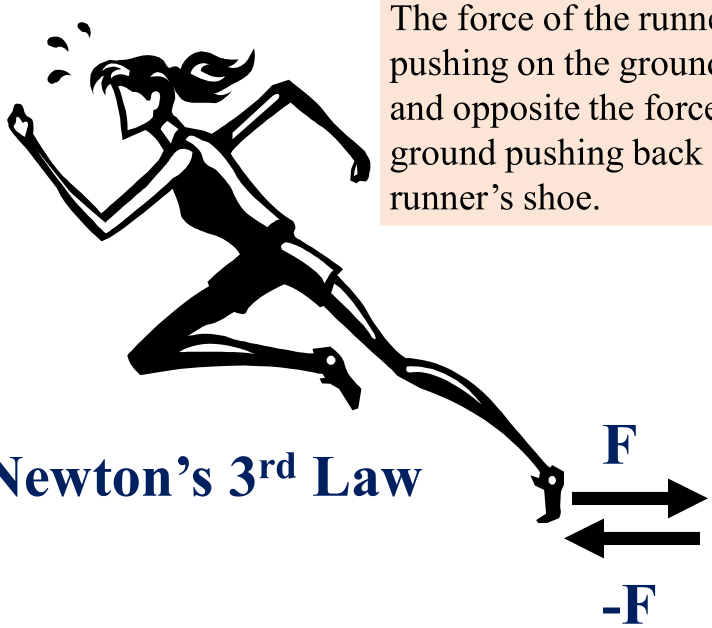
Newton's 3rd Law

Common expression: "Every action has an equal and opposite reaction"

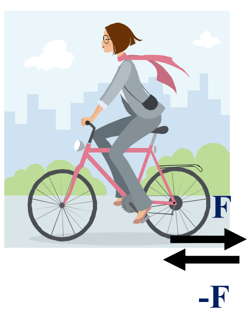
Better expression: All forces come in pairs. These paired forces…

- Have equal magnitude
- Are in opposite directions
- Act on different objects

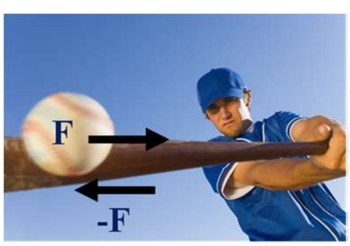
The force of the runner's shoe pushing on the ground is equal and opposite the force of the ground pushing back on the runner's shoe.



Newton's 3rd Law



The force of the bicycle tire pushing on the road surface is equal and opposite the force of the road surface pushing back on the bicycle tire.



The force of the baseball bat striking the baseball is equal and opposite the force of the baseball pushing back on the bat.

Balanced & Unbalanced Force

Does *every* force applied to an object cause it to accelerate?

Net Force

The **net force ($\vec{F}_{net}$)** on an object is the vector sum of *all* the forces being applied to the object.

Net force is the cause of acceleration:

- $\vec{F}_{net}$ = 0 N means no acceleration occurs, constant velocity
- $\vec{F}_{net} \neq$ 0 N means acceleration occurs, changing velocity

Balanced Forces

Unbalanced Forces

Balanced forces

Two or more forces that are equal in magnitude and opposite in direction. The net force is zero ($F_{net} = 0$ N)

Object's state of motion remains constant.

- **Objects that are motionless will remain motionless.**
- **Objects in motion will maintain a constant velocity (straight-line at a uniform rate)**

Unbalanced forces

- **Unequal forces act upon the same object.**
  - $F_{net} \neq 0$ N
- **Net force in the direction of the greater force.**
- **The object will accelerate; object's state of motion will change in velocity (direction or speed).**

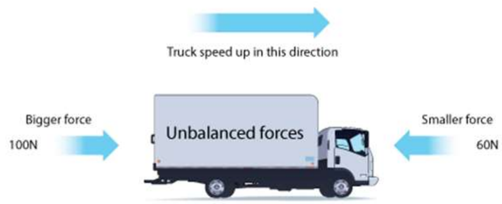
Unbalanced forces

Two or more forces that are not equal in magnitude and opposite in direction.

Object will accelerate in direction of net force.
- **Object will get faster or slower with time.**
- **Object may change direction with time.**

Balanced Forces
- Net force = 0 N
- No acceleration.

Unbalanced Forces
- Net force = -100 N
- Acceleration to the left.



Unbalanced Forces
- Net force = + 40 N
- Acceleration to the right.

Free Body Diagrams

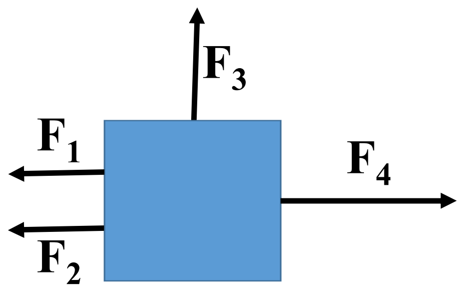
How do we model the forces acting on an object?

Free Body Diagram (FBD)

In physics, we model the forces acting on an object by drawing a picture called a **free body diagram (FBD)**

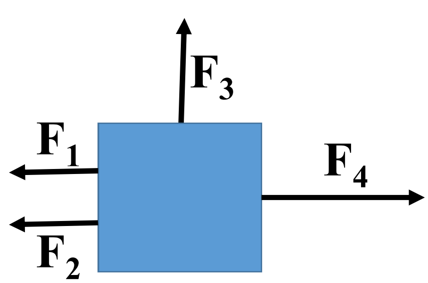
FBDs show the magnitude and direction of all forces acting on an object

IMPORTANT: FBDs only show the forces acting **ON** the object (external forces), NOT the forces exerted **BY** the object



Drawing a FBD

- Draw the object as a box
- For all forces acting ON the object, draw a force vector on the box
- The lengths of the vectors correspond to their magnitudes
  - Larger magnitude forces should be longer than smaller magnitude forces



Using a FBD to Find Net Force

1. **Draw the FREE BODY DIAGRAM using vector arrows. Label the vector arrows with their respective magnitude and directions**

2. **Add the vectors that are along the same line (East-West and North-South)**
   - **Calculate overall force in North-South direction**
   - **Calculate overall force in East-West direction**

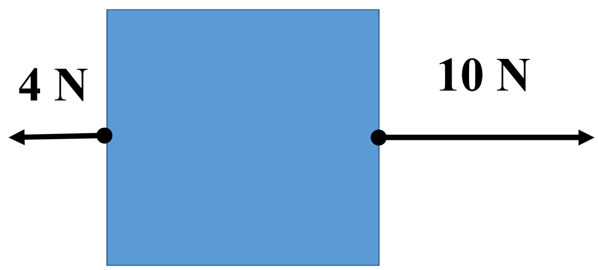
3. **Redraw the FBD showing only the overall forces in the N-S and E-W directions**

Using a FBD to Find Net Force

4. **Add together the overall N-S force and the overall E-W force to determine the NET FORCE. Use the Pythagorean Theorem to add forces in perpendicular directions**

5. **Divide the net force by the mass of the object to calculate the acceleration of the object**

Example 1: Solve for the NET FORCE.

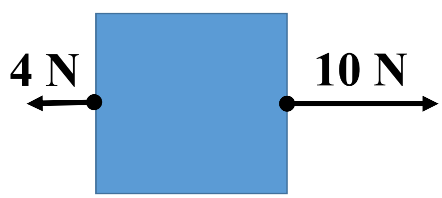


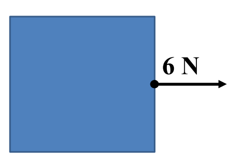
1. Draw the FBD. (done)
2. Calculate N-S force

   0 N + 0 N = 0 N

   Calculate E-W force

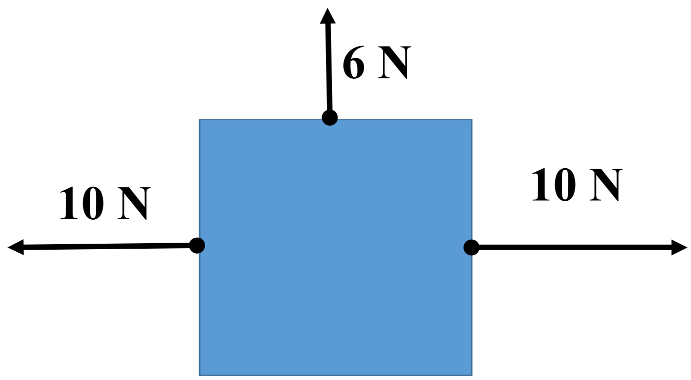
   +10 N + -4 N = +6 N
3. Redraw using only remaining forces.





The net force is **6 N East**. It is the ONE remaining force. No additional steps need to be taken.

Example 2: Solve for the NET FORCE.

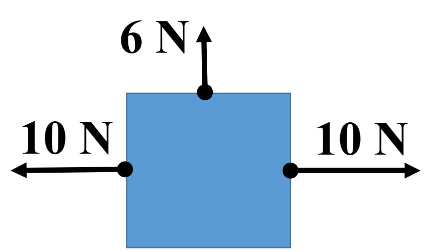


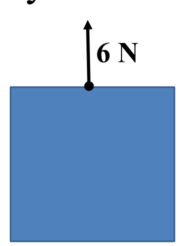
1. Draw the FBD. (done)
2. Calculate N-S force

   +6 N + 0 N = +6 N

   Calculate E-W force

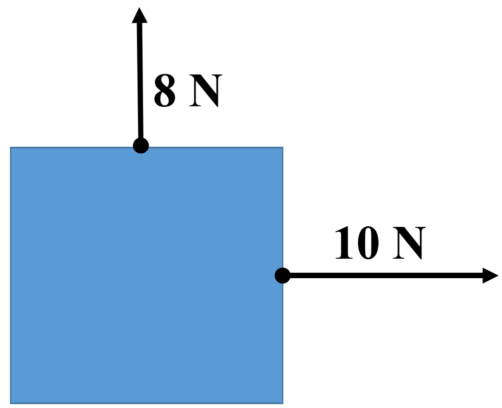
   +10 N + -10 N = 0 N
3. Redraw using only remaining forces.





The net force is **6 N North**. It is the ONE remaining force. No additional steps need to be taken.

Example 3: Solve for the NET FORCE.

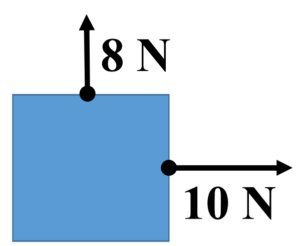


1. Draw the FBD. (done)
2. Calculate N-S force

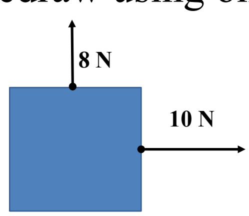
   +8 N + 0 N = +8 N

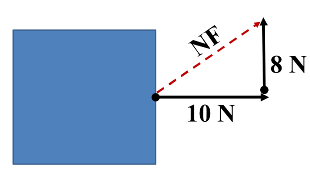
   Calculate E-W force

   +10 N + 0 N = +10 N



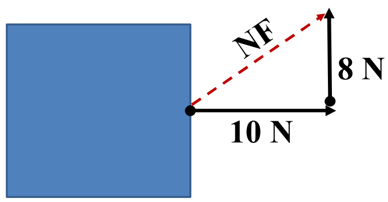
3. Redraw using only remaining forces.





There are two remaining forces. Note, you must use the **Pythagorean theorem** to calculate the net force.

Step 4: Use Pythagorean theorem if two forces remain and you can form a right triangle.

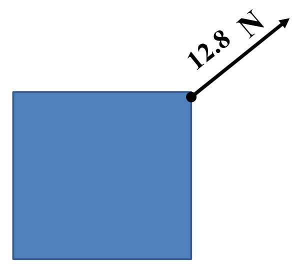


$$NF = C = \sqrt{A^2 + B^2}$$

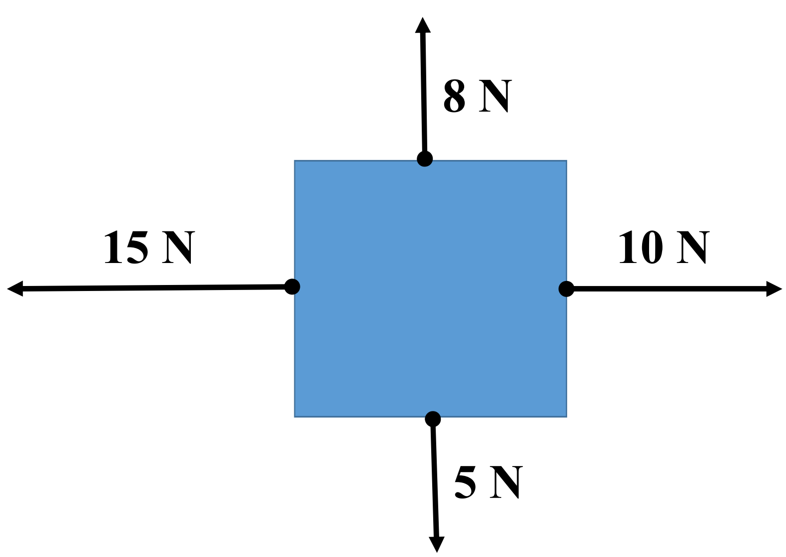
$$NF = \sqrt{(8)^2 + (10)^2} = \sqrt{164}$$

$$NF = 12.8 \text{ N}$$

Redraw with only the ONE net force.



Example 4: Solve for the NET FORCE.

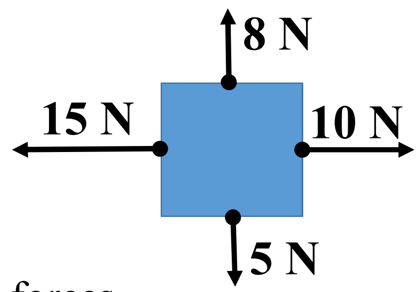


1. Draw the FBD. (done)
2. Calculate N-S force

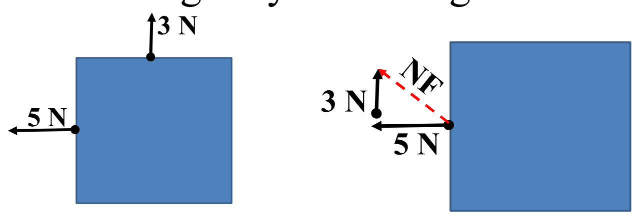
   +8 N + -5 N = +3 N

   Calculate E-W force

   +10 N + -15 N = -5 N

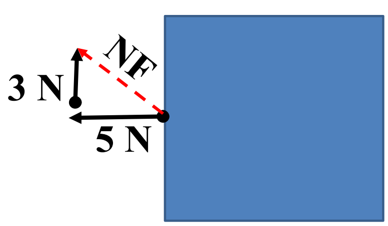


3. Redraw using only remaining forces.



There are two remaining forces. Note, you must use the **Pythagorean theorem** to calculate the net force.

Step 4: Use Pythagorean theorem if two forces remain and you can form a right triangle.

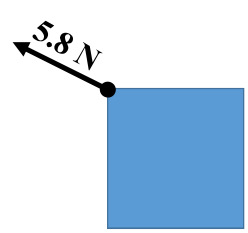


$$NF = C = \sqrt{A^2 + B^2}$$

$$NF = \sqrt{(3)^2 + (5)^2} = \sqrt{34}$$

$$NF = 5.8 \text{ N}$$

Redraw with only the ONE net force.



More Complex FBDs

Forces

Applied force ($\vec{F}_a$): Force applied on the object by the person in the scenario

- For example, when you push a shopping cart, your hand is supplying the applied force

Normal force ($\vec{F}_N$): Force applied on an object by the surface that is supporting the object

- Is **always** perpendicular to the supporting surface
- For example, when you stand on the ground, the ground applies a normal force on your feet

Forces

Gravity ($\vec{F}_g$): Force of the Earth pulling down on every object with mass

- **Always** points straight downward toward Earth's surface

Friction ($\vec{F}_f$): Force that opposes motion when two surfaces slide against each other

- Is parallel to the sliding surfaces
- Always points in the direction to oppose movement or *potential* movement

Inclined Surface