Preview

What do you think?

- What is a force?
- Are any forces acting on your book as it rests on your desk?
  - If so, describe them.
  - Make a sketch showing any forces on the book.
- What units are used to measure force?
- Can forces exist without contact between objects? Explain.

Forces

- Forces can change motion.
  - Start movement, stop movement, or change the direction of movement
  - Cause an object in motion to speed up or slow down

Forces

- Contact forces
  - Pushes or pulls requiring physical contact between the objects
  - Baseball and bat

- Field forces
  - Objects create force fields that act on other objects.
  - Gravity, static electricity, magnetism

Units of Force

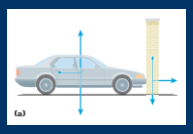
- The SI unit of force is the newton (N).
  - Named for Sir Isaac Newton
  - Defined as the force required to accelerate a 1 kg mass at a rate of 1 m/s^2
  - Approximately 1/4 pound
- Other units are shown below.

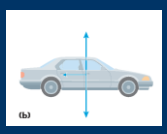
Table 1 Units of Mass, Acceleration, and Force

System	Mass	Acceleration	Force
SI	kg	m/s^2	$N = kg \cdot m/s^2$
cgs	g	cm/s^2	$dyne = g \cdot cm/s^2$
Avoirdupois	slug	ft/s^2	$lb = slug \cdot ft/s^2$

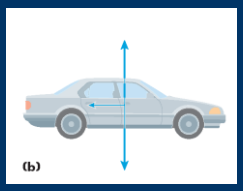
Force Diagrams

- Forces are vectors (magnitude and direction).
- Force diagram (a)
  - Shows all forces acting during an interaction
    - On the car and on the wall
- Free-body diagram (b)
  - Shows only forces acting on the object of interest
    - On the car





Free-Body Diagrams



- Three forces are shown on the car.
  - Describe each force by explaining the source of the force and where it acts on the car.
  - Is each force a contact force or a field force?

Now what do you think?

- What is a force?
- What forces act on your book as it rests on your desk?
  - Make a sketch showing any forces on the book.
  - Are they contact forces or field forces?
- What SI unit is used to measure force?
  - What equivalent basic SI units measure force?

What do you think?

- Imagine the following two situations:
  - Pushing a puck across an air hockey table
  - Pushing a book across a lab table
- What should your finger do in each case to maintain a *constant speed* for the object as it moves across the table or desk? (Choose from below.)
  - A quick push or force, then release the object
  - Maintain a constant force as you push the object
  - Increase or decrease the force as you push the object
- Explain your choice for the puck and the book.

Newton's First Law

- Experimentation led Galileo to the idea that objects maintain their state of motion or rest.
- Newton developed the idea further, in what is now known as Newton's first law of motion:

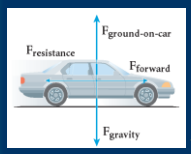
NEWTON'S FIRST LAW

An object at rest remains at rest, and an object in motion continues in motion with constant velocity (that is, constant speed in a straight line) unless the object experiences a net external force.

Newton's First Law

- Called the *law of inertia*
- Inertia
  - Tendency of an object *not* to accelerate
  - Mass is a measure of inertia
    - More mass produces more resistance to a change in velocity
- Which object in each pair has more inertia?
  - A baseball at rest or a tennis ball at rest
    - Answer: the baseball
  - A tennis ball moving at 125 mi/h or a baseball at rest
    - Answer: the baseball

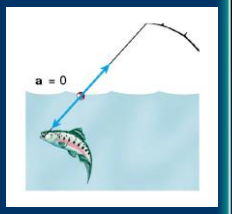
Net Force - the Sum of the Forces



- This car is moving with a constant velocity.
  - $F_{forward}$ = road pushing the tires
  - $F_{resistance}$ = force caused by friction and air
  - Forces are balanced
- Velocity is constant because the net force (F_{net}) is zero.

Equilibrium

- The state in which the net force is zero.
  - All forces are balanced.
  - Object is at rest or travels with constant velocity.
- In the diagram, the bob on the fishing line is in equilibrium.
  - The forces cancel each other.
  - If either force changes, acceleration will occur.



Classroom Practice Problem

- An agricultural student is designing a support system to keep a tree upright. Two wires have been attached to the tree and placed at right angles to each other (parallel to the ground). One wire exerts a force of 30.0 N and the other exerts a force of 40.0 N. Determine where to place a third wire and how much force it should exert so that the net force on the tree is zero.
- Answer: 50.0 N at 143° from the 40.0 N force

Now what do you think?

- Imagine the following two situations:
  - Pushing a puck across an air hockey table
  - Pushing a book across a lab table
- What should your finger do in each case to maintain a *constant speed* for the object as it moves across the table or desk? (Choose from below.)
  - A quick push or force, then release the object
  - Maintain a constant force as you push the object
  - Increase or decrease the force as you push the object
- Explain your choice for the puck and the book.

What do you think?

- If a net force acts on an object, what type of ***motion*** will be observed?
  - Why?
- How would this motion be affected by the amount of force?
- Are there any other factors that might affect this motion?

Newton's Second Law

NEWTON'S SECOND LAW

The acceleration of an object is directly proportional to the net force acting on the object and inversely proportional to the object's mass.

- Increasing the force will increase the acceleration.
  - Which produces a greater acceleration on a 3-kg model airplane, a force of 5 N or a force of 7 N?
    - Answer: the 7 N force
- Increasing the mass will decrease the acceleration.
  - A force of 5 N is exerted on two model airplanes, one with a mass of 3 kg and one with a mass of 4 kg. Which has a greater acceleration?
    - Answer: the 3 kg airplane

Newton's Second Law (Equation Form)

NEWTON'S SECOND LAW

$$\Sigma \mathbf{F} = m\mathbf{a}$$

net force = mass × acceleration

- $\Sigma \mathbf{F}$ represents the *vector sum* of all forces acting on an object.
  - $\Sigma \mathbf{F} = \mathbf{F}_{net}$
  - Units for force: mass units (kg) × acceleration units (m/s^2)
  - The units $kg \cdot m/s^2$ are also called newtons (N).

Classroom Practice Problem

- Space-shuttle astronauts experience accelerations of about 35 m/s^2 during takeoff. What force does a 75 kg astronaut experience during an acceleration of this magnitude?
- Answer: 2600 $kg \cdot m/s^2$ or 2600 N

What do you think?

- Two football players, Alex and Jason, collide head-on. They have the same mass and the same speed before the collision. How does the force on Alex compare to the force on Jason? Why do you think so?
  - Sketch each player as a stick figure.
  - Place a velocity vector above each player.
  - Draw the force vector on each and label it (i.e. F_{JA} is the force of Jason on Alex).

What do you think?

- Suppose Alex has twice the mass of Jason. How would the forces compare?
  - Why do you think so?
  - Sketch as before.
- Suppose Alex has twice the mass and Jason is at rest. How would the forces compare?
  - Why do you think so?
  - Sketch as before.

Newton's Third Law

- Forces always exist in pairs.
  - You push down on the chair, the chair pushes up on you
  - Called the action force and reaction force
  - Occur simultaneously so *either* force is the action force

Newton's Third Law

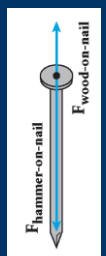
NEWTON'S THIRD LAW

If two objects interact, the magnitude of the force exerted on object 1 by object 2 is equal to the magnitude of the force simultaneously exerted on object 2 by object 1, and these two forces are opposite in direction.

- For every action force there is an equal and opposite reaction force.
- The forces act on different objects.
  - Therefore, they do not balance or cancel each other.
  - The motion of each object depends on the net force on that object.

Hammer Striking a Nail

- What are the action/reaction pairs for a hammer striking a nail into wood?
  - Force of hammer on nail = force of nail on hammer
  - Force of wood on nail = force of nail on wood
- Which of the action/reaction forces above act on the nail?
  - Force of hammer on nail (downward)
  - Force of wood on nail (upward)
- Does the nail move? If so, how?
  - $F_{hammer\text{-}on\text{-}nail} > F_{wood\text{-}on\text{-}nail}$ so the nail accelerates downward



Hammer Striking a Nail

- What forces act on the hammer?
  - Force of nail on hammer (upward)
  - Force of hand on hammer (downward)
- Does the hammer move? If so, how?
  - $F_{nail\text{-}on\text{-}hammer} > F_{hand\text{-}on\text{-}hammer}$ so the hammer accelerates upward or slows down
- The hammer and nail accelerate in opposite directions.

Action-Reaction: A Book on a Desk

Action Force	Reaction Force
• The desk pushes up on the book.	• The book pushes down on the desk.
• Earth pulls down on the book (force of gravity).	• The book pulls up on Earth.

Action-Reaction: A Falling Book

Action	Reaction
• Earth pulls down on the book (force of gravity).	• The book pulls up on Earth.
• What is the result of the action force (if this is the only force on the book)? – Unbalanced force produces an acceleration of -9.81 m/s^2.	• What is the result of the reaction force? • Unbalanced force produces a very small upward acceleration (because the mass of Earth is so large).

Now what do you think?

- If a net force acts on an object, what type of ***motion*** will be observed?
  - Why?
- How would this motion be affected by the amount of force?
- Are there any other factors that might affect this motion?

Now what do you think?

Two football players, Alex and Jason, collide head-on. For each scenario below, do the following:

- Sketch each player as a stick figure.
- Place a velocity vector above each player.
- Draw the force vector on each and label it.
- Draw the acceleration vector above each player.

- Scenario 1: Alex and Jason have the same mass and the same speed before the collision.
- Scenario 2: Alex has twice the mass of Jason, and they both have the same speed before the collision.
- Scenario 3: Alex has twice the mass and Jason is at rest.

What do you think?

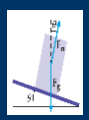
- How do the quantities *weight* and *mass* differ from each other?
- Which of the following terms is most closely related to the term *friction*?
  - Heat, energy, force, velocity
- Explain the relationship.

Weight and Mass

- Mass is the amount of matter in an object.
  - Kilograms, slugs
- Weight is a measure of the gravitational force on an object.
  - Newtons, pounds
  - Depends on the acceleration of gravity
- Weight = mass × acceleration of gravity
  - $W = ma_g$ where $a_g = 9.81\ m/s^2$ on Earth
  - Depends on location
    - a_g varies slightly with location on Earth.
    - a_g is different on other planets.

Normal Force

- Force on an object perpendicular to the surface (F_n)
- It may equal the weight (F_g), as it does here.
- It does not always equal the weight (F_g), as in the second example.
- $F_n = mg \cos \theta$



Static Friction

- Force that prevents motion
- Abbreviated **F_s**

- How does the applied force (**F**) compare to the frictional force ($\mathbf{F_s}$)?
- Would F_s change if **F** was reduced? If so, how?
- If **F** is increased significantly, will $\mathbf{F_s}$ change? If so, how?
- Are there any limits on the value for $\mathbf{F_s}$?

Kinetic Friction

- Force between surfaces that opposes movement
- Abbreviated F_k
- Does not depend on the speed

- Using the picture, describe the motion you would observe.
  - The jug will accelerate.
- How could the person push the jug at a constant speed?
  - Reduce F so it equals F_k.

Friction

Click below to watch the Visual Concept.

Visual Concept

Calculating the Force of Friction (F_f)

- F_f is directly proportional to F_n (normal force).

$$F_f = \mu F_n \qquad \mu = \frac{F_f}{F_n}$$

- Coefficient of friction (μ):
  - Determined by the nature of the two surfaces
  - μ_s is for static friction.
  - μ_k is for kinetic friction.
  - $\mu_s > \mu_k$

Typical Coefficients of Friction

- Values for μ have no units and are approximate.

Table 2 Coefficients of Friction (Approximate Values)

	μ_s	μ_k		μ_s	μ_k
steel on steel	0.74	0.57	waxed wood on wet snow	0.14	0.1
aluminum on steel	0.61	0.47	waxed wood on dry snow	—	0.04
rubber on dry concrete	1.0	0.8	metal on metal (lubricated)	0.15	0.06
rubber on wet concrete	—	0.5	ice on ice	0.1	0.03
wood on wood	0.4	0.2	Teflon on Teflon	0.04	0.04
glass on glass	0.9	0.4	synovial joints in humans	0.01	0.003

Everyday Forces

Click below to watch the Visual Concept.

Visual Concept

Classroom Practice Problem

- **A 24 kg crate initially at rest on a horizontal floor requires a 75 N horizontal force to set it in motion. Find the coefficient of static friction between the crate and the floor.**
  - Draw a free-body diagram and use it to find:
    - the weight
    - the normal force ($\mathbf{F}_n$)
    - the force of friction ($\mathbf{F}_f$)
  - Find the coefficient of friction.
- Answer: $\mu_s = 0.32$

Classroom Practice Problem

- **A student attaches a rope to a 20.0 kg box of books. He pulls with a force of 90.0 N at an angle of 30.0° with the horizontal. The coefficient of kinetic friction between the box and the sidewalk is 0.500. Find the magnitude of the acceleration of the box.**
  - Start with a free-body diagram.
  - Determine the net force.
  - Find the acceleration.

- Answer: $a = 0.12\ m/s^2$

The Four Fundamental Forces

- Electromagnetic
  - Caused by interactions between protons and electrons
  - Produces friction
- Gravitational
  - The weakest force
- Strong nuclear force
  - The strongest force
  - Short range
- Weak nuclear force
  - Short range

Now what do you think?

- How do the quantities *weight* and *mass* differ from each other?
- Which of the following terms is most closely related to the term *friction*?
  - Heat, energy, force, velocity
- Explain the relationship.