Preview

- Objectives
- Force
- Force Diagrams

Objectives

- **Describe** how force affects the motion of an object.
- **Interpret** and **construct** free body diagrams.

Force

Click below to watch the Visual Concept.

Visual Concept

Force

- A **force** is an action exerted on an object which may change the object's state of rest or motion.
- **Forces** can cause **accelerations.**
- The SI unit of force is the **newton, N.**
- Forces can act through **contact** or at a **distance.**

End of Slide

Comparing Contact and Field Forces

Click below to watch the Visual Concept.

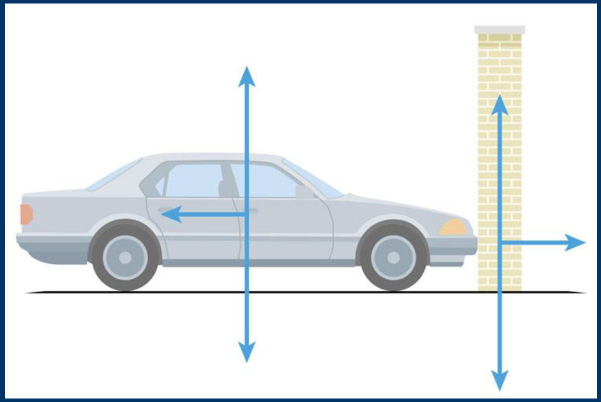
Visual Concept

Force Diagrams

- The effect of a force depends on both **magnitude** and **direction.** Thus, force is a **vector** quantity.
- Diagrams that show force vectors as arrows are called **force diagrams.**
- Force diagrams that show only the forces acting on a single object are called **free-body diagrams.**

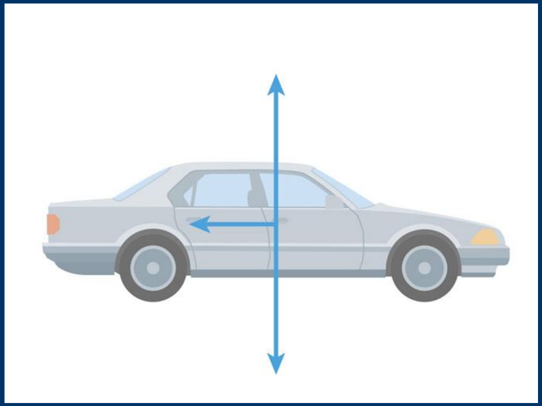
Force Diagrams, *continued*

Force Diagram



In a force diagram, vector arrows represent all the forces acting in a situation.

Free-Body Diagram



A free-body diagram shows only the forces acting on the object of interest—in this case, the car.

Drawing a Free-Body Diagram

Click below to watch the Visual Concept.

Visual Concept

Preview

- Objectives
- Newton's First Law
- Net Force
- Sample Problem
- Inertia
- Equilibrium

Objectives

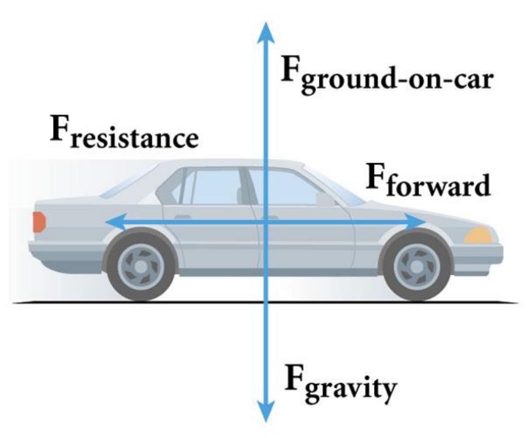
- **Explain** the relationship between the motion of an object and the net external force acting on the object.
- **Determine** the net external force on an object.
- **Calculate** the force required to bring an object into equilibrium.

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.
- In other words, when the net external force on an object is zero, the object's acceleration (or the change in the object's velocity) is zero.

Net Force

- **Newton's first law** refers to the **net force** on an object. The net force is the **vector sum** of all forces acting on an object.
- The **net force** on an object can be found by using the methods for finding resultant vectors.

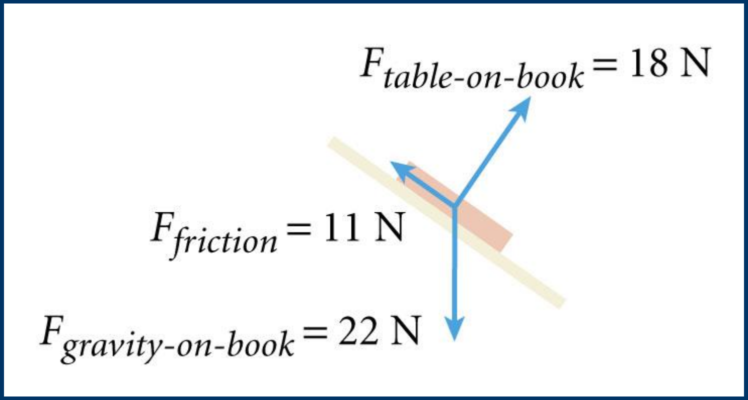


Although several forces are acting on this car, the vector sum of the forces is zero. Thus, the net force is zero, and the car moves at a constant velocity.

Sample Problem

Determining Net Force

Derek leaves his physics book on top of a drafting table that is inclined at a 35° angle. The free-body diagram below shows the forces acting on the book. Find the net force acting on the book.



End of Slide

Sample Problem, *continued*

1. Define the problem, and identify the variables.

Given:

$F_{gravity\text{-}on\text{-}book} = F_g = 22\ \text{N}$

$F_{friction} = F_f = 11\ \text{N}$

$F_{table\text{-}on\text{-}book} = F_t = 18\ \text{N}$

Unknown:

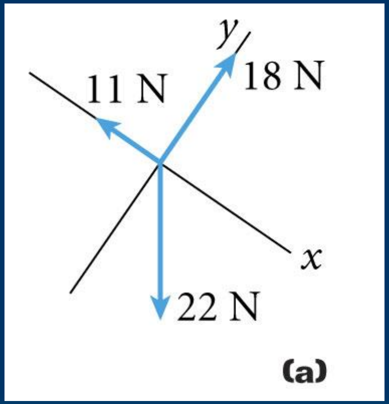
$F_{net} = ?$

End of Slide

Sample Problem, *continued*

2. Select a coordinate system, and apply it to the free-body diagram.

Choose the *x*-axis parallel to and the *y*-axis perpendicular to the incline of the table, as shown in **(a).** This coordinate system is the most convenient because only one force needs to be resolved into *x* and *y* components.

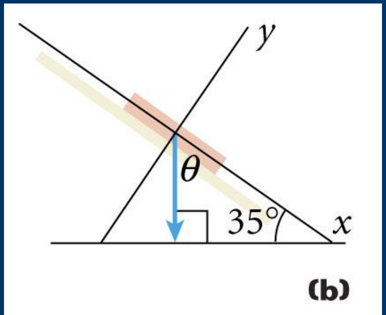


Tip: *To simplify the problem, always choose the coordinate system in which as many forces as possible lie on the x- and y-axes.*

Sample Problem, *continued*

3. Find the *x* and *y* components of all vectors.

Draw a sketch, as shown in **(b),** to help find the components of the vector $\mathbf{F_g}$. The angle θ is equal to 180°– 90° – 35° = 55°.

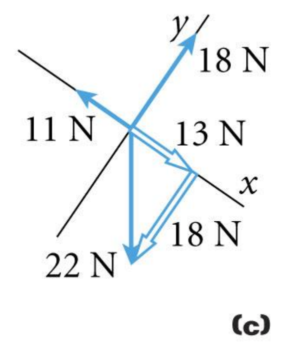


$$\cos\ \theta = \frac{F_{g,x}}{F_g} \qquad \sin\ \theta = \frac{F_{g,y}}{F_g}$$

$$F_{g,x} = F_g \cos\ \theta \qquad F_{g,y} = F_g \sin\ \theta$$

$$F_{g,x} = (22\ \text{N})(\cos 55°) \qquad F_{g,x} = (22\ \text{N})(\sin 55°)$$

$$F_{g,x} = 13\ \text{N} \qquad F_{g,x} = 18\ \text{N}$$



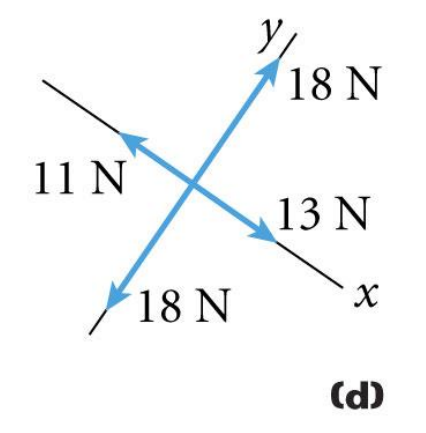
End of Slide

Add both components to the free-body diagram, as shown in **(c).**

Sample Problem, *continued*

4. Find the net force in both the *x* and *y* directions.

Diagram **(d)** shows another free-body diagram of the book, now with forces acting only along the *x*- and *y*-axes.



For the *x* direction:

$\Sigma F_x = F_{g,x} - F_f$

$\Sigma F_x = 13\ \text{N} - 11\ \text{N}$

$\Sigma F_x = 2\ \text{N}$

For the *y* direction:

$\Sigma F_y = F_t - F_{g,y}$

$\Sigma F_y = 18\ \text{N} - 18\ \text{N}$

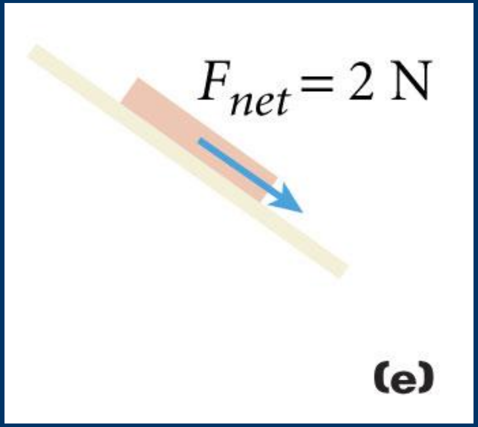
$\Sigma F_y = 0\ \text{N}$

End of Slide

Sample Problem, *continued*

5. Find the net force.

Add the net forces in the *x* and *y* directions together as vectors to find the total net force. In this case, $\mathbf{F}_{net}$ = 2 N in the +*x* direction, as shown in **(e).** Thus, the book accelerates down the incline.



End Of Slide

Inertia

- **Inertia** is the tendency of an object to resist being moved or, if the object is moving, to resist a change in speed or direction.
- **Newton's first law** is often referred to as the **law of inertia** because it states that in the absence of a net force, a body will preserve its state of motion.
- **Mass** is a measure of inertia.

End of Slide

Mass and Inertia

Click below to watch the Visual Concept.

Visual Concept

Equilibrium

- **Equilibrium** is the state in which the net force on an object is zero.
- Objects that are either **at rest** or moving with **constant velocity** are said to be in equilibrium.
- **Newton's first law** describes objects in equilibrium.

Tip: *To determine whether a body is in equilibrium, find the net force. If the net force is zero, the body is in equilibrium. If there is a net force, a second force equal and opposite to this net force will put the body in equilibrium.*

Preview

Objectives

- **Describe** an object's acceleration in terms of its mass and the net force acting on it.
- **Predict** the direction and magnitude of the acceleration caused by a known net force.
- **Identify** action-reaction pairs.

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.

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

net force = mass × acceleration

$\Sigma \mathbf{F}$ *represents the vector sum of all external forces acting on the object, or the net force.*

End of Slide

Newton's Second Law

Click below to watch the Visual Concept.

Visual Concept

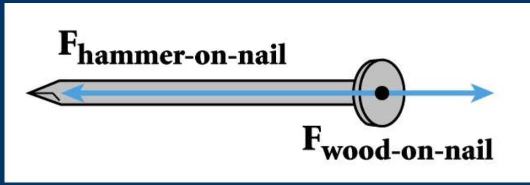
Newton's Third Law

- 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.
- In other words, **for every action, there is an equal and opposite reaction.**
- Because the forces coexist, either force can be called the action or the reaction.

End of Slide

Action and Reaction Forces

- Action-reaction pairs do not imply that the net force on either object is zero.
- The action-reaction forces are equal and opposite, but either object may still have a net force on it.



Consider driving a nail into wood with a hammer. The force that the nail exerts on the hammer is equal and opposite to the force that the hammer exerts on the nail. But there is a net force acting on the nail, which drives the nail into the wood.

Newton's Third Law

Click below to watch the Visual Concept.

Visual Concept

Preview

Objectives

- **Explain** the difference between mass and weight.
- **Find** the direction and magnitude of normal forces.
- **Describe** air resistance as a form of friction.
- **Use** coefficients of friction to calculate frictional force.

End of Slide

Weight

- The **gravitational force** (**F_g**) exerted on an object by Earth is a **vector** quantity, directed toward the center of Earth.

- The **magnitude** of this force (F_g) is a scalar quantity called **weight.**

- Weight changes with the location of an object in the universe.

End of Slide

Weight, *continued*

- **Calculating weight at any location:**

  $F_g = ma_g$

  a_g = free-fall acceleration at that location

- **Calculating weight on Earth's surface:**

  $a_g = g = 9.81\ \text{m/s}^2$

  $F_g = mg = m(9.81\ \text{m/s}^2)$

End of Slide

Comparing Mass and Weight

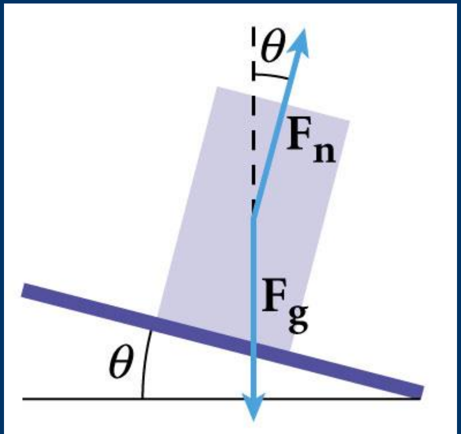
Click below to watch the Visual Concept.

Visual Concept

Normal Force

- The **normal force** acts on a surface in a direction **perpendicular** to the surface.

- The normal force is not always opposite in direction to the force due to gravity.



  – In the absence of other forces, the normal force is equal and opposite to the component of gravitational force that is perpendicular to the contact surface.
  – In this example, $F_n = mg \cos \theta$.

End Of Slide

Normal Force

Click below to watch the Visual Concept.

Visual Concept

Friction

- **Static friction** is a force that resists the initiation of sliding motion between two surfaces that are in contact and at rest.
- **Kinetic friction** is the force that opposes the movement of two surfaces that are in contact and are sliding over each other.
- **Kinetic friction** is always **less** than the **maximum static friction.**

End of Slide

Friction

Click below to watch the Visual Concept.

Visual Concept

Friction Forces in Free-Body Diagrams

- In free-body diagrams, the force of friction is always **parallel** to the surface of contact.
- The force of **kinetic friction** is always opposite the direction of motion.
- To determine the direction of the force of **static friction,** use the principle of equilibrium. For an object in equilibrium, the frictional force must point in the direction that results in a net force of zero.

End of Slide

The Coefficient of Friction

- The quantity that expresses the dependence of frictional forces on the particular surfaces in contact is called the **coefficient of friction, μ.**

- **Coefficient of kinetic friction:**

$$\mu_k = \frac{F_k}{F_n}$$

- **Coefficient of static friction:**

$$\mu_s = \frac{F_{s,max}}{F_n}$$

End of Slide

Coefficient of Friction

Coefficients of Friction

	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

Sample Problem

Overcoming Friction

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 acceleration of the box.

Sample Problem, *continued*

1. Define

Given:

$m = 20.0$ kg

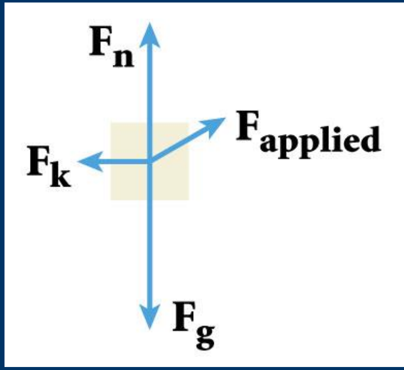
$\mu_k = 0.500$

$F_{applied} = 90.0$ N at $\theta = 30.0^\circ$

Unknown:

$\mathbf{a} = ?$

Diagram:

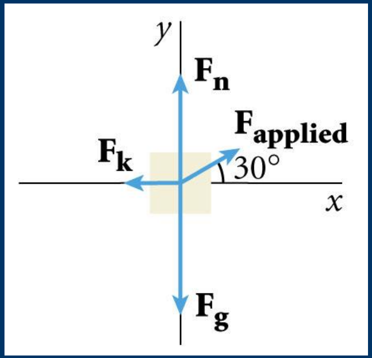


Sample Problem, *continued*

2. Plan

Choose a convenient coordinate system, and find the *x* and *y* components of all forces.

The diagram on the right shows the most convenient coordinate system, because the only force to resolve into components is $\mathbf{F}_{applied}$.



$F_{applied,y}$ = (90.0 N)(sin 30.0º) = 45.0 N (upward)

$F_{applied,x}$ = (90.0 N)(cos 30.0º) = 77.9 N (to the right)

End Of Slide

Sample Problem, *continued*

Choose an equation or situation:

A. Find the normal force, F_n, by applying the condition of equilibrium in the vertical direction:

$$\Sigma F_y = 0$$

B. Calculate the force of kinetic friction on the box:

$$F_k = \mu_k F_n$$

C. Apply Newton's second law along the horizontal direction to find the acceleration of the box:

$$\Sigma F_x = ma_x$$

Sample Problem, *continued*

3. Calculate

A. To apply the condition of equilibrium in the vertical direction, you need to account for all of the forces in the *y* direction:

F_g, F_n, and $F_{applied,y}$. You know $F_{applied,y}$ and can use the box's mass to find F_g.

$$F_{applied,y} = 45.0 \text{ N}$$

$$F_g = (20.0 \text{ kg})(9.81 \text{ m/s}^2) = 196 \text{ N}$$

Next, apply the equilibrium condition, $\Sigma F_y = 0$, and solve for F_n.

$$\Sigma F_y = F_n + F_{applied,y} - F_g = 0$$

$$F_n + 45.0 \text{ N} - 196 \text{ N} = 0$$

$$F_n = -45.0 \text{ N} + 196 \text{ N} = 151 \text{ N}$$

Tip: *Remember to pay attention to the direction of forces. In this step, F_g is subtracted from F_n and $F_{applied,y}$ because F_g is directed downward.*

Sample Problem, *continued*

B. Use the normal force to find the force of kinetic friction.

$$F_k = \mu_k F_n = (0.500)(151 \text{ N}) = 75.5 \text{ N}$$

C. Use Newton's second law to determine the horizontal acceleration.

$$\Sigma F_x = F_{applied} - F_k = ma_x$$

$$a_x = \frac{F_{applied,x} - F_k}{m} = \frac{77.9 \text{ N} - 75.5 \text{ N}}{20.0 \text{ kg}} = \frac{2.4 \text{ N}}{20.0 \text{ kg}} = \frac{2.4 \text{ kg} \bullet \text{m/s}^2}{20.0 \text{ kg}}$$

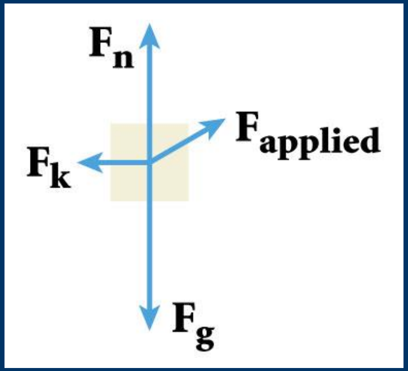
a = 0.12 m/s^2 to the right

End of Slide

Sample Problem, *continued*

4. Evaluate

The box accelerates in the direction of the net force, in accordance with Newton's second law. The normal force is not equal in magnitude to the weight because the *y* component of the student's pull on the rope helps support the box.



Air Resistance

- **Air resistance** is a form of **friction.** Whenever an object moves through a fluid medium, such as air or water, the fluid provides a resistance to the object's motion.

- For a falling object, when the upward force of air resistance balances the downward gravitational force, the net force on the object is zero. The object continues to move downward with a constant maximum speed, called the **terminal speed.**

Fundamental Forces

- There are four fundamental forces:
  - **Electromagnetic force**
  - **Gravitational force**
  - **Strong nuclear force**
  - **Weak nuclear force**

- The four fundamental forces are all **field forces.**