Chapter 4





#### Chapter 4

Use Newton's laws to solve problems.

- Determine the magnitude and direction of the net force that causes a change in an object's motion.
- Classify forces according to the agents that cause them.







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Resources

Chapter 4

**Chapter 4: Forces in One Dimension** 

Section 4.1: Force and Motion

Section 4.2: Using Newton's Laws

Section 4.3: Interaction Forces



In this section you will:

- **Define** force.
- Apply Newton's second law to solve problems.
- **Explain** the meaning of Newton's first law.

### **Force and Motion**

- A force is defined as a push or pull exerted on an object.
- Forces can cause objects to speed up, slow down, or change direction as they move.
- Based on the definitions of velocity and acceleration, a force exerted on an object causes that object's velocity to change; that is, a force causes an acceleration.

### **Force and Motion**

- Consider a textbook resting on a table. How can you cause it to move?
- Two possibilities are that you can push on it or you can pull on it. The push or pull is a force that you exert on the textbook.
- If you push harder on an object, you have a greater effect on its motion.
- The direction in which force is exerted also matters. If you push the book to the right, the book moves towards right.
- The symbol *F* is a vector and represents the size and direction of a force, while *F* represents only the magnitude.

### **Force and Motion**

- When considering how a force affects motion, it is important to identify the object of interest. This object is called the system.
- Everything around the object that exerts forces on it is called the external world.



### **Contact Forces and Field Forces**

- Think about the different ways in which you could move a textbook.
- You could touch it directly and push or pull it, or you could tie a string around it and pull on the string. These are examples of contact forces.
- A contact force exists when an object from the external world touches a system and thereby exerts a force on it.



### **Contact Forces and Field Forces**

- If you drop a book, the gravitational force of Earth causes the book to accelerate, whether or not Earth is actually touching it. This is an example of a field force.
- Field forces are exerted without contact.
- Forces result from interactions; thus, each force has a specific and identifiable cause called the agent.
- Without both an agent and a system, a force does not exist.
- A physical model which represents the forces acting on a system, is called a free-body diagram.

#### **Contact Forces and Field Forces**



- To determine how force, acceleration, and velocity are related, perform the following experiment.
- Begin by considering a simple situation of one controlled force exerted horizontally on an object.
- The horizontal direction is a good place to start because gravity does not act horizontally.
- Also, to reduce complications resulting from the object rubbing against the surface, do the experiments on a very smooth surface, such as ice or a very well-polished table, and use an object with wheels that spin easily.

- You need to be able to exert a constant and controlled force on an object.
- A stretched rubber band exerts a pulling force; the farther you stretch it, the greater the force with which it pulls back.
- Stretch the rubber band for a constant distance of 1 cm to exert a constant force on the cart.



- If you perform this experiment and determine the cart's velocity for some period of time, you can construct a graph as shown here.
- The graph indicates that the constant increase in the velocity is a result of the constant acceleration the stretched rubber band gives the cart.



- To determine how acceleration depends on force, increase the force applied on the cart gradually.
- To get a greater amount of force, stretch the rubber band farther.
- Plot a velocity-time graph for each 2 cm, 3 cm and so on and calculate the acceleration.



- Plot the accelerations and forces for all the trials to make a force-acceleration graph.
- The relationship between the force and acceleration is linear, where the greater the force is, the greater the resulting acceleration.



- To determine the physical meaning of the slope on the force-acceleration graph, increase the number of carts gradually.
- A plot of the force versus acceleration for one, two, and three carts indicates that if the same force is applied in each situation, the acceleration of two carts is the acceleration of one cart, and the acceleration of three carts is the acceleration of one cart.



- This means that as the number of carts is increased, a greater force is needed to produce the same acceleration.
- The slopes of the lines in the graph depend upon the number of carts; that is, the slope depends on the total mass of the carts.



- If the slope, k, is defined as the reciprocal of the mass
- The equation
  indicates that a force applied
  to an object causes the object
  to accelerate.



- The formula, , tells you that if you double the force, you will double the object's acceleration.
- If you apply the same force to several different objects, the one with the most mass will have the smallest acceleration and the one with the least mass will have the greatest acceleration.
- If you apply the same force to several different objects, the one with the most mass will have the smallest acceleration and the one with the least mass will have the greatest acceleration.
- One unit of force causes a 1-kg mass to accelerate at 1 m/s<sup>2</sup>, so one force unit has the dimensions 1 kg·m/s<sup>2</sup> or one newton and is represented by N.

### **Combining Forces**

- When the force vectors are in the same direction, they can be replaced by a vector with a length equal to their combined length.
- If the forces are in opposite directions, the resulting vector is the length of the difference between the two vectors, in the direction of the greater force.
- Vector sum of all the forces on an object is net force.



### Newton's Second Law

The observation that acceleration of an object is proportional to  $\sim$ the net force exerted on it and inversely proportional to its mass is the **Newton's second law**, which can be represented in the

following equation.



Newton's second law states that the acceleration of an object is  $\sim$ equal to the sum of the forces acting on the object, divided by the mass of the object. Example



### **Newton's Second Law**

- Here is a useful strategy for finding how the motion of an object depends on the forces exerted on it.
- First, identify all the forces acting on the object.
- Draw a free-body diagram showing the direction and relative strength of each force acting on the system.

#### **Newton's Second Law**

- Then, add the forces to find the net force.
- Next, use Newton's second law to calculate the acceleration.
- Finally, if necessary, use kinematics to find the velocity or position of the object.

- What is the motion of an object with no net force acting on it? A stationary object with no net force acting on it will stay at its position.
- Galileo did many experiments, and he concluded that in the ideal case of zero resistance, horizontal motion would never stop.
- Galileo was the first to recognize that the general principles of motion could be found by extrapolating experimental results to the ideal case, in which there is no resistance to slow down an object's motion.

- In the absence of a net force, the motion (or lack of motion) of both the moving object and the stationary object continues as it was. Newton recognized this and generalized Galileo's results in a single statement.
- This statement, "an object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero," is called **Newton's first law.**

- **Newton's first law** is sometimes called the law of inertia.
- Inertia is the tendency of an object to resist change.
- If an object is at rest, it tends to remain at rest.
- If it is moving at a constant velocity, it tends to continue moving at that velocity.
- Forces are results of interactions between two objects; they are not properties of single objects, so inertia cannot be a force.

- If the net force on an object is zero, then the object is in equilibrium.
- An object is in equilibrium if it is at rest or if it is moving at a constant velocity.
- Newton's first law identifies a net force as something that disturbs the state of equilibrium.
- Thus, if there is no net force acting on the object, then the object does not experience a change in speed or direction and is in equilibrium.

- Some of the common types of forces are displayed on the right.
- When analyzing forces and motion, it is important to keep in mind that the world is dominated by resistance.
   Newton's ideal, resistancefree world is not easy to visualize.

Some Types of Forces			
Force	Symbol	Definition	Direction
Friction	F <sub>f</sub>	The contact force that acts to oppose sliding motion between surfaces	Parallel to the surface and opposite the direction of sliding
Normal	F <sub>N</sub>	The contact force exerted by a surface on an object	Perpendicular to and away from the surface
Spring	<b>F</b> <sub>sp</sub>	A restoring force; that is, the push or pull a spring exerts on an object	Opposite the displacement of the object at the end of the spring
Tension	F	The pull exerted by a string, rope, or cable when attached to a body and pulled taut	Away from the object and parallel to the string, rope, or cable at the point of attachment
Thrust	<b>F</b> <sub>thrust</sub>	A general term for the forces that move objects such as rockets, planes, cars, and people	In the same direction as the acceleration of the object, barring any resistive forces
Weight	<b>F</b> g	A field force due to gravitational attraction between two objects, generally Earth and an object	Straight down toward the center of Earth

### **Question 1**

Two horses are pulling a 100-kg cart in the same direction, applying a force of 50 N each. What is the acceleration of the cart?

- A. 2 m/s<sup>2</sup>
- **B.** 1 m/s<sup>2</sup>
- C. 0.5 m/s<sup>2</sup>
- D. 0 m/s<sup>2</sup>

Answer 1

Answer: B

**Reason:** If we consider positive direction to be the direction of pull then, according to Newton's second law,



### **Question 2**

Two friends Mary and Maria are trying to pull a 10-kg chair in opposite directions. If Maria applied a force of 60 N and Mary applied a force of 40 N, in which direction will the chair move and with what acceleration?

- A. The chair will move towards Mary with an acceleration of  $2 \text{ m/s}^2$ .
- B. The chair will move towards Mary with an acceleration of 10 m/s<sup>2</sup>.
- C. The chair will move towards Maria with an acceleration of  $2 \text{ m/s}^2$ .
- D. The chair will move towards Maria with an acceleration of 10 m/s<sup>2</sup>.

Answer 2

Answer: C

**Reason:** Since the force is applied in opposite direction, if we consider Maria's direction of pull to be positive direction then, net force = 60 N - 40 N = 20 N. Thus, the chair will move towards Maria with an acceleration.



### **Question 3**

State Newton's first law.

### Answer 3

Newton's first law states that "an object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero".

In this section you will:

- Describe how the weight and the mass of an object are related.
- **Differentiate** between actual weight and apparent weight.

#### **Using Newton's Second Law**

- Newton's second law tells you that the weight force, *F*<sub>g</sub>, exerted on an object of mass *m* is
- Consider a free-falling ball in midair. It is touching nothing and air resistance can be neglected, the only force acting on it is *Fg*.


#### **Using Newton's Second Law**

- The ball's acceleration is g. So, Newton's second law, then becomes
- Both the force and the acceleration are downward.
- The magnitude of an object's weight is equal to its mass times the acceleration due to gravity.



#### **Using Newton's Second Law**

- How does a bathroom scale work?
- When you stand on the scale, the spring in the scale exerts an upward force on you because you are in contact with it.
- Because you are not accelerating, the net force acting on you must be zero.
- The spring force,  $F_{sp}$ , upwards must be the same magnitude as your weight,  $F_{g}$ , downwards.



#### Fighting Over a Toy

Anudja is holding a stuffed dog, with a mass of 0.30 kg, when Sarah decides that she wants it and tries to pull it away from Anudja. If Sarah pulls horizontally on the dog with a force of 10.0 N and Anudja pulls with a horizontal force of 11.0 N, what is the horizontal acceleration of the dog?

#### **Fighting Over a Toy**



## Step 1: Analyze and Sketch the Problem

#### **Fighting Over a Toy**



Sketch the situation and identify the dog as the system and the direction in which Anudja pulls as positive.



#### Fighting Over a Toy

Identify known and unknown variables.



# Known:Unknown:m = 0.30 kga = ? $F_{\text{Anudja on dog}} = 11.0 \text{ N}$ $F_{\text{Sarah on dog}} = 10.0 \text{ N}$



#### **Fighting Over a Toy**



## Step 2: Solve for the Unknown

#### Fighting Over a Toy



Use Newton's second law to solve for a.





#### **Fighting Over a Toy**



Substitute 
$$F_{net} = F_{Anudja \text{ on } dog} + (-F_{Sarah \text{ on } dog})$$



#### Fighting Over a Toy



Substitute  $F_{\text{Anudja on dog}} = 11.0 \text{ N}$ ,  $F_{\text{Sarah on dog}} = 10.0 \text{ N}$ , m = 0.30 kg $a = \frac{11.0 \text{ N} - 10.0 \text{ N}}{0.30 \text{ kg}}$ 



# $a = 3.3 \text{ m/s}^2$ toward Anudja



# Step 3: Evaluate the Answer

#### **Fighting Over a Toy**



Are the units correct?

 $m/s^2$  is the correct unit for acceleration.

#### Does the sign make sense?

The acceleration is in the positive direction because Anudja is pulling in the positive direction with a greater force than Sarah is pulling in the negative direction.

#### Is the magnitude realistic?

It is a reasonable acceleration for a light, stuffed toy.

#### **Fighting Over a Toy**



The steps covered were:

- **Step 1:** Analyze and Sketch the Problem
  - Sketch the situation.
  - Identify the dog as the system and the direction in which Anudja pulls as positive.
  - Draw the free-body diagram. Label the forces.
- **Step 2:** Solve for the Unknown
- **Step 3:** Evaluate the Answer

#### **Apparent Weight**



#### **Drag Force and Terminal Velocity**

- When an object moves through any fluid, such as air or water, the fluid exerts a drag force on the moving object in the direction opposite to its motion.
- A drag force is the force exerted by a fluid on the object moving through the fluid.
- This force is dependent on the motion of the object, the properties of the object, and the properties of the fluid (viscosity and temperature) that the object is moving through.
- As the ball's velocity increases, so does the drag force. The constant velocity that is reached when the drag force equals the force of gravity is called the terminal velocity.

#### **Drag Force and Terminal Velocity**



#### **Question 1**

If mass of a person on Earth is 20 kg, what will be his mass on moon? (Gravity on Moon is six times less than the gravity on Earth.)



Answer 1

Answer: C

**Reason:** Mass of an object does not change with the change in gravity, only the weight changes.

#### **Question 2**

Your mass is 100 kg, and you are standing on a bathroom scale in an elevator. What is the scale reading when the elevator is falling freely?



Answer 2

Answer: B

**Reason:** Since the elevator is falling freely with acceleration *g*, the contact force between elevator and you is zero. As scale reading displays the contact force, it would be zero.

#### **Question 3**

In which of the following cases will your apparent weight be greater than your real weight?

- A. The elevator is at rest.
- B. The elevator is accelerating in upward direction.
- C. The elevator is accelerating in downward direction.
- D. Apparent weight is never greater than real weight.

Answer 3

Answer: B

**Reason:** When the elevator is moving upwards, your apparent weight (where *m* is your mass and *a* is the acceleration of the elevator). So your apparent becomes more than your real weight.

#### In this section you will:

- **Define** Newton's third law.
- Explain the tension in ropes and strings in terms of Newton's third law.
- **Define** the normal force.
- Determine the value of the normal force by applying Newton's second law.

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When a softball with a mass of 0.18 kg is dropped, its acceleration toward Earth is equal to g, the acceleration due to gravity. What is the force on Earth due to the ball, and what is Earth's resulting acceleration? Earth's mass is  $6.0 \times 10^{24}$  kg.



## Step 1: Analyze and Sketch the Problem



Draw free-body diagrams for the two systems: the ball and Earth and connect the interaction pair by a dashed line.





Identify known and unknown variables.



Known:

**Unknown:** 



## Step 2: Solve for the Unknown



#### Use Newton's second and third laws to find a<sub>Earth</sub>.





Substitute a = -g





#### Substitute $m_{\text{ball}} = 0.18 \text{ kg}, g = 9.80 \text{ m/s}^2$

# $\frac{1}{2} \int_{-\infty}^{\infty} \frac{1}{|S||^{2}} = \frac{1}{|S||^{2}} \int_{-\infty}^{\infty} \frac{1}{|$





# Use Newton's second and third laws to solve for $F_{\text{Earth on ball}}$ and $a_{\text{Earth}}$ .

 $F_{
m bell on Earth} = -F_{
m Earth on ball}$ 

= -(1.8 N)


## Substitute $F_{\text{Earth on ball}} = -1.8 \text{ N}$





Use Newton's second and third laws to find a<sub>Earth.</sub>





## Substitute $F_{\text{net}} = 1.8 \text{ N}$ , $m_{\text{Earth}} = 6.0 \times 10^{24} \text{ kg}$

## 1.8 N <u>8</u> <sup>45</sup> 01 <sup>24</sup> 0.0 <sup>10</sup> <sup>Ind</sup> methad<sup>05</sup>

 $-2.9 \times 10^{-25}$  m/s<sup>2</sup> toward the softball





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- Draw free-body diagrams for the two systems: the ball and Earth.
- Connect the interaction pair by a dashed line.

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 $F_{\rm A \, on \, B} = -F_{\rm B \, on \, A}$ 

A. B. C. D.

**Answer: D** 

**Reason:** 

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	$F_1 = 100 \text{ N}$	
$F_2 = 100 \text{ N}$ $F_1 = 100 \text{ N}$	$F_2 = 100 \text{ N}$	$F_2 = 200 \text{ N}$ $F_1 = 100 \text{ N}$
$F_{\text{net}} = 0 \text{ N}$	<i>F</i> <sub>net</sub> = 200 N	$F_{\text{net}} = 100 \text{ N}$
Equal forces Opposite directions	Equal forces Same direction	Unequal forces Opposite directions

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Anudja is holding a stuffed dog, with a mass of 0.30 kg, when Sarah decides that she wants it and tries to pull it away from Anudja. If Sarah pulls horizontally on the dog with a force of 10.0 N and Anudja pulls with a horizontal force of 11.0 N, what is the horizontal acceleration of the dog?



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