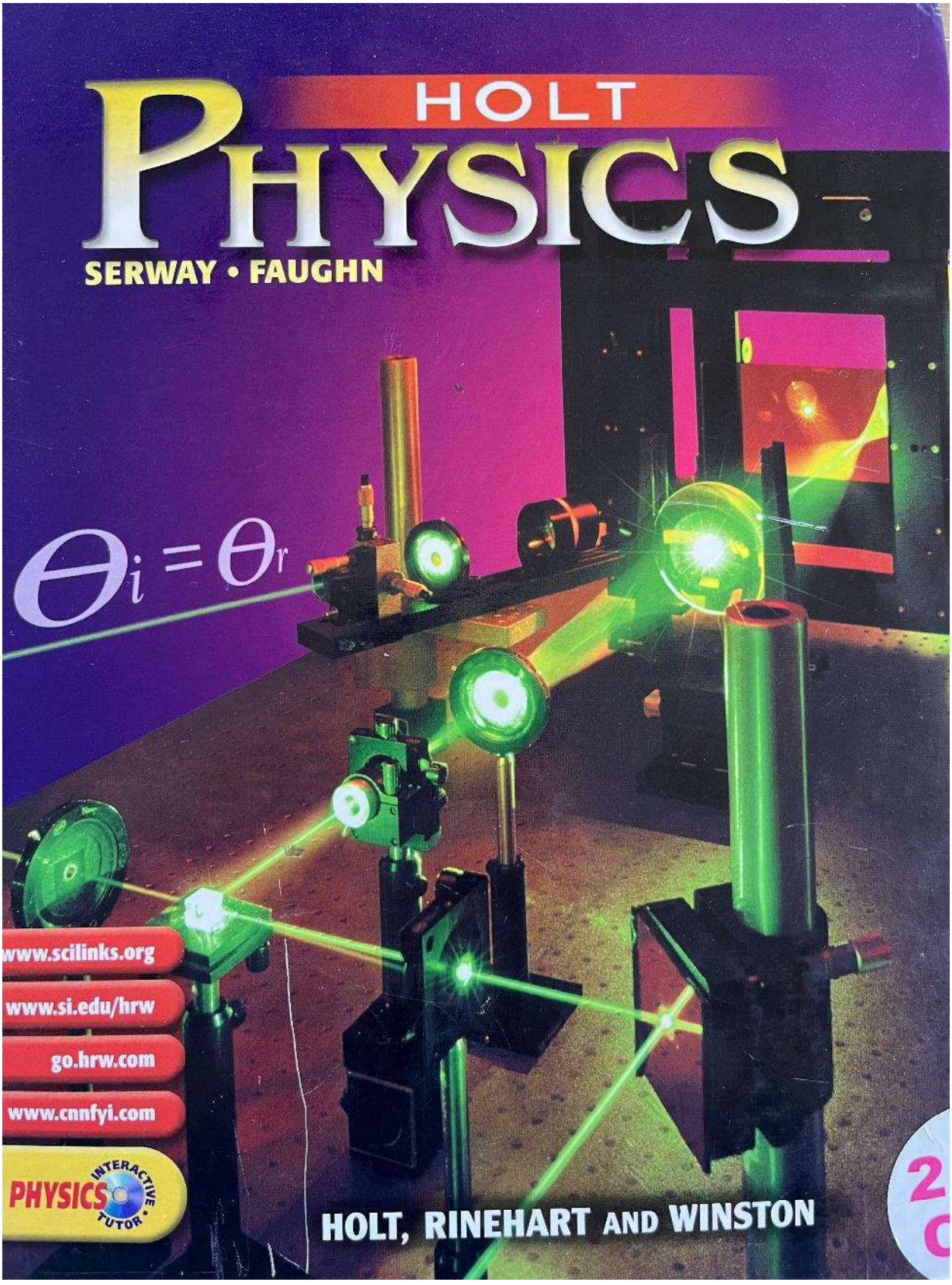


UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011

HOLT PHYSICS

SERWAY • FAUGHN



HOLT, RINEHART AND WINSTON

A Harcourt Classroom Education Company

Austin • New York • Orlando • Atlanta • San Francisco • Boston • Dallas • Toronto • London

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011

Authors

Raymond A. Serway
Professor Emeritus
North Carolina State University



Jerry S. Faughn
Professor Emeritus
Eastern Kentucky University



Cover Photo: © Lawrence Manning/CORBIS
Cover Design: Jason Wilson

Copyright © 2002 by Raymond A. Serway

Copyright © 2002 by Holt, Rinehart and Winston

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Requests for permission to make copies of any part of the work should be mailed to the following address: Permissions Department, Holt, Rinehart and Winston, 10801 N. MoPac Expressway, Austin, Texas 78759.

For permission to reprint copyrighted material, grateful acknowledgment is made to the following sources:

***sci*LINKS** is owned and provided by the National Science Teacher's Association. All rights reserved.

The name of the **Smithsonian Institution** and the sunburst logo are registered trademarks of the Smithsonian Institution. The copyright in the Smithsonian website and Smithsonian website pages are owned by the Smithsonian Institution. All other material owned and provided by Holt, Rinehart and Winston under copyright appearing above.

Copyright © 2000 **CNN** and **CNNfyi.com** are trademarks of Cable News Network LP, LLLP, a Time Warner Company. All rights reserved. Copyright © 2000 Turner Learning logos are trademarks of Turner Learning, Inc., a Time Warner Company. All rights reserved.

CBL, Calculator-Based Laboratory, and TI-GRAPH LINK are trademarks of Texas Instruments.

Printed in the United States of America
10 11 12 13 14 048 08 07 06 05 04
ISBN 0-03-056544-8

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011

4-1 Changes in motion

4-1 SECTION OBJECTIVES

- **Explain how force affects the motion of an object.**
- **Distinguish between contact forces and field forces.**
- **Interpret and construct free-body diagrams.**

force

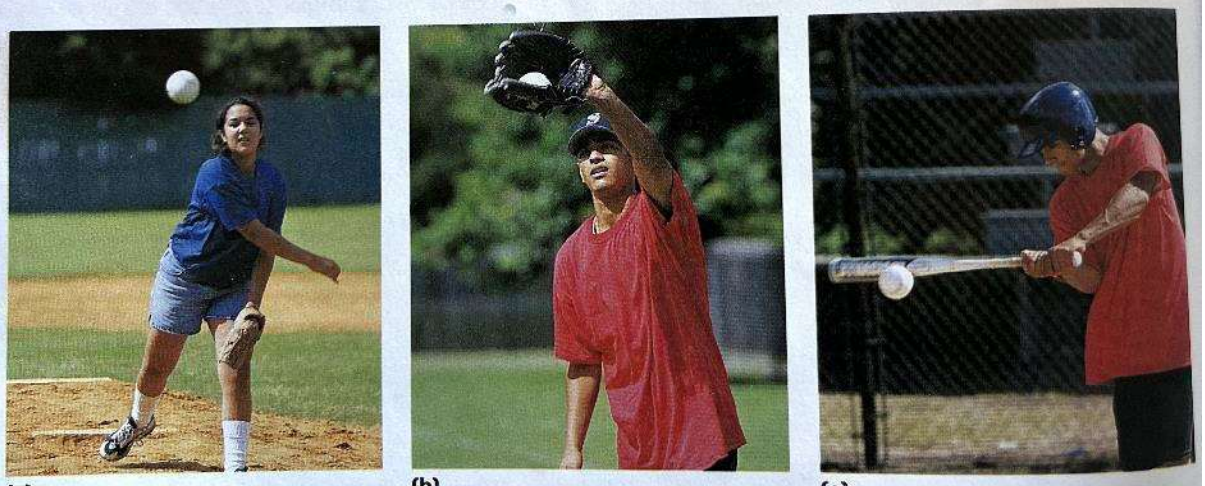
the cause of an acceleration, or the change in an object's velocity

FORCE

When we think of **force**, we usually imagine a *push* or a *pull* exerted on some object. For instance, you exert a force on a ball when you throw or kick it, and you exert a force on a chair when you sit in it. Force represents the interaction of an object with its environment.

Forces cause changes in velocity

In many situations, a force exerted on an object can change the object's velocity. Some examples of this are shown in **Figure 4-1.** A force can cause a stationary object to move, as when you throw a ball. Force also causes moving objects to stop, as when brakes stop your car or when you catch a ball. A force can also cause a moving object to change its direction, such as when a baseball collides with a bat and flies off in another direction. Notice that each of these cases involves a change in velocity—an acceleration.



(a) (b) (c)

Figure 4-1
Force can cause objects to **(a)** start moving, **(b)** stop moving, or **(c)** change direction.

The SI unit of force is the newton

The SI unit of force is the newton, named after Sir Isaac Newton (1642–1727), whose work contributed much to the modern understanding of force and motion. The newton (N) is defined as the amount of force that, when acting on a 1 kg mass, produces an acceleration of 1 m/s^2. Therefore, $1\ N = 1\ kg \times 1\ m/s^2$.

The weight of an object is a measure of the magnitude of the gravitational force exerted on the object. It is the result of the interaction of an object's mass with the gravitational field of another object, such as Earth. Many of the terms

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 4 of 16

internetconnect

SCILINKS NSTA

TOPIC: Forces
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2041

FORCE DIAGRAMS

If you give a toy car a light push, it does not move as fast as it does when you give a harder push. The effect of a force depends on its magnitude, and the magnitude of the force of the second push is greater. The effect of a force on an object's motion also depends on the direction of the force. For example, if you push the toy car from the front, the car will move in a different direction than if you push it from behind.

force diagram

a diagram of the objects involved in a situation and the forces exerted on the objects

Force is a vector

Because the effect of a force depends on its magnitude and direction, force is a vector quantity. Diagrams that show force vectors as arrows, like **Figure 4-3(a)**, are called **force diagrams.** In this book, the arrows used to represent forces are blue. The tail of the arrow is attached to the object on which the force is acting. These diagrams can be used as tools in analyzing collisions and other situations.

At this point, we will disregard the size and shape of objects and assume that all forces act on a point at the center of an object. In force diagrams, all forces are drawn as if they act on that point, no matter where the force is applied.

A free-body diagram helps analyze a situation

Once engineers analyzing a test-car crash have identified all the forces involved, they isolate the car from the other objects in its environment. One of their goals is to determine which forces affect the car and its passengers. **Figure 4-3(b)** is a free-body diagram. It represents the same collision as the force diagram **(a),** but it shows only the car and the forces acting on it. The forces exerted *by* the car on other objects are not included in the free-body diagram because they do not affect the motion of the car.

A free-body diagram is used to analyze only the forces affecting the motion of a single object. Free-body diagrams are constructed and analyzed just like other vector diagrams. In Section 4-2, you will learn to use free-body diagrams to find component and resultant forces. In this section, you will learn to draw free-body diagrams for situations described in this book.

Quick Lab

Force and Changes in Motion

MATERIALS LIST

- ✔ 1 toy car
- ✔ 1 book

Use a toy car and a book to model a car colliding with a brick wall. Observe the motion of the car before and after the crash. Identify as many changes in its motion, such as a change in speed or in direction, as you can. Make a list of all the changes, and try to identify the forces that caused them. Make a force diagram of the collision.

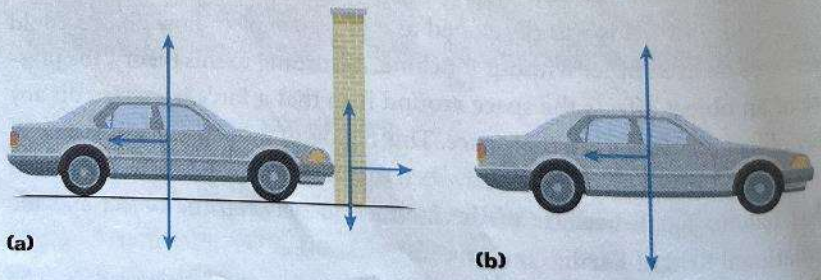


Figure 4-3

(a) In a force diagram, vector arrows represent all the forces acting in a situation. **(b)** A free-body diagram shows only the forces acting on the object of interest—in this case, the car.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 5 of 16

4-2 Newton's first law

4-2 SECTION OBJECTIVES

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

INERTIA

A hovercraft, such as the one in **Figure 4-5,** glides along the surface of the water on a cushion of air. Physicists study examples like this to determine exactly what effect forces have on the motion of objects.

The first step is to examine the motion of the object before forces are applied. A common misconception is that an object with no force acting on it will always be at rest. To test whether this is true, consider the example of sliding a block on different surfaces. First imagine a block on a deep, thick carpet. If you apply a force by pushing the block, it will begin sliding, but soon after you remove the force, the block will come to rest. Next imagine pushing the same block across a smooth waxed floor. When you push with the same force, the block will slide much farther before coming to rest.



Figure 4-5
A hovercraft floats on a cushion of air above the water. Air provides less resistance to motion than water does.

In the 1630s, Galileo realized that a block sliding on a perfectly smooth surface would slide forever in the absence of an applied force. He concluded correctly that it is not the nature of an object to *stop* once it is set in motion; rather, it is an object's nature to *maintain its state of motion.*

This concept was further developed by Newton in 1687 and has come to be 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.

inertia

the tendency of an object to maintain its state of motion

The tendency of an object not to accelerate is called **inertia.** Newton's first law is often referred to as the *law of inertia* because it states that in the absence of forces, a body will preserve its state of motion. In other words, Newton's first law says that *when the net external force on an object is zero, its acceleration (or the change in its velocity) is zero.*

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 6 of 16

Acceleration is determined by net external force

Consider a car traveling at a constant velocity. Newton's first law tells us that the net external force on the car must be equal to zero. However, **Figure 4-6** shows that there are many forces acting on a car in motion. The vector $\mathbf{F}_{\text{forward}}$ represents the forward force of the road on the tires. The vector $\mathbf{F}_{\text{resistance}}$, which acts in the opposite direction, is due partly to friction between the road surface and tires and partly to air resistance. The vector $\mathbf{F}_{\text{gravity}}$ represents the downward force of gravity on the car, and the vector $\mathbf{F}_{\text{ground-on-car}}$ represents the upward force the road exerts on the car.

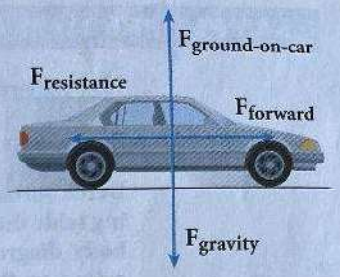


Figure 4-6
Although there are several forces acting on this car, the vector sum of the forces is zero, so the car moves at a constant velocity.

To understand how a car can maintain a constant velocity under the influence of so many forces, it is necessary to understand the distinction between external force and net external force. An *external force* is a single force that acts on an object as a result of the interaction between the object and its environment. All four forces in **Figure 4-6** are external forces acting on the car. The **net external force** is the vector sum of all the forces acting on an object.

net external force

the total force resulting from a combination of external forces on an object; sometimes called the resultant force

When all external forces acting on an object are known, the net external force can be found using the methods for finding resultant vectors. That means an object's acceleration is determined by the combination of all the forces acting on it. The net external force is equivalent to the one force that would produce the same effect on the object as all the external forces combined. In other words, the object's acceleration is the same as if the net external force were the only force acting on the object.

Consider **Figure 4-7,** in which two teams are playing tug-of-war. If both teams pull on the rope with equal but opposite force **(a),** the net external force on the rope is equal to zero. The knot in the center of the rope will be at rest, even though forces are pulling the rope in opposite directions. When one team increases the force of its pull **(b),** the knot will experience a net external force equal to the difference in the forces, and it will accelerate in the direction of the greater pull.

Examples like this show how an object can be in equilibrium even when many forces act on it. For example, although there are four forces acting on the car in **Figure 4-6,** the car will maintain its constant velocity as long as the vector sum of these forces is equal to zero.



Figure 4-7
(a) When there is no net force, the knot is at rest. **(b)** When there is a net force to the right, the knot moves to the right.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 7 of 16

SAMPLE PROBLEM 4A

Net external force

PROBLEM

Derek leaves his physics book on top of a drafting table that is inclined at a 35° angle. The free-body diagram in Figure 4-8 shows the forces acting on the book. Find the net external force acting on the book, and determine whether the book will remain at rest in this position.

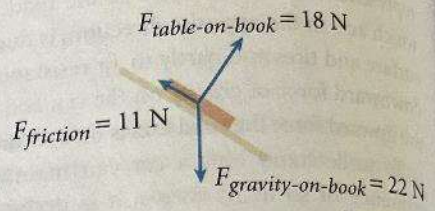


Figure 4-8

SOLUTION

1. Define the problem and identify the variables.

Given: $F_{gravity\text{-}on\text{-}book} = 22$ N
$F_{friction} = 11$ N
$F_{table\text{-}on\text{-}book} = 18$ N

Unknown: $F_{net} = ?$

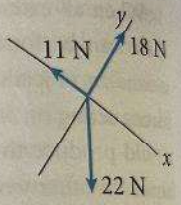


Figure 4-9

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 **Figure 4-9.** This is the most convenient coordinate system because only the force of gravity on the book needs to be resolved into x and y components. All other forces are either along the x-axis or the y-axis.

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

Draw a sketch as shown in **Figure 4-10** to help find the x component and y component of the vector $\mathbf{F}_{\text{gravity-on-book}}$. Gravity acts at a 90° angle to the surface of Earth, and the x-axis is at a 35° angle to Earth's surface. Therefore, θ, the angle between the gravity vector and the x-axis, is the third angle in this right triangle and is equal to 55°.

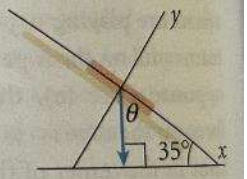


Figure 4-10

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

$$F_{g,x} = F_g \cos\theta = (22\text{ N})(\cos 55°) = 13\text{ N}$$

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

$$F_{g,y} = F_g \sin\theta = (22\text{ N})(\sin 55°) = 18\text{ N}$$

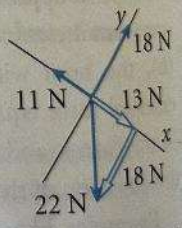


Figure 4-11

Now those components can be added to the free-body diagram, as shown in **Figure 4-11.**

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

Figure 4-12 shows another free-body diagram of the book, now with forces acting only along the x- and y-axes.

For the x direction: $\Sigma F_x = F_{g,x} - F_{friction}$

$$\Sigma F_x = 13\text{ N} - 11\text{ N} = 2\text{ N}$$

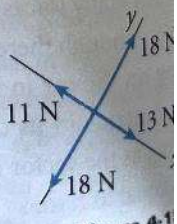


Figure 4-12

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 8 of 16

For the y direction: $\Sigma F_y = F_{table\text{-}on\text{-}book} - F_{g,y}$

$$\Sigma F_y = 18\ \text{N} - 18\ \text{N} = 0\ \text{N}$$

5. Find the net external force.

The net force in the y direction is equal to zero, so the net external force is equal to the net force in the positive x direction, 2 N positive.

$$\boxed{F_{net} = 2\ \text{N}}$$

6. Evaluate your answer.

The net external force acts on the book in the downhill direction. Therefore, the book will experience an acceleration in the downhill direction, and it will slide off the table, as shown **Figure 4-13.**

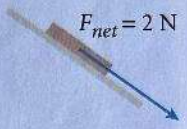


Figure 4-13

PRACTICE 4A

Net external force

1. A man is pulling on his dog with a force of 70.0 N directed at an angle of +30.0° to the horizontal. Find the x and y components of this force.
2. A crate is pulled to the right with a force of 82.0 N, to the left with a force of 115 N, upward with a force of 565 N, and downward with a force of 236 N.
   a. Find the net external force in the x direction.
   b. Find the net external force in the y direction.
   c. Find the magnitude and direction of the net external force on the crate.
3. A gust of wind blows an apple from a tree. As the apple falls, the force of gravity on the apple is 9.25 N downward, and the force of the wind on the apple is 1.05 N to the right. Find the magnitude and direction of the net external force on the apple.
4. The wind exerts a force of 452 N north on a sailboat, while the water exerts a force of 325 N west on the sailboat. Find the magnitude and direction of the net external force on the sailboat.

Mass is a measurement of inertia

Imagine a basketball and a golf ball at rest side by side on the ground. Newton's first law states that both remain at rest as long as no net external force acts on them. Now imagine supplying a net force by striking each ball with a golf club. If the two are struck with equal force, the golf ball will accelerate much more than the basketball. The basketball experiences a smaller acceleration because it has more inertia than the golf ball.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 9 of 16

As the example of the golf ball and the basketball shows, the inertia of an object is proportional to its mass. The greater the mass of a body, the less the body accelerates under an applied force. Similarly, a light object will undergo a larger acceleration than a heavy object under the same force. Therefore, mass, which is a measure of the amount of matter in an object, is also a measure of the inertia of an object.

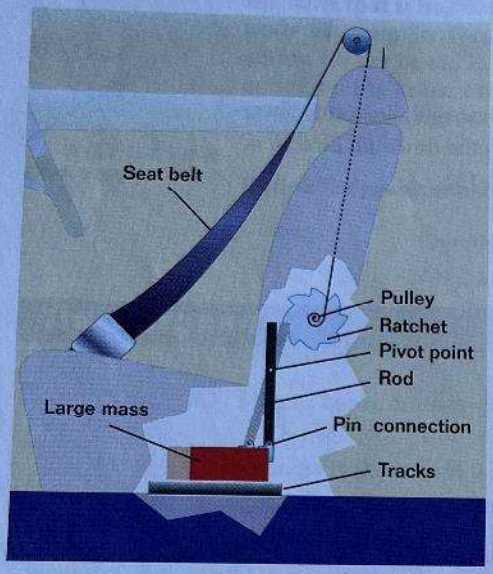


Figure 4-14
When the car suddenly slows down, inertia causes the large mass under the seat to continue moving, which activates the lock on the safety belt.

Objects in motion tend to stay in motion

Imagine a crash-test dummy not wearing a seat belt at the moment of a collision. Even after the car stops, the dummy will continue to move forward with the same velocity until acted on by some force. In this case, the force stopping the dummy would be the force exerted on the dummy by the dashboard of the car.

The purpose of a seat belt is to prevent serious injury by holding a passenger firmly in place in the event of a collision. A seat belt may also lock when a car rapidly slows down or turns a corner. While inertia causes passengers in a car to continue moving forward as the car slows down, inertia also causes seat belts to lock into place.

Figure 4-14 illustrates how one type of shoulder harness operates. Under normal conditions, the ratchet turns freely to allow the harness to wind or unwind along the pulley. In a collision, the car undergoes a large acceleration and rapidly comes to rest. The large mass under the seat, because of its inertia, continues to slide forward along the tracks. The pin connection between the mass and the rod causes the rod to pivot and lock the ratchet wheel in place. At this point the harness no longer unwinds, and the seat belt holds the passenger firmly in place.

EQUILIBRIUM

equilibrium

the state in which there is no change in a body's motion

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, whether they are at rest or moving with a constant velocity. Newton's first law states one condition that must be true for equilibrium: the net external force acting on a body in equilibrium must be equal to zero.

Quick Lab

Inertia

MATERIALS LIST

- ✔ skateboard or cart
- ✔ several toy balls with different masses

SAFETY CAUTION

Perform this experiment away from walls and furniture that can be damaged.

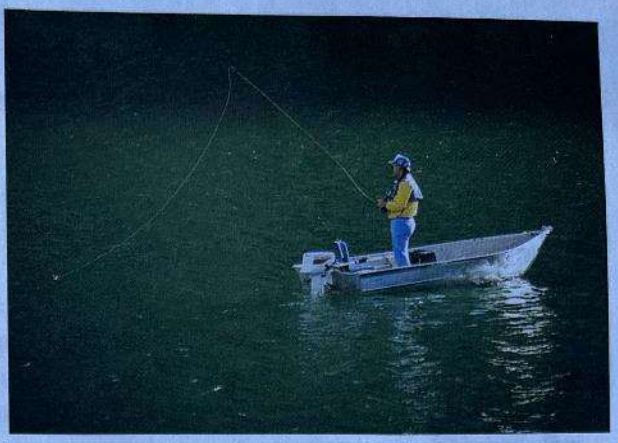
Place a small ball near the back of a skateboard or cart. Push the skateboard across the floor and into a wall or other solid barrier. Observe what happens to the ball when the skateboard hits the wall. Perform several trials, placing the ball in different positions, such as in the middle of the skateboard and near the front of the skateboard. Repeat all trials using balls with different masses, and compare the results. Perform this experiment at different speeds, and compare the results.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 10 of 16

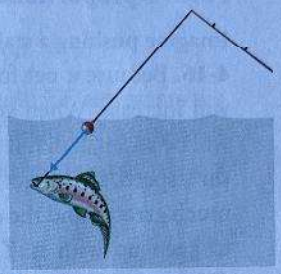
The bob on the fishing line in **Figure 4-15(a)** is at rest. Therefore, we know that the net external force on the fishing bob is equal to zero. Imagine that a fish bites the bait, as shown in **Figure 4-15(b).** The fish exerts a force on the line. Because a net external force is acting on the line, the bob accelerates downward and disappears under the water. To return the bob to equilibrium, the person fishing must apply a force to the fishing line.

The force that brings an accelerating object into equilibrium must be equal and opposite to the force causing the object to accelerate. Therefore, if the person pulls on the line and applies a force to the bob that is equal and opposite to the force exerted by the fish, the net external force on the bob is equal to zero. This is shown in **Figure 4-15(c).**

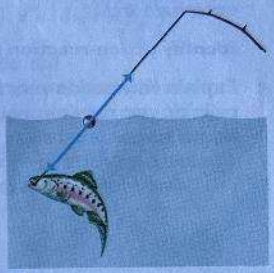
An object is in equilibrium when the vector sum of the forces acting on it is equal to zero. Usually, the easiest way to determine whether a body is in equilibrium is to assign a coordinate system and resolve all forces into their x and y components. When the sum of all forces in the x direction is equal to zero (that is, $\Sigma F_x = 0$) and the sum of all forces in the y direction is equal to zero (that is, $\Sigma F_y = 0$), then the vector sum of *all* forces acting on the body is equal to zero and the body is in equilibrium.



(a)



(b)



(c)

Figure 4-15
(a) The bob on this fishing line is at rest. **(b)** When it is acted on by a net external force, it accelerates until **(c)** an equal and opposite external force is applied and the net external force is zero.

Section Review

1. Can an object be in equilibrium if only one force acts on it?
2. If a car is traveling westward with a constant velocity of 20 m/s, what is the net external force acting on it?
3. If a car is accelerating downhill under a net force of 3674 N, what force must the brakes exert to cause the car to have a constant velocity?
4. **Physics in Action** The sensor in the torso of a crash-test dummy records the magnitude of the net external force acting on it. If the dummy is thrown forward with a force of 130.0 N while simultaneously being hit from the side with a force of 4500.0 N, what force will the sensor report?
5. **Physics in Action** What force will the seat belt have to exert on the dummy in item 4 to hold the dummy in the seat?

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 11 of 16

4-3 *Newton's second and third laws*

4-3 SECTION OBJECTIVES

- **Describe the acceleration of an object in terms of its mass and the net external force acting on it.**
- **Predict the direction and magnitude of the acceleration caused by a known net external force.**
- **Identify action-reaction pairs.**
- **Explain why action-reaction pairs do not result in equilibrium.**

NEWTON'S SECOND LAW

From Newton's first law, we know that an object with no net external force acting on it is in a state of equilibrium. We also know that an object experiencing a net external force undergoes a change in its velocity. But exactly how much does a known force affect the motion of an object?

Force is proportional to mass and acceleration

Imagine pushing a stalled car through a level intersection, as shown in **Figure 4-16.** Because a net force causes an object to accelerate, the speed of the car will increase. When you push the car by yourself, however, the acceleration will be so small that it will take a long time for you to notice an increase in the car's speed. If you get several friends to help you, the net force on the car is much greater, and the car will soon be moving so fast that you will have to run to keep up with it. This happens because the acceleration of an object is directly proportional to the net external force acting on it.

Experience pushing objects reveals that the mass of an object also affects its acceleration. If you push a bowling ball and a tennis ball with the same force, the tennis ball will accelerate quickly, while the bowling ball will accelerate slowly. Similarly, a lightweight car accelerates faster than a heavy truck if the same force is applied to both. It requires much less force to accelerate a low-mass object than it does to accelerate a high-mass object at the same rate. This is because an object with smaller mass has less inertia, or tendency to maintain its state of motion, than an object with greater mass.

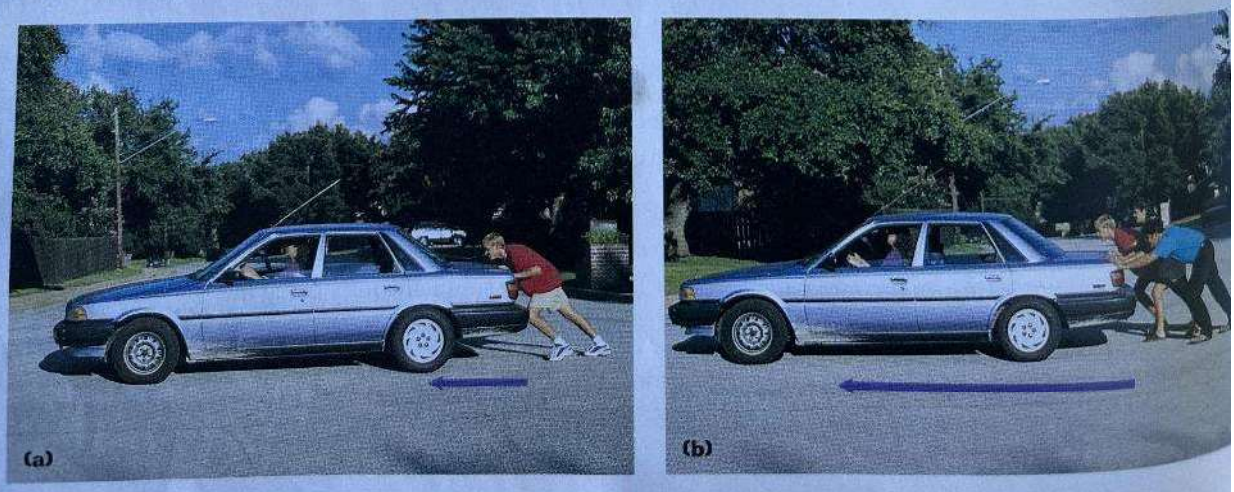


Figure 4-16
(a) A small force on an object causes a small acceleration, but **(b)** a larger force causes a larger acceleration.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 12 of 16

Newton's second law relates force, mass, and acceleration

The relationships between mass, force, and acceleration are quantified in **Newton's second law.**

NEWTON'S SECOND LAW

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

According to Newton's second law, if equal forces are applied to two objects of different masses, the object with greater mass will experience a smaller acceleration, and the object with less mass will experience a greater acceleration.

In equation form, we can state Newton's law as

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

$$\text{net external force} = \text{mass} \times \text{acceleration}$$

where **a** is the acceleration of the object, m is its mass, and $\Sigma\mathbf{F}$ represents the *vector sum of all external forces acting on the object.* This relationship makes it possible, when the mass of the object is known, to determine what effect a given force will have on an object's motion.



Module 4
"Force and Inertia"
provides an interactive lesson with guided problem-solving practice to teach you about forces and Newton's laws.

SAMPLE PROBLEM 4B

Newton's second law

PROBLEM

Roberto and Laura are studying across from each other at a wide table. Laura slides a 2.2 kg book toward Roberto. If the net external force acting on the book is 2.6 N to the right, what is the book's acceleration?

SOLUTION

Given: $m = 2.2\ \text{kg}$

$\mathbf{F}_{\text{net}} = \Sigma\mathbf{F} = 2.6\ \text{N}$, to the right

Unknown: $a = ?$

Use Newton's second law, and solve for a.

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

$$a = \frac{2.6\ \text{N}}{2.2\ \text{kg}}$$

$$a = 1.2\ \text{m/s}^2 \text{ to the right}$$

CALCULATOR SOLUTION

Your calculator will give you an answer of 1.1818 . . . for the acceleration. Because all values in the problem have only two significant digits, this value must be rounded up to 1.2.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 13 of 16

PRACTICE 4B

Newton's second law

1. The net external force on the propeller of a 3.2 kg model airplane is 7.0 N forward. What is the acceleration of the airplane?
2. The net external force on a golf cart is 390 N north. If the cart has a total mass of 270 kg, what are the magnitude and direction of its acceleration?
3. A car has a mass of 1.50×10^3 kg. If the force acting on the car is 6.75×10^3 N to the east, what is the car's acceleration?
4. A 2.0 kg otter starts from rest at the top of a muddy incline 85 cm long and slides down to the bottom in 0.50 s. What net external force acts on the otter along the incline?
5. A soccer ball kicked with a force of 13.5 N accelerates at 6.5 m/s^2 to the right. What is the mass of the ball?

Conceptual Challenge

1. Gravity and rocks

The force of gravity is twice as great on a 2 kg rock as it is on a 1 kg rock. Why doesn't the 2 kg rock have a greater free-fall acceleration?

2. Leaking truck

A truck loaded with sand accelerates at 0.5 m/s^2 on the highway. If the driving force on the truck remains constant, what happens to the truck's acceleration if sand leaks at a constant rate from a hole in the truck bed?



In solving problems, it is often easier to break the equation for Newton's second law into components. The sum of forces acting in the x direction equals the mass times the acceleration in the x direction ($\Sigma F_x = ma_x$), and the sum of forces in the y direction equals the mass times the acceleration in the y direction ($\Sigma F_y = ma_y$). If the net external force is zero, then $\mathbf{a} = 0$, which corresponds to the equilibrium situation where $\mathbf{v}$ is either constant or zero.

NEWTON'S THIRD LAW

A force is exerted on an object when that object interacts with some other object in its environment. Consider a moving car colliding with a concrete barrier. The car exerts a force on the barrier at the moment of collision, just as you apply force to a door when you push it or to a ball when you kick it. Furthermore, the barrier exerts a force on the car so that the car rapidly slows down after coming into contact with the barrier.

Forces always exist in pairs

From examples like this, Newton recognized that a single isolated force cannot exist. Instead, *forces always exist in pairs.* The car exerts a force on the barrier, and at the same time, the barrier exerts a force on the car. Newton described this type of situation with his **third law of motion.**

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.

internetconnect

SCILINKS NSTA

TOPIC: Newton's laws
GO TO: www.scilinks.org
***sci*LINKS CODE:** HF2042

An alternative statement of this law is that *for every action there is an equal and opposite reaction.* When two objects interact with one another, the forces they mutually exert on each other are called an **action-reaction pair.** The force that object 1 exerts on object 2 is sometimes called the *action force,* while the force that object 2 exerts on object 1 is called the *reaction force.* The action force is equal in magnitude and opposite in direction to the reaction force. The terms *action* and *reaction* sometimes cause confusion because they are used a little differently in physics than they are in everyday speech. In everyday speech, the word *reaction* is used to refer to something that happens *after* and *in response to* an event. In physics, however, the reaction force occurs at exactly the same time as the action force.

action-reaction pair

a pair of simultaneous equal but opposite forces resulting from the interaction of two objects

Because the forces coexist, either force can be called the action or the reaction. For example, you could call the force the car exerts on the barrier the action and the force the barrier exerts on the car the reaction. Likewise, you could choose to call the force the barrier exerts on the car the action and to call the force the car exerts on the barrier the reaction.

Action and reaction forces each act on different objects

The most important thing to remember about action-reaction pairs is that each force acts on a different object. Consider the task of driving a nail into a block of wood, as illustrated in **Figure 4-17.** To accelerate the nail and drive it into the block, the hammer exerts a force on the nail. According to Newton's third law, the nail exerts a force on the hammer that is equal to the magnitude of the force the hammer exerts on the nail.



Figure 4-17
The nail exerts a force on the hammer that is equal and opposite to the force the hammer exerts on the nail.

The concept of action-reaction pairs is a common source of confusion because some people assume incorrectly that the equal and opposite forces balance one another and make any change in the state of motion impossible. If the nail exerts a force on the hammer that is equal to the force the hammer exerts on the nail, why doesn't the nail remain at rest?

Because they act on different objects, action-reaction pairs do not result in equilibrium. The motion of the nail is affected only by the forces acting on the nail. The force the nail exerts on the hammer affects only the hammer, not the nail. To determine whether the nail will accelerate, draw a free-body diagram to isolate the forces acting on the nail alone, as shown in **Figure 4-18.** The force of the nail on the hammer is not included in the diagram because it does not affect the motion of the nail. According to the diagram, the nail will be driven into the wood because there is a net external force acting on the nail.



Figure 4-18
The net external force acting on the nail drives it to the left into the wood.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 15 of 16

CONCEPT PREVIEW

Gravitational force is covered in Chapter 7, Section 7-3.

Field forces also exist in pairs

Newton's third law also applies to field forces. For example, consider the gravitational force exerted by Earth on an object. During calibration at the crash-test site, engineers calibrate the sensors in the heads of crash-test dummies by removing the heads and dropping them from a known height.

The force Earth exerts on a dummy's head is $\mathbf{F_g}$. Let's call this force the action. What is the reaction? Because $\mathbf{F_g}$ is the force exerted on the falling head by Earth, the reaction to $\mathbf{F_g}$ is the force exerted on Earth by the falling head.

According to Newton's third law, the force of the dummy on Earth is equal to the force of Earth on the dummy. Thus, as a falling object accelerates toward Earth, Earth also accelerates toward the object.

The thought that Earth accelerates toward the dummy's head may seem to contradict our experience. One way to make sense of this is to refer to Newton's second law. The mass of Earth is much greater than that of the dummy's head. Therefore, while the dummy's head undergoes a large acceleration due to the force of Earth, the acceleration of Earth due to this reaction force is negligibly small because of its enormous mass.

Section Review

1. A 6.0 kg object undergoes an acceleration of 2.0 m/s^2.
   - **a.** What is the magnitude of the net external force acting on it?
   - **b.** If this same force is applied to a 4.0 kg object, what acceleration is produced?
2. A child pulls a wagon with a horizontal force, causing it to accelerate. Newton's third law says that the wagon exerts an equal and opposite force on the child. How can the wagon accelerate? (*Hint:* Draw a free-body diagram for each object to help you answer this question.)
3. Identify the action-reaction pairs in the following situations:
   - **a.** a person takes a step
   - **b.** a snowball hits someone in the back
   - **c.** a baseball player catches a ball
   - **d.** a gust of wind strikes a window
4. The forces acting on a sailboat are 390 N north and 180 N east. If the boat (including crew) has a mass of 270 kg, what are the magnitude and direction of its acceleration?
5. **Physics in Action** If a small sports car collides head-on with a massive truck, which vehicle experiences the greater impact force? Which vehicle experiences the greater acceleration? Explain.

UNDER ARMOUR, INC. v. ATHALONZ, LLC
IPR2024-00639
ATHALONZ EXHIBIT 2011
Page 16 of 16