6.2 Newton's Second Law

What kind of change happens when forces are not balanced? The answer is *acceleration*. Acceleration is a change in velocity (speed or direction). Newton's second law describes how acceleration depends on both force and mass.

The three main ideas of the second law

What is the second law about?

Newton's first law tells us that motion cannot change without a net force. The second law tells us exactly what kind of change is caused by unbalanced forces. The second law answers questions like: "How much force does it take to change the speed of a 1,000-kg car from 0 to 80 km/h?" Anyone who does anything involving motion needs to understand the second law.

The three main ideas

Here are the three big ideas covered by the second law.

1. Acceleration is the result of unbalanced forces.
2. A larger force makes a proportionally larger acceleration.
3. Acceleration is inversely proportional to mass.

Unbalanced forces cause acceleration

The first law tells us that objects in motion can continue to move even without any net force. This is true as long as the motion is at a constant speed and in a straight line. The second law says that any unbalanced force results in acceleration. We know that acceleration causes changes in velocity (speed or direction). Putting these two ideas together tells us two things about force and motion: (1) Unbalanced forces cause changes in speed, direction, or both; and (2) any time there is a change in speed or direction, there *must be an unbalanced force acting*.

Force and motion connect through acceleration

The second law is the connection between force, mass, and motion. The connection occurs through *acceleration*, which results in *changes* in speed and/or direction. In fact, the unit of force (newton) is defined by the second law (Figure 6.5).

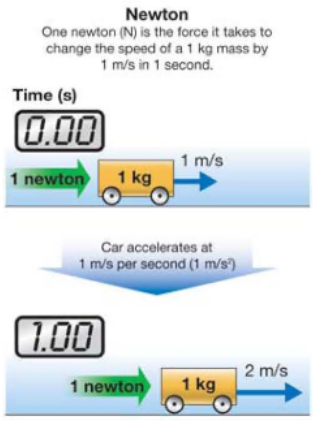


Figure 6.5: *The newton, a unit of force, is defined in terms of the acceleration it can create.*

Acceleration and force

Acceleration is proportional to force

The second law says that acceleration is *proportional* to force. What does this mean? It means that, all other things being equal, if the force doubles, the acceleration also doubles. If the force is reduced by half, the acceleration is also reduced by half (Figure 6.6).

Example: A robot mail cart

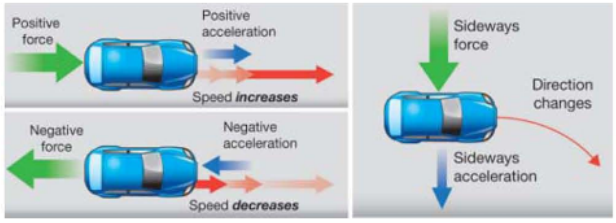
Here is an example. Two engineers are each asked to design a battery-operated motor for a robot mail cart. The cart is supposed to drive around to people's offices and stop so they can collect their mail. One engineer chooses a motor that produces a force of 50 newtons. The other chooses a motor that produces a force of 100 newtons.

The acceleration of the mail cart

The robot with the smaller motor goes from rest to a top speed of 4 m/s in 4 seconds. The acceleration is 1 m/s^2. The robot with the larger motor accelerates to the same top speed in 2 seconds. Its acceleration is 2 m/s^2. Both robots reach the same top speed. The one with the bigger motor accelerates to its top speed twice as fast because it uses twice as much force. Of course, the one with the bigger motor drains its batteries faster too, because there is also a trade-off between acceleration and energy.

Acceleration is in the direction of the net force

Another important factor of the second law is that the acceleration is always in the same direction as the net force. A force in the positive direction causes acceleration in the positive direction. A force in the negative direction causes acceleration in the negative direction. A sideways net force causes a sideways acceleration and makes the object turn.



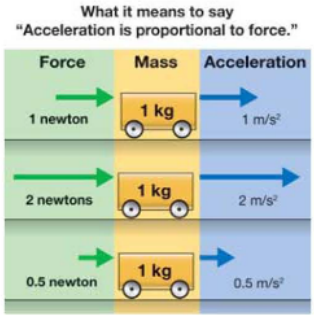


Figure 6.6: *"Acceleration is proportional to force" means that if force is increased or decreased, acceleration will be increased or decreased by the same factor.*

STUDY SKILLS

Reviewing the Newton

One newton is the force needed to change the speed of 1 kilogram by 1 m/s in 1 second. This means that:

$1\ N = 1\ kg \cdot m/s^2$

Or you can say 1 newton equals 1 kilogram-meter per second squared.

Acceleration and mass

Mass and acceleration The greater the mass, the smaller the acceleration for a given force (Figure 6.7). This means that acceleration is *inversely proportional* to mass. When the forces stay the same, increasing the mass decreases the acceleration. For example, an object with twice the mass will have half the acceleration if the same force is applied. An object with half the mass will have twice the acceleration.

Why mass reduces acceleration Acceleration decreases with mass because mass creates inertia. Remember, inertia is the property of matter that resists changes in motion (acceleration). More mass means more inertia, and therefore more resistance to acceleration.

Newton's second law Force causes acceleration and mass resists acceleration. **Newton's second law** relates the force on an object, the mass of the object, and the object's acceleration.

The acceleration caused by a net force is proportional to force and inversely proportional to mass.

The formula for the second law The relationships between force, mass, and acceleration are described in the formula for Newton's second law.

NEWTON'S SECOND LAW

$$\text{Acceleration (m/s}^2\text{)}\ a = \frac{F}{m}\ \begin{matrix}\text{Force (N)}\\ \text{Mass (kg)}\end{matrix}$$

VOCABULARY

Newton's second law - a law of motion that states that acceleration is equal to force divided by mass.

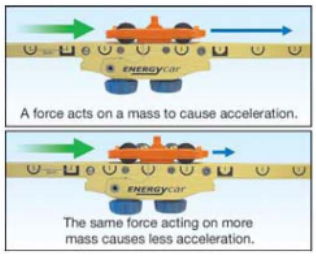


Figure 6.7: *How acceleration is affected by mass.*

SOLVE IT!

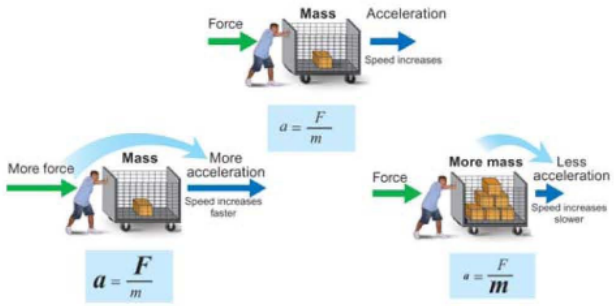
Answer the following questions to test your understanding of Newton's second law.

1. Force is tripled but mass stays the same. What happens to acceleration?
2. Acceleration decreases but the force is the same. What must have happened to the mass?

Summarizing the second law

Writing the second law

You can use Newton's second law to calculate force, mass, or acceleration if two of the three values are known. As you solve problems, keep in mind the concepts shown below. Larger force leads to larger acceleration. Larger mass leads to smaller acceleration.



Net force and the second law

Newton's second law explains the effect of the *net force* on motion. You must consider all the forces that are acting and add them up to find the net force. Then you use the net force to calculate any acceleration. You can also use the second law to calculate net force from a given mass and acceleration.

To use Newton's second law properly, keep the following important ideas in mind.

1. The *net* force is what causes acceleration.
2. If there is *no* acceleration, the net force *must* be zero.
3. If there *is* acceleration, there *must* also be a net force.
4. The force unit of newtons is based on kilograms, meters, and seconds.

SCIENCE FACT

Newton vs. Einstein

In 2005, The Royal Society of London took a poll of scientists and members of the public to see whether Sir Isaac Newton or Albert Einstein contributed more to science and humankind. The results were close in this heated debate! But, Sir Isaac Newton came out the winner! Here are the results.

Greater contribution to science	Newton	Einstein
Public	61.8%	38.2%
Scientists	86.2%	13.8%
Greater contribution to humankind		
Public	50.1%	49.9%
Scientists	60.9%	39.1%

Now, take your own poll to find out what people think about Newton and Einstein and their impact on science and our world.

Solving Problems: Newton's Second Law

A car has a mass of 1,000 kg. If a net force of 2,000 N is exerted on the car, what is the car's acceleration?

1. Looking for: You are asked for the car's acceleration.

2. Given: You are given mass (kg) and net force (N). Recall that 1 N = 1 kg · m/s^2.

3. Relationships: acceleration = force ÷ mass

4. Solution: acceleration = (2,000 N) ÷ (1,000 kg) = 2 m/s^2

Your turn...

a. As you coast down a hill on your bicycle, you accelerate at 0.5 m/s^2. If the total mass of your body and the bicycle is 80 kilograms, what is the net force pulling you down the hill?

b. What is the mass of an object that is experiencing a net force of 200 N and an acceleration of 500 m/s^2?

c. Recall that speed = distance ÷ time. The ratio of distance ÷ time is the same as the *slope* of a distance vs. time graph. That means speed is the slope of the distance vs. time graph. Acceleration is speed ÷ time. Use this graph of speed vs. time to find acceleration (the slope of this graph).

TECHNOLOGY

Race Car Design

Race cars are designed to have strong engines that produce large forces between the car and the road. They are also designed to be lightweight. Why is this combination of high forces and low mass useful for the design of a race car? Use Newton's second law to explain.

SOLVE FIRST LOOK LATER

a. 40 N

b. 0.40 kg

c. 10 m/s^2

Section 6.2 Review

1. What are the three main ideas associated with Newton's second law of motion? List them using your own words.
2. What conditions are necessary for acceleration to occur?
3. One kilogram-meter per second squared is also equal to what unit?
4. How much force would you need to cause a 20-kilogram object to accelerate in a straight line to 20 m/s^2?
5. Different forces are applied to cars of different masses. The acceleration is measured for each combination of force and mass. Graph the data and determine the acceleration. Force goes on the *y*-axis and mass goes on the *x*-axis. Be sure to label each axis and give your graph a title.

Force (N)	Mass (kg)
5	1
10	2
15	3
20	4

6. A 2-kilogram rabbit starts from rest and is moving at 6 m/s after 3 seconds. What net force must be exerted on the rabbit (by the ground) to cause this change in speed? (Figure 6.8)
7. Explain how changing force or mass affects the acceleration of an object. Provide one example to support your answer.
8. A tow truck pulls a 1,500-kilogram car with a net force of 4,000 newtons. What is the acceleration of the car?
9. A potato launcher uses a spring that can apply a force of 20 newtons to potatoes. A physics student launched a 100-gram potato, a 150-gram potato, and a 200-gram potato with the launcher. Which potato had the greatest acceleration?
10. An experiment measures the speed of a motorcycle and rider (total mass = 250 kg) every 2 seconds (Figure 6.9). The motorcycle moves in a straight line. What is the net force acting on the motorcycle and rider?

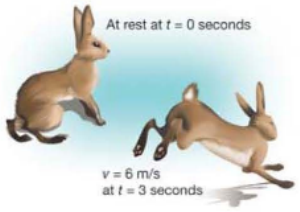


Figure 6.8: *Question 6.*

Speed	Time
0 m/s	0 s
5 m/s	2 s
10 m/s	4 s
15 m/s	6 s
20 m/s	8 s

Figure 6.9: *Question 10.*