Newton's Second Law

Recall
Acceleration describes how quickly motion changes. Specifically, it is the rate of change of velocity.

$$\vec{a} = \frac{\overrightarrow{\Delta v}}{\Delta t}$$

In this lesson we will examine the cause of acceleration: force.

Force Causes Acceleration

Newton's first law states that in order to change an object's state of motion, a force must be applied to it. Most often, the force we apply is not the only force acting on an object. The sum of all the forces acting on an object is called the **net force**.

Note: Force is a vector quantity.

Example 1
Two children are having a tug-of-war. One child pulls east with a force of 25 N. The other pulls west with a force of 15 N. What is the net force acting on a point at the center of the rope?

If the net force acting on an object is zero, we say that the forces are **balanced**. When this is the case, the acceleration of the object will be zero. In other words, the object's state of motion will not change.

If the net force on an object is not zero, we say that the forces are **unbalanced**. When this is the case, the object will have a non-zero acceleration. In other words, the object will either speed up, slow down, or change direction.

Note: The acceleration of a body is directly proportional to the net force acting on it. This means that as you increase the net force, the acceleration will increase by the same factor.

Mass Resists Acceleration

Mass is a measure of an object's inertia. Thus, the more mass an object has the harder it is to change its state of motion. We say that the acceleration of an object, for a given force, is inversely proportional to its mass. This means that if the mass of an object is increased, its acceleration will decrease by the same factor (under the influence of a given force).

Newton Combined these two relationships to form **Newton's second law** of motion. It states that:

> The acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

This is more commonly written in the form of an equation:

$$\vec{a} = \frac{\sum \vec{F}}{m}$$

Example 2

If a car experiences an acceleration of $2\ \text{m/s}^2$ while under the influence of a 2000 N net force, what is its mass?

Friction

Friction is like any other force and affects motion. Friction always acts

- between materials that are in contact with each other
- in a direction to oppose motion.

The force of friction between the surfaces depends on the kinds of materials in contact and on how much the surfaces are pressed together. For example, rubber against concrete produces more friction than steel against steel.

Friction is not restricted to solids sliding over one another. Friction also occurs in liquids and gases, both of which are called **fluids**. Fluid friction occurs as an object pushes aside the fluid it is moving through. **Air resistance**, which is the friction acting on something moving through air, is a very common form of fluid friction.

When friction is present, an object may move with a constant velocity even when an outside force is applied to it. In such a case, the friction force just balances the applied force. The net force is zero, so there is no acceleration.

Motion Worksheet #7

1. What is meant by the net force that acts on an object?

2. Suppose a cart is being moved by a certain net force. If the net force is doubled, by how much does the cart's acceleration change?

3. Suppose a cart is being moved by a certain net force. If a load is dumped into the cart so its mass is doubled, by how much does the acceleration change?

4. Distinguish between the concepts directly proportional and inversely proportional.

5. State Newton's second law in words and then in the form of an equation.

6. How much force does a 20 000 kg rocket develop to accelerate $1\,\text{m/s}^2$?

7. In what direction does friction act with respect to the motion of a sliding object?

8. If the force of friction acting on a sliding crate is 100 N, how much force must be applied to maintain a constant velocity? What will be the net force acting on the crate? What will be the acceleration?

9. Calculate the acceleration of a 2000 kg single-engine airplane just before takeoff when the thrust of its engine is 500 N.

10. Calculate the acceleration of a 300 000 kg jumbo jet just before takeoff when the thrust for each of its four engines is 30 000 N.

11. Calculate the acceleration if you push with a 20 N horizontal force on a 2 kg block on a horizontal friction-free air table.

12. What would the acceleration in question 11 be if there were a 4 N frictional force acting on the block?

13. What is the difference between saying that one quantity is proportional to another and saying it is equal to another?

14. If an object has no acceleration, can you conclude that no forces are exerted on it? Explain.

15. If a 1 N force accelerates a 1 kg mass at $1\,\text{m/s}^2$, what is the acceleration caused by a net force of 2 N on a 2 kg mass?

16. What is the acceleration of a 747 jumbo jet, mass 30 000 kg, in takeoff when the thrust for each of its four engines is 30 000 N?

17. A certain force applied to a 2 kg mass accelerates the mass at $3\ \text{m/s}^2$. How much acceleration will the same force produce on a 4 kg mass?

18. A horizontal force of 100 N is required to push a crate across a factory floor at a constant speed. What is the net force acting on the crate? What is the force of friction acting on the crate?

Motion Worksheet #7 Key

1. The sum of all forces acting on the object.

2. It doubles.

3. It halves.

4. Directly – increasing one variable increases the other by the same factor. Inversely – increasing one variable decreases the other by the same factor.

5. Acceleration is directly proportional to net force, in the same direction as the net force, and inversely proportional to mass; $\vec{a} = \overrightarrow{\sum F} \big/ m$.

6. 20 000 N

7. Friction always acts opposite to the direction of motion.

8. 100 N; zero net force; zero acceleration.

9. $0.25\ \text{m/s}^2$

10. $0.4\ \text{m/s}^2$

11. $10\ \text{m/s}^2$

12. $8\ \text{m/s}^2$

13. Proportional – a change in one quantity results in a corresponding change in the other.
    Equal – when two quantities are equal, they are identical.

14. No, you can only conclude that the net force acting on it is zero.

15. $1\ \text{m/s}^2$

16. $4\ \text{m/s}^2$

17. $1.5\ \text{m/s}^2$

18. Net force is zero, because its acceleration is zero; 100 N.