Section 4: Newton's Laws and Momentum

The following maps the videos in this section to the Texas Essential Knowledge and Skills for Physics TAC §112.39(c).

4.01 Newton's First Law
- Physics (4)(D)

4.02 Newton's Second Law
- Physics (4)(D)
- Physics (4)(E)

4.03 Newton's Third Law
- Physics (4)(E)

4.04 Momentum and Impulse
- Physics (6)(C)

4.05 Conservation of Momentum
- Physics (6)(D)

Note: Unless stated otherwise, any sample data is fictitious and used solely for teaching purposes.

4.01
Newton's First Law

Newton's First Law – The net force acting on an object is zero if and only if that object is moving with a constant velocity.

- Newton's First Law is an "if and only if" statement, meaning that its converse is true: If the net force acting on an object is zero, then the object is moving with a constant velocity.
- An object that remains at rest is technically *moving with a constant velocity* of zero.
- The ***net force*** acting on an object is the vector sum of all forces acting on it.

- Force is measured in units of ***Newtons (N)***. The following are some examples of forces you will regularly encounter:
  - The gravitational force (weight)
  - The normal (or natural) force
  - Friction
  - Tension
  - Elastic (spring) force

STUDY EDGE TIP

The wording of problems can tip you off that Newton's First Law applies in different ways. "At rest," "at constant speed in a straight line," and "without acceleration" all mean the same thing as "constant velocity."

1. In gym class, two teams are playing tug-of-war. Suppose Team A pulls left on a rope with a force of 2000 N, and Team B pulls right on the same rope with a force of 1800 N. Calculate the net force on the rope. Based only on Newton's First law, what can we say about the acceleration of the rope in this situation?

2. The net force acting on an object is zero. Which of the following is true? Select all that apply.

   A. The object is traveling with a constant velocity.
   B. The object is not traveling in a circle.
   C. The object is traveling with a constant speed.
   D. The object is not accelerating.
   E. The object is at rest.

4.02
Newton's Second Law

Newton's Second Law – An object's acceleration is directly proportional to the net force acting on it and inversely proportional to the object's mass.

- Mathematically stated, $a = \frac{F_{net}}{m}$, or, as it is more commonly written, $F_{net} = ma$.

- Another way to write F_{net} is ___________.

- Remember that when an object is moving with a constant velocity (including zero velocity), $a = 0$.

- When determining the net force on an object, it is useful to draw a force diagram first.

- The variables a and F_{net} are both vectors that point in the same direction.

Force diagram – A basic picture of a single object with labeled vector arrows, coming from its center, to represent all forces acting on it

Note: Force diagrams are sometimes also referred to as ***free body diagrams***.

1. Draw a force diagram for (a) a book sitting on your desk, (b) a baseball soaring through the air after having been pitched, and (c) a tennis ball as it horizontally strikes a vertical tennis racket. Determine the approximate direction of the acceleration of each object.

STUDY EDGE TIP

With problems involving Newton's Second Law:

1. Draw a force diagram.
2. Break all diagonal forces into x- and y-components.
3. Write a summation of all forces in the x- and y-directions separately.
4. Set the net force equal to ma in each direction.
5. Determine whether the acceleration is zero, based on physical clues.

2. Suppose Sasha pulls a 15-kg rolling suitcase across a horizontal floor, and it accelerates horizontally at a rate of 1 m/s^2. If her arm and the handle of the suitcase make a 60° angle with the floor, then with how much force is she pulling?

4.03
Newton's Third Law

Newton's Third Law – For every action force, there exists a reaction force, which is

- of the same type as the action force,
- in the opposite direction to the action force,
- equal in magnitude to the action force, and
- acting upon a different object than the action force.

1. Draw a force diagram for a 1.5-kg book sitting on a horizontal table. Calculate the magnitude, and state the direction, of each force acting on it. Next, for each force acting on the book, identify the reaction force and state its magnitude and direction.

STUDY EDGE TIP

Since action and reaction forces always act upon different objects, an action force and its corresponding reaction force will never appear on the same force diagram.

4.04
Momentum and Impulse

Momentum – The quantity of motion possessed by an object, represented by $\mathbf{p}$

- Think of momentum as the level of difficulty of stopping a particular moving object.
- The more mass an object has, the harder it is to stop. The faster an object is moving, the harder it is to stop.
- Mathematically, $\mathbf{p} =$ _________.
- The units of momentum are kilogram-meters per second $\left(\frac{\text{kg}\cdot\text{m}}{\text{s}}\right)$.
- Momentum has direction associated with it; therefore, it is a _______________ quantity.

Impulse – A change in momentum

- Impulse has the same units as momentum, since it is simply a change in momentum.
- A force acting over a period of time produces an impulse.
- Mathematically, $\Delta\mathbf{p}$ = ___________________ = _____________________.

1. Which would be more difficult to stop: a 1500-kg full-sized car traveling at 5 m/s, or a 0.25-kg toy truck traveling at 40 m/s?

2. Suppose a 0.15-kg baseball is pitched horizontally toward a batter at 35 m/s. When struck, the bat is in contact with the ball for 0.06 s, and then the ball travels horizontally back toward the pitcher at 40 m/s. Calculate the average force delivered to the ball by the bat during the hit.

4.05
Conservation of Momentum

The Law of Conservation of Momentum – The total momentum of a closed system remains the same over time.

- A ***closed system*** is a collection of objects that interact only with one another.
- Momentum is a vector quantity, so the total momentum is a vector sum. Direction matters!

STUDY EDGE TIP

To apply the law of conservation of momentum:

1. Write an expression for the total momentum of your system in one axis (e.g., x or y) in the initial state.
2. Write an expression for the total momentum of your system in that same axis (e.g., x or y) in the final state.
3. Set the expressions equal to each other and solve for what's unknown.
4. For two-dimensional problems, repeat this process in the other axis.

1. Suppose a 10-g dart is shot horizontally, at a speed of 20 m/s, directly at a 1-kg wooden block sitting atop a frictionless, flat, horizontal surface. If the dart sticks to the block upon impact, with what speed do they slide across the surface afterward?

2. Suppose a 0.15-kg firecracker explodes and breaks into two unequal pieces. One piece, containing two thirds of the mass of the original firecracker, flies leftward at 4 m/s. What is the velocity of the second piece immediately after the explosion?