

Lesson 2

Linear Motion and Inertia

Introduction: Connecting Your Learning

Lesson 2 introduces the concepts of mass, inertia, and force. The motion produced because of the forces on an object is described in terms of how far the object moves in a given amount of time and how fast the object is moving at any particular time. The motion is restricted to uniform acceleration motion in a straight line. The concept of net force and the relationship between net force, mass, and acceleration is introduced. The motion of objects freely falling or thrown in the air under the influence of gravity near the Earth's surface is described.

Readings, Resources, and Assignments

Required Textbook Readings

Newtonian Physics

Chapter 2, pp. 69 to 85

Chapter 3, pp. 91 to 105

Check Prior Knowledge

Before reading Chapter 2 in the textbook, check your prior knowledge by answering these true/false questions. If the answer is false, how could it be changed so the answer is true?

1. If a person goes to the moon, the person's mass changes while their weight remains the same.
2. When it comes to speed, 60 miles per hour is faster than 60 meters per second.
3. The density of 1,000 bricks is greater than the density of a single identical brick.
4. Massive objects free fall (ignoring air resistance) faster than objects with a smaller mass.
5. The speed of a body is proportional to its weight.
6. In the absence of any force, an object will naturally come to rest.
7. The air collapsing behind an arrow projects it through the air.
8. Under a constant force, a moving object has constant acceleration.
9. Under constant net force, an object moves at constant speed.
10. The velocity-time graph of an accelerating object is a horizontal straight line.

Lesson Objectives

By the end of this lesson, you should be able to:

1. Compare Aristotle's concept of motion and inertia with the concepts of motion and falling bodies introduced by Galileo.
2. Calculate the density of an object given the mass and volume. In addition, given any two of the three quantities (i.e., mass, volume, or density), calculate the unknown quantity.
3. Explain the difference between mass and weight.
4. Describe an object in free fall in terms of displacement, velocity, and acceleration as functions of time.
5. Analyze graphs of displacement versus time and velocity versus time that describe the motion of an object. Alternatively, given a description of the motion, make a simple sketch of the graph that represents the motion.

Approaching the Objectives

This lesson is comprised of four sections:

Section 1: Early Concepts of Motion and Inertia

Section 2: Mass, Density, and Inertia

Section 3: Displacement, Velocity, and Acceleration

Section 4: Freely Falling Bodies

Section 1: Early Concepts of Motion and Inertia

Begin this section by reading Chapter 2, Section 2.4, pp. 80 to 83 in the *Newtonian Physics* textbook. People's understanding of motion today is just the opposite of how motion was understood for over 2,000 years. Until the sixteenth century, early philosophers like Aristotle and his followers believed that objects had to contain some property (i.e., a force or impetus) that allowed the object to keep moving in a straight line. Now, people know that just the opposite is true. Once an object moves, it will continue to move forever, unless there is a net force on the object to change its motion. The key difference between the early concepts of motion and the concept of motion today is based on experimentation versus philosophy. Some of these common-sense beliefs concerning the motion of objects remain with many people today. Therefore, it might be said that some current science students still hang on (perhaps subconsciously) to the same beliefs that formed an "understanding" for 2,000 years. It may be interesting to examine how learners today relate to some of these common-sense beliefs.

Consider this true/false statement:

True or False

Under a constant force, a moving object has constant acceleration.

The answer to this question is found at the end of the lesson. It is interesting to note that only 15% of college freshmen physics students at a major university answered this question correctly when asked on a survey. Therefore, today some of these common-sense notions concerning the motion of objects are still believed to be true even though they have been shown to be false. The next section focuses on mass, density, and the property of an object to resist a change in its motion. This property is called inertia.

Section 2: Mass, Density, and Inertia

Mass is one of the seven fundamental quantities used to describe the world. Mass is sometimes defined in terms of how much matter is present in an object. Mass has specified units of measurement. The SI unit is the kilogram (kg). An object with a mass of two kilograms contains more matter than an object with a mass of one kilogram. Another way to view mass is in terms of how easy or difficult it is to change the motion of an object (i.e., speed it up or slow it down). Mass is often referred to as a measure of an object's inertia. Inertia is a property of an object to resist a change in motion. A property of an object does not have units. Therefore, inertia is a property of matter and mass is a measure of that property. Another quantity associated with an object is the volume of the object. Volume and mass are two completely different quantities. Mass refers to how much matter exists in an object, and volume refers to how much space the object occupies. Mass is measured in units of kilograms (or grams), and volume is measured in cubic units (i.e., cubic meters (m^3), cubic centimeters (cm^3), cubic inches (in^3), etc.). A very useful quantity is obtained by the ratio of mass divided by volume. This quantity is referred to as density. Density is especially useful when describing a particular type of matter because density does not depend on the quantity of the material (i.e., one brick has the same density as 1,000 bricks made of the same material). Density has units that are determined by the units used for the mass and the volume. Based on this, what is the SI unit for density? **The answer is found at end of lesson.**

Some practical applications choose to report density in terms of an area density (instead of volume density). Bone density is a common example of this. Bone density has become a measurement of interest, especially in aging females. Standardized bone density is usually reported in milligrams per square centimeter (mg/cm^2). This is not a true density (i.e., mass divided by volume), but this practice is widely accepted and widely used. Going a step further, some applications refer to a linear (one-dimensional) density. An example might be the electrical resistance in a wire per meter or some other length measurement (e.g., foot, mile, kilometer, etc.). When the term "density" is used in real applications, it doesn't always mean mass divided by volume. This illustrates the importance of understanding the context in which the words are being used.

Section 3: Displacement, Velocity, and Acceleration

Begin this section by reading Chapter 2, Sections 2.2 and 2.3, pp. 73 to 79 in the *Newtonian Physics* textbook. Displacement is the distance measured from a starting position to a final position. The displacement does not include any deviations from the straight-line path. In fact, if the object returns to its original starting position (no matter how far the distance traveled was (i.e., the distance an odometer would measure), the displacement would be zero because there was no distance between the initial and final positions. The displacement includes a description of the direction of travel. There are many different ways to describe direction. One way is using the compass rose (i.e., north, south, east, and west). Other methods involve using an angle measured from some arbitrary axis or reference frame. The common slogan, "All motion is relative," implies that a frame of reference must be selected as an anchor point, and the motion is measured and described using that point as a reference. When a measurable quantity has a direction associated with it, the quantity is referred to as a vector. A vector represents a quantity that has both magnitude (amount) and direction. Displacement is a vector quantity. On the other hand, total distance traveled does not include direction, because the direction may be (but does not necessarily have to be) changing. Quantities that do not include direction are called scalars.

Based on what is known so far, predict whether the quantities are vectors or scalars. (The answers are found at the end of the lesson.)

Quantity	Vector or Scalar
Distance traveled	
Speed	
Force	
Mass	
Temperature	

Velocity and Speed

The steps used to [calculate velocity](#) are provided by the Kahn Academy.

Velocity and speed are related because they both are a measurement of length divided by a time. Velocity is found by dividing the displacement by the time interval over which the displacement took place. For example, if an object traveled from the starting point (Point A) to a position 25 meters east of the starting point (Point B) in 5 seconds, what was the car's velocity?

Velocity equals displacement divided by time = 25 m east / 5 s = 5 m/s east

If the same object traveled in a zigzag motion and actually covered 50 m (as measured by an odometer like on a car), but did so in 5 seconds as well, then the object's speed would equal 50 meters divided by 5 seconds.

Speed = 50 m / 5 s = 10 m/s. The speed is consistent because the object had to go twice as fast to travel twice the total distance in the same amount of time.

Acceleration

Begin this section by reading [Chapter 3, Sections 3.2 and 3.3, pp. 95 to 101](#) in the *Newtonian Physics* textbook. Acceleration is a term that describes how fast or slow an object's velocity is changing. If the velocity is not changing, the acceleration is zero, regardless of how fast or slow the object is moving. Acceleration is a vector because acceleration has a direction associated with it. If the object is speeding up, the acceleration is positive. If the object is slowing down, the acceleration is negative. Normally, the standard coordinate system looks like this:



The standard convention dictates that motion to the right is positive, while motion to the left is negative. Likewise, up is positive, and down is negative. It is imperative to note that these directions are arbitrary. The critical issue is that the vector directions are defined and the diagram is properly labeled. If it is more convenient to define motion downward as a positive, do that. Just make sure you define and label accordingly.

Therefore, if an object moves to the right and speeds up, then the velocity is positive and the acceleration is positive. If the object moves to the left and slows down, the velocity is negative and the acceleration is negative. Determine the velocity as zero, positive, or negative in the examples below. Answers are found at the end of the lesson.

An object thrown straight up in the air has a velocity that is _____ and an acceleration that is _____.

When the ball reaches the top of the path, the velocity is _____ and the acceleration is _____.

On the return trip back to Earth, the velocity of the ball is _____ and the acceleration is _____.

Section 4: Freely Falling Bodies

Begin this section by reading **Chapter 3, Section 3.1, pp. 91 to 94** in the *Newtonian Physics* textbook.

The steps used to [calculate the acceleration of a free falling body](#) are provided by the Kahn Academy.

The ideas, concepts, and equations for freely falling bodies can be applied to objects that are actually falling toward the Earth or those thrown up in the air that will eventually reach a maximum height and then fall back to the Earth.

Learners often have the misconception that the acceleration of an object does not change when the object is tossed up, reaches a maximum height, turns around, and falls back to the earth. The acceleration due to gravity remains constant during this process (assuming no air resistance and a perfect world). The gravitational force is due to the attraction between the Earth and the object under consideration and is always attractive in nature. The force is always directed toward the center of the earth (assuming a perfect spherical Earth with uniform mass distribution).

Ignoring air resistance, use the chart below to consider the acceleration of an object falling from a very tall building. Instead of using 9.8 m/s^2 for the acceleration due to gravity, round this off to 10 m/s^2 to make the calculations easier.

During the first second, the velocity (speed) is increasing at a uniform rate throughout that second. At the end of the first second, the velocity (speed) at that instant is 10 m/s because the acceleration (change in velocity per change in time) is $10 \text{ meters per second per second}$.

Note: Speed is used to avoid attaching a direction to each number.

The average speed is the sum of the initial speed (i.e., zero) and the final speed (10 m/s) divided by 2. This is the normal method for finding the average.

$$\text{Average speed} = (0 \text{ m/s} + 10 \text{ m/s})/2 = 5 \text{ m/s}$$

If the average speed during that first second was 5 m/s, then in one second, the object must have traveled:
5m/s x 1 s = 5 m

Since this was the first second of travel, the total distance traveled is also 5 m. It is important to recognize that, in the spaces that follow, the distances become additive.

The acceleration is constant, so the acceleration remains 10 m/s².

In the last column on the right, use the equation $d = \frac{1}{2}gt^2$ to verify that the numbers in the total distance traveled column match the numbers found by using the equation. Both columns show that the object traveled a total distance of five meters.

$$d = \frac{1}{2}gt^2$$
$$d = \frac{1}{2}(10\text{ m/s}^2)(1\text{ s})^2$$
$$d = 5\text{ m}$$

Now, use these ideas to find the values for the next nine seconds of travel.

Using the ideas and concepts you just learned, calculate the values for the next nine seconds of travel. Answers are located at the end of the lesson.						
Time (s)	Speed (m/s)	Average speed during the interval (m/s)	Distance traveled (m)	Total distance traveled (m)	Acceleration (m/s ²)	$d = \frac{1}{2}gt^2$ $g = 10\text{ m/s}^2$
0	0	0	0	0	10	0
1	10	5	5	5	10	5
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
8	-	-	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-

View the entire chart with the correct values. This is located at the end of the lesson.

Be sure to read the remaining sections from **Chapter 3, Section 3.5, pp. 105 to 106.**

This lesson provided the foundation for the study of physics. Kinematics addresses the questions of where an object is, how fast it is moving, and how much faster (or slower) it is getting, all as functions of time. This is the usual starting block for the branch of physics referred to as classical mechanics. Lesson 3 explores Newton's three laws of motion and provides the link between the description of motion and the dynamics of what causes the motion. The relationship between force and acceleration, one of the simplest and yet most profound relationships found in science, provides this critical link between motion and dynamics.

Practice Answers

Check Prior Knowledge

1. If a person goes to the moon, the person's *mass* changes whereby their *weight* remains the same. **False**
2. When it comes to speed, 60 miles per hour is faster than 60 meters per second. **False**
3. The density of 1,000 bricks is greater than the density of a single identical brick. **False**
4. Massive objects free fall (ignoring air resistance) faster than objects with a smaller mass. **False**
5. The speed of a body is proportional to its weight. **False**
6. In the absence of any force, an object will naturally come to rest. **False**
7. The air collapsing behind an arrow projects it through the air. **False**
8. Under a constant force, a moving object has constant acceleration. **False**
9. Under constant net force, an object moves at constant speed. **False**
10. The velocity-time graph of an accelerating object is a horizontal straight line. **False**

Section 1: Early Concepts of Motion and Inertia

Under a constant force, a moving object has constant acceleration. **False**

Section 2: Mass, Density, and Inertia

Based on this, what is the SI unit for density? **kg/m³**

Section 3: Displacement, Velocity, and Acceleration

Quantity	Vector or Scalar
Distance traveled	Scalar
Speed	Scalar
Force	Vector
Mass	Scalar
Temperature	Scalar

Acceleration

An object thrown straight up in the air has a velocity that is **POSITIVE** and an acceleration that is **NEGATIVE**.

When the ball reaches the top of the path, the velocity is **ZERO** and the acceleration is **NEGATIVE**.

On the return trip back to Earth, the velocity of the ball is **NEGATIVE** and the acceleration is **NEGATIVE**.

Section 4: Freely Falling Bodies

Time (s)	Speed (m / s)	Average speed during the interval (m / s)	Distance traveled (m)	Total distance traveled (m)	Acceleration (m / s ²)	$d = 1/2 g t^2$ $g = 10 \text{ m / s}^2$
0	0	0	0	0	10	0
1	10	5	5	5	10	5
2	20	15	15	20	10	20
3	30	25	25	45	10	45
4	40	35	35	80	10	80
5	50	45	45	125	10	125
6	60	55	55	180	10	180
7	70	65	65	245	10	245
8	80	75	75	320	10	320
9	90	85	85	405	10	405
10	100	95	95	500	10	500