Lesson 4
Momentum and Energy

Introduction: Connecting Your Learning

The previous lessons concentrated on the forces that cause objects to change motion. Lesson 4 will introduce momentum and energy, as related to both kinematics and dynamics. The lesson also discusses the conservation laws describing the motion resulting when two objects interact with one another. When a collision occurs, momentum and energy are transferred between the colliding objects. The concept of mechanical energy is introduced and explained in terms of the kinetic (energy of motion) and potential (energy of position) energies of the objects under consideration. The concepts of work and power are discussed in terms of how work can alter the kinetic energy of the system of objects. Power is related to the rate at which work enters or leaves a system or the rate that energy is expended. This lesson also explores the six simple machines that can make it easier to perform work or multiply forces. The scientific literature section in the lesson explores online scientific encyclopedias.

Readings, Resources, and Assignments	
Required Textbook Readings	*Conceptual Physics* Chapter 2, pp. 39-62

Check Prior Knowledge

Determine the answer to each of these true/false statements. (Answers are located at the end of the lesson.)

1. Large objects always have more momentum than smaller objects.
2. An impulse on an object causes the momentum of the object to change.
3. Less energy is needed to perform work with a machine.

Focusing Your Learning

Lesson Objectives

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

1. Discuss the momentum-impulse relationship.
2. Describe the three classes of collisions and apply the conservation of momentum principle to solve collisions involving two moving objects.

3. Calculate the changes in the potential and kinetic energy of a system that result when work is done on or by the system.

4. Apply conservation of mechanical energy principles to systems of particles possessing potential and kinetic energy.

5. Explain how simple machines can be used to multiply forces and increase the mechanical advantage when performing work.

Approaching the Objectives

This lesson is comprised of five sections:

Section 1: Momentum and Impulse

Section 2: Conservation of Momentum

Section 3: Work-Energy Principle

Section 4: Conservation of Mechanical Energy

Section 5: Simple Machines and Mechanical Advantage

Section 1: Momentum and Impulse

Begin this section by reading Chapter 2, Section 2.3, pp. 42 to 54 in the *Conceptual Physics* textbook.

View the video from Khan Academy on Momentum.

The term momentum is sometimes referred to as the quantity of motion. Momentum is a vector quantity because momentum has a direction associated with it. Momentum is defined as the product of an object's mass and velocity. Objects with a small mass and a large velocity can have the same momentum as an object with a large mass and a small velocity. When a net force is applied to an object over a specified time interval, the momentum of the object will change. This force multiplied by the time interval over which the force is applied is referred to as impulse. So impulse ($F\Delta t$) = Impulse = the change in momentum Δ (mv). Note the Greek letter Δ is the commonly used symbol that means "change in." The units for momentum are kg·m/s [mass x velocity]. The commonly used units for impulse are N·s [force x time]. So, it follows that a kg·m/s is the same thing as N·s. Impulse and momentum have the same units, but are they the same thing?

The answer is no! Impulse is the change in momentum and not the momentum of the object itself. To restate, applying a force to an object over time (impulse) causes the motion of the object (momentum) to change.

Answer the following True/False questions: (Check your answers at the end of the lesson.)

1. Objects can possess momentum.

2. Fast objects always have more momentum than slower objects.

3. Momentum has direction.

4. Momentum and impulse both have the same units.

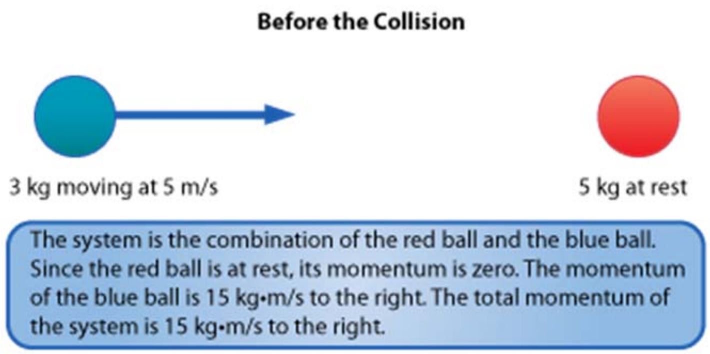
5. Momentum and impulse represent the same quantity.

6. A 2 kg object moving at 5 m/s has the same momentum as a 1 kg object moving twice as fast.

The next section focuses on the concept that makes momentum one of the most powerful quantities found in the physical world. In an isolated system of particles (or objects), the initial momentum of the system before the particles or objects interact (i.e., collide or hit each other) is the same as the final momentum after the interaction or collision. This includes the magnitude (amount), as well as the direction.

Section 2: Conservation of Momentum

The key to applying the conservation of momentum principle is to isolate the system of objects under consideration. If two objects (e.g., billiard balls) are going to collide, the system is the two colliding objects. The force that one object exerts on the other during the collision is considered an internal force and is not considered a force that would cause a change in the momentum of the system.



There are three basic collision scenarios:

1. Perfectly elastic: In this scenario, no energy is lost in the collision, including light, heat, or sound, and all energy remains the same. Such a situation is idealized and does not occur in nature. Some collisions, like those that involve colliding gas particles, are close to ideal, so elastic collisions are sometimes used to make approximations, which, in turn, simplify the mathematical calculations needed to analyze the event. The momentum and energy stay the same in a perfectly elastic collision.

2. Partially inelastic: During a partially inelastic collision, the objects bounce off each other. Some energy is converted to other forms such as heat, light, and sound. The momentum stays the same, while energy is lost (or converted to other forms).

3. Totally inelastic: In a totally inelastic collision, the objects stick together and become one object. Momentum of the system stays the same, and energy is lost or converted to other forms.

Note: In all three types of collisions, the momentum of the system stays the same. This fact makes momentum conservation a very powerful tool in analyzing the motion of the objects before and after an interaction.

In the collision described above, assuming the red ball and the blue ball stick together, describe the motion after the collision.

Solution:

Since the initial momentum of the system was 15 kg·m/s to the right, this means the final momentum of the system must also be 15 kg·m/s to the right. When the masses stick together, the combined mass is 3 kg plus 5 kg = 8 kg.

Initial momentum = final momentum

15 kg·m/s to the right = 8 kg · Final velocity of the system (both balls stuck together)

Final velocity = [15 kg·m/s to the right]/ 8kg

Final velocity = 1.875 m/s to the right

The next section introduces the two terms of work and power. Work is defined as the force applied to an object multiplied by the distance through which the force acts. The other term is power. Power is the rate at which work is done or energy is consumed.

Section 3: Work-Energy Principle

Begin this section by reading Chapter 2, Section 2.5, pp. 58 to 59 in the *Conceptual Physics* textbook. View these videos from Khan Academy on Work and Energy Part 1 and Part 2.

Work and energy have the same units (i.e., joules), but work and energy do not represent the same quantities. Work causes a change in the time of the system. When money is deposited, it may go into checking, savings, or both. When work is done, the result may be an increase in the KE, the PE, or both. If a force is applied through a distance, work is done. If this work causes an increase in the distance above the ground (h) but no change in speed or velocity, then the energy change is potential. If the object's height above the ground remains the same but the speed increases, the energy change is kinetic. If the height and speed increase, then both kinetic and potential energy increase.

The work-energy principle is very useful when the PE remains constant, because then the work is equal to the change in kinetic energy.

$$\text{Work} = KE_{final} - KE_{initial}$$

Power is the rate at which work is done or energy is expended. The SI unit for power is the joule/second (J/s) or the watt. This quantity has no direction associated with it, so power is a scalar.

The next section discusses one of the many types of energy found in nature. This energy is referred to as mechanical energy, which has two forms. Kinetic energy is the energy an object possesses due to the object's motion, while potential energy is due to the object's position in the gravitational field. The sum of the two types of energy is referred to as Total Mechanical Energy (TME).

Section 4: Conservation of Mechanical Energy

View the video from Khan Academy on Conservation of Energy.

When an object is moving, the object has kinetic energy (KE). This energy depends on the mass of the object and the object's speed. Kinetic energy equals ½ mv^2. Kinetic energy does not have a direction, so it is a scalar quantity. The units for kinetic energy are Joules (J). A 1 kg object moving at 1 m/s has a kinetic energy of 1/2 joule (J).

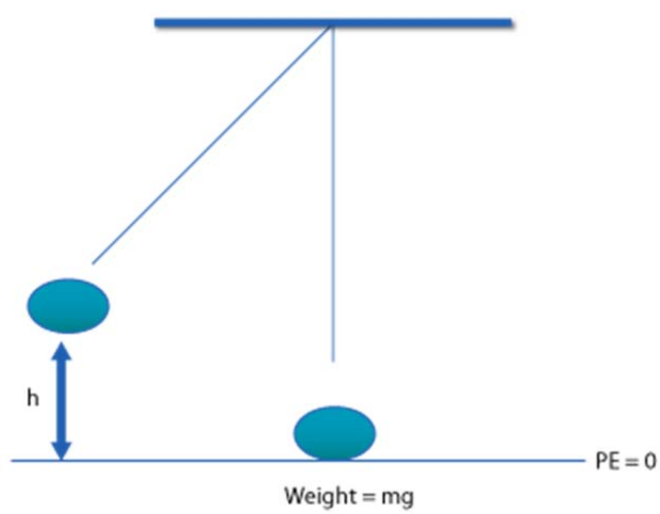
Answer the following questions and check your answers at the end of the lesson:

A 1 kg object moving at 2 m/s has a kinetic energy of ___ J.

An object at rest has a kinetic energy of ___ J.

Objects may store energy due to their position in the gravitational field. An object gains potential energy when it is lifted in a direction opposite from its natural tendency to move due to gravity, which is down in most cases. Potential energy is equal to the object's weight (mass x the acceleration due to gravity multiplied by the distance the object was lifted). It is important to note that the initial position (where potential energy is defined to be zero) is completely arbitrary. Therefore, the change in the height is the relevant measurement and not the absolute height.

The Total Mechanical Energy (TME) is analogous to the total money in a combined checking-savings account. The checking account is like the kinetic energy and the savings account is like potential energy. Within a system, energy can be converted from kinetic to potential just like money can be transferred from savings to checking. As long as no energy enters or leaves the system, the total energy remains constant. In the bank analogy, as long as there are no deposits or withdrawals, the total of the two balances remains the same. Consider a simple pendulum:



Use $g = 10 m/s^2$

Mass (m) = 1.0 kg

Height (h) = 10 m

If the pendulum bob is at rest and released from height (h), how fast will the pendulum be moving when it is at the bottom of the swing? When the pendulum bob is at rest, all the mechanical energy is potential energy PE. PE = mgh = 1 kg·10m/s^2 ·10 m = 100 J

As the pendulum falls, the speed increases as the potential energy decreases. At the bottom of the swing, the PE is zero and the KE is the maximum. Using the conservation of energy principle, the KE is equal to 100 J. Since KE = ½ mv^2, it follows that the velocity is equal to:

$$v = (2\ KE/m)^{1/2}$$

Note: Raising an expression to the ½ power is the same as taking the square root of the expression

v = 14.1 m/s at the bottom.

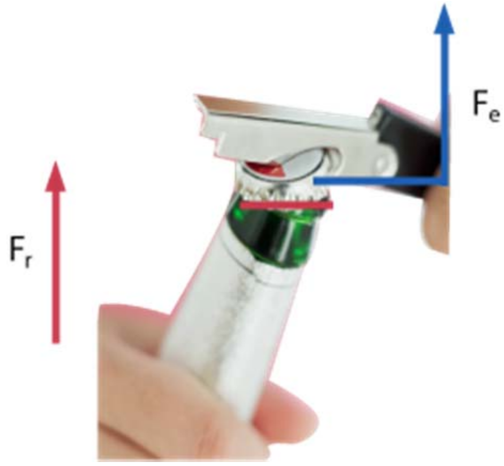
The next section applies energy, work, and power and discusses methods by which simple machines can be used to multiply forces and achieve a mechanical advantage when performing work.

Section 5: Simple Machines and Mechanical Advantage

A machine changes either the magnitude or the direction of a force as the force transmits energy to the task being accomplished. No matter how complex the machine appears to be, all machines are a combination of simple machines. Perform a Web search and locate images of the simple machines shown below.

Machine	Principle of Operation	Common Example
Lever		
Pulley		
Wheel and axle		
Inclined plane		
Wedge		
Screw		

The ratio of the resistive force to the effort force is called the mechanical advantage (MA). Visualize a common bottle opener.



The upward red vector represents the resistive force. The small distance shown in red represents the distance over which the resistive force is applied. Notice a much smaller effort force (shown in blue) is required if applied over a longer distance. The work (force x distance) is the same. The mechanical advantage is F_r/F_e.

The efficiency of the machine is the ratio of the work output to the work input expressed as a percent. The efficiency of an ideal machine is 1.0. This is 100% efficiency. Real machines are always less efficient; therefore, the efficiency is less than one.

Classify these common tools in terms of simple machines. The answers can be found at the end of the lesson.

Tool	Simple Machine
Screwdriver	
Pliers	
Chisel	
Nail puller	

Summarizing Your Learning

This lesson explored two of the most powerful conservation laws in physical science: (1) the conservation of linear momentum and (2) the conservation of mechanical energy (potential energy plus kinetic energy). One of the reasons that the conservation of momentum is such a powerful tool is that in the absence of outside forces, the initial vector momentum of a system is equal to the final vector momentum of the system regardless of the type of collision (or explosion) and regardless if energy is converted to other forms. The next lesson explores the concept of gravity in detail and describes rotational motion.

Practice Answers

Check Prior Knowledge

Large objects always have more momentum than smaller objects. FALSE

An impulse on an object causes the momentum of the object to change. TRUE

Less energy is needed to perform work with a machine. FALSE

Section 1: Momentum and Impulse

1. Objects can possess momentum.

   TRUE

2. Fast objects always have more momentum than slower objects.

   FALSE. The slower object can have more mass.

3. Momentum has direction.

   TRUE

4. Momentum and impulse both have the same units.

   TRUE

5. Momentum and impulse represent the same quantity.

   FALSE. Impulse is the CHANGE in momentum.

6. A 2 kg object moving at 5 m/s has the same momentum as a 1 kg object moving twice as fast.

   TRUE. Both have a momentum of 10 kg·m/s

Section 4: Conservation of Mechanical Energy

A 1 kg object moving at 2 m/s has a kinetic energy of 2 J.

An object at rest has a kinetic energy of 0 J.

Section 5: Simple Machines and Mechanical Advantage

Tool	Simple Machine
Screwdriver	WHEEL AND AXLE
Pliers	LEVER
Chisel	WEDGE
Nail puller	LEVER