Course Learning Outcomes for Unit II

Upon completion of this unit, students should be able to:

2. Illustrate the scientific method within everyday situations.
   2.1 Identify the appropriate formulas necessary to solve specific scenario questions.
   2.2 Calculate and analyze the acceleration and the force in various situations.

3. Explain Newton's laws of motion at work in common phenomena.
   3.1 Solve problems using the law of motion.
   3.2 Explore the relationship between the first and second laws.
   3.3 Identify action-reaction pair in the third law.

Required Unit Resources

Chapter 3: Kinematics in Two Dimensions

Chapter 4: Forces and Newton's Laws of Motion

Unit Lesson

The Concept of Force and Mass

A *force* is a push or pull, and it is a vector quantity. Contact forces arise from the physical contact between two objects. Noncontact forces are also called action-at-a-distance forces because they arise without physical contact between two objects. More sophisticatedly, a force is an external influence on an object that causes it to accelerate relative to an inertial reference frame where no acceleration occurs. The direction of the force is the same as that of the acceleration.

Mass is an intrinsic property of an object that measures its resistance to acceleration. That is, mass is a measure of the object's inertia. In dynamics, mass represents the inertia of a body or that body's resistance to any change in its state of motion. Mass is a scalar quantity characterizing a body, and it does not depend on the body's location or state of motion (Cutnell et al., 2022).

Many people think that weight is the same term for mass; however, it is not! Mass is a measure of the amount of material contained in an object and does not depend on any gravitational force acting on it. Mass is constant. On the other hand, weight is the gravitational force acting on an object. It depends on the mass of the object and the gravitational acceleration of the object attracting it. That is, weight W is the product of the mass m and the acceleration g due to gravity.

$$W = mg$$

Your weight will vary if you measure it on other celestial bodies, but your mass does not change. For instance, if you measure your weight on Jupiter, it will be greater than that on Earth. On the moon, however, your weight will be less than that on Earth. The larger the gravitational pull, the greater your weight.

Friction

When an object is in contact with a surface, the surface exerts a force on the object. The perpendicular component of the force to the surface is called *normal force* (please look at Figure 4.13 in section 4.8 in Chapter 4 of your eTextbook) and the parallel component of the force to the surface is called frictional force, or simply friction. In order to initiate the motion of the object, the applied force must overcome the friction. The direction of the friction is opposite to that of the applied force. The frictional force is proportional to the normal force. Usually, the friction increases on an uneven surface.

In general, there are two kinds of frictional forces: static and kinetic. The static friction prevents an object from moving. In order to move the object, the applied force must overcome the static friction. Once the object is in motion, the kinetic friction is now an obstacle for the moving object (Cutnell et al., 2022). Be sure to review the coefficients of friction for various surfaces in Table 4.2 located in section 4.9 of Chapter 4 in your eTextbook.

Newton's Three Laws

Newton's three laws are about forces that change the motion of objects and are based on total momentum conservation. In a simple expression, momentum is a quantity defined as mass multiplied by velocity. We will learn about momentum in detail in Unit IV.

The first law is the *law of inertia*. This is the same law by Galileo's inertia interpretation. Unless there is no external force, an object that is at rest stays at rest, and one that is in motion continues to move (Shipman, Wilson, & Todd, 2009). That is, there is a tendency for an object to keep its original property. The inertia of an object is measured by its mass. The more massive the object, the more inertia it has. For instance, when a bus driver stops suddenly, a man in the rear seat moves forward. This is because the man's inertia that was previously in motion wants to stay in motion. In fact, this law of inertia is a special case of Newton's second law.

The second law is the *law of motion or acceleration*. Force (F) = mass (m) x acceleration (a) (Shipman et al., 2009). This is the most useful formula because it can describe the dynamics of motion in detail. We can picture how velocities change with respect to time when forces are applied. Simply, it can be expressed with the mathematical formula $F = ma$.

$$F = ma$$

The SI unit of force is the mass unit (kg) times the acceleration unit (m/s^2), and thus [kg m/s^2], which is defined as [N]. That is, 1 newton = 1 N = 1 kg m/s^2

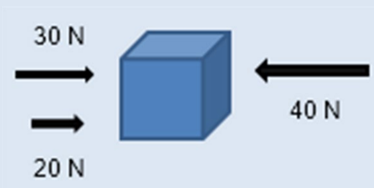
Here, the force is summed over all applied forces exerted on an object. It accelerates the object relative to an inertial reference frame. Remember that the directions of force and acceleration are identical. Mass that opposes acceleration is an intrinsic property of an object and is a gauge of inertia. Acceleration is a change of velocity. That is, acceleration indicates how much the velocity has been increased or decreased during a certain amount of time. If the velocity is constant, which means the acceleration is zero, then there is no applied force. This is exactly the case for Newton's first law. There is no distinction between an object that is in motion with a constant velocity and one that is at rest. One example of accelerated motion is circular motion. Even though the speed of the object is constant, the direction of the movement is changing, so the velocity is not constant.

Sample Question 1: A lunar exploration vehicle was made by a research team, and it weighs about six times more than it will on the moon. In order to have the same acceleration on the moon as well as on the Earth, what will be the net force acting on the vehicle? Will it be greater than, less than, or the same as that required on Earth?

Solution: According to Newton's second law, the net force is $F = ma$. Here, m is the vehicle's mass and a is the acceleration. The net force depends on the mass for a constant acceleration. Here, the mass of the vehicle is constant. Therefore, the same net force would be required.

Sample Question 2: You and your friend are pushing a box in the same direction. Its mass is 200 kg. You apply 20 N to the box, while your friend applies 30 N. A force created by friction is 40 N in the opposite direction. What is the acceleration of the box?

Solution: There are three forces acting in this system, and the net force should be added up. Two of them are acting toward the same direction, and the remaining is acting in the opposite direction, as you can see below. Thus, the net force F = 30 N + 20 N – 40 N = 10 N. From Newton's 2nd law, $F = ma$. The mass of box is given by 200 kg. Therefore, the acceleration $a = F / m$ = 10 N / 200 kg = 0.05 m/s^2



The third law is the *law of action-reaction*. The forces exist in pairs. The magnitudes of forces are equal, but their directions are opposite (Shipman et al., 2009). That is, every action has an equal and opposite reaction. For example, when you push a wall on a slippery floor, you feel that your feet are moving backward. The push force exerted by you is the same as that by the wall. That is, the two forces are equal in magnitudes, but opposite in direction. Review Example 4 located in section 4.9 of Chapter 4 in your eTextbook (Cutnell et al., 2022).

Sample Question 3: An astronaut pushes on the spacecraft with a force of 40 N near the International Space Station. His mass is 90 kg, and the spacecraft's mass is 10,000 kg. What are the accelerations of the space craft and the astronaut?

Solution: According to Newton's third law, when the astronaut applies the force to the spacecraft, the spacecraft also applies the same amount of force to the astronaut. That is, the magnitudes of the two forces are identical, but the directions are different.

From the second law of Newton, the acceleration of the spacecraft is a_s = 40 N / 10,000 kg = 0.004 m/s^2. The acceleration of the astronaut is a_a = -40 N / 90 kg = -0.44 m/s^2. Note that the magnitudes of the action and reaction forces are always equal, but they do not have the same acceleration unless they have the same mass.

Free Fall

Every object on Earth falls downward because of Earth's gravity. Earth's gravity points to the center of Earth. If there is no air, all of the falling objects should experience the same acceleration. Recall from the Unit I Lesson that in order to prove this, an astronaut, David Scott of the Apollo 15 mission, performed the experiment on the moon.

When we ignore the air resistance and assume the constant acceleration, we say that the falling object is in free fall. The acceleration of the freely falling body is due to gravitational acceleration *g*, and it is about 10 m/s^2 on the surface of the Earth. However, the object is at considerably high altitude, the acceleration due to gravity is not constant. The gravitational acceleration is inversely proportional to the square of the distance from the center of the Earth to the object.

The Fundamental Forces

All the different forces observed in nature can be explained in terms of four basic interactions that occur between elementary particles: gravitational force, electromagnetic force, strong nuclear force, and weak nuclear force. The associated particles for the strong force are mainly gluons and pi nucleons.

The main role of the strong force is to hold the nuclei of atoms together. Principally, it is attractive; however, it can sometimes act in a repulsive way with proper conditions. The strong nuclear interaction has a very powerful strength of the force, but it is very short-ranged (about 10^{-13} cm). The attractive force only works well within the size of the nucleus. The role of a neutron is very important to maintain the structure of the nucleus. A repulsive force exists between two protons because they have the same charge. Remember that in the influence of electrostatic force two like charges repel, and two opposite charges attract. Thus, more neutrons than protons are needed to keep the stable nucleus as the atomic number increases. The maximum proton number is 83 with 126 neutrons for the stable structure in nature. All nuclei that have an atomic number greater than 83 are unstable because the binding force to hold the nuclei is weak and disintegrates or rearranges its structure. This is known as radioactivity. The radioactive decay or neutrino interactions can be explained by the weak force, and its strength is weak with a short range. The associated particles for the weak nuclear force are known as intermediated vector bosons such as W^+, W^-, and Z^0. They are spin 1 particles, and their masses are greater than 80 GeV.

The electromagnetic force is responsible for electric and magnetic effects. The phenomena of electricity and magnetism look different; however, they are very closely related to each other. A changing electric field can create a magnetic field and vice versa. In order to combine electricity and magnetism, James Maxwell created the elegant mathematical formalism, Maxwell's Equations, in the 19th century. Maxwell's Equations contain integrated information regarding the fundamental properties of electricity and magnetism with their unique properties. It has both attractive and repulsive properties. For instance, there is an attractive force between opposite electric charges and a repulsive force between the same charges. It is a somewhat long-ranged force but much weaker than the strong force. The electromagnetic spectrum ranges from radio waves, which have long wavelengths and low frequencies, to gamma rays, which have short wavelengths and high frequencies. Thus, we can see that visible light, gamma rays, and microwaves are all the same; they are all types of electromagnetic radiations and differ only in their wavelengths. The associated particle for the electromagnetic force is the photon, and it is known as a massless spin 1 particle.

The last fundamental force is *gravity*. We will study this force in detail in the next unit. The gravitational force works well on a larger scale and is long-ranged, and it has a distinctive property. It is always attractive, not repulsive. The gravitational force is well-described by Newton's universal law of gravitation. It states that the attractive force between two objects in the universe is proportional to the product of the mass of one object and that of other objects and is inversely proportional to the square of the separation between two objects. The associated particle for the gravitational force is known as a massless spin 2 particle, a graviton; however, it has not been discovered yet. For a further detailed explanation, please visit the webpage "Fundamental Forces".

References

Cutnell, J. D., Johnson, K. W., Young, D., & Stadler, S. (2022). *Physics* (12th ed.). Wiley.

Hewitt, P. G. (2015). *Conceptual physics* (12th ed.). Pearson.

Shipman, J. T., Wilson, J. D., & Todd, A. W. (2009). *An introduction to physical science* (12th ed.). Cengage Learning.

Suggested Unit Resources

In order to access the following resource, click the link below.

You can explore the three laws by Newton with quantitative descriptions at the website below.

Nave, R. (n.d.). *Newton's first law*. HyperPhysics. http://hyperphysics.phy-astr.gsu.edu/hbase/Newt.html

Learning Activities (Nongraded)

Nongraded Learning Activities are provided to aid students in their course of study. You do not have to submit them. If you have questions, contact your instructor for further guidance and information.

1. Solve Questions 71–75 under Physics in Biology, Medicine, and Sports in Chapter 3 of your eTextbook.
2. Solve Questions 91–103 under Physics in Biology, Medicine, and Sports in Chapter 4 of your eTextbook.