Answer to Essential Question 8.6: Linear momentum is not conserved for any orbit, because linear momentum is a vector and the direction of the momentum changes. The magnitude of the linear momentum is constant for the circular orbit, but not for any of the others. Linear momentum is not conserved because the Sun exerts a net force on the orbiting object.

Chapter Summary

Essential Idea

Gravity is one of the four fundamental forces in the universe, and it strongly influences each of us all the time. In addition, because the way objects with mass interact with each other is similar to the way objects with charge interact with one another, the material covered in this chapter lays a foundation for our understanding of charged particles in Chapters 16 and 17.

Newton's Law of Universal Gravitation

The gravitational force an object of mass *M* exerts on an object of mass *m* when the distance between their centers-of-mass is *r* is known as Newton's Law of Universal Gravitation:

$$\vec{F}_G = -\frac{GmM}{r^2}\hat{r}$$ (Equation 8.1: **Gravitational force between two objects**)

where $G = 6.67\times10^{-11} N\ m^2 / kg^2$ is the universal gravitational constant. The magnitude of the force is equal to GmM / r^2 while the direction is given by $-\hat{r}$, which means that the force is attractive, directed back toward the object exerting the force.

The Gravitational Field, $\vec{g}$

In previous chapters we have referred to $\vec{g}$ as "the acceleration due to gravity", but a more appropriate name is "the strength of the local gravitational field". A field is something that has a magnitude and direction at all points in space. It is also one way to examine how an object with mass influences the space around it. The gravitational field can be defined as the gravitational force per unit mass:

$$\vec{g} = \frac{\vec{F}_G}{m}.$$ (Equation 8.2: **Gravitational field**)

For an object of mass *M*, such as the Earth, the gravitational field outside of the object that is produced by that object is:

$$\vec{g} = -\frac{GM}{r^2}\hat{r},$$ (Equation 8.3: **Gravitational field from a point mass**)

where *r* is the distance from the center of the object to the point. The magnitude of the field is GM / r^2, while the direction is given by $-\hat{r}$, which simply means that the field is directed back toward the object producing the field.

Gravitational Potential Energy

Previously we have defined gravitational potential energy as *mgh*, but that applies only in a uniform gravitational field. More generally the gravitational potential energy associated with the interaction between objects of mass *m* and *M*, separated by a distance *r*, is given by:

$$U_G = -\frac{GmM}{r} .$$ (Equation 8.4: **Gravitational potential energy**)

The negative sign is associated with the fact that gravitational interactions are always attractive. In other words, the force of gravity always causes objects to attract one another, rather then repel one another.

Orbits and Energy

When an object is held in orbit around another object via the force of gravity, the total energy is always negative, indicating that the system is bound. If the total energy in the system is positive then the system is not bound, and the objects tend to fly apart from one another.

In the special case of a circular orbit, the total energy is half the value of the gravitational potential energy, as well as equal in magnitude, but opposite in sign, to the kinetic energy of the orbiting object.