# Summary

**THE BIG IDEA** **Everything pulls on everything else.**

## 13.1 The Falling Apple

**Newton reasoned that the moon is falling toward Earth for the same reason an apple falls from a tree—they are both pulled by Earth's gravity.**

- Newton understood the concept of inertia, that without an outside force, moving objects continue to move at constant speed in a straight line. He knew that if an object undergoes a change in speed or direction, then a force is responsible.

## 13.2 The Falling Moon

**The moon is actually falling toward Earth but has great enough tangential velocity to avoid hitting Earth.**

- Newton reasoned that the moon must be falling *around* Earth. The moon falls in the sense that it falls beneath the straight line it would follow if no force acted on it. He hypothesized that the moon was a projectile circling Earth under the attraction of gravity.
- Newton compared the motion of the moon to a cannonball fired from the top of a high mountain. If the cannonball were fired with enough speed, its path would become a circle and the cannonball would circle indefinitely.
- Both the orbiting cannonball and the moon have a component of velocity parallel to Earth's surface. This sideways or *tangential velocity* is sufficient to ensure nearly circular motion *around* Earth rather than *into* it.
- Newton reasoned that the mass of the moon should not affect how it falls, just as mass has no effect on the acceleration of freely falling objects on Earth. How far the moon falls should relate only to its *distance* from Earth's center.

## 13.3 The Falling Earth

**Newton's theory of gravity confirmed the Copernican theory of the solar system.**

- The planets don't crash into the sun because they have tangential velocities. If the tangential velocities of the planets were reduced to zero, their motion would be straight toward the sun and they would indeed crash into it. Any objects in the solar system with insufficient tangential velocities have long ago crashed into the sun.

## 13.4 Newton's Law of Universal Gravitation

**Newton discovered that gravity is universal. Everything pulls on everything else in a way that involves only mass and distance.**

- Newton's **law of universal gravitation** states that every object attracts every other object with a force that for any two objects is directly proportional to the mass of each object.
- The law of universal gravitation can be expressed in equation form: $F = G\,(m_1 m_2/d^2)$, where $m_1$ and $m_2$ are the objects' masses, and $d$ is the distance between their centers of mass.
- The **universal gravitational constant,** $G$, in the equation describes the strength of gravity. In scientific notation, $G = 6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$. The value of $G$ tells us that the force of gravity is a very weak force. It is the weakest of the presently known four fundamental forces.

## 13.5 Gravity and Distance: The Inverse-Square Law

**Gravity decreases according to the inverse square law. The force of gravity weakens as the square of distance.**

- When a quantity varies as the inverse square of its distance from its source, it follows an **inverse-square law.** For example, the inverse square of 3 is $\left(\frac{1}{3}\right)^2$, or $\frac{1}{9}$.
- This law applies to all cases where the effect from a localized source spreads evenly throughout the surrounding space, such as the weakening of gravity with distance. Other examples are light, radiation, and sound.

## 13.6 Gravitational Field

**Earth can be thought of as being surrounded by a gravitational field that interacts with objects and causes them to experience gravitational forces.**

- A **gravitational field** occupies the space surrounding a massive body. A gravitational field is an example of a *force field,* for any mass in the field space experiences a force.
- Iron filings sprinkled over a sheet of paper on top of a magnet reveal the shape of the magnet's magnetic field. The pattern of filings shows the strength and direction of the magnetic field at different locations around the magnet. Earth is a giant magnet and, like all magnets, is surrounded by a magnetic field.
- The strength of Earth's gravitational field, like the strength of its force on objects, follows the inverse-square law. Earth's gravitational field is strongest near Earth's surface and weaker at greater distances from Earth.

## 13.7 Gravitational Field Inside a Planet

**The gravitational field of Earth at its center is zero!**

- The gravitational field of Earth exists inside Earth as well as outside.
- If you traveled through an imaginary hole drilled completely through Earth, you'd gain speed as you fell from the North Pole toward the center of Earth, and lose speed moving away from the center toward the South Pole.

## 13.8 Weight and Weightlessness

**Pressure against Earth is the sensation we interpret as weight.**

- The force of gravity, like any force, causes acceleration. Because we are almost always in contact with Earth, we think of gravity primarily as something that presses us against Earth rather than as something that accelerates us.
- If you stand on a scale, gravity pulls you against the supporting floor and scale, and the floor and scale push upward on you. This pair of forces compresses a spring-like gauge inside the scale. The weight reading on the scale is linked to the amount of compression.
- **Weightlessness** is not the absence of gravity; rather, it is the absence of a support force. Astronauts in orbit are without a support force and experience weightlessness.

## 13.9 Ocean Tides

**Newton showed that the ocean tides are caused by *differences* in the gravitational pull of the moon on opposite sides of Earth.**

- The moon's gravitational attraction is stronger on Earth's oceans closer to the moon, and weaker on the oceans farther from the moon. This difference causes the oceans to bulge out on opposite sides of Earth. Because Earth spins, a fixed point on Earth passes beneath both bulges each day, producing two high tides and two low tides.
- A **spring tide** is a high or low tide that occurs when the sun, Earth, and moon are all lined up. The tides due to the sun and the moon coincide, making high tides higher than average and low tides lower than average. Spring tides occur during a new or full moon.
- A **neap tide** occurs when the moon is halfway between a new moon and a full moon. The pulls of the moon and sun are perpendicular to each other. As a result, the solar and lunar tides do not overlap, so the high tides are not as high and low tides are not as low.

## 13.10 Black Holes

**When a massive star collapses into a black hole, there is no change in the gravitational field at any point beyond the original radius of the star.**

- Two main processes occur continuously in stars like our sun: gravitation, which tends to pull solar material inward, and thermonuclear fusion, which blows material outward.
- If the fusion rate increases, the sun will get hotter and bigger; if the fusion rate decreases, the sun will get cooler and smaller.
- When the sun runs out of fusion fuel (hydrogen), gravitation will dominate and the sun will start to collapse. The collapse will cause helium to fuse into carbon, and the sun will expand into a *red giant*. When the helium is used up, the sun will collapse into a *black dwarf.*
- For stars more massive than the sun, once thermonuclear fusion ends, gravitational collapse will take over, eventually forming a **black hole.** The density of a black hole is so great that its enormous gravitational field prevents even light from escaping. The gravitational field beyond the original radius of the star is no different after the collapse than before.

## 13.11 Universal Gravitation

**The formulation of the law of universal gravitation is one of the major reasons for the success in science that followed, for it provided hope that other phenomena of the world might also be described by equally simple and universal laws.**

- Earth is round because of gravitation. Earth attracted itself together before it became solid. Any "corners" of Earth have been pulled in so that Earth is a giant sphere.
- The solar system began when a slightly rotating ball of interstellar gas contracted due to mutual gravitation. To conserve angular momentum, the rotational speed of the ball of gas increased, causing the particles to sweep out into a disk shape.
- The deviation of an orbiting object from its path around a center of force caused by the action of an additional center of force is called a **perturbation.**
- The planet Neptune was discovered when a perturbation in the orbit of Uranus led scientists to conclude that a disturbing body beyond the orbit of Uranus was the culprit.
- According to current scientific understanding, the universe originated and grew from the explosion of a primordial fireball some 13.7 billion years ago. This is the "Big Bang" theory of the origin of the universe. All the matter of the universe was hurled outward from this event and continues in an outward expansion.
- More recent evidence suggests the universe is not only expanding, but *accelerating* outward. It is pushed by an antigravity *dark energy* that makes up an estimated 73 percent of the universe. Twenty-three percent of the universe is composed of the yet-to-be discovered particles of exotic *dark matter.* Ordinary matter makes up only 4 percent.