

Big Picture

Gravity is one of the four fundamental forces of our universe. Although it is the weakest of the forces, it is the one that people have the most experience with. The equations and concepts below explain gravity in a way that is consistent with classical mechanics, but the theory of general relativity is required for a complete explanation of our modern understanding of gravity.

Key Terms

Law of Universal Gravitation: Any two objects in the universe are attracted to each other by a force proportional to the masses of the two objects and inversely proportional to the square of the distance between the center of mass of each object. This law determines the force of gravity on all objects at any point in space. SI units: N

Gravitational Field: A force field that surrounds massive objects with acceleration vectors that pull smaller objects towards itself. The magnitude of the vector is equal to the acceleration of the object due to gravity at that distance from the object. SI units: m/s^2

Fields: Something that helps us keep track of forces.

Satellites: An object orbiting another object.

Kepler's Laws of Planetary Motion

Kepler came up with three laws of motion that describe the movements of the planets based on his observations of the solar system before Newton developed the law of universal gravitation. It is possible to derive Kepler's laws from the law of universal gravitation and Newton's laws of motion. Kepler's laws are:

1. Planets orbit in an ellipse with the sun at one of the foci.
2. For a given period of time, the angular displacement for a planet will always be equal. To the right is a diagram illustrating this law.
3. The square of the orbital period is proportional to the cube of half the length of the major axis of the planet's orbit.



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Satellites

In physics, anything orbiting another body is considered a satellite. For example, the Moon is considered to be Earth's satellite even though it is not referred to as a "satellite."

Satellites are able to stay in space despite being pulled down by gravity because of their horizontal velocity. Newton explains this concept by using an example: if we throw a ball horizontally, it will gradually fall to the ground. If we throw the ball much faster, it will travel for a longer time before hitting the ground because we threw it faster and because the Earth's surface curves away from the ball as it is pulled down by gravity. Hypothetically, if we throw the ball fast enough, the distance that the Earth's surface curves away from the ball will equal the distance the ball falls. Without air resistance, the ball would continue to fly around the earth forever.



The speeds necessary for satellite motion are extremely high. For example, the International Space Station has an average linear speed of about 17,200 mph (~7,700 m/s). This is why all satellites exist outside the Earth's atmosphere, where there is no air resistance to slow them down or to generate heat that would set the satellite on fire.

Important Equations

Law of Universal Gravitation: $F_g = \frac{Gm_1m_2}{r^2}$

F_g - force of gravity
 m - mass

G - gravitational constant = $6.674 \times 10^{-11} \text{ N}(\text{m/kg})^2$
 r - distance between objects

Near Earth's surface, we can approximate: $g = \frac{Gm_{\text{Earth}}}{r_{\text{Earth}}^2} = 9.8 \text{ m/s}^2$

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