

Gravitational Force and Kepler's Laws

In the previous article, we examined circular motion and mentioned that planets also exhibit circular motion. So, if planets move in circular orbits, what is the force that provides the centripetal acceleration that keeps them in orbit? In this article, we will learn the answer to this question together.

The force that provides centripetal acceleration must be an attractive force, and we call this the gravitational force. Gravitational force is the attractive force exerted by planets or celestial bodies on the objects located on them. This force explains the motion of planets around the Sun, the Moon remaining in Earth's orbit, and objects falling to the ground.

The Law of Universal Gravitation is a universal force that exists between all objects in the universe. The foundations of this concept were laid by Isaac Newton's Law of Universal Gravitation. This law states that everything with mass exerts a gravitational force. As objects become more massive, the gravitational force they exert increases. Gravitational force is inversely proportional to distance; that is, the closer two objects are, the more strongly they attract each other. The magnitude of the gravitational force exerted by a celestial body on objects depends on the mass of that celestial body and the distance between the object and the celestial body, in other words, the radius of the celestial body. As the distance between the object and the celestial body increases, gravitational force decreases; as the distance decreases, gravitational force increases. Thus, each object attracts every other object with a force that is directly proportional to their masses and inversely proportional to the square of the distance between them. This law is expressed mathematically as:

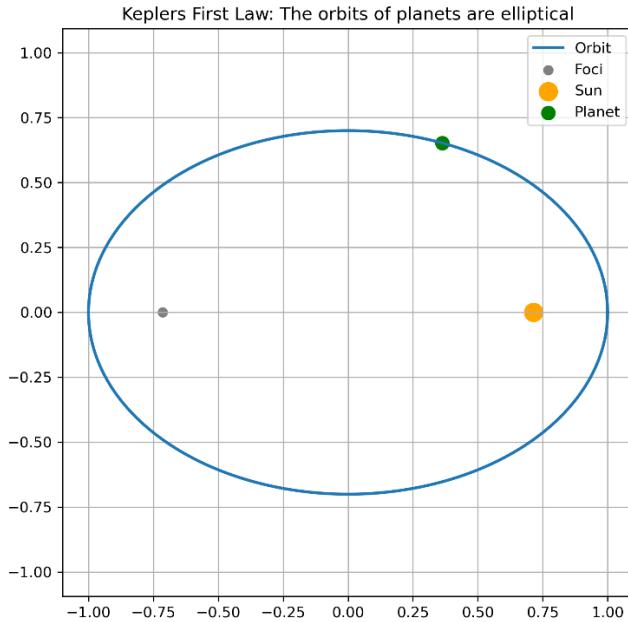
$$F = G \cdot m_1 \cdot m_2 / r^2$$

The mass of the Earth exerts a gravitational force on our mass, and this forms our weight. So, how would our weight change on a planet with a smaller mass than Earth? The answer: Our weight would be less than it is on Earth. Moreover, not only large celestial bodies such as Earth exert gravitational force on us, but we also exert gravitational force on Earth; however, because Earth is extremely massive, the force we exert does not affect it. Gravitational force acts not only on objects with mass but also on light. The greatest example of this is black holes.

The orbital motion of planets around the Sun plays a role in many phenomena—from days to seasons. This motion is explained by Johannes Kepler's three laws, known as Kepler's Laws. Before discussing Kepler's first law, we must recall the concept of an ellipse. We should all be familiar with the fact that Earth's orbit is elliptical. The most important feature of an ellipse is that it is a closed curve with two foci. A circle is a special case of an ellipse; it emerges when the two foci of the ellipse coincide. The orbits of Earth and the other planets are not perfect circles but elliptical. Kepler's first law tells us this: Every planet moves in an elliptical orbit with the Sun located at one of its foci. This law states that planets follow an elliptical path around the Sun, not a perfect circle.

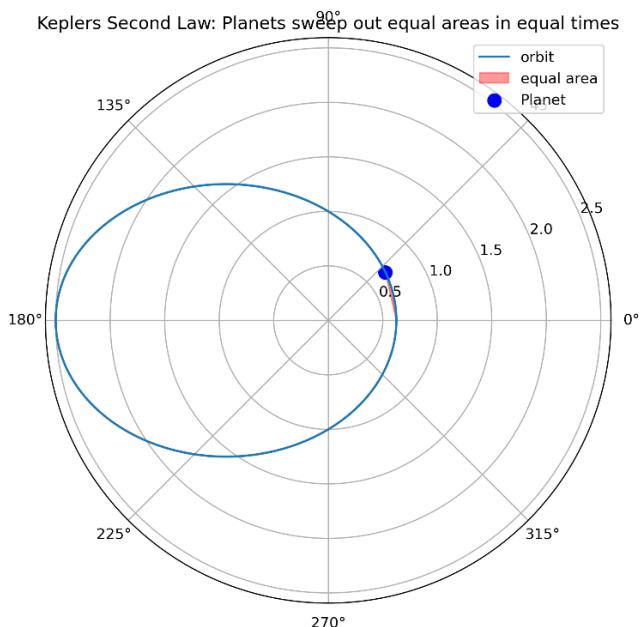
The shape of an ellipse is expressed by a number called eccentricity. As the eccentricity value approaches 0, the shape of the ellipse becomes more like a circle. It can have a value between 0 and 1; when it is 0, the orbit is a perfect circle, and as it approaches 1, the ellipse becomes more elongated.

Figure 1: Keplers First Law.



Kepler's second law states that a planet sweeps out equal areas in equal intervals of time while orbiting the Sun, even though its distance from the Sun changes. In other words, when a planet is closer to the Sun, it moves faster, and when it is farther, it moves more slowly. This is due to the variation of the Sun's gravitational force with distance. For example, Earth reaches its closest position to the Sun at the beginning of January. During this period, its orbital speed is at its maximum. At the beginning of July, it is at its farthest position from the Sun, and its orbital speed is at its minimum. Therefore, Earth's motion around the Sun is not completely constant; its speed changes throughout its orbit. As a result, summer in the Northern Hemisphere lasts about five days longer than winter. In the Southern Hemisphere, the opposite occurs; summer is shorter, and winter is longer.

Figure 2: Keplers Second Law.



Kepler's third law is known as the Law of Periods. It explains the mathematical relationship between the orbital period of planets around the Sun and their average distance from the Sun. It is expressed as follows: The square of a planet's orbital period (T^2) is directly proportional to the cube of the semi-major axis of its orbit (a^3). That is, the farther a planet is from the Sun, the longer it takes to complete an orbit. Kepler's third law explains why planets rotate at different speeds depending on their distance from the Sun. It is used not only to describe planetary motion but also to calculate the orbits of moons, artificial satellites, and other celestial bodies.

In conclusion, Kepler's third law is one of the most powerful mathematical relationships explaining the structure of the Solar System. This law is used not only to describe the motion of planets but also to calculate the orbits of moons, artificial satellites, and other celestial bodies.

Figure 3: Keplers Third Law.

