

Newton, Kepler, and Planetary Motion Lab

In 1687 Isaac Newton published *Philosophiae Naturalis Principia Mathematica*, a work of immense and profound impact. Newton's pronounced three laws of motion and a law of universal gravitation. They were a united set of principles which applied not only to the heavens but also to the earth in a uniform way. Their simplicity and extremely broad applicability forever changed astronomy.

1st Law of Motion: Law of Inertia

A body remains at rest, or moves in a straight line (at a constant velocity), unless acted upon by a net outside force.

The law of inertia did not originate with Newton, nevertheless it is integral to his system of mechanics. An object in motion will remain in motion unless something acts upon it. Because a planet is moving in an ellipse (i.e. not a straight line) this law states that there must be some "force" acting upon the planet. If there were no force, the planet would fly off in a straight line.

2nd Law of Motion: $F = ma$ (mass x acceleration)

The acceleration of an object is proportional to the force acting upon it.

The first law says that if no force is acting on an object, it will remain in motion. The second law tells how the motion will change when a force acts upon the object. Velocity is how fast an object is moving (speed or magnitude) **and** the direction it is moving. Acceleration is a change in velocity. An accelerating object can either change how fast it is moving, the direction it is moving, or both. The more force acting on an object (which is a result of the mass), the more acceleration. The more mass of an object, the less it will accelerate.

3rd Law: Law of Reciprocal Actions

For every action, there is an equal and opposite reaction.

The law can be more fully stated as, "Whenever one body exerts force upon a second body, the second body exerts an equal and opposite force upon the first body." That is, when the sun pulls on a planet with the force of gravity, the planet pulls on the sun with a force of equal magnitude. But, because the sun is so much more massive than the planet, Newton's second law says that the sun will experience much less acceleration.

Law of Universal Gravitation

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

Every object in the Universe attracts every other object with a force directed along the line of centers for the two objects that is proportional to the product of their masses and inversely proportional to the square of the separation between the two objects. While the law does not explain what gravity is, it does say how the force of gravity works. From this law and his laws of motion, Newton was able to derive all of Kepler's Laws of Planetary Motion.

Kepler's Laws of Planetary Motion – simplified

KEPLER'S FIRST LAW DESCRIBES THE SHAPE OF AN ORBIT

The orbit of a planet around the Sun (or of a satellite around a planet) is not a perfect circle. It is an ellipse—a “flattened” circle. The Sun (or the center of the planet) occupies one focus of the ellipse. A **focus** is one of the two internal points that help determine the shape of an ellipse. The distance from one focus to any point on the ellipse and then back to the second focus is always the same.

KEPLER'S SECOND LAW DESCRIBES THE WAY AN OBJECT'S SPEED VARIES ALONG ITS ORBIT

A planet's orbital speed changes, depending on how far it is from the Sun. The closer a planet is to the Sun, the stronger the Sun's gravitational pull on it, and the faster the planet moves. The farther it is from the Sun, the weaker the Sun's gravitational pull, and the slower it moves in its orbit.

KEPLER'S THIRD LAW COMPARES THE MOTION OF OBJECTS IN ORBITS OF DIFFERENT SIZES

A planet farther from the Sun not only has a longer path than a closer planet, but it also travels slower, since the Sun's gravitational pull on it is weaker. Therefore, the larger a planet's orbit, the longer the planet takes to complete it.