

Isaac Newton (1642 - 1727)

Isaac Newton was born on Christmas Day 1642 (actually, January 4, 1643 according to the Gregorian calendar) in Woolsthorpe, Lincolnshire, England. He was educated at Cambridge University and did most of his groundbreaking work in gravity and motion while he was in his twenties. He worked out his law of universal gravity and three laws of motion back home in Woolsthorpe while Cambridge was closed during an outbreak of the Black Plague. However, he set this work aside for a number of years and did not prepare it for publication until he was urged to do so by members of the Royal Society, especially Edmond Halley. The work was finally published in 1687 under the title ***Philosophiae Naturalis Principia Mathematica (The Mathematical Principles of Natural Philosophy)***. In this publication he presented compelling mathematical and physical arguments as to why planets move around the sun (and why moons move around planets) in elliptical orbits, as discovered by Kepler. In addition to his work on the mechanics of planetary motion, Newton did pioneering work in optics, demonstrating that white sunlight is composed of all of visible colors and inventing the reflecting telescope.

Law of Universal Gravitation

Every material body in the universe is attracted to every other material body in the universe by a gravitational force proportional to the product of the masses divided by the square of the separation between the centers. The force of gravitational attraction **F** between any two masses is given by:

$$\mathbf{F} = \mathbf{G}(m_1m_2)/r^2$$

Here, **m₁** is the mass of one body, **m₂** is the mass of the second body, **r** is the separation between their centers, and **G** is the gravitational constant.

Newton's Three Laws of Motion

First Law

A body continues doing what it is already doing, either remaining at rest or moving with a uniform (constant) velocity until acted upon by an external force. This is also known as the ***Law of Inertia***.

Second Law

The force acting on a body is always proportional to the mass of the body times the acceleration (change of velocity) experienced by that body.

$$\mathbf{F} = m\mathbf{a}$$

Here, ***m*** is the mass of the body and ***a*** is the acceleration experienced by that body. Remember, acceleration can be either a change in speed, or a change in direction, or both.

Third Law

For every action (or force) there is an equal and opposite reaction (a force of equal magnitude directed in the opposite direction). If you push on a wall, the wall pushes back on you with exactly the same amount of force as you apply to the wall.

THEORIES OF THE WORLD: 1543-1687

<i>HELIOCENTRIC</i>	<i>GEOCENTRIC</i>
<p><u>Copernicus</u> (1543)</p> <ol style="list-style-type: none"> 1. Natural explanation of retrograde motion. 2. Natural explanation of why Mercury and Venus stay close to the Sun. 3. Straightforward way to obtain relative size of the solar system. 4. Predictions of planetary positions no better than Ptolemy, but are <i>just as good</i> and somewhat easier to calculate 	<p><u>Objections to Copernicus</u></p> <ol style="list-style-type: none"> 1. Evidence of our senses indicates that the Earth does not move. 2. No parallax shift seen when Earth moves from one side of its orbit to the other 3. Position predictions no better than Ptolemy. 4. Heliocentric view implies that planets are "worlds", and this cannot be verified. 5. Does not fit current (Aristotle's) physical theory: <ol style="list-style-type: none"> a. Objects fall to Earth because Earth is at the center of the universe. b. Planets move because they are connected to interlocked crystalline spheres 6. What keeps the planets moving?
<p><u>Kepler</u> (1619)</p> <ol style="list-style-type: none"> 1. Use of elliptical orbits make predictions much more accurate than Ptolemy's. 2. Three laws of planetary motion agree with observation 	<p><u>Objections to Kepler</u></p> <p>Okay, the predictions are much better but:</p> <ol style="list-style-type: none"> 1. Still no sensual evidence that the Earth is moving. 2. Still no parallax shift 3. Still no evidence that the planets are <i>worlds</i> 4. Still contradicts known physics
<p><u>Galileo</u> (1632)</p> <p>Observations with the telescope demonstrate:</p> <ol style="list-style-type: none"> 1. The Moon is a <i>world</i> 2. Jupiter is a sphere and has satellites (at least some celestial objects are not moving around the Earth, a.k.a. <i>the center of the universe</i>) 3. Phases of Venus show that at least Venus must be orbiting the Sun (only way to get a <i>full</i> Venus). 4. The existence of stars not visible to the naked eye indicates the universe is very large, as required to explain lack of 	<p><u>Objections to Galileo</u></p> <ol style="list-style-type: none"> 1. Observations are not straight-forward – spherical and chromatic aberrations in telescope distort images, leaving them open to interpretation. <p>If we accept the observations, the planets (at least the Moon) are worlds, Jupiter is a miniature solar system, at least Venus is orbiting the Sun, but:</p> <ol style="list-style-type: none"> 2. Still no evidence that the Earth is moving

parallax.	3. Still contradicts “ known ” physics
<p><u>Newton</u> (1687)</p> <ol style="list-style-type: none"> 1. Proposed <i>universal</i> gravity, a property of all matter (predicts that objects will be attracted to all large masses like the Sun, Moon and planets, not just Earth). 2. Showed that an inverse square law for gravity will automatically produce elliptical orbits. 3. Gravity plus three laws of motion replaces physics of Aristotle (i.e., explained why planets keep moving) 	<p><u>Objections to Newton</u></p> <p>Okay, everything seems to work, but:</p> <ol style="list-style-type: none"> 1. Physics is very strange - implies gravity is a mysterious “force field” acting across a void. 2. Still no experimental evidence that the Earth is moving.

The Scientific Revolution

The period from **1543** (the publication of Copernicus' *Revolutions**) to **1687** (the publication of Newton's *Principia****) is usually referred to as the *Scientific Revolution*. During this period the belief in a static Earth at the center of the universe was replaced by a heliocentric solar system in which earth is simply one of six planets orbiting the sun. Newton's theory which explained in precise mathematical language how this all worked encouraged scholars of the day to believe that every aspect of the natural world could be explained by following the scientific method based on theory and experiment rather than by deductive logic based on authority.

What was known in 1700

- The Sun is the center of the solar system.
- All planets orbit the Sun
- Earth is one of the planets
 - The **year** is defined as one complete revolution of the Earth around the Sun
 - The **day** is defined as one complete rotation of the Earth on its axis
 - The **month** is defined as one complete revolution of the Moon around the Earth (same as in the geocentric system)
 - **Precession** is defined as a slow “wobble” as the Earth rotates
- The diameters of planetary orbits (e.g., Earth is 93,000,000 miles from the Sun)
- The diameters of the Sun, moon and planets (e.g., Jupiter is 11 times and the Sun is 109 times the diameter of the Earth)
- The stars are very far away (otherwise they would exhibit parallax)
- The set of physical laws formulated by Newton (universal gravity and the three laws of motion) explained *quantitatively* why the solar system works the way it does.

* *On the Revolutions of the Heavenly Orbs*

*** *The Mathematical Principles of Natural Philosophy*