"FROM NEWTON TO EINSTEIN"
CHRONOLOGY

306BC Ptolemy I: Establishes, in Alexandria Egypt, the school called "*Museum*".

300BC Euclid of Alexandria: Publishes the *Elements,* in which he introduces five postulates of geometry, including the famous
Fifth postulate : "If a straight line falling on two straight lines make the interior angles on the same side less than two right angles, the two straight lines, if produced indefinitely, will meet on that side on which the angles are less than two right angles."

1543 Nicholas Copernicus (1473-1543): *De Revolutionibus.* He argues that the sun is the center of the solar system.

***1609 Kepler** (1571-1630): *Astronomia Nova.* Introduces "Kepler's Laws" of planetary motion, which he derives from empirical observations of the planets:
First law: Planets move in elliptical orbits about the sun with the sun fixed at one focus of the ellipse.
Second law: The velocity of a planet varies in such a way that the line joining the planet to the sun sweeps out equal areas in equal times.
Third law: The square of the time required by a planet for one revolution around the sun is proportional to the cube of its mean distance from the sun, with the same constant of proportionality for all planets.

Galileo (1564-1642): Invents telescope.

1637 Descartes (1596-1650): *Discours de la methode* .

1684 Leibniz(1645-1716): Writes his first paper on calculus.

*1687 **Sir Isaac Newton** (1642-1727): *Philosophical Naturalis Principia Mathematica* or *"Principia"*. Derives Kepler's laws from the two basic principles:

Newton's second law: Force = Mass x Acceleration

Newton's law of gravitation: $F = GM_pM_s/r^2$

The measure of mass that appears in Newton's second law is called the *inertial mass,* while M_p and M_s are the *gravitational mass* of a body. The fact that the measure of inertial mass of a body is equal to its gravitational mass is a remarkable coincidence implicit in Newton's laws, and the principle that these two measures of mass are the same is called the *Equivalence principle.* This coincidence is explained 230 years later in Einstein's theory of general relativity, 1916.

1854 **Georg Friedrich Bernard Riemann** (1826-1866): *Uber die Hypothesen, welche der Geometrie zu Grunde liegen,* translated: *"On the assumptions that lie at the foundations of geometry".* In this fundamental paper in geometry, Riemann defines a way to measure the intrinsic curvature in three and four dimensional space and space-time by defining the *Riemann curvature tensor* R . In 1916, Einstein derives the Einstein equation $G=8\pi T$, which equates the curvature G (which is defined directly in terms of R) with T, the stress energy tensor, which measures "the amount of mass present".

1827 **Carl Friedrich Gauss** (1777-1855): *Disquisitiones generales circa superficies curvas.* First understood curvature as an intrinsic property of two dimensional surfaces.

1832 **Nikolai Ivanovich Lobachevski** (1793-1856): Construction of the two-dimensional space of constant negative curvature that satisfied all of Euclid's axioms except the parallel postulate (thus verifying that the fifth axiom of Euclid was not a consequence of the remaining four).

1832 **Janos Bolyai:** *Absolute science of space.*

*1845 **Urbain Jean Joseph LeVerrier** (1811-1877): Reports that the observed precession in the orbit of the planet Mercury is approximately 43 seconds of an arc per century off from the precession predicted to occur by Newton's theory due to the influence of the other planets in the solar system.

1846 **John Couch Adams** (1819-1892) and **Urbain Jean Joseph LeVerrier:** Predict the existence and position of the planet Neptune. This is one of the great triumphs of Newton's theory because the existence of the planet Neptune was deduced from irregularities in the orbit of Uranus as compared with its predicted orbit according to Newton's laws.

1871 **Felix Klein** (1849-1925): Gives the first Analytical construction of the Gauss-Bolyai-Lobachevski geometry.

1873 **James Clerk Maxwell:** *Electricity and Magnetism* establishing *"Maxwell's Equations"*, which describe the propagation of electro-magnetic waves (light). The failure of the equations to be invariant under a change of inertial observer was resolved by Einstein's special theory of relativity, which was put forward in 1905.

1889 **Roland von Eotvos:** Showed experimentally that the inertial mass agreed with the gravitational mass to within a factor of one in 10^{-9} (in their ratio).

1893 **Ernst Mach** (1836-1916): *Die Mechanik in ihrer Entwicklung*. In this he launches the first constructive attack on the Newtonian principle of absolute space.

1905 **Albert Einstein** (1879-1955): Puts forward the special theory of relativity (among other things).

1916 **Albert Einstein:** *Die Grundlagen der Allgemeinen Relativitatstheorie,* translated *"The Foundation of the General Theory of Relativity".* In this paper he gave a derivation of the fundamental law which governs gravitating bodies, and now goes by the name of the Einstein equation, $G = 8\pi T$. Here G stands for the Einstein curvature tensor (constructed from the Riemann curvature tensor) and T is the stress energy tensor, a measure of the "matter present". This replaced Newtons theory of gravity by taking the fundamental point of view that gravitational effects are a consequence of space-time curvature. As a mathematical consequence of this law, Einstein showed that the precession in the perihelion of the orbit of the planet Mercury is predicted by his theory to be exactly 43 seconds of an arc per century different from the perihelion shift predicted by Newton's theory, thus explaining the discrepancy observed by LeVerrier in 1859, giving the first experimental evidence that Newton's theory was only an approximation to Einstein's more general theory. Einstein himself considered this to be the greatest achievement of his career.

& Craig Tracy

1990 **Blake Temple** (1951-): Publishes *From Newton to Einstein* in the American Mathematical Monthly, thus presenting Einstein's derivation of the perihelion shift in Mercury's orbit at a level accessible to advanced undergraduate mathematics majors.

Figure 1.3 Founders of the Special Theory of Relativity, at the First Solvay Conference in 1911.