Between Newton and Einstein, James Clerk Maxwell Stands Alone

1687, Sir Isaac Newton

In his *Principia Mathematica*, Newton gave the foundations of classical mechanics and gravity:

1. An object which is not acted on by an external force is either at rest or moving in a straight line at a constant velocity
2. The force on an object is equal to its mass times its acceleration
3. To every force, there is an equal and opposite reaction
4. The gravitational force of attraction between two bodies of masses m and M separated by distance d is given by $f = G{\cdot}mM/d^2$ where G is a universal constant.

Newton showed that these laws explained Kepler's Laws of planetary motion where the planet orbits are elliptical rather than circular.

1865, James Clerk Maxwell

In "*A Dynamical Theory of the Electromagnetic Field*", Maxwell produced the first complete set of equations governing electricity and magnetism, expressed in terms of fields. In his electromagnetic wave theory he calculated the propagation speed in air using only the available data on its electric and magnetic properties. Comparing the velocity of the waves with the velocity of light, as previously measured by Fizeau, he came to this remarkable conclusion:

> *This velocity is so nearly that of light that it seems we have strong reason to conclude that light itself (including radiant heat and other radiations if any) is an electromagnetic disturbance in the form of waves.*

Maxwell's electromagnetic theory, and the resulting equations, were consequently the greatest advance in scientific knowledge since Newton's Principia.

1905-16, Albert Einstein

According the Newton, space and time are completely separate so all observers agree about time and distance irrespective of where they are or how they are moving. Thus an observer moving towards a source of light will see the speed of light increase. Einstein fundamentally disagreed with this on the grounds that the measured speed of light in free space is always the same. His revolutionary new theory on Special Relativity, proposed that the scales of distance and time should vary with the velocity of the observer. He used Maxwell's equations as justification by showing that Special Relativity made the speed of electromagnetic waves including light invariable, as observed. The consequences were that no material body may exceed the speed of light, and that time passes more slowly for a moving body than for one remaining at rest.

Einstein later published his theory of General Relativity which was formulated as a *field theory*. This proposed that massive bodies would distort the geometry of the surrounding space and time, to produce gravitational attraction. This gives the same result as Newton's law, but with additional consequences for very massive bodies:

1. Light passing close to the Sun will be bent by the effect of its mass on the curvature of space-time
2. The perihelion of Mercury (the point at which the planet is closest to the Sun) will precess from one orbit to the next
3. Clocks will run more slowly in a gravitational field.

All of these predictions have since been verified. Maxwell had originated the idea representing physical phenomena with a field theory governed by mathematical equations, and in tribute to this Einstein later said:

> *This change in the conception of reality is the most profound and the most fruitful that physics has experienced since the time of Newton*.

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