CORMAC O'RAIFEARTAIGH EXPLAINS THE BACKGROUND TO EINSTEIN'S SPECIAL THEORY OF RELATIVELY, WHICH IS 100 YEARS OLD THIS YEAR, AND ITS ENORMOUS IMPACT ON SCIENCE.

Relatively speaking

In 1905,a number of papers by a young German physicist named Albert Einstein were published in the scientific journal *Annalen der Physik*. Two of these papers represented radical departures from traditional scientific ideas and laid the foundations for the twin revolutions of 20th century physics (Quantum Theory and the Theory of Relativity). While Einstein received the Nobel Prize for his contribution to quantum theory, it was his work on relativity that was to establish him as the most important scientist of the 20th century.

GALILEAN RELATIVITY

The word relativity is associated with the study of relative motion. The great Italian scientist, Galileo Galilei, was the first to articulate the so-called Principle of Relativity. Noticing that an object, released from a height inside the cabin of a ship at rest, experienced precisely the same drop as it did when the ship was moving steadily, Galileo deduced that the basic laws of mechanics were indifferent to whether a ship (or other frame of reference) was at rest or moving at constant velocity (uniform motion). All measurements performed in reference frames in relative uniform motion were equivalent, and there was no absolute rest frame of reference for measurement. As a consequence, experiments performed entirely inside the cabin of a smoothly moving ship would not reveal the motion of the ship. Galileo's principle of relativity was a welcome development for the Copernican view of the world, as it went some way towards explaining how people could go about their daily business independent of the Earth's motion around the Sun (although strictly speaking, the motion of the Earth is not uniform).

LIGHT AND THE ETHER

By the end of the 19th century, great strides forward had been made in other areas of science such as electricity, magnetism and optics. In particular, Maxwell's theory of electromagnetism suggested that electricity and magnetism were manifestations of a single phenomenon and that light itself was an electromagnetic wave travelling at a speed of 300,000 kilometres per second (c). Since all known waves required a medium in order to travel, it was assumed that light must travel through a medium known as the ether. It seemed there did exist an absolute frame of reference for measurement after all - c was presumably the speed of light relative to the ether. Surely measurements of the speed of light conducted aboard a ship moving through the ether would yield a different answer for c, revealing the motion of the ship relative to the ether? Following this line of reasoning, a series of ingenious optical experiments was undertaken by Michelson in order to measure the motion of the Earth itself relative to the ether. However, a null result was obtained in every case.

ENTER EINSTEIN

In Bern, Switzerland, a young patent clerk was greatly puzzled by the conflict between Maxwell's theory of electromagnetism and Galileo's principle of relativity. The young Einstein was particularly conscious of the well-known observation that the induction of an electric current in a loop of wire by a magnet, depends only on the relative motion of magnet and loop - an experimental result that was curiously reminiscent of relativity in mechanics. Taken together with the unsuccessful attempts to discover any motion of the Earth relative to the ether, Einstein boldly decided that: 'the phenomena of electrodynamics, as well as of mechanics, possess no properties corresponding to the idea of absolute rest.'

SPECIAL THEORY

Einstein postulated that Galileo's relativity principle must be replaced by a new, universal relativity principle that included electromagnetic as well as mechanical measurements

"...the laws of all physics are the same for observers in uniform relative motion" From electromagnetism, he added a second postulate "...the velocity of light in empty space has a constant value c, independent of its source, for all observers in uniform relative motion"

The above two postulates form the basis of what became known as the Special Theory of Relativity. In essence, the young Einstein suggested that relativity applied to electromagnetism - and if this could not be predicted by traditional mechanics (Galileo's principle), then mechanics itself must be revised!

TODAY

Nowadays,modern particle accelerators ("atom-smashers") provide a vast databank of experimental evidence supporting the Special Theory. Particles accelerated to unimaginably large energies are observed to conform to the speed limit set by the speed of light. Measurements of the speed of light emitted from certain particles travelling at high speed show it to be independent of their motion. The dramatic relativistic effect of mass increase is routinely observed,and evidence of fast-moving electrons with the apparent mass of Hydrogen atoms has been recorded. Exotic particles and anti-particles with extremely short lifespans are created out of pure energy ($E = mc^2$) and exhibit the relativistic effects of time dilation and length contraction.Indeed, every particle detector in the world is designed to relativistic specifications.

Today, few theoreticians concern themselves with the postulates of Special Relativity. Instead,a great many of them ponder the related,but much more complex, General Theory of Relativity. By 1915,Einstein had extended his theory of relativity to describe the motion of bodies moving with non-uniform (accelerated) relative motion. This theory resulted in a reappraisal of gravity as a geometric curvature of space-time. While the Special Theory has played a crucial role in our understanding of the nucleus and its particles,the General Theory has shaped our understanding of the origin and evolution of the Universe - from Big Bang theory to the theory of black holes.However, the General Theory is incomplete, and work on the theory continues to this day.

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Special Relativity predicts that an object travelling at a speed close to the speed of light will experience - as measured by a stationary observer - a slowing down of time, a contraction of distance, and an increase in mass.

That is

"Measurements of time, distance and mass are NOT ABSOLUTE,but depend on the relative motion of the observer and the object being measured"

Application

The dependence of mass on speed led to a relation between the energy (E) of a body and its mass (m) :

$E = mc^2$

where c is a constant.This relation implies that mass is a form of energy, a discovery of enormous scientific and technological importance.

IMPACT

The Special Theory was vigorously debated for a few years. Since many of its predictions concerned the motion of bodies moving at tremendously high speed, much supporting evidence was not to emerge until the advent of particle accelerators (some evidence did appear in 1909 and 1919).However, scientists became convinced by the internal logic of the theory and by the important insights it offered into other areas of science, notably radioactivity, nuclear physics,and the study of elementary particles.

Although it had been known since 1896 that certain radioactive elements continuously gave off energy, the source of this energy was a great mystery. Einstein's mass-energy equivalence $E= mc^2$ offered a startling explanation:minute changes in the mass of the atoms of the element were being released as energy. Dramatic support for this view of radioactivity was offered by the Irish scientist, Ernest Walton,in 1932;on disintegrating the atomic nucleus by artificial means,he showed that the energy released,correlated with that predicted by special relativity. It was realised that radioactivity induced by the splitting of the nucleus,could be an important source of energy (nuclear fission),a realisation that quickly led to the development of nuclear power, and, unfortunately, nuclear weapons.

$E= mc^2$ also offered an explanation for one of the greatest mysteries of all - the energy source of the Sun.It was realised that extremely high temperatures and pressures in the Sun cause a continuous crushing of hydrogen nuclei into helium, with a net loss of mass that is released as energy (nuclear fusion).One of the greatest challenges of modern science is the re-creation of nuclear fusion in the laboratory, a process that could deliver an almost limitless supply of clean energy.

Special relativity played a key role in the study of elementary particles.A typical example was the case of muon decay:elementary particles of extremely short lifespan that are produced by the collision of cosmic rays with gas in the upper atmosphere, it was a great mystery how muons survived long enough to be detected in abundance down at sea-level.Relativistic calculations showed that muons (travelling at high speed relative to Earth) experienced a dilation of time sufficient to survive the trip.

IMPLICATIONS

A startling implication of the new theory was that there was no absolute reference frame for the measurement of time, as was assumed in traditional mechanics. Two observers in relative motion could measure elapsed time differently, and not even agree that two events were simultaneous.Observers moving at high speed relative to one another would see time running slowly in each other's reference frame, a phenomenon known as time dilation.They would also see distances in each other's reference frame contracted, a phenomenon known as length contraction.(A passenger walking on a train travelling through a station at tremendously high speed would see the station-master as squashed and walking unnaturally slowly, while the station-master would see the passenger as squashed and slowed).

The second postulate implied an upper limit for the speed of any body. This led to the prediction that the mass of a body was not a constant,but a property that increased with velocity, increasing the body's resistance to motion.A natural speed limit was set by the speed of light,since light comprised 'particles' of zero mass.

From the relativistic dependence of mass on velocity, Einstein,later in 1905,deduced a direct relation between mass and energy - the famous equation $E = mc^2$. Since c is a constant,the relation implied that mass was simply a form of energy, a tremendously important result that went far beyond the physics of relative motion.