THE ORIGIN, NATURE AND FUTURE OF THE UNIVERSE

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For many people, the most interesting area in physics is cosmology - the study of the universe as a whole, including theories of its origin, evolution, large-scale structure, and future. It would take a profound lack of imagination not to be engaged by these topics, and, consequently, most people are familiar with the general idea that the universe is thought to have began in a titanic explosion called The Big Bang. The Big Bang Theory is currently in the ascendent in cosmology to describe, not only the origin, but many other features of the universe.

The earliest cosmological theories, dating back to 4,000 years BC, held that the earth is at the centre of the universe and that the other heavenly bodies rotate around it. This position generally held until 1543 when Copernicus (1473-1543) proposed that the planets revolve in circular orbits around the sun, which sits at the centre of the universe. Kepler (1571-1630) agreed with this view, but discovered that the planets move in elliptical orbits and at different speeds according to 3 laws (Kepler's Laws). Galileo (1564-1642) first observed the planets with a telescope and championed the Copernican model. Sir Isaac Newton (1642-1727) showed that Kepler's Laws could be derived from his own general laws of motion and gravitation - the laws of physics held sway in the heavens as well as on earth.

The light-year is a unit of astronomical distance. Light travels at a speed of 186,000 miles per second, and a light-year is the distance it travels in 1 year. Our solar system is part of the Milky Way galaxy, which is estimated to be roughly 100,000 light-years in diameter. Our sun is not stationary in the galaxy - it takes about 250 million years to travel once around the centre of the galaxy. The Milky Way galaxy contains about 200,000 million stars.

There are about 100 billion other galaxies in the universe beyond our Milky Way. The nearest spiral galaxy to us is the Andromeda galaxy - 2.2 million light years away. In 1912, an American astronomer Vesto Slipher reported that the wavelength of light reaching us from distant galaxies is stretched out towards longer (red) wavelengths. This is called the red shift, and it showed that most galaxies were receding from the Milky Way at a speed of several hundred kilometres per second. Another American astronomer, Edwin Hubble found that the more remote the galaxy, the greater is its recession velocity. He formulated a law (Hubble's Law, 1929) which states that the recession velocity of a galaxy is proportional to its distance from us. The ratio of the recession velocity of a galaxy to its distance is called the Hubble constant, one of the most important numbers in cosmology. Efforts are ongoing to get more and more reliable estimates of this constant.

Looking out into space from earth we can see all other galaxies, in all directions, moving away from us. Does this mean that our galaxy is at the centre of the universe? No. The true situation is more accurately visualised by thinking of a balloon with evenly spaced dots painted on it to represent the galaxies. As the balloon is inflated, an observer on any spot will see all the other spots moving away, just as observers on earth see all galaxies receding from the Milky Way. The universe is expanding like a balloon.

Albert Einstein in 1917 put forward a model of the universe based on his new general theory of relativity. According to his model, the universe could not be static, but must be either contracting or expanding. The expansion of the universe had not yet been observed. Einstein refused to believe the conclusions inherent in his own equations, and he introduced a 'cosmological constant' in them to produce a static universe. He thus missed the chance to predict the expansion of the universe. He later declared this to be ‘the greatest mistake of my life’.

Imagine that the behaviour of the universe from the very beginning was recorded on film. The camera at present observes the universe expanding in all directions. But if you run the film backwards, the universe will be seen to get smaller and smaller, until eventually it is reduced to an infinitely small and infinitely dense point. This is thought to be the origin of the universe, and it is proposed that this point erupted in a titanic explosion about 15 billion years ago. The extremely high density in the primeval point would cause the universe to expand rapidly. This was originally proposed by the Russian-American physicist George Gamow in 1948 and is called the Big Bang Theory of the origin of the universe.

It is now believed (proposed by Alan Guth) that right at the very start the universe expanded at an exponential rate (inflation). During this phase which lasted a split-second the size of the universe grew from 10^{20} times smaller than a proton to about the size of a grapefruit. Inflation then stopped and the universe continued to expand at a steady rate into the universe we have today.

Gamow proposed that the various elements observed today in the universe were formed within the first minutes of the big bang when the extremely high temperature and density fused subatomic particles into the chemical elements. It is now believed that hydrogen and helium were the main products of the big bang, with the heavier elements formed later in the stars. As the universe expanded, the hydrogen and helium cooled and condensed into stars and galaxies. This theory explains the basis for the expanding universe and for Hubble's Law.

The electromagnetic radiation energy released in the big bang was initially at a very high temperature, but, as the universe expanded, it cooled down. This radiation should now have a temperature of about 3 degrees above absolute zero. This background relic microwave radiation was discovered in 1965 and provides important evidence in support of the big bang theory. In 1992 tiny ripples were found in this otherwise smooth background radiation. The ripples indicate the early existence of clusters of matter, from which the first galaxies formed.

Will the universe continue to expand forever? This depends on the average density of matter in the universe. If the density is below a certain critical value, the gravitational attraction between the galaxies will not be great enough to eventually reverse the expansion, which will go on forever. If the density exceeds the critical value (estimated at five by ten to the power of minus 30 grams per cubic centimetre) the expansion will eventually be halted and contraction will set in. This would end in the gravitational collapse of the whole universe. If that happened, perhaps the universe would explode again, having reached an infinitely small dense point, later to collapse again, and so-on forever.

Astronomers do not yet know accurately how much mass is in the universe. Ninety per cent, and more, of the mass in the universe - the so called ‘dark matter’ - can only be inferred to be present, since it is undetectable directly by current measuring apparatus. Until this dark matter has been accurately measured and characterised, the question of whether the universe will continue to expand forever or end up in ‘the big crunch’ will remain unanswered.

(This article first appeared in The Irish Times, May 27, 1996.)