Profound truths

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Niels Bohr, the famous theoretical physicist, who was one of the pioneers of quantum theory that revolutionized physics almost hundred years ago, is reported to have said that a profound truth is one whose opposite also is true. I shall discuss a few profound truths that satisfy this criterion.

Is light made of particles or waves?

In this famous controversy, Newton was an advocate of the corpuscular theory of light, while Fresnel, Young and Huygens developed the wave theory of light which was in good agreement with the observed phenomena such as interference and diffraction of light. But the great merit of Newton was that he sensed the inadequacy of a pure corpuscular theory and so endowed the corpuscles with a bit of wave-like nature, which he called 'fits'. Maxwell discovered that light is an electromagnetic wave and thus solved the problem of what kind of wave light is. Finally in quantum mechanics, light is described both as a wave and a particle, the photon. In fact the same turns out to be true of all elementary particles like the electron; the electron is both a particle and a wave in quantum mechanics.

Is gravitation a force or is it a property of space?

Aristotle is supposed to have taught that while smoke goes up to the sky, a stone drops down to the ground because this is the nature of the 'up' and 'down'. Galileo and Newton attributed the motion of bodies to gravitational force. Galileo discovered the correct way to describe motion and Newton completed the picture by enunciating his laws of motion and the law of gravitational force. So the stone falls down due to the gravitational force of the Earth. But Einstein replaced Newton's gravitational force by the property of space (actually space–time) around the Earth. In Einstein's theory, the stone just follows the path allowed by the curvature of space caused by the Earth.

George Bernard Shaw, who introduced Einstein to a London audience when the latter made his first visit to the city after he became famous, is reported to have said: 'From the time of Aristotle everybody knew the stone drops down while smoke goes up, because that is in the nature of things and in the nature of space. A famous English man, Newton, told us that is all wrong. Bodies move because of gravitational force. Now I am introducing to you a German Professor who has recently proved that Newton is wrong and Aristotle was correct.'

Of course, there is a bit of literary licence in what Bernard Shaw said, but one cannot deny that there is an element of truth in what he said. Einstein restored gravity to a property of space (or rather space–time) which is nearer to the Aristotlean view.

Ptolemy or Copernicus: who is right?

For more than a millennium the geocentric model of the Universe prevailed and Ptolemy and his successors succeeded in erecting a fairly accurate model of the motion of the planets using a complicated system of circles and epicycles. Copernicus replaced it by the solar model in which all the planets, including the Earth go around the Sun. This is called the Copernican revolution, since the dethroning of the Earth as the centre of the Universe had profound consequences in human thought going much beyond astronomy. Astronomy itself progressed greatly and the story of Galileo, Tycho Brahe, Kepler and Newton is well-known. Physics and all of science got a big boost after Newton showed that objects in the Heavens as well as on the Earth are governed by the same laws of nature.

So it is an accepted truth that planets go around the Sun rather than the Earth. But what is the big difference? Both are in fact correct (as was first pointed out by Fred Hoyle). One can do astronomy as well as physics in both frames of reference – in one frame of reference the Sun is at rest and in the other, the Earth is at rest. One can go from one frame of reference to the other by a transformation of coordinates. In fact in Einstein's general relativity all frames of reference are equivalent.

However, we must point out that although both Ptolemy and Copernicus are right, the Ptolemaic system led to a deadend as far as science is concerned. The Copernican view led to real progress in astronomy and physics, as indicated above. Often, one version of a profound truth may be more fruitful for the progress of science, at least for a while.

S-Matrix theory versus quantum field theory

The inward-bound path of discovery unravelling the mysteries of matter and the forces holding it together – at deeper and ever deeper levels – culminated after a hundred years in the following picture of structure repeating inside structure:

$$\text{Atoms} \rightarrow \text{Nuclei} \rightarrow \text{Nucleons} \rightarrow \text{Quarks} \rightarrow ?$$

The distance scale travelled thus far is from 10^{-8} cm (size of the atom) to less than 10^{-17} cm. Quarks which are the constituents of the nucleons (protons and neutrons) are seen to be point-like down to the scale of 10^{-17} cm probed so far. Are there further structures below that scale? Only future can tell.

But at our present level of knowledge, quarks and electrons are the fundamental particles out of which all known forms of matter are composed and their dynamics is governed by Quantum Field Theory (QFT).

In this inward-bound journey, the question: 'are some particles more fundamental than others?', was faced and answered. The decade 1956–1965 was an important epoch in this inward-bound journey. Actually, it was the golden age of hadrons (strongly interacting particles like the nucleons). Hundreds of these particles were discovered and under the influence of this deluge, QFT was declared dead and an alternate philosophy called S-matrix theory was proposed, its chief proponent being G. F. Chew. In this theory all the hundreds of hadrons were regarded as equally elementary and this was called the principle of nuclear democracy. Ultimately this approach turned out to be a dead end.

A different line of attack spearheaded by M. Gell-Mann proved more successful. We have to omit many interesting technical points here. Starting with quarks as the elementary constituents of hadrons, this finally led to the QFT of all hadrons.

Although Gell-Mann and Zweig independently proposed the idea of quarks in 1964, it took many years before quarks emerged as a physical reality. Gell-Mann himself was tentative and said that quarks are only mathematical. The chief reason for the reluctance to accept quarks as constituents of hadrons was the prevalent S-matrix philosophy at that time. The idea of quarks as being more elementary or more primary than the other hadrons was repugnant to the whole scheme of nuclear democracy. In fact, in a public lecture at the Tata Institute of Fundamental Research, Mumbai in the late 1960s, Chew claimed that relativity theory and quantum mechanics implied the impossibility of anything more fundamental than the hadrons. Nevertheless, quarks have been vindicated.

However, one must not conclude that the S-matrix approach was a complete failure. Although it was a failure as a theory of hadrons, it is this approach that gave rise to String Theory, which may turn out to be the correct theory of much more than hadrons! Most importantly, this theory in which all elementary particles occur as mere vibrations of a string, promises to solve the so far intractable problem of quantum gravity too. Further, in current research in QFT, there are already signs of S-matrix concepts creeping in.

For more on the tortuous history of quarks and the many twists and turns in the historical panorama of high-energy physics, one may read Rajasekaran[1,2].

Big Bang versus Steady-State Universe

Was the Universe born at some time in the past and is it destined to die at some time in the future? Or is the Universe forever? Surely this is a profound question.

It is now believed by cosmologists that the Universe started about 13 billion years ago as a tiny fireball and expanded to its present size, and is still expanding. This is the big bang model of the Universe originally due to Lemaitre and George Gamow. There exists the rival model of the steady-state Universe developed by Bondi, Gold, Hoyle and Narlikar, which provided an interesting alternative. However, in the past decades observational evidence, especially the discovery of cosmic microwave radiation which is the relic radiation left over from the initial fireball and the detailed precision data on the radiation matching what is expected from the Big Bang Universe, seems to have more or less killed the steady-state model.

But, is the steady-state Universe really dead? No. Although the Universe does evolve in time, it may be cyclic, expansion following contraction and the whole cycle repeating forever. Already there are attempts by cosmologists to answer the question: what existed before the Big Bang? All this might lead to a bigger picture in which the Big Bang explosion may be only one of the episodes and the Universe on the whole might be forever! So the question cannot be decided that easily. The jury is still out.

Evolution versus intelligent design?

Finally we come to the most profound of all questions. Is science complete, or is there something beyond, that is hidden from us?

Scientists have traced the history of the Universe for 13 billion years – from the Big Bang, to the formation of stars and galaxies, to the formation of planets – evolution of life on the Earth from primitive forms to the human being with a wonderful mind that is now asking what is the meaning of all this. The general scientific view is that everything evolved by itself by the inherent 'laws of nature'. The specific path that evolution of life itself took on this insignificant corner of the Universe has a lot to do with randomness and chance. Randomness and the survival of the fittest have resulted in what we see and experience.

Science has also probed the inner workings of matter and the forces that hold them together, down to a size 17 orders of magnitude smaller than a centimetre. No one has any clue about the meaning of all the beauty of the structures and concepts that human intellect has revealed in this inward-bound quest.

The amazing success of science has led to the dominant view among the scientists: 'Do not look for any meaning hidden behind all that science has revealed.'

There is however the opposite view: 'There are more things in Heaven and Earth, Horatio, Than are dreamt of in your philosophy' – Shakespeare in *Hamlet*, Act I, Scene V.

Great thinkers with perceptive minds have realized this. They have been inspired by something beyond science, which they have grasped intuitively. Even scientists are uneasy by the emptiness of a world view that does not go beyond science. Some scientists articulate it, some do not.

This essay started with Niels Bohr. He enunciated the concept of complementarity while wrestling with the conundrums and contradictions of early quantum theory. Bohr advocated that the contrary views must be regarded as complementary with each other and both are required for a complete perception of physical reality. Maybe the same applies to the question under discussion. A fuller picture of the Universe may require going beyond science.

1. Rajasekaran, G., www.arXiv.org:physics/0602131.
2. Rajasekaran, G., In *India in the World of Physics: Then and Now* (ed. Mitra, A. N.), Pearson Longman, Delhi, pp. 361–392.

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