An Infinity of Questions

(Outlook Magazine, Anniversary Issue, October 29, 2016)

In May, 1543, as the Polish polymath Nicolaus Copernicus lay on his deathbed, he was presented with the printed version of his magnum opus, "De Revolutionibus Orbium Coelestium". With this work, Copernicus managed to not just overturn centuries' old dogma regarding the structure of the cosmos, but also relegated human beings from the centre of the Universe to an insignificant corner. The beginning of what is called the Scientific Revolution can also be dated to the publication of this important work which proposed a heliocentric instead of a geocentric world.

The Scientific Revolution is when we take science as we now know it to begin. Bacon, Gilbert, Galileo, Harvey, Boyle, Hooke and Newton were amongst the pioneers of this new approach to understanding nature- an approach which placed experimentation and mathematical formulation at its heart while also adopting a mechanistic view of nature. Institutions like the Royal Society and the French Academy of Sciences also played an important role especially during the Enlightenment which followed this period.

The paradigm shift in the study of nature ultimately led to the development of more efficient machines and instruments and the Industrial Revolution. Better instruments led to new discoveries which helped resolve many issues in science. At the dawn of the 20th century, science had assumed a hegemonic role hitherto the privilege of religion in understanding and ordering the cosmos- Darwin had a solution for our origins, Maxwell had solved the mystery of light with his electromagnetic theory, Dalton's atomic theory had proved successful in understanding matter at the smallest scales and Koch and Pasteur had made significant advances in our understanding of the causes and prevention of disease.

In 1900, Lord Kelvin is reported to have said that there is nothing new left to be discovered in physics and all that remains is more and more precise measurement. This hubristic confidence of the scientists was obviously misplaced. As more and more experimental and observational evidence came along, it was clear that Nature had many more mysteries in its fold which needed to be solved. Our understanding of the very large, namely the cosmos was clearly incomplete. On the other hand, the very small, that is the atomic domain, also posed a challenge to understanding within the framework of existing theories. Similarly, though much was known about the human body, medicine was still at a point where people had a higher chance of dying if they went to a doctor than otherwise. Of course, an understanding of life at the most fundamental level was completely missing at this stage. Finally, even though agricultural production had increased in the last few centuries because of technology, it was entering a plateau with stagnant productivity leading to a fear of a Malthusian catastrophe.

Start with the very large. Although, the observations of Brahe and Kepler, together with the theoretical framework provided by Newtonian physics, seemed to explain the motions of heavenly objects, new observations of the cosmos needed to be explained. In particular, astronomers found a huge number of galaxies, apart from our own Milky Way, in the universe. Some of these galaxies exhibited peculiar properties which needed explanation. As it turned out, in the second decade of the 20th century, Albert Einstein developed what has been called the most beautiful theory in physics- the general theory of relativity which provided an alternative view of gravity. Einstein's theory was a new way of looking at the universe where gravity was a property of the space-time itself. This led to the development of cosmological models which attempted to explain the observations which were accumulating at a rapid pace because of development of better instruments.

Interestingly, Einstein's theory reduced to the more familiar Newtonian theory for most of the cases of interest. Thus, the motion of the planets in the solar system could still be well explained with Newtonian theory as would the calculation of the path of rockets and satellites. It was only in extreme cases of intense gravity that Einstein's theory would really be tested. Unfortunately, these were not amenable to our instruments for almost a century because the effect is extremely small. And then in 1974, two astronomers discovered a star system called a binary (where two stars are orbiting each other, the most familiar binary being the dog star or Sirius) populated by a particular kind of star called pulsar. The pulsars orbiting each other were getting closer to each other in exactly the way that Einstein's theory predicted.

The most spectacular confirmation of the theory however came in 2016 when a multinational collaboration, LIGO detected gravitational waves which are predicted by Einstein's theory. The extremely sensitive instruments detected the passing of a gravitational wave produced when two black holes collided some 1.3 billion years ago and a part of the energy was emitted in the form of these waves.

Although Einstein's theory has been verified, our understanding of the cosmos is still terribly incomplete. We don't know if there are other universes apart from our own. We know for instance that black holes exist but their exact nature is still a mystery. And as it turns out, we don't actually know what exactly the universe is made of!

Our understanding of the very small similarly underwent a radical change in the first few decades of the previous century. The quantum theory formulated by Bohr, Heisenberg, Dirac and Schrödinger among others seemed to not only explain the nature of matter but also could in principle account for all of chemistry. Over the next 7 decades, more detailed theories of the structure of matter were formulated, culminating in the so called Standard Model of Particle Physics. This model, populated with exotic sounding particles like truth and beauty quarks, seemed to agree very well with the observations. By the turn of the century, there was a general consensus that our understanding of the very small was pretty satisfactory. Interestingly, an essential ingredient in the theory was a mysterious particle called the Higgs boson which remained elusive despite many efforts to detect it.

All this changed in 2013 when a gargantuan particle accelerator appropriately called the Large Hadron Collider (LHC) found the particle thereby confirming what the scientists anyway believed to be true. The so-called God particle seemed to have exactly the properties as demanded by the theory. With the discovery of the Higgs particle, our understanding of the microscopic world seemed almost complete. Almost, because a major gap existed in the formulation of a truly universal theory.

This was the grand synthesis or the Holy Grail- the fitting together of the two great intellectual achievements of the 20th century, quantum mechanics and Einstein's theory. Although some of the best minds, including Einstein himself, have struggled with trying to unite these two theories, success has eluded them. Last few decades has seen the emergence of highly mathematical and seemingly unphysical models called String Theories. These theories are extremely elegant mathematically but don't seem to have any connection with the real world. Thus, at the most fundamental level, our understanding of the very small, though vastly better than at any time in our history, is still very much incomplete.

In the field of medicine too, the first few years of the previous century marked a turning point. In 1928, the serendipitous discovery of penicillin by Fleming has been responsible for saving hundreds of millions of lives. This along with tremendous advances in diagnostics, medicinal chemistry and vaccine technology has decreased morbidity and mortality rates hugely. Major challenges still remain – the threat posed by the emergence of new diseases like HIV Aids and Ebola, an exponential increase in lifestyle diseases like diabetes and cardiac disease as well as effective treatment of cancer to name a few. Important as these are, possibly the most serious threat to public health is the emergence of antibiotic resistant microbes.

Over the last century, scientists have been able to isolate a large number of antibiotics (mostly from soil bacteria it turns out) which unfortunately have been used indiscriminately. The most extensive use of antibiotics has been for growth promotion in livestock and poultry. In a spectacular example of survival of the fittest, this has led to an emergence of microbes which are resistant to all the known antibiotics. Coupled with the fact that there are no new antibiotics in the drug pipeline has led to scientists predicting a nightmare scenario where even a small cut which becomes infected might be fatal because of lack of effective pharmacological antidotes. The situation is so alarming that the United Nations had called a special session to discuss possible solutions in September 2016.

In biology too, there had been steady progress, though the big discovery came only in the middle of the century. In 1953, the molecular structure of the DNA was identified and over the next few decades, the essential basis of life at the molecular level had been fairly well understood. The fitting together of molecular biology, that is the understanding of the molecular components of life and theory of evolution led to what is called modern evolutionary synthesis.

The 1970s saw the birth of recombinant DNA technology which opened up the field of biotechnology. Tools like Polymerase Chain Reaction (PCR) allowed scientists to greatly speed up genetic analysis and soon whole genomes of several species were being sequenced. The ambitious Human Genome Project started in 1988 was the watershed movement in humanity's quest to understand itself. Rapid sequencing techniques developed subsequently along with an exponential increase in computing power have made sequencing the human genome extremely inexpensive and quick.

As the technology to manipulate genes evolved, the biotechnology industry boomed with many applications in agriculture, pharmacology and even industry. Pest resistant plants, medicinal agents manufactured by genetically modified bacteria and even bacteria to clean up chemical spills are all part of our post-industrial world today. In 1996, the first mammal to be cloned, the sheep Dolly gained worldwide fame though it also evoked fears of the technology being misused as in the popular novel and film, "The Boys from Brazil".

One of the biggest breakthroughs in genetic engineering came in 2012 with the advent of a technique called CRISPR. This enormously significant advance has applications in many areas including genome engineering and medicine. It has also made possible selective editing of any genome including the human genome. The easy and cheap availability of these tools has provoked a lot of discussion among the scientists on the ethics of tampering with the human genome.

Despite the stupendous progress in our understanding of biological systems, we are still nowhere near answering several fundamental questions. We are, for instance, still not certain about how life began from a chemical soup some 4 billion years ago. The essential question of what is consciousness and how does it relate to our biological makeup is still open as is the conundrum of how a minute difference in the genetic makeup between humans and chimpanzees lead to us being what we are.

Some 10-12000 years ago, somewhere in the Levant, a bunch of hunter gatherers realised that they could domesticate wild grass and have a steady source of food. This Neolithic revolution ultimately led to the growth of cities and civilizations. Ultimately, everything was predicated on agriculture. Increasing the agricultural output for most of human history was mostly a matter of bringing new land under cultivation. Of course new technologies like selective breeding of plants, better implements etc. played a vital role. However, by the beginning of the 20th century, it was clear that our agricultural output will not be enough to sustain the growing population. The soil fertility was being rapidly depleted and yields were plateauing.

During the early years of the 20th century, Fritz Haber invented a technique to use atmospheric nitrogen to manufacture ammonia cheaply and efficiently. This allowed the essentially limitless nitrogen in the air to be used as fertilizer since ammonia is a precursor for making fertilizer. The availability of nitrogenous fertilizers allowed agricultural yields to increase dramatically and thus averted a catastrophe. The advances in medicine had resulted in a sharp decline in the mortality rates and hence a huge increase in population. The development of high yielding varieties and pesticides etc. also allowed grain yields to be sufficient to feed the rapidly increasing population.

However, in recent years, fears of a climate induced agricultural crisis are again looming large. Our planet is inexorably getting warmer and this could lead to highly unusual weather phenomena. A sharp dip in agricultural production could easily result because of these factors. Increasing yields by increased use of fertilizers is no longer sufficient. Instead, scientists are trying to replicate nature and use genetic engineering to increase cereal yields.

Photosynthesis or the process of turning water, carbon dioxide and sunlight into food is how we humans get all our food ultimately. It turns out that, depending on the specific chemical reaction, there are two kinds of photosynthesis, C3 and C4 type. C3 type is less suited to thrive in hot and dry areas than C4 plants. They are also less efficient in converting energy into food than C4 plants. Unfortunately, the most important cereals, rice and barley are C3 while maize and sugarcane are C4.

An important project underway is to use genetic engineering to see if genes responsible for C4 photosynthesis can be incorporated into the most widely grown varieties of rice. This will not only improve the food content of rice but also make possible its cultivation in more extreme conditions. If this is successful, it will prove to be as important a development in agriculture as the Haber process was in the previous century.

That science (and the derivative technologies) has made immense progress in the last 100 years is of course incontrovertible. Nevertheless, there are many fundamental questions which science has not been able to answer. Thus for instance, the nature of time itself is a bit of a mystery as yet. Is our universe the only universe that exists or are there multiple universes which we cannot access? Why does matter exist at all given that the early universe started off with equal quantities of matter and antimatter, which should have annihilated each other long ago? Of course, scientists like to believe that it is only a matter of time before these mysteries would be solved.

However, nature has recently stuck a final nail in the coffin of anthropic supremacists. At the turn of the new millennium, observations of a particular kind of heavenly object called Supernova showed that ordinary matter, the stuff which we and our iPhones are made of, is only 4% of the total matter in the universe. The other 96% is a combination of mysterious stuff called dark matter and dark energy about which we know almost nothing. Thus, not only are we not at the centre of the universe, we are not even made of the stuff which most of the universe is made of. Copernicus would surely be smiling in his grave!

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