Some recent developments in the world of physics

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In this Article I shall describe a few important developments taken place in the world of physics. As we all know the world of science is witnessing rapid developments and the knowledge is accumulating at a very fast rate. Every now and then, new specializations are emerging, opening new frontiers and leading to new technologies. The world of Physics has its own share of excitement. Physical Sciences have not only helped in pushing the frontiers of knowledge, unfolding the mysteries of nature, but have also led to the creation of many new technologies. It is fair to say that most of the high technologies of today are directly or indirectly based on research in physics. Basic equipment used as a research tool in many of the sciences of today also owes its development to physics. Physics is thus of fundamental importance both for its applications to technology, and for understanding the deep mysteries of nature.

Regarding applications to technology, physics has led to the development of powerful new technologies. For instance, the discovery of nuclear fission made available to mankind vast amounts of energy stored inside atoms. This brought about the Nuclear Age. Then, in the 1960's the study of how electrons move inside solids brought about the invention of the transistor and, later, the micro-chip, thus signaling the revolution in electronics. Another major development came from the study of radiation from atoms. The lasers which made their debut in 1960 are now used in almost all fields of science and technology, and have become common place in our daily life. Since the invention, peak power of a pulsed laser has increased by 12-15 orders of magnitude.

The field of plasma physics promises a lasting solution to the Energy problem of mankind through the development of fusion based power reactors. Plasma state popularly known as the fourth state of matter has also demonstrated important technological and industrial applications. Plasma and fusion-related technologies are fast entering a world market estimated at over USD 200 billion per year.

In Plasma Physics, new and important branches have emerged in recent years - Quark Gluon Plasma which is believed to have existed in the Early Universe and for which strong signals have been observed in the CERN Experiments and now at the relativistic heavy ion collision experiments at Brookhaven National Lab New York. Another important branch is Plasma Condensation with possible application of producing artificial diamonds and for providing understanding of Condensed Matter Physics Phenomena at a new level.

The field of Condensed Matter Physics its provides a good example in which basic research and technological developments go hand in hand. Whereas theoretical advances have helped in understanding semiconductors and superconductivity, remarkable inroads have been made in the technological developments of transistors, integrated circuits and superconductors. One of the enduring themes in Condensed Matter Physics is to look for Order Phenomena in highly complex forms of matter - this is like searching order in chaos. The Nobel prize in physics for the year 1991 went to a French Professor Pierre de Gennes who did precisely that. Among other things, he successfully explained the behaviour of Liquid Crystals and Polymers. Liquid Crystals have optical properties that can easily be manipulated, so they are valuable for information displays. They are now used in microelectronic hardware.

High temperature superconductivity, a major break-through in the last few years promises far reaching implications for power generation public transport.

The study of electrons at extremely low temperature (close to absolute zero) and under very powerful magnetic fields (30 T) has led to a breakthrough in our understanding of quantum physics, making the mysterious quantum effects visible. As you know, the famous Hall Effect was originally studied more than hundred years ago at the room temperature and at moderate magnetic field. In 1980, German Physicist Klaus Von Klitzing performing a similar experiment but now at extremely low temperature and high magnetic field discovered that the Hall resistance does not vary with magnetic field in linear fashion, but stepwise (step height being $\hbar/e^2$!). In other words, the Hall resistance is quantized and at the quantized resistance values, normal ohmic resistance disappears and the material becomes in a sense superconducting. Von Klitzing received the 1985 Nobel prize for that discovery known as the integer quantum Hall effect. On further refinement of the experimental studies, new steps in the Hall resistance both above below the integral value were found. In other words, fractional quantum Hall effect was discovered. 1998 Nobel Prize was awarded for this idea.

Besides applications to technology, physics by itself is a fascinating subject. I would like to cite just a couple of examples from the not too distant past. The unification of weak and electromagnetic interactions by Salam and Weinberg, one of the great achievements of 20th Century has revealed the intrinsic simplicity and beauty of nature. This theory is a highly successful theory. Years of confrontation with experimental data of ever increasing accuracy have left the theory intact. No wonder it has come to be named as the Standard Model.

The search for simplicity at the deepest level has been one of the enduring themes of physics. In this quest, perhaps the greatest development has been the quark model of matter. In the early 1960's, theorists proposed that the known fundamental particles were really composites, made up of more fundamental objects called quarks. The Nobel prize for the year 19901 was awarded for experimental confirmation of that theory. In the (deep inelastic) experiments performed, the electrons were fired at protons and neutrons and the way they bounced off these particles showed that the targets were made up of tiny concentrations of matter - the quarks. This work reminds you of the famous Rutherford experiment in which particles were fired at gold foil to determine the atomic structure.

The Nobel Prize for the year 1995 went to two scientists, Frederick Reines and Martin Perl - the former had proved the existence of the elusive electron neutrino in 1956 and the latter proved the existence of the "tau" lepton in 1976. These particles along with the discovery of "top-quark" completed the family of elementary particles which are regarded as the building blocks of matter according to the Salam - Weinberg Standard Model.

The 1997 Nobel Prize in Physics was shared by 3 Scientists- Steven Chu of Stanford, Cohen Tannoudji of Paris and William Phillips of Maryland for developing new techniques for cooling and trapping of atoms with laser light. The laser light in this case acts as a thick liquid called Optical molasses through which the atoms are slowed down and thus individual atoms can be studied with great accuracy.

In one of the experiments performed, helium atoms were crawling along at a speed of only 2 cm/sec (an extraordinary feet) and that speed corresponded to a temperature of a fraction of a microkelvin- so close to the absolute zero temperature.

This novel method has many possible applications. Indeed it has already formed the basis for the discovery of Bose-Einstein Condensate - a bizarre state of matter in which atoms merge into a single wave-like entity much like a beam of laser light - thus causing atoms to sing in unison. The existence of such a state of matter was predicted way back in 1920's by Bose and Einstein. Einstein at the time had doubts that such a material could be demonstrated. But after 70 years and many technical advances, the feet was achieved by three scientists, who shared the Nobel Prize for the year 2001. These so called "atom laser" could in future draw microscopic computer circuits many times tinier than the smallest in use today, to build extremely fast, powerful and compact computers. Atom lasers could also power very accurate guidance systems and gravity meters that could pinpoint the position of airliners and spacecraft to within a few centimeters.

In the realm of Astrophysics and Cosmology, the theory of General Relativity has led to the notion of an Expanding Universe. The observation of the background radiation which is a relic from the time of the birth of the Universe has helped us understand how the Universe itself had started. Mindboggling objects like quasars and pulsars have been discovered in the sky. Subramanyam Chandrasekhar who was born in Lahore in 1910 shared the 1983 Nobel prize for his theory of evolution of stars. The Nobel prize for the year 1993 went to two scientists who had found a binary pulsar, a pair of pulsars whirling around each other in tight formation. According to Einstein's theory, two such heavy objects orbiting each other should give off gravitational waves, causing energy loss and consequently pushing the objects closer to each other. Indeed the partner pulsars in the binary complex were found to approach each other at a rate of 1 mm per year.

The latest Nobel Prize in Physics for the year 2002 was awarded to three scientists: Raymond Davis, Masatoshi Koshiba and Riccardo Giacconi, the first two were responsible for their detection of Cosmic Neutrinos and the 3rd for discovery of Cosmic X-ray Sources. In the 1960s Davis was the first to detect neutrinos coming from the sun. His detector was a huge tank filled with 600 tonnes of fluid, which was placed in a mine. Over a period of 30 years, he succeeded in capturing a total of 2000 neutrinos from the Sun. However, the number of neutrinos recorded, fell short of the predictions and thus was born the "solar neutrino problem". The best explanation for the shortfall was that the electron neutrinos made in the solar core, as products of nuclear fusion reactions, might transform (while in flight toward Earth) into other types of neutrino such as muon neutrinos, which could not be recorded in the detectors.

This hypothesis was put to test in the Kamiokande detector in Japan, which had been earlier designed to find evidence for proton decay which didn't occur. Koshiba and his collaborators enlarged the detector (Super-Kamiokande) and finally affirmed that neutrinos were indeed transforming from one type to the other. Further evidence came from the Sudbury Neutrino Observatory (SNO) in UK which is capable of directly detecting all three types of neutrino. It was reported that all solar neutrinos were duly accounted for.

As for x-ray astrophysics, Giacconi was the first to employ an x-ray telescope in space (1962) and observe specific x-ray sources outside our solar system. Then followed decades of new orbiting x-ray telescopes and notable x-ray discoveries were made including the detection of x-rays from sources, such as comets, black holes, quasars, and neutron stars. These two discoveries have opened up two new branches of astrophysics providing two new windows on the Universe.

I have mentioned only a few developments taken place in physics. The world of physics is full of such fascinating examples.