A few Nobel Prizes in physics: About how and how much physicists have contributed in technology

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Engineers and technocrats have an un-understandable attitude of neglecting basic sciences (of which physics is a major part) in their career. It is a different question as to how much they lose in doing so, if they decide to have a career in frontier areas of science and technology. Based on many facts, one may note that many disciplines in engineering are direct extensions of the works that physicists carried out in classical as well as in the modern era. Secondly, trends emerging on the horizons of today's physics are likely to show new horizons to the existing technologies.

The Nobel Prize has been the most prestigious international prize given in physics, chemistry, physiology or medicine, literature and peace, and it still remains the world's most prestigious prize in the area of science. In this article, an attempt has been made to review noteworthy contributions made by Nobel laureates in physics to the field of technology. The review does not claim to completely explain how much physics means to technology. This is because it excludes many worthy contributions that have not earned Nobel Prizes ($E = mc^2$, for example). It also excludes contributions from the pre-Nobel era, such as those from Newton, Faraday, Ampere, Hertz, Henry, Joule, Maxwell, Young, Gibbs, Bernoulli, Kelvin, Carnot, etc.

What is physics and what it means to technology

Physics, which is sometimes called as natural philosophy, is a science of matter, energy and their interactions as experienced in our universe. This 'definition' hardly represents what physics exactly means and allows physics to overlap on almost every branch of science and technology. Disciplines like chemical physics, biophysics, mathematical physics, geophysics, astrophysics and engineering physics clearly indicate the all-inclusive nature of this subject. One remarkable difference between physics and other disciplines is that while other sciences attempt to explain a phenomenon using the principles peculiar to their own field, physics tries to explain the same phenomenon using generalized and a minimum set of (or possibly using single) principles. Throughout its course of development, physics has evolved through interlocking of theory, experiment and technology. Though many branches like thermodynamics, electronics, fluid mechanics, materials science, electromagnetic engineering, etc. have branched-off from physics during the course of its evolution, physics still continues with its original aim of understanding nature and natural phenomena. For a technocrat or an engineer, physics is just like a 'window' through which he/she can observe nature in a scientific manner.

The beginning: discovery of X-rays

In 1895, Wilhelm Röntgen (Munich University, Germany, Nobel Prize in 1901) discovered peculiar radiations, which were hitherto unknown. He investigated many properties of these radiations and called them 'X-rays'. The ability of X-rays to penetrate through materials such as wood, paper, plastic, tissue and human organs and their inability to penetrate through bones, needle and bullets made the X-radiation immediately applicable in radiography and customs checking.

Many physicists contributed their share in understanding the nature and properties of X-rays. It was through such efforts that many applications of X-rays, such as X-ray crystallography, X-ray spectroscopy and CT scanning were established. Such attempts also provided many useful links for understanding the nature of matter and energy.

Quantum mechanics and our understanding of matter and energy

The universe around us is made up of matter and energy. In technology also, devices and machines are fabricated using various materials and operated using various forms of energy. The materials and various forms of energies that we exploit for technological applications exhibit myriad of properties. Why does nature around us appear in diversified yet symmetric forms? Why do properties change from element to element? Most of these questions find their answers in quantum mechanics. The materials are composed of atoms and molecules and the energy consists of photons. Quantum mechanics is a discipline which explains these basic building blocks and their interactions.

One of the major triumphs of quantum mechanics is that it has succeeded in understanding atoms, their electronic configurations, and their interactions with themselves and with external agencies such as the photons. It is basically the atomic structure that governs physical as well as chemical behaviour of an element, or its compounds. The history of evolution of quantum ideas and their association with technology is quite interesting.

The atomic hypothesis was proposed by Dalton. Faraday suggested that the atom possessed negative electricity. J. J. Thomson (University of Cambridge, UK, Nobel Prize in 1906) measured the minimum quantum of electricity that the simplest atom like hydrogen possessed. Thomson's experiments were based on the action of electric and magnetic fields on cathode rays. He called this quantum of atomic electricity as electron. Complete understanding of the number and arrangement of these electrons in atoms of various elements then took twenty years of experimental and theoretical research. One major step in this understanding was the discovery of the nucleus. Ernest Rutherford (Victoria University, UK, Nobel Prize in chemistry in 1908) established that the entire positive charge and almost the entire mass of atom existed within an extremely tiny sphere within the atom called as nucleus. Scattering experiments on alpha particles, which led to this discovery, also indicated that the size of nucleus was ten thousand times smaller than that of atom. (Remarkably, the size of an atom itself is ten thousand times smaller that that of the cross-section of a human hair!)

The number of electrons in an atom of a given element and their arrangement could be understood due to Nobel Prize-winning works related with X-rays. Charles Barkla (Edinburgh University UK, Nobel Prize in 1917) had indicated that X-rays emitted from various elements were characteristic to the properties of those elements. Laue and Braggs had established the foundations of X-ray diffraction. H. G. J. Moseley measured the characteristic frequencies of X-rays emitted from various elements using Bragg's spectrometer. He found that there was a linear relation between the square root frequency of such characteristic X-rays and the atomic number of Rutherford's nucleus. It was the atomic number and corresponding positive charge on the nucleus, which would decide how many electrons it could hold (to a first approximation) around itself in a given atom.

Thomson's plum-pudding model and Rutherford's planetary model about the arrangement of the electrons in atom could not explain how the atoms were stable and their spectra were discrete. It was Niels Bohr (Copenhagen University, Denmark, Nobel Prize in 1922) who introduced the quantum ideas to explain the discreteness of the atomic spectra. Bohr's model included an idea of quantized atomic orbits where electrons would move around the nucleus without emitting any radiation. This was against the classical Maxwellian theory of electromagnetic waves, but consistent with the experimental observations of atomic spectra. Though Bohr was the first physicist to introduce quantum ideas in the atomic regime, his provisional theory could not answer why electrons would move in 'certain allowed orbits' and not in others. Moreover, his theory could not go beyond the hydrogen atom.

The answer to the questions such as why electronic orbits in atoms were quantized was explained in an interesting manner. The works done in the period 1901–23 by three Nobel laureates, including Max Planck (Berlin University, Germany, Nobel Prize in 1918), Albert Einstein (Max Planck Institute, Germany, Nobel Prize in 1921) and Arthur Compton (University of Chicago, USA, Nobel prize shared in 1927) indicated that Maxwell's wave theory of electromagnetic radiation would not work in some experimental situations. Radiations such as infrared waves, light and X-rays exhibited particle-like properties in their experiments. Interestingly, such radiations retained their wave-like properties in classical experiments such as interference and diffraction. Though such wave–particle dualism of radiations appeared like a dilemma, each view was correct in the domain of its own experiments. In 1923, De Broglie (Sorbonne University, France, Nobel Prize in 1929) boldly extended this idea of duality of radiations to electrons (and in fact to all material particles). He made a suggestion that if atomic electrons were treated as localized wavegroups, then quantization of electron orbits in atoms could be logically explained. According to De Broglie, only those orbits would exist in which electron-waves could be smoothly fitted; other orbits would not exist. The wave theory of matter, which was applicable to all material objects, including electrons, was experimentally confirmed by C. J. Davisson (Bell Telephone Laboratories, USA) and G. P. Thomson (London University, UK), both of whom shared the Nobel Prize in 1937. The experimental verifications were based on electron diffraction experiments. Electron diffraction also opened a new research tool for analysis of materials.

According to Erwin Schrödinger (Berlin University, Germany, Nobel Prize shared in 1933), such matter waves associated with electrons (and all subatomic particles) would satisfy a sort of universal wave equation, the Schrödinger's equation. This equation was used to study many problems, including hydrogen atom and made many predictions, which were experimentally verified. Schrödinger could not correctly physically interpret the wave-function, which appeared as a solution of his equation. Such interpretation was given by Max Born (Edinburgh University, UK, Nobel Prize shared in 1954) in terms of probabilities that electrons could possess a given set of properties at a given time.

Paul A. M. Dirac (University of Cambridge, UK, Nobel Prize shared in 1933) applied Schrödinger's equation to electrons with relativistic considerations and predicted two properties of electrons. One was that the electron would posses spin and it would possess an antiparticle. Both these predictions were experimentally verified.

The solutions of Schrödinger's equation, when applied to an atom, required three quantum numbers for describing atomic structure. Wolfgang Pauli (Princeton University, USA, Nobel Prize in 1945) suggested that a fourth quantum number was also necessary. This was the spin quantum number. Pauli also introduced an exclusion principle, according to which each electron in an atom would possess a set of four quantum numbers, which were exclusively characteristic to that electron itself. No two electrons in a given atom could possess the same set of quantum numbers.

Pauli's exclusion principle along with the above-mentioned quantum principles were a major key in understanding the electronic configuration of atoms of various elements. The electronic configuration of atoms themselves is a key in understanding why atoms and corresponding elements exhibit myriad of physical and chemical properties. The quantum mechanics of atoms, molecules and their interactions answers why there is so much diversity in nature. It can be said that principally it is quantum mechanics that rules modern technology.

Role of quantum mechanics in technology

In spite of its success in explaining matter and energy in terms of their basic building blocks, many times, students of technological disciplines tend to ignore quantum mechanics by treating it as an abstract theory. This is due to a wrong perception. Quantum mechanics plays a decisive role when technology becomes delicate, i.e. devices become exceedingly small. Transistor (whose invention helped in reduction of size, cost, power consumption of electronic gadgets and enhancement of their speeds), electron microscope (which is playing a prime role in nanotechnology research) and laser (whose applications in CD ROMs and fibre optics boosted the IT revolution) are all based on quantum concepts. Moreover, superconductivity, photonics, spintronics and nanotechnolgy, which promise to give a completely different and better shape to existing technologies, are also an outcome of our understanding of matter and energy, which would have not been possible without quantum mechanics.

Physics and analytical instrumentation

Progress in science and technology requires sophisticated techniques for precise measurement and analysis. Many such techniques that are widely used in science and technology, are the outcome of Nobel Prize-winning ideas.

After the discovery of X-rays and after a suggestion that they were electromagnetic waves, attempts were made to measure their wavelengths. These attempts faced technical difficulties due to extremely small wavelength of X-rays, which was beyond the reach of existing diffraction gratings. It appeared to Max Von Laue (Frankfurt University, Germany, Nobel Prize in 1914.) that crystals with regular arrangement of atoms and extremely small atomic spacing could serve the purpose of tiny diffraction gratings. He obtained X-ray diffraction patterns of crystals on photographic plates. These patterns were found characteristic of the crystals, which diffracted the X-rays. This meant that crystals could be analysed by studying their X-ray diffraction patterns. But Laue's procedures were too indirect and complicated. Simplification occurred due to the works by W. H. Bragg (London University, UK), and his son W. L. Bragg (Victoria University, UK), both of whom shared a Nobel Prize in 1915. The Braggs developed a simplified theory of X-ray diffraction by considering crystals as an arrangement of atom-enriched planes of various regular orientations. The Braggs' formula, which was developed during this work, formed the basis of the Braggs' X-ray-spectrometer. The Braggs studied many crystals using their spectrometer. This work formed the basis of X-rays crystallography, a technique that is widely used for analysis of crystalline and semi-crystalline materials. X-ray spectrometers are also used in X-ray spectroscopy, which is one of the important research tools in elemental analysis.

X-ray spectrometers can thus be considered as super-microscopes, but X-ray procedures are indirect. A direct way is based on optical microscopes. However, optical microscopes have several limitations, one of which is that the wavelength of light is nearly 0.0005 mm. Many fine objects and specimens such as viruses, molecules, nano-materials or nano-devices are beyond the reach of optical microscopes as their sizes are smaller than the wavelength of light. Two extremely powerful microscopes, the 'scanning electron microscope' (SEM) and 'scanning tunnelling microscope' (STM) were developed by Ernst Ruska (Max Planck Institute, Germany), Gerd Binnig and Heinrich Rohrer (IBM Lab, Switzerland), all of whom shared the Nobel Prize in 1986. These microscopes are based on wave-like properties of electrons. In SEM, the objects are imaged using electrons and then magnified using magnetic lenses. In the tunnelling microscope, objects are scanned using an extremely fine tip, which records the electrons tunnelling from the surface of the specimen to the tip of microscope. Both these microscopes have become essential tools in materials and nanotechnology research.

K. F. Braun (Strasbourg University) who shared the Nobel Prize in 1909 for his contributions in wireless telegraphy, is also well known for design of the first Cathode Ray Oscilloscope (CRO). The CRO is a multipurpose graphical display device. It can be used to display many analogue functions like AC voltages. All other functions (including heart beats) which can be transduced to an electronic signal, can also be displayed and analysed. The CRO is not only an important analytical instrument, but the CRT-based displays in televisions and computers are also modified versions of Braun's CRO.

Many a time surface analysis, dimensional analysis, or stress analysis, or study of short-duration phenomena requires 3D perspective of the components, devices and processes. During his attempts to improve the resolution of microscopes, Dennis Gabor (Imperial College, London, UK, Nobel Prize in 1971) outlined ideas behind 3D photography (holography). Ordinary photographs can only give two-dimensional perspective of a three-dimensional object. This is because in ordinary photography, only intensity variations can be recorded. Gabor's technique involves recording phase variations in addition to intensity variations. Since such 3D photography provides a real perspective of objects, the analysis becomes more precise.

Felix Bloch (Stanford University, USA) and Edward Purcell (Harvard University, USA), who shared the Nobel Prize in 1952, formulated another important technique for characterization of materials, which is known as Nuclear Magnetic Resonance (NMR) technique. This technique is based on a quantum property of subatomic particles, according to which nuclear particles like protons have a kind of spin motion. The frequency with which these protons spin in a given material is entirely characteristic of that material itself. Thus the materials can be identified or analysed by determining the frequencies at which their protons spin. This can be done by transmitting radio waves inside the materials and determining the frequencies at which they tune with the spin motions of the protons.

Spectroscopy in all regimes, including infrared, ultraviolet and visible light remains one of the widely used research tools in science as well as in technology. A Nobel Prize awarded to Sir C. V. Raman in 1930 (at that time in Calcutta University) for the discovery of the Raman effect, has formed the basis of Raman spectroscopy. The Raman spectroscopy is especially useful for analysis of molecular species. The light scattered from the specimens carries characteristic frequencies, whose analysis provides insights to the structure, dynamical and other properties of specimens.

Physics and biomedical instrumentation

ECG, CT scanning and MRI techniques that have made medical diagnosis more certain and treatments more precise have been awarded Nobel Prizes in physiology or medicine and the techniques are extensions of concepts in physics.

Willem Einthoven (Leiden University, Netherlands, Nobel Prize in physiology or medicine in 1924), discovered a method of registering extremely weak electrical signals associated with processes in the human body such as heart beats, retina movements or the nervous system. He also established that each person has his own characteristic ECG and any disorder in the body processes is reflected in the ECG. Later on, the sensitive galvanometer in Einthoven's ECG method was replaced by Braun's CRO, which made the method more sophisticated.

Wilhelm Roentgen himself had taken the first X-ray photograph of his wife's hand, a technique that we now know as X-ray radiography. But the photograph was a two-dimensional image of 3D bone structure, i.e. the third dimension could not be recorded. Additionally, X-ray radiography could not be used to image fleshy organs. A physicist, Allan M. Cormack (Tufts University, USA) and Godfrey N. Hounsfield (Central Research Labs, London, UK), both of whom shared the Nobel Prize in physiology or medicine in 1979, overcame all these limitations by inventing Computer Assisted Tomography (CAT scanning method). CAT (or CT) scanning is based on recording the cross-sections of density differences in the organs using X-rays and converting these records in signals with the aid of an X-ray detector. The signals are then fed to a computer, which converts them into an image using calculations based on Fourier transforms. All human organs, including the brain can be imaged using CT scanning.

X-ray methods are many times invasive due to possibility of cell damage. A recent method called as Magnetic Resonance Imaging (MRI) for the invention of which the Nobel Prize in physiology or medicine in 2003 was jointly awarded to Paul Lauterbur (University of Illinois, USA) and Sir Peter Mansfield (University of Nottingham, UK), is entirely non-invasive. Human organs, including the brain contain water. Water contains hydrogen nuclei, i.e. protons which have spin motions. If the organ is subjected to a varying magnetic field, then depending upon their position in the organ and depending upon their clockwise or anticlockwise spins, the protons acquire an energy distribution, which is characteristic of the organ's structure. The energy distribution and consequently the organ structure can be determined by sending radio waves in the organ and tuning them with the spin/energy distribution of protons in the organ. An image is obtained when the radio signals are fed to the computer and then processed. As radio waves are million times less energetic than X-rays, the MRI technique is noninvasive.

Physics and electronics and telecommunications

Today's electronics is mainly based on three inventions. One is the transistor, second is the integrated circuit (IC) and the third is wireless telegraphy. All these have been invented by physicists.

The old electronics was based on valves and triodes. These were quite bulky, slow and power-consuming. The quantum mechanical understanding of properties of semiconductors led to the invention of the transistor, which overcame all such difficulties. William Shockley (Beckman Instruments, USA), John Bardeen (University of Illinois, USA) and Walter Brattain (Bell Telephone Laboratories, USA), all of whom shared the Nobel Prize in 1956, discovered that the current through semiconductor junctions could be controlled (rather amplified) if a third electrode was introduced between them. This was the first transistor, which consisted of two gold slabs at the ends of germanium slice of width 1/64th inch. It could amplify the signal sixteen times. A transistor amplifies the signals just like triodes but quite elegantly, i.e. at lower size, less power, lower price and in less time. Invention of the transistor was a unique step towards miniaturization of electronic gadgets. If the transistor were not invented, then mobile phones would have been of the size of monuments and computers would have been of the size of buildings! Moreover, they would be unaffordable, much slower and would have required frequent debugging.

The microprocessors, which are the brains of modern computers, require electronic circuits with several thousand transistors mounted on a single circuit board. Soldering several thousand transistors on a single circuit board would be a laborious and error-prone task. Jack Kilby (Texas Instruments USA, Nobel Prize shared in 2000) devised a method, using which several thousand transistors could be integrated on a single semiconductor chip by employing different processing techniques at different parts. This was the birth of IC, another major step towards device miniaturization.

In addition to integration, what was also being demanded was the speed of the electronic circuits. Herbert Kroemer (University of California, USA) and Zhores Alferov (St. Petersburg, Russia), who shared the Nobel Prize in 2000, invented semiconductor heterostructures, which consist of a combination of different semiconductors whose structures are different but properties fit in with each other. Transistors made of such heterostructures are fast and are used as logic gates in microprocessors, amplifiers in cellphones and in RADAR receivers. The semiconductor heterostructures were also responsible for efficient and compact laser diodes, which are used in CD-ROMs, CD players and laser printers.

Telecommunication, which has brought the world closer, is based on transmitting voice, video and data signals over several kilometres using radio waves, microwaves and light. This technology finds its roots in the early works of Guglielmo Marconi (Marconi Wireless Telegraph Co, UK) and K. F. Braun (Strasbourg University, Germany), both of whom shared a Nobel Prize in 1909. Electromagnetic waves were known due to early works of Faraday, Maxwell and Hertz. Around 1900, it was known that the electromagnetic oscillations across capacitors could be transmitted over few metres. Marconi, using his circuits, could transmit these electromagnetic disturbances over 20 km. Marconi's networks suffered problems of attenuation and distortion, which were later rectified by K. F. Braun.

Physics and information technology

Information Technology (IT) is based on processing, communicating and presenting information. This requires computers, world wide web, laser and photonic devices. Physicists have made decisive contributions in these areas also.

The world's first electronic digital computer was built by physicists. A physicist, John Atansoff and his physics graduate student, Clifford Berry designed the computer in the basement of the Physics Department, Iowa State University in 1939. The second electronic digital computer called ENIAC was also built by a physicist, John Mauchly in 1945. Both these computers were bulky, costly and required frequent debugging. The computers could become fast, compact and affordable due to invention of transistor and IC, which have been mentioned earlier. Where the valve-based computers would have taken several hundred hours to perform some calculations, today's transistor and IC-based computers can perform them in a few seconds!

The world wide web was invented by a physics graduate, Tim Berners-Lee (Oxford University) and a physicist, D. M. Sendall to facilitate exchange of information that thousands of physicists at the European Center for Nuclear Research (CERN, Geneva) required. Lee also developed the first web-browser and conventions such as URL (Uniform Resource Locator) and HTTP (Hypertext Transfer Protocol).

The Internet is also based on CD-ROMs, which require laser for recording and retrieving information. The laser is outcome of a brilliant suggestion made by Einstein in 1917. According to him, if an atom in an excited state receives a resonating photon, it can de-excite by emitting two exactly identical photons. This process, called as coherent amplification, if properly controlled, can emit an extremely powerful and directional beam of light called the laser. Einstein's idea was brought into reality by Charles Towns (Massachusetts Institute of Technology, USA), Nicholay Basov and Aleksandr

Prokorov (both from Labedev Physical Institute, USSR), all of whom shared the Nobel Prize in 1964. Lasers also find applications in many other areas, including laser printers, CD players, cutting, welding, ranging and communications.

Another major contribution from Einstein towards technology is the discovery of the law of the photoelectric effect, for which he was awarded the Nobel Prize in 1921. This effect is related with emission of electrons from materials when exposed to light. The photoelectric effect forms the basis of all opto-electronic devices, ranging from laser diodes to solar cells and photodiodes to optocouplers. All these devices, have become essential components of photonics, a rapidly growing branch of electronics.

Superconductivity: the key for an entirely new world of technologies

In 1911, H. Kamerlingh Onnes (Leiden University, the Netherlands, Nobel Prize in 1913) discovered a mysterious phenomenon, where he found that resistance of mercury suddenly disappeared when it was cooled below 4 K. This phenomenon, which is called as superconductivity, remains one of the most researched but still a mysterious phenomenon. Many physicists have contributed in the theoretical and experimental research on superconductivity. Though the concept itself is attractive and promising enough, many possible applications of superconductivity are still away from reality. This is due to several problems. One of these problems is that, though many metals and compounds exhibit superconductivity, they do so at low temperatures, low current densities and low magnetic fields, conditions that cannot be achieved without effort and expense. The second problem is the unavailability of a complete theory of superconductivity. Four Nobel Prizes awarded in this field in 1972, 1973, 1987 and 2003 have given certain breakthroughs due to which hopes in practical superconductivity are still alive.

The most successful and experimentally confirmed theory of superconductivity was formulated by John Bardeen (University of Illinois, USA), Leon Cooper (Brown University, USA), and John Scrieffer (University of Pennsylvania, USA), all of whom shared the Nobel Prize in 1972. This theory, which is commonly called as BCS theory, is based on the proposition that at low temperatures, a quantum mechanical interaction between electrons and the superconducting crystal allows electrons to form Cooper pairs. At macroscopic scale, this results in a gigantic coherent state, which results in a large current. The BCS theory not only made many predictions which were experimentally confirmed, but it also stimulated worldwide research on superconductivity.

J. Georg Bednorz and K. Alexander Müller (IBM Research Lab, Switzerland, Nobel Prize in 1987) discovered superconductivity in ceramic materials (one example is lanthanum–barium–copper oxide) at low temperatures, but at temperatures much higher than those of other superconductors known till that time. This has promised the possibility of a room-temperature superconductor. Since the low temperatures required by such ceramic superconductors are achievable using liquid nitrogen, practical applications, including MAGLEVs and superconducting power transmission may be realized in future.

The Nobel Prize in 2003 was shared by Alexei Abrikosov (Argonne National Lab, USA) and Vitaly L. Ginzburg (Lebedev Physical Institute, Russia) for predicting and discovering the type-II superconductors, which maintain superconductivity at fairly strong magnetic fields. This has made it possible to generate high magnetic fields using superconducting electromagnets.

Though a room-temperature superconductor does not exist today, many applications of low temperature superconductors have been realized. A few of these applications were invented by Leo Esaki (IBM Research Center, USA), Ivar Giaever (General Electric Company, USA) and Brain Josephson (University of Cambridge, UK), all of whom shared the Nobel Prize in 1973. All these applications are related to a unique quantum phenomenon called tunnelling. The wave-like properties of electrons allow them to cross barriers even if their energies are insufficient to do so. Esaki designed a tunnel diode using this effect, which found applications in high-frequency electronics, while Geiver demonstrated tunnelling currents through metal junctions joined by oxidative insulating barriers. Josephson designed Josephson junctions (SQUIDS) by sandwiching an extremely thin insulating layer between two superconductors. Josephson junctions are used for measuring extremely weak magnetic fields, such as those from the brain or heart. These junctions can also record extremely weak temperatures.

Four other promising applications of superconductivity are MAGLEVs, MRI, thermonuclear fusion and superconducting power transmission. MAGLEVs (magnetically levitated ultra-speed trains) are based on the fact that superconductors are perfectly diamagnetic, i.e. they expel magnetic fields. MRI requires extremely strong magnetic fields, which can be generated using superconducting electromagnets. The strong magnetic fields which are required for confining the plasma in nuclear fusion reactors, can also be generated using superconducting electromagnets. Power transmission based on superconducting cables will reduce resistive losses to incredibly low values. It has been demonstrated that a current of several amperes persisted in a superconductor for two and half years without any appreciable loss.

Physics and novel materials

Progress in technology has been possible due to the fact that nature has gifted us several materials with novel properties. Three special classes of novel materials, including ferrites, liquid crystals and conducting polymers, which are being used or likely to be used in technology, are related with Nobel Prize-winning works by physicists.

Three basic kinds of magnetism, namely diamagnetism, paramagnetism and ferromagnetism were known due to works of physicists, including Ampere, Wiess, Heisenberg and Bohr. A fourth kind of magnetism called anti-ferromagnetism and its special case, ferrimagnetism were discovered by Louis Néel (University of Grenoble, France, Nobel Prize shared in 1970). Ferrimagnetic materials, which are commercially known as ferrites, exhibit strong magnetic properties in addition to comparatively high resitivities. This prevents Eddy current losses. Ferrites find applications in many areas, including computer floppies and recording tapes. Their ability to prevent Eddy current losses makes them applicable in recording heads, high frequency transformers, electromagnets, aerials and antennas.

Liquid crystalline materials are well known for their applications in the screens of laptops, calculators, wristwatches and mobiles. These semi-ordered materials, which offer compact and low power display devices, were discovered by a botanist, Reintzer but later understood and named by physicist, Otto Lehman. Many properties of liquid crystals could be predicted and understood due to a theory proposed by Pierre Gennes (College de France, France, Nobel Prize in 1991), in which he identified analogies between magnetic materials, polymers and liquid crystals.

The giant organic molecules commonly termed as polymers, are well known for their diversifying properties and applications. But most of the polymers are insulating. Alan J. Heeger (University of California, USA), Alan Macdiarmid (University of Pennsylvania, USA) and Hideki Shirakawa (University of Tsukuba, Japan), all of whom shared the Nobel Prize in chemistry in 2000, discovered conducting polymers accidentally. While attempting to polymerize acetylene, their guest researcher added excess catalyst due to which they got a silver-like lustrous film instead of the expected black polyacetylene. But it was not conducting. Ten years later, while collaborating with Allen Heeger (a physicist), they found that when this film was oxidized in the presence of iodine, its conductivity increased ten million times! This was the discovery of conducting plastic. Such conducting (as well as semi-conducting and light-emitting) plastics are leading towards molecular electronics, a discipline which promises cheaper counterparts of silicon-based electronic devices. Such devices include the eco-friendly plastic batteries (which could replace combustion engines in the cars), plastic solar cells or luminous plastics which may enlighten houses in the future.

Physics and the nuclear age

Nuclear energy, which is mainly based on fission reactors, contributes 17% share in the world's electricity production today. Fusion reactors, which are planned in the future, may solve our energy problems permanently. Possession of nuclear bombs is considered as a criterion for super-power. Intense research in nuclear physics during 1911–52 is responsible for this nuclear age.

Rutherford, who discovered the nucleus in 1911, is also known for two other pioneering contributions in nuclear physics. His alpha-particle scattering experiments led him to discovery of the proton (1915) and the first artificial nuclear transmutation (1919). The artificial nuclear transmutations not only made it possible to convert one element into another, but also led to applications in power generation.

After discovering the proton, Rutherford indicated that the nucleus might consist of yet another type of particle, which would be as heavy as the proton but an electrically neutral one. He also gave an advanced name to this particle, the neutron. Experimental confirmation of the neutron was not an easy task, as its interaction with matter would be extremely weak. Some nuclear reactions involving helium, lithium, beryllium and carbon were found to produce extremely penetrating radiations, which were thought to be gamma rays at first. It was the careful work, logical thinking and intuition of James Chadwick (student of Rutherford, Liverpool University, London, UK; Nobel Prize in 1935) due to which these radiations were discovered as neutrons.

Neutrons were soon recognized as powerful projectiles for nuclear transmutations. Enrico Fermi (Rome University, Italy, Nobel Prize in 1938) was the first physicist who used neutrons to produce several radioactive elements. Fermi also found that neutrons became more effective for disintegrations if they were slowed down by passing through paraffin. He also suggested that irradiating uranium by such neutrons could further extend the periodic table, which was known at that time only up to uranium. The expectation was that uranium would become beta-radioactive and thereby decay into elements of higher atomic numbers. This suggestion turned into the discovery of nuclear fission.

Otto Hahn (Max Planck Institute, Germany, Nobel Prize in chemistry in 1944) and his colleagues, while working over Fermi's suggestion came across an unexpected result. The neutron-irradiated uranium in their experiments did not produce any transuranic element, but was 'broken' into middle mass nuclides. This was the discovery of fission. Otto Hahn also predicted that this reaction could proceed like a chain reaction and therefore could be explosive. The world saw a dark side of nuclear energy, when a nuclear bomb based on uncontrolled chain reactions exploded in 1945. But the peaceful use of nuclear energy was not far away. Fermi designed the first nuclear reactor using controlled fission. Fermi's reactor was a prototype, but in the next 50 years more than 500 reactors have been built, which are contributing to 17% share in the world's electricity production. Fission-based nuclear energy could not progress at the required pace due to setbacks of a few accidents and radioactive pollution.

In Hahn's fission reactions, an atom of uranium broke in an explosive manner. Explosions (uncontrolled and controlled) can also occur if lighter elements are fused into heavier ones. Such reactions, which are called nuclear fusion reactions, constitute the chief energy production mechanism in stars. We, at a distance of 150 million km from the sun, are receiving solar energy at the rate of 1400 W/m^2. This is because the sun is radiating at the rate of 10^{26} J/s. It has been doing so for last billions of years and will continue doing so for billions of years. Hans Bethe (Cornell University, USA, Nobel Prize in 1967) showed, without any ambiguity, that the processes responsible for such large energy production in stars were not ordinary ones like burning of coal or chemical reactions, but it was mainly from nuclear fusion in which lighter elements such as hydrogen fused into relatively heavier elements like helium.

A duplication of such stellar fusion reactions on the earth may solve our energy problems on a permanent basis. Though several technical problems have not yet allowed this to happen at commercial level, many attempts are being made to bring about success. Such attempts are based on magnetic confinement (tokamaks) and inertial confinement (laser fusion). Deuterium required for such reactions is abundantly available in sea water.

The frontiers of today's applied physics

The frontiers of today's applied physics are attractive. Nanotechnology, spintronics (magneto-electronics) and molecular electronics are the three disciplines where physics is likely to provide many breakthroughs, which may boost the technological progress.

According to Moore's law, ICs are shrinking every year. This trend indicates that in the next a few years, electronic components will reduce in their size up to a few nanometres. Such devices would escape from day-to-day physics and enter into the realm of quantum physics. This is leading towards nanotechnology, a promising discipline, which deals with designing materials and devices at atomic or molecular scale. Nanotechnology promises applications in almost every discipline of technology as well as day-to-day life. A nanotube made up of C_{60} molecule has the strength ten times greater than that of steel. The nanodevices, nanomaterials and nanomachines, which will follow from this research, will exhibit better properties than today's macro or micro analogues. Nanotechnology promises faster computers with better storage capacities, better medical diagnosis and treatments, and materials tailored with superior properties.

Today's electronic devices use charge properties of electrons. An entirely different discipline called spintronics is coming up rapidly. Spintronics will be based on the quantum property of electrons, namely its spin. The spin motions assign magnetic properties to electrons, which indicates that spin devices will be operated using magnetic field instead of electric field. The spin valve and spin transistor, GMR (Giant Magneto Resistance) and MRAMS (Magnetic Random Access Memory) have been designed at laboratory scale. The spin computer in the future will be based on qubits instead of bits. Qubits are quantum bits, i.e. 1 and 0 in today's digital electronics will be replaced by clockwise and anticlockwise spins of electrons. Such quantum computers will be several times faster and would possess better storage capacity than today's classical computers.

Epilogue

A glance at the review of more than thirty-five Nobel Prizes in physics indicates how much physics is linked with today's technologies. Remarkably, many amongst these Nobel Prizes in 'applied' physics have been awarded to physicists in colleges and universities and more than five Nobel Prizes in 'pure' physics (particle physics and astrophysics) have been awarded to physicists working at Massachusetts Institute of Technology and California Institute of Technology!

All this makes the author of this article to genuinely feel that if physics is allowed to flourish in engineering and technological atmosphere, then it still has an unlimited potential of giving new shapes and showing new horizons to existing technologies. What is only required from engineers and technocrats is a right approach and of course, an unbiased attitude towards this subject!

[The author has referred to presentation speeches and Nobel lectures for the Nobel Prizes in physics awarded in the years 1901, 1906, 1909, 1913, 1914, 1915, 1917, 1918, 1921, 1922, 1927, 1929, 1930, 1933, 1935, 1937, 1938, 1945, 1952, 1954, 1956, 1964, 1967, 1970, 1971, 1972, 1973, 1986, 1987, 1991, 2000, and 2003. Nobel Prizes awarded in chemistry (1908, 1944 and 2000) and physiology or medicine (1924, 1979 and 2003) have also been referred. All these are available on the official website of the Nobel Foundation www.nobelprize.org]

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