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EVOLUTION OF SOLID STATE PHYSICS AND ITS INDUSTRIAL APPLICATIONS

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Abstract:

The role of physics, particularly in the development of civilization, is discussed in this paper. Various branches of physics have been identified. The impact of physics in the development of civilization, particularly in the light of new discoveries and inventions, has been described.

Introduction

Physics is one of the primary and essential branches of the basic sciences. One can define physics as a branch of science, which studies the physical properties of matter and energy. Science is systematic thinking about a subject. Matter exists in three states, Solid, Liquid and Gas. Physics covers the study of all these three states. Very few other branches of science cover such a wide spectrum of states of matter. Some of the main branches of physics are enumerated here in this paper. Important discoveries made by famous scientists are discussed with their implications for industry.

The main branches of physics, which have significant impact on industry are solid state physics, laser physics, chemical physics, bio-physics, nuclear physics and atomic physics. Yet there are many other branches of physics, which are equally important for the development of industry.

The period between eighth and thirteenth century AD has been the glorious Islamic era of Knowledge and Learning. In this period, the Muslims not only reviewed the available / existing knowledge of medicine, mathematics, astronomy and philosophy, but they also undertook researches in each of these branches of science and technology to give it new dimensions. It was because of the creative efforts of the Muslim scientists that an era of enlightenment was ushered in the world.

The Muslim scientists contributed a great deal to the study of physics during the eighth century AD, when Yaqubal Kindi made discoveries about sound and its nature. He compiled his research on geometrical optics in the form of a book. The most important personality among the scientists of the Fatimid period is Abu Ali Bin – Hasan – Bin – Hussain – Bin – Al - Haitham. His magnum opus is "Kitabul Manazir". It is the first comprehensive book of the world, which deals with light, a branch of physics. In his this book al-Haitham discovered the nature of light and described it as a kind of "energy". He differentiated between luminous and non-luminous objects. He has divided the objects on which light falls into three kinds as transparent, translucent and opaque. He gave the correct definition of a ray of light and constructed a pin - hole camera. It was Ibn-al-Haitham, who gave the two laws of reflection of light. He had a clear concept of refraction of light. He carried out his research on spherical mirrors and gave detailed information about the images formed by them.

In the thirteenth century AD, the Muslims suffered a lot at the hands of Genghis Khan and the Mangols, and consequently, the possibility of revival of scientific researches by Muslims declined as libraries, observatories and laboratories were set on fire. In a few years, millions of Muslims, in different countries, were put to death. Those who survived were mentally paralyzed and lost all interest in life.

The Europeans, however, remained safe from the devastation caused by the Mongols. They had established links with the Muslim scientists especially those of Egypt and Spain from the ninth century AD and started emulating the scientific methods of the Muslims. This created an interest in the study of science among the Europeans. On the whole the result was that the Muslims, who had been the leaders in scientific research for seven hundred years, were thrown in the background. In the fourteenth and fifteenth centuries AD, their place was taken by the scientists of the West. The Islamic era of science came to an end in the fourteenth century and the European period of science started, which continues up to the present time.

The first half of the twentieth century AD was marked by an amazing expansion of our knowledge in the field of physics. The appearance of the Theory of Relativity introduced to us the concept of the relationship between space and time. The discoveries in the atomic and corpuscular scale, that followed, introduced us to a New World, till then totally unknown. Thus we came to know about those electrically charged particles, which we call now electrons, protons, atomic nuclei and units of radiant energy, known as photons. More recently, the discovery of neutrons, positrons and mesons has made new additions to the list of the elementary particles.

The novel quantum theory that developed from the researches of Max Plank, on black body radiations, and the work of Neil Bohr enabled us to build-up a rational conception of the structure of the atom. Next followed Wave Mechanics, which was an improved and modified form of quantum theory. The duality, between waves and particles predicting the beautiful phenomenon of the diffraction of light, further refined the theory of atoms and molecules. Atomic physics next tackled the difficult study of the nucleus of the atom. At the very beginning of this century, the phenomenon of Natural Radioactivity demonstrated, the complexity of the nucleus structure. Physicists soon found the means to disrupt atomic nuclei and identified both the elements of which they are made-up of. The phenomenon that accompanies their transformations was also uncovered.

X-rays discovered by Rontgen in 1895, are short (typically ~ 10^{-10} m) wavelengths of electromagnetic radiation. They are widely used in medicine to (a) locate bone fracture and (b) destroy cancer cells. They are used to locate internal imperfections in welded joints and castings and moulds. The x-ray diffraction techniques identify the ores/minerals and strength of complex organic molecules and are used for the elucidation of crystal structures and for other parametric studies.

The study of Cosmic Rays and their effects on the atmosphere have also brought us important complementary information. Today, in spite of still existing uncertainties regarding the correct interpretation of intra-nucleus phenomenon, nuclear physics is continually making progress. We are all aware of the resounding success it has recently achieved. As for the utilization of nuclear energy, it is certainly destined to usher in an extra-ordinarily futuristic era in history.

Atomic physics has not only been the instrument of marvelous progress on the theoretical side, it has also been equally beneficial with regard to practical applications. The thermionic valve, the photoelectric cell and thousands of appliances utilize the properties of electrons and have been of immense utility in the various fields of electronics and radio-techniques.

In order to explain the operation of semiconductor devices, it is necessary to have some understanding of semiconductor materials and the motion of charges within them. An examination of a specific design procedure, for semiconductor device, involves approximate solutions. It also involves insight into the relationships between the internal processes of the device, and its external electrical characteristics. Circuits are analyzed in terms of the physical properties. It is an acceptable proposition that an engineer must have a deeper understanding of the operation of electron devices than just the ability to use specific devices in the circuits. In order to exercise versatility, he must not only understand what characteristics and parameters are, but also the rationale underlying them. He must understand the reasons for the physical limitations of the devices with regard to voltage, current, and temperature. With this background, he will be easily able to absorb new devices into his repertoire of useful instruments. He will be able to use them to their fullest capacity without over reaching their areas of usefulness.

J.E. Lilienfeld, during the first world war started work on the conduction of current in semiconductors but could not get any positive results. He abandoned this work on account of being unaware of the knowledge of charge trapping mechanisms in local states. However, after a lapse of considerable time, he restarted this work and achieved success. He obtained a US patent in 1930 for his Canadian filed application. In his this patent, Lilienfeld suggested the possibility of discovery of a field - effect transistor, whose performance was dependent upon the modifying of the surface conduction of a semiconductor by varying the applied voltage on the field plate across the semiconductor slab. But this proposed transistor was not developed due to the non-availability of a suitable technology in 1925.

During the second world war, scientists focused their attention on semiconductors. Bardeen, J., Brattain and Shockley, in 1948 discovered the cat's whisker transistor, leading to the development of PNP and NPN transistors and some other varieties of bipolar transistors. This led the scientists and the technologists to Buildup Hybrid Integrated Circuits with discrete electronic components on a copper track vero-board or copper coated board or on a single substrate. This brought a revolution in the electronics industry.

The 50s were the decade in which semiconductor devices rose to prominence after the discovery of transistor action and attained great industrial significance. In that decade, most of the research and engineering work were directed towards the elemental semiconductor viz Germanium. Consequently, a new era of solid-state electronics was initiated. Later on, studies on semiconductor surfaces led the scientists to the advent of Planar Technology———Photolithographic Technique.

One of the early products of Planar Technology was the Insulated Gate Field - Effect Transistor (the so-called, Metal – Oxide - Semiconductor Transistor (MOST), which was first suggested by Lilienfeld in 1928, and was developed in 1963. The action of these devices depends upon modifying the surface conduction of a semiconductor by varying the voltage across the MOST structures. The 1960s can be considered as the decade in which **Silicon** semiconductor devices and integrated circuits i.e monolithic circuits made by **Planar Technology**, overtook **Germanium** devices. This technology brought a revolution and miniaturized electronics viz. physical electronics leading to microelectronics. Thus, from 1960 the era of microelectronics started leading to the miniaturization of electronic components and from 1963 all types of surface field - effect transistors e.g., IGFET / MOSFET, and JFET, CMOS and CCDs appeared in the open market of advanced countries, replacing old fashioned transistors, NPN & PNP. Later, mass production also started and another big revolution once more in the Electronics Industry occured.

Monolithic Integrated Circuits “ICs” were developed SSIC, MSIC, LSIC VLSI and V VLSIC and Microprocessors appeared in industry. Chart I presents a synoptic view of the developments of solid state based devices.

In recent years, there has been dramatic advancements in **physics** and applications of what might be termed opto-electronic devices have expanded exponentially. This has been due to (i) the development of laser, with its rapidly growing list of applications and (ii) the staggering growth in semiconductor device electronics.

The scope of what is meant by **opto-electronics** is not clearly defined. However, we take the optical range to be in the region 0 to 20 μm. The optical systems incorporate electro - optic components such as Pockel's cells and other semiconductor devices. The recent development of optical communications is a prime example of a system which incorporates a wide range of devices. Indeed, our use of the term opto-electronics reflects the types of component and system used in optical communications. Undoubtedly, the enormous potential of optical communications is to a large degree responsible for the rapid growth in the sales of opto-electronic devices. This growth is likely to be sustained by other developments such as video recording and optical data storage. Because of its nature, opto-electronics relies heavily on the twin disciplines of optics and solid - state physics.

Lasers are one of the biggest achievements made in the second half of the twentieth century AD. They are quantum generators, working in the optical region of the light spectrum or simply generators of light.

The principle on which they work is based on the amplification of the electromagnetic oscillations by forced transition in atoms and molecules. This kind of radiation was predicted by Albert Einstein in as early as 1917, when he studied the equilibrium between the energy of atomic systems and their radiation. Therefore, it would be, perhaps true to say that the history of the creation of lasers began in the second decade of the twentieth century AD. Yet at that time, nobody was aware of the potential value of this phenomenon. In 1940, the Soviet scientist V. Fabrikant, analyzing the gas discharge spectrum, pointed out that induced radiation effect could be employed for attaining amplification of light. In 1951, V. Fabrikant together with F. Butayeva and M. Vudynsky, carried out the first experiment in this direction.

In 1952, scientists in three countries — N. Basov and A. Prokhorov in the USSR, C. Townsend, J. Gordn and H. Zeiger in the USA and J. Weber in Canada — simultaneously and independently suggested a new principle of generating and amplifying microwave frequency — electromagnetic oscillations based on the use of the induced radiation phenomenon. This allowed the reaction of quantum generators for the nanometer and decimeter frequency bands, then known as masers. These devices displayed a very high stability of frequency.

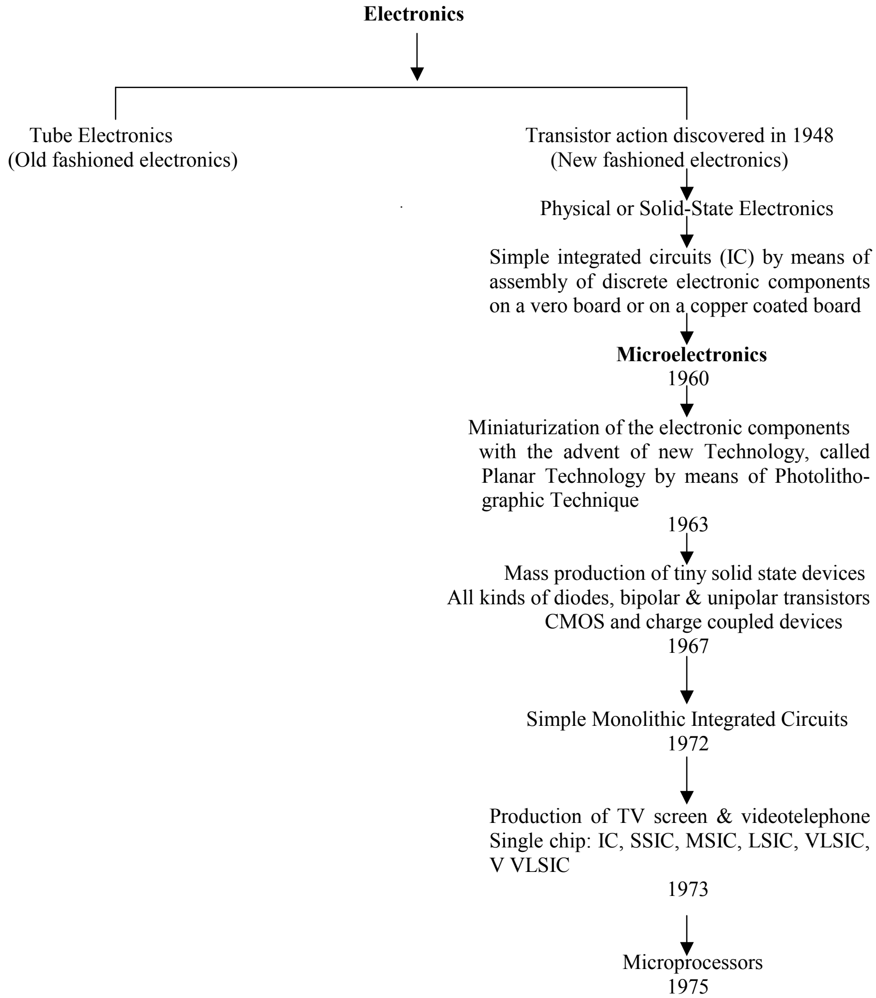
The earliest quantum generators were pulsed radiation, lying in the red region of the optical spectrum. The excitement was produced by means of a powerful light source. With the appearance of the optical quantum generator, the word laser came into existence, which is an acronym of "Light Amplification by Stimulated Emission of Radiation". A year later in 1961, the American scientists A. Javan, W. Bennett and D. Herriott constructed a gas laser with a mixture of Helium and Neon as the active medium. The active medium in the laser was excited by the electromagnetic field of a high frequency generator. This was a continuously working or continuous wave (CW) laser.

At present more than a hundred substances are used in lasers as the active media. Generation has been obtained with crystals activated glasses, plastics, gases, liquids, semiconductors, and plasma etc. as active media. Use can also be made of organic compounds activated with ions of rare earth elements.

Success has been achieved in obtaining generations by employing common water vapours and even air. A new class of gas laser, the so called ion laser, has also been created. The operating wavelength range of the present day optical quantum generators extends from 0.3μm to 538 μm (1.3×10^{15} to 5.57×10^{11} Hz).

One may gather from this short sketch how significant is the contribution made by solid state physics to industrial development in the modern world.

Chart 1. Development of Solid State Technology Based Manufacturing



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