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THE GIFTS OF PHYSICS TO MODERN MEDICINE

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ABSTRACT

The advancement of medical science was, and is, and will always be dependent on the progress of fundamental sciences like mathematics, physics and chemistry. It is true that pure science is not rapidly converted to applied science. That has always to depend on further technological advancement and on craftsmen's innovation. The role of physics in the evolution of some modern medical equipment – both diagnostic and therapeutic, is simply unique. A chemical pathology laboratory comprises, overall physics (i.e. laboratory machinery, pressures, radioactivity, voltage, etc).

Introduction

'The Book of Nature is written in Mathematical Characters' – said Galileo Galilei (1564 – 1642) and nothing is static in nature; nature is dynamic. That earth moves around the sun (helio-centric – Greek – 'helios' – 'sun') was the discovery of Nicolaus Copernicus (1473 – 1543). Nature is in motion. William Harvey (1578-1657) influenced by both Galileo and Copernicus; blood is not static inside the body; it circulates. A physician's mentor was the astro-physicists. Here lies the importance of fundamental sciences in the making of modern medicine. The year – "1543" is the "Anna Mirabilis" in the relationship between Natural Sciences and Medical Sciences when "De Revolutionitus Orbrium Coelestium (On the Revolution of Heavenly Bodies) of Nicholaus Copernicus and "De Humani Corporis Fabrica Libri Septem" (The Seven Books on the Structure of the Human Body) of Andreas Vesalius (1514-1564) were published. It was an auspicious year. The Evolutionary Tree of Medicine is given in ANNEX –I.

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The discoveries of eminent physicists like Wilhem Conrad Roentgen (1845 – 1923), First Nobel Laureate in Physics in 1901, Albert Einstein (1879 – 1955), Nobel Laureate in Physics in 1921, and Georg Von Bekesy (1899 – 1972), Nobel Laureate in Physiology on Medicine in 1961 made significant contribution to the development of many essential medical equipments. Medical men like Niels Ryberg Finsen (1860 – 1904), Nobel Laureate in Physiology on Medicine in 1903, and Willem Einthoven (1860 – 1927), Nobel Laureate in Physiology on Medicine in 1924 also applied principles of physics in the making of medical instruments used in both therapeutic and diagnostic fields.

Medical Equipments

1. X – RAYS

X-rays are invisible electro-magnetic radiation having a much shorter wavelength than light, between 10^8 and 3×10^{-11} metres. It was discovered by Wilhelm Rontgen in 1895. Originally this was called Rontgen rays. An anatomist, Rudolf von Kolliker (1817 – 1905), who was the subject at a lecture demonstration by Rontgen, proposed that the rays be called 'X' and they subsequently received the discoverer's name. They are produced by transitions of electrons in the inner levels of excited atoms or by rapid deceleration of charged particles. A common means of production is by firing electrons into a copper target. X-rays are useful in medicine since different components of the body absorb x-rays, to a different extent, but enough radiation passes through the body to register on a photographic plate beyond. X-rays pass through wood, metal and other materials, unlike light and heat waves.

Being an avid photographer, he set up a film before the screen, laid his wife's hand on the plate, and got the world's first x-ray picture, showing both bones and the wedding-ring! Weeks later (December 28th, 1895) he sent a report to the scientific academy (Medical – Physical Society) in Wurzburg - 'On a New Kind of Radiation' (Ubereine neue Antvon Strahlen) : It was his first communication. The second, on January 13th, 1896, was in Berlin in the presence of Kaiser Wilhelm II. The last time the spoke in public on the subject of x-ray was again in Wurzberg on January 23rd, 1896.

At the end of the presentation his friend Professor von Kolliker lent his hand for the production of a radiography in front of the audience. On March 9 and 10, 1897 Rontgen published two other papers on this subject. That was all …

The news of Rontgen's discovery spread, at first by the press, (ANNEX – II). On January 2, 1896 Rontgen sent a reprint of his report of December 28, 1895 to his fellow physicists, including Franz Serfin Exner (1849 – 1926) in Vienna, Frederich Wilhelm Kohlrausch (1840 – 1910) in Gottingen, Henri Poincare (1854 – 1910) in Paris and Arthur Schuster (1851 – 1934) in Manchester. The information spread from friend to friend, and Exner passed it to Ernst Lecher (1856 – 1926), son of the editor of the Freie Presse of Vienna. This is the reason why the first public mention of the discovery of x-rays was published in Vienna on Sunday, January 5, 1896 in the Freie Presse (ANNEX – II). From these, a small number of European daily papers became aware of the discovery, the first London publication appearing in Monday's Daily Chronicle. On January 6, 1896 a cable from the Evening Standard Correspondent informed the rest of the world. The first notice of Rontgen's discovery in a scientific periodical was published on January 8, 1896 entitled 'Electrical Photography Through Solids' in the Electrical Engineer of New York. The text was the one used for the international news. On January 11, 1896 the same information was published in the medical press - both in the Medical Record of New York and the Lancet of London.

Rontgen took no patent on his work, and it is a tragedy that he died in some poverty in the period of high inflation in Germany after the World War I (1914 – 1918).

The tentative applications of x-rays marked the beginning of diagnostic radiology. They were promoted by a break-through some months after Rontgen's discovery: the discovery of 'radio-active' materials (uranium salts) that generate rays spontaneously by Antoine Henri Becquerel (1852 – 1908), Pierre Curie (1859 – 1906) and Marya Sklodowska Curie (1867 – 1934), who jointly won the Nobel Prize for Physics in 1903. Radiotherapy (later used to treat cancer) began with Becquerel's observation that radium carried in his pocket produced a burn. The S I Unit of radioactivity is the Becquerel unit (Bq) defined as an activity of one disintegration per second. Marie Curie was awarded the Nobel Prize for Chemistry in 1911 for her discovery of polonium and radium – till today she happens to be the first and only double Nobel Laureate in two subjects – Physics and Chemistry (also first lady Nobel Laureate).

Satiric Poem in 'Punch' Magazine, London in 1896

"O Rontgen, then the news is true, and not a trick of idle rumour that bids us each beware of you, and of your grim and graveyard humour. We do not want, like Dr Swift, to take our flesh off and to pose in our bones, or show each little rift and joint for you to poke your nose in".

Other Rays

Many more kinds of rays were gradually recognised, including electro-magnetic waves (such as radio, x-ray and gamma ray photons) as well as particles like electrons and neutrons. In time, rays of varying energy could be produced by sources ranging from low-voltage x-ray tubes to high voltage linear accelerator on radioactive elements like cobalt. The world of atoms and nuclei was brought into service of medicine. Recently, Electron Beam Tomography (Greek – 'tomo' – slicing) EBT, is used to assess the vascular health of the heart.

Ultra Sound

Modern medical ultra-sound has its origin in the work on marine SONAR (SOund NAvigation and Ranging), during the First World War. Ultrasonics is the branch of physics dealing with the theory and application of ultrasound : soundwaves occurring at frequencies too high to be heard by the human ear (that is above 20KHz). During 1930's experiments were initiated into the possibility of using these high frequency sound waves for medical diagnostic purpose.

All sound waves consist merely of mechanical vibrations conducted through a medium. Audible sound waves fall in the range of 20 – 20,000 cycles per second (now termed hertz or Hz); frequencies above this level area called ultrasound. The frequencies employed in medical diagnostic and therapeutic devices normally lie in the range of 1 – 10 million Hz (1 – 10 MHz). At this frequency, the sound can be focused in as much the same way as light. Despite its high frequency, the sound is still conducted merely as mechanical vibrations within the tissues and is therefore devoid of the potentially damaging ionisation associated with x-rays. As the sound travels through the tissues it is partly reflected at any point where there is a change in tissue density, the strength of the echo being proportional to the density change at the interface. As the sound travels at a constant speed in soft tissues, echoes occurring from deeper structures take longer to return to the surface and thus the depth and direction of the tissue giving rise to an echo can be determined by appropriate electronic apparatus like computer. Accurate representation of the structure of body organs (medical scanning) can be made. It is produced and detected by high frequency transducers.

Echo aortography is the application of ultrasound techniques to the diagnosis and study of the aorta, particularly the abdominal aorta. Echo cardiography is the ultrasound cardiography using ultrasound in the investigation of the heart and great vessels and diagnosis of cardio vascular lesions, especially mitral disease, pericardial effusion, and abdominal aortic aneurysm. Doppler ultrasonography techniques are used to augment two dimensional echo cardiogram by allowing velocities to be registered within the echo cardiographic image. Echo encephalography uses reflected ultrasound in the diagnosis of intracranial processes.

Tomography In Nuclear Medicine

Tomography (Greek word – 'tomos' – a cutting (section) and 'grapho' – to write) is a technique using x-rays on ultrasound in which a clear image of structures in a single plane of body tissues at a particular depth is achieved.

It is sectional roentgenography – planigraphy, planography, stratigraphy and laminagraphy taken by having the x-ray tube in a curvilinear motion synchronous with reciprocal film motion while the patient remains motionless; the selected plane for imaging remains stationary on the moving film while structures in all other planes have a relative displacement on the film and therefore obliterated or blurred.

Computerised axial tomography (CAT) is a method of obtaining a three-dimensional view of the interior of an object by building up a series of sectional views. It is an elaboration of x-ray techniques. X-ray is two-dimensional.

Positron Emission Tomography (PET) is tomographic imaging of local metabolic and physiological functions in tissues, the image being formed by computer synthesis of data transmitted by positron-emitting radionuclides often incorporated into natural biochemical substances and administered to the patient; a computer traces the path of photons (produced by collision of positrons emitted by the radio-active biochemical with the negatively charged electrons normally present in the tissue cells) and produces a composite image, often in colour, representing the metabolic level of the biochemicals in the tissues, as an indicator of the presence or absence of disease.

Single Photon Emission Computed Tomography (SPECT) is imaging of local metabolic and physiological functions in tissues – the image being formed by computer synthesis of data transmitted by single gamma photons emitted by radionucleides administered in suitable form to the patient.

Magnetic Resonance Imaging (MRI)

Electrons in motion produce a magnetic field. In a permanent magnet, such as a horseshoe magnet, the field is generated by electron spinning inside the atoms of the magnet. In an electromagnet (a temporary magnet) the field is generated by electrons flowing from atom to atom through wires (an electric current). Such a field is called electromagnetic field. MRI is the technique using a magnetic field to cause resonance within atoms, producing an image by means of the resonance.

Patient lies on a bed placed inside a powerful electromagnet, whose field is of the same frequency as hydrogen – the element most common in living tissue (H_2O = Hydrogen Oxide). Hydrogen is everywhere in the body, and it is detected everywhere, but its concentration varies greatly – very little in bone, more in muscle, more in certain glands and less in others, a great deal in blood, even more in urine and so on. This varying concentration is detected, stored by a computer and analysed and made into a computer-graphic picture. By changing the direction of the magnetic field continually, obtaining numerous pictures, a three dimensional image is obtained. MRI is non-invasive and relatively harmless.

Magnetocardiography is measurement of the magnetic field of the heart; produced by the same ionic currents that generate electrocardiograms, and shows the characteristics – P, QRS, T and U waves. Magnetoencephalogram (MEG) is gausstime ('gauss' – a unit of magnetic flux density named after the German physicist and mathematician Karl Friederich Gauss (1777 – 1855) – equal to one ten – thousandth of a 'tesla' – the unit of magnetic flux density in the SI (Systeme International) System named after the US electrical engineer – Nikola Tesla (1856 – 1943). Magnetoencephalography is the process of recording the brain's magnetic field. Magnet is also used in therapy (magnetotherapy).

Nuclear Magnetic Resonance (NMR) uses the nucleus of a single atom which has its own natural frequency. Frequency of hydrogen nuclei is different from that of oxygen. Because every kind of atomic nucleus responds (resonates) to its own unique frequency, these frequencies are signatures of the atomic elements in a mixture. With the added use of a strong magnetic field, substances can be analysed for their composition, a process called nuclear magnetic resonance. NMR is harmless and can be used to assess the physiological and biochemical functions of different organs. Metabolism and utilisation of oxygen and glucose can also be assessed by this method.

Laser

The name 'Laser' is an acronym of 'Light Amplification by Stimulated Emission of Radiation'. It is a system of coherent application of energy; it is a device which produces light, infrared or ultraviolet radiation with special properties, using a system of excited atoms. The first working model of Laser was built in 1960 by the US physicist Theodore Harold Maiman (1927 -), following theoretical work by Charles Hard Townes (1915 -), Nobel Laureate in Physics 1964 for development of MASER (Microwave Amplification by Stimulated Emission of Radiation) and Arthur Leonard Schawlow (1921 -), Nobel Laureate in Physics in 1981. Atoms absorb energy in well-defined amounts, raising electrons to excited states; the electrons are said to move from one energy level to a level of higher energy. An atom is a unit of matter, consisting of a nucleus of positively charged protons and unchanged (neutral) neutrons, orbited by negatively charged electrons. A complete atom has the same number of electrons as protons balancing the charge. The nucleus is a Pandora's box of sub-particles or elementary particles like Leptons, Photons, Gravitons, Bosons, Gluons, Mesons, Baryons etc. After being excited, an electron usually returns to its original level after less than 10^{-8} seconds, releasing energy as photon of light.

Photon is the quantum or particle of light – a particle that transmits the energy in light, x-rays and other forms of electro-magnetic radiation. Light and other electro magnetic radiation comprises a stream of photons. If photon of energy similar to that of another photon about to be released strikes the excited atom, then the proton production is more rapid; this is called 'stimulated emission' after Einstein's work on photo electricity in 1917. The result is two photons identical in phase moving in the same direction. Should these photons themselves interact with more excited atoms, eventually a cascade of identical photons will be produced, all moving in one direction. Laser action depends on the choice of special atomic systems for which an energy supply is able to raise large numbers of atoms to excited states, ready to emit photons when stimulated. Mirrors at either end of the 'Laser' reflect light end-to-end inside the 'Laser' to maintain its action. At one end, the mirror is partially transparent allowing a portion of light to escape to produce a Laser beam. Typically, energy is supplied to the 'Laser' by electrical discharge or a powerful light source.

'Laser' light is monochromatic (all one colour, coherent in step, produced as a beam which does not spread, and travels large distances undiminished in intensity. The light is produced either as a continuous beam or as pulses.

'Laser' has got many uses; in medicine it is used on phototherapy, eye and brain surgery, and in other aspects of surgery. 'Laser' waves have high energy – can be focused to a microscopic point and are perfectly sterile, and cause minimal bleeding and scarring.

Medical 'Lasers' are made mainly of carbon dioxide, argon or materials like neodymium and YAG (Yttrium – Aluminium – Garnet). They cut tissue rapidly by heating and coagulating it, or by producing photochemical reactions. some of these optical 'knives' or 'cauters' are employed in eye surgery, while others penetrate more deeply for tumour treatment. The beam can also be aimed from inside the body with endoscopy. However, 'Lasers' will never fully replace the mechanical scalpel, but their uses are expanding steadily in all fields of surgery.

Interestingly, it was Einstein who unveiled the fundamental theoretical basis of 'Laser' first in 1905 in his Nobel Prize-winning work – 'On a Heuristic Point of View

Concerning the Production and Transformation of Light' (Annalen der Physik, Vol 17, p891-921, 1905 - all his five epoch-making papers were published in the same volume : 1905 – Anna Mirabilis of Einstein) and then elaborated it in 1917. This turned out to be his sole contribution to medicine. The practical application of his photoelectric theory has been the "electric eye" used for opening and closing doors by remote control, for detecting intruders, for counting and sorting good and for making radio and television possible. Einstein is the theoretical father of LASER; US experimental physicist – Robert A. Millikan (1868-1953), Nobel Laureate in Physics, 1923, confirmed Einstein's theory of the photoelectric effect.

Electrocardiography

Einthoven devised a sensitive string galvanometer by using a fine wire stretched between the poles of a magnet. when a current passed through the wire it was deflected, and optical system magnified this for recording. Electrocardiography is the investigation of the electrical activity of the heart. The electric voltages produced by heart beats can be recorded from the surface of the skin in the form of an electrocardiograph (ECG). Electrodes are attached to the skin of the limbs and chest, and voltages of between various pairs of electrodes are recorded on sensitive electronic machines. Einthoven made electrocardigraphs (ECG's) from the chest wall and from contacts on the arms and legs, and described his results from 1903 onwards. Einthoven and others (especially Thomas Lewis of University College Hospital, London) related the ECG tracings to clinical data for coronary artery disease and other heart diseases. This became an important diagnostic method, and Einthoven won a Nobel Prize in 1924. Electrocardiography is second only to the discovery of x-rays by Rontgen in importance among the physical methods used in clinical medicine.

Fibreoptic Endoscopy

In 1868, Oesophagoscope and gastroscopes (half a metre long pipe fitted with a light and lenses) were introduced. Light conduction was a formidable obstacle for endoscopes. It was solved when transmission along aligned bundles of specially coated flexible glass fibres was achieved [(H H Hopkins and Kapany NS – A flexibile fibrescope, using static scanning. Nature (Lond.) Vol. 173, p39-41, 1954)]. In 1954, Hopkins and

Kapany summarised their achievement and introduced new terminology : '….. an optical unit has been devised, which will convey optical images along a flexible axis. The unit comprises a bundle of fibres of glass, or other transparent material, and it therefore appears appropriate to introduce the term 'fibrescope' to denote it. An obvious use of the unit is to replace the train of lenses employed in conventional endoscopes'.

At present, endoscopes, some with electronic devices like video, are used extensively for both diagnostic and therapeutic purpose. Many more ingenious developments and applications of the technology are currently at the point of availability viz; wireless capsule endoscopy for examination of the small bowel, high magnification endoscopy for detection of minute lesions and confocal microscopy to obtain histological information at endoscopy.

Microscope

Microscope is an instrument for producing enlarged images of small objects. Microscopes range from simple single lens magnifiers to complex electronic instruments. Simple microscope is a good example of an ordinary magnifying glass and has only one lens which can magnify clearly perhaps 10 – 20 times. The compound microscope has sets of convex lens at each end of a tube. The first set of lens (the objective) forms an enlarged image of the object, and the second set (the eye piece) enlarges the image. The compound microscope was first made into an effective instrument by Galileo Galilei (1564-1642). It was, as it were, a by-product of his invention of the telescope. Both simple and compound microscopes make use of light waves and are therefore called light or optical microscopes. Magnifying power is limited to about 2000 times and if pushed higher, images become fuzzy because these microscopes cannot form images of objects that are smaller than the light waves. In 1925, Joseph Bernard, a London microscopist devised the ultra violet microscope achieving 2,500 times magnification and larger viruses could be seen for the first time by naked eye. The Belgian, L. L. Morton (1901-1979) used the physical principles of electrons to devise the electron microscope. Electrons have a wave motion similar to that of light but have a wavelength which is 10,000 times shorter. Objects could now be magnified many times over. By the end of 1930's a magnification of close to 40,000 times was achieved, so that the innermost secrets of the human cells and of small particles called viruses were laid bare to the scientific eye. To get higher magnification, something even smaller than light waves – beams of electrons need to be used. Electron beams cannot be used in optical microscopes because, unlike light waves, they are not bent by glass tubes. But electromagnetic fields can bend them, to form images. In electron microscopes, ring shaped electro-magnets act as lens with beams of electrons spreading them out into cones, like the cone of water in the showerhead. However, the images formed by electrons are invisible to human eyes. To make them visible, the images are formed on a glass screen coated like a television tube with material that glows when struck by electrons. These are two basic kinds of electron microscopes, both capable of magnification of 1 million times or more. In transmission electron microscopes, the electron beams are transmitted through extremely thin slices of the material being examined. In scanning electron microscopes, a thin beam of electrons sweeps back and forth over the specimen. The electrons scan the material without penetrating it, so there is no need to slice it thin. This makes it possible to examine and photograph very small living objects. The images produced by this instrument have a strongly three-dimensional character.

In video-intensification microscopy the coupling of image intensifiers and video techniques to light microscopy systems makes it possible to amplify dim images a million fold. Minute quantities of fluorescent material can be located and it is possible to continue to examine light-sensitive fluorescent material over long time intervals using weak illumination. The use of computers has developed better and more flexible lens systems and also video-enhanced microscopy systems where random background information is subtracted electronically from the image, giving greatly improved image quality. Lasers have been employed to record three-dimensional photographic plate – that is the application of holographic methods. they may also be used to vaporise selected parts of a specimen. Spectrometers built into the systems analyse the vapour and hence allow correlation of structure and chemical composition. Recent innovations include scanning acoustic microscopy where the object is scanned by a tightly focused acoustic beam, the method being capable of giving information from the interior of optically opaque material. In electron microscopy, the use of a variety of histo-chemical and immunochemical methods allows the identification of specific chemicals in their subcellular locations.

Microscope is also used in the surgery of minute structures (microsurgery).

Spectroscopy

It is the study of energy levels in atoms or molecules, using absorbed or emitted electro-magnetic radiation. Inner atomic electrons give spectra in the x-ray region; outer atomic electrons give visible light spectra; the rotation and vibration of molecules give infrared spectra; the precession of nuclear magnetic moments gives radio-wave spectra. Many types of spectroscopy exist, often used to identify the structure of an unknown substance or to detect the presence of known substances, drugs etc. It is widely used in clinical chemistry.

Finsen Lamp

It is a high power device to emit concentrated or converged and filtered rays which have bactericidal properties. Ultraviolet sections of sunlight have strong bactericidal power. Finsen, a Dutch physician, is considered as the founder of modern photo-dynamic therapy. Modern treatments like radiation and drug therapy owe a lot to Finsen's pioneering work with light therapy. He was awarded the Nobel Prize in Physiology on Medicine in 1903, in recognition of his contribution to the treatment of diseases especially lupus vulgaris, with concentrated light radiation whereby he has opened a new avenue for medical science. From the age of 23 years he was an invalid and directed from his bed the Light Institute which he founded in Copenhagen in 1896.

Audio Meter

The new audiometer that can be operated by the patient was designed by the Hungarian scientist George von Bekesy, Nobel Laureate in Physiology or Medicine in 1961 and is based on his discovery of the physical means by which sound is analysed and communicated in the cochlea, a portion of the inner ear. The vibratory tissue, most important for hearing, is the basilar membrane stretching the length of the snail-shaped cochlea and dividing into two interior canals. Bekesy found that sound travels along the basilar membrane in a series of waves, and he demonstrated that these waves peak at different places on the membrane; low frequency to the end of the cochlea and high frequencies near its entrance or base. He discovered that the location of nerve receptors and the number of receptors involved are the most important factors in determining pitch and loudness. His research led to the construction of two cochlea models and highly sensitive instruments that made it possible to understand the hearing process differentiate between certain forms of deafness, and select proper treatment more accurately.

Ophthalmoscope

'In the whole history of medicine there is no more beautiful episode than the invention of the ophthalmoscope, and physiology has few greater triumphs', thus wrote American ophthalmologist Edward G Loring in hi 'Textbook of Ophthalmology Part 1' in 1892 (London, England : Henry Kimton), 2 years before the death of Herman Ludwig Ferdinand von Helmholtz (1821-1894) – the great German physicist and physiologist of the 19th Century. Helmholtz first demonstrated that there were three essential elements to the working of an ophthalmoscope : a source of illumination, a reflecting surface to direct light toward the eye, and a means of correcting an out-of-focus image on the fundus. Over the last 100 years or more since his time, the essential elements have been achieved. In the process candle lamp oil lamp, gas lamp were used for illumination – prisms and lenses for reflecting light. Method of correction needed mirrors and condensing lenses.

An ophthalmoscope is basically an apparatus for illuminating the retina using a battery and small bulb. For normal vision the ophthalmoscope consists simply of a small hole to look through and a source of illumination. The light is reflected into the eye by a mirror. The observer looks directly through the hole in the centre of the mirror. The ophthalmoscope has lenses to correct for visual defects of either the observer or subject.

Miscellany

Human body is a physico-chemical consortium. Hence the basic principles of physics and chemistry are widely applied in the detection of any irregularity or aberration inside the consortium as well as in its correction or normalisation. Electrical activity is assessed for diagnostic purpose : electro-encephalography (EEG) for recording the electrical activity of the brain, using electrodes applied to the scalp, and usually recorded as a tracing on paper; electrolaryngography for recording the vibrations of the vocal cords electronically – electrodes are attached to the neck on each side of the thyroid cartilage, and the vocal cord as traces on the screen – the rises and falls of the fundamental frequency of the vibrations (corresponding largely to the intonation of the voice) – now widely used in speech science, in relation to both normal and abnormal use of the voice; electromyography to study muscular contractions which take place during speech – muscles produce tiny amounts of electrical activity when they contact – activity recorded by applying electrodes to the individual muscles of the vocal tract and displaying the signals on a screen or on paper.

In December 1896, W. B. Cannon (1871-1945), still a student of Harvard Medical School, noted that if bismuth salts were fed to animals, they allowed a visualization of the gut on a fluorescent screen. This technique was applied to humans from 1904, barium sulphate being used to opacify the gut so that structural abnormalities in the stomach, duodenum and the rest of the intestine could now be diagnosed.

Electro convulsive therapy (ECT) is a highly successful treatment for patients with severe mental depression in which a current is passed through the brain of an anaesthetised patient. In 1937 Ugo Cerletti (1877- ?) and Lucio Bini (1908 - ?) of Rome first used an electrical method (110 volts for half a second) to produce convulsion.

The Nuclear Medicine

The use of radioactive tracers in diagnostic and therapeutic medicine is widespread to day since 1971. This new medical speciality was recognised by the American Medical Association through the establishment of the American Board of Nuclear Medicine. About one in three hospitalised in a modern hospital will have a diagnostic procedure performed in which a radio-active tracer has an essential role, i.e. assessment of haemodynamic response of the heart during exercise in the diagnosis of coronary artery disease, by a scintillation camera assessment of blood flow in the lungs in pulmonary embolism, plasma levels of hormones to assess hypo or hyperactivity of endocrine glands and so on.

The Hungarian radio-chemist – Gyorgy de Hevesy (1885-1966), Nobel Laureate in Chemistry in 1943, is the father of the development of techniques and methods for the practical use of radioisotopes in analysis. In his Nobel Lecture Hevesy stated: 'The application of isotopic indicators opens new lines of approach not only to the solution of known problems but also by directing our attention to trains of thought not previously considered. Isotopic indicators open the only way to determine the rate, place and sequence of formation of many molecular constituents of the living organisms. The very existence of such methods was instrumental in opening new trains of thought in demonstrating the dynamicity of metabolic processes in concentrating our interest on the problem of velocity of fundamental biological processes'.

The use of radioactive tracers – Nuclear Medicine rather Medicine of Radiophysics – has made possible an improvement in perception and conceptualisation of disease in ways we never dreamt of only a few decades ago. Nuclear imaging provides us with symbolic representations of pattern and changes in the spatial and temporal distribution of the chemicals that make up living organisms. To picture a biological system, including human, at a single instant in time is inadequate; we must also concern ourselves with the perception of events that occur one after the other; motion and dynamic change are the essence of physiology. Limiting our perception to static patterns is equivalent to assuming that nothing ever happens. Therefore, our images must be concerned with time, with the order of events and their duration, with the periodicity of body processes, such as the beating of the heart, the emptying of the gall bladder, and so forth.

The distribution of x-ray densities as in computerised axial tomography, or the spatial and temporal distribution of chemical substances within the body as in nuclear medicine imaging or the distribution of body surfaces that reflect sound waves, as in ultrasonics, the use of electromagnetic spectrum as, source of information about the patient's bodily structure and function are some of the gifts of physics to modern medicine. Microscopes and biopsy techniques are the new essential tools in the hand of clinicians to precisely understand the pathophysiology of diseases at the cellular level. Radiochemicals (Technitium – 99m) and radio – pharmaceuticals offer added advantage.

Advances in the field of medicine have been along three lines : better chemicals, better instruments and better quantification. Tomography in nuclear medicine is of two types : single photon emission computed tomography (SPECT) and positron emission computed tomography (PECT). The latter permits more accurate quantification, but the former provides significant improvement over planar imaging, where the three-dimensional distribution of radio-activity is projected on to a single plane. Positron tomography has made possible measurement of regional glucose metabolism in regions of the brain, such as the frontal lobes, auditory cortex, striatum, thalamus and visual cortex. It has been possible to show the biochemical events related to the psychological processes of vision and hearing, a major achievement in the history of psychology and philosophy. In the study of brain, both SPECT and PECT have their greatest impact. It is now possible to demonstrate by imaging dopamine, serotonin and opiate receptors in the living human brain.

Physics And New Dentistry

State-of-the-art dental technology now offers faster, better and less intrusive services. Physics and modern technology has made dental procedures safer, more-effective, faster and hassle free for most patients. Radiovisiography (RVG), intra-oral camera, CAD-CAM, electronic anaesthesia, fibre-optic hand piece and Lasers are now used to treat common dental maladies.

RVG or computerised digital radiography makes use of an electronic sensor instead of a conventional X-ray film. The electronic sensor captures the X-ray and sends it to the computer. This technology gives an incredible advantage over conventional X-rays in diagnosis as a sharp and clear image of the concerned tooth and periodontal structures is available on the screen in seconds. The dental surgeon can zoom in on a certain portion of the image and manipulate the image in a wide variety of ways to diagnose the underlying pathology before commencing treatment. This technology also conspicuously reduces patient and staff radiation exposures and keeps environment green by eliminating chemical wastes.

Another technology-driven diagnostic aid is the intra-oral camera. It is a tiny video camera which tours the mouth picking up images that could be enlarged on a television or a computer monitor enabling the patient to view his own oral exam. Periodontal disease, cavities, plaque, stain, fractured restorations and other oral conditions can be diagnosed early with this terrific tool. Intra-oral images help the patient better understand his dental condition and treatment options as he can see what the dental surgeon is describing.

Electronic anaesthesia uses a device, which has a receptor placed on the patient's gum and another unit held in the patient's hand with which the comfort level can be adjusted. The system sends out a "wave" to block the body's naturally occurring electrical pain signals where the dental treatment is being done. The patient does feel a tingling sensation on the gum.

Electronic anaesthesia is the most modern dental technology and is under consideration for future use in dentistry.

The dental air turbine hand piece is a *sine qua non* for the dental surgeon. It is an equipment that is indispensable in operative dentistry. The airotor hand piece has a bur fitted into its head. When the hand piece is connected to the motor, the bur rotates at a high speed of 370,000-430,000 rpm (depending on the hand piece type). The bur is usually made of tungsten carbide or diamond grits. The hand piece is held by the dental surgeon like a pen and is carried into the oral cavity to the carious tooth where the rotating bur's firm cutting action removes carious lesions in seconds. The airotor hand piece also has a water spray directed towards the bur tip to minimise the heat generated during cutting. The chic dental hand piece made of stainless steel body is one of the most prized possessions of a dental surgeon. The latest technological advancement has been the development of Fibre optic high-speed air turbine hand pieces. This classy equipment has fibre-optic lightening systems, which illuminate the cavity while the dental surgeon prepares it. The lights look like the headlights of a car directed towards the bur tip. Now, cavity cutting will be more precise and faster.

Electronically pre-programmed dental chair is available where the patient can be positioned in the ideal posture for a particular treatment simply by pushing a button. The modern chairs are fully equipped called a mobile dental clinic.

Lasers are being used in dentistry to perform periodontal surgery (like gingivectomy) to expose dental implants, to relieve the pain of a pathos ulcers and mouth sores, to collect biopsy samples and many such dental procedures. It is presumed that very soon laser might be used to cut cavities where a flash of light would be enough to remove caries. Carbon dioxide and argon lasers are the commonly used ones in dentistry.

CAD-CAM (computer-aided design and computer-aided machining) system is nowadays being used in prosthetics for crown and bridgework. A CAD-CAM system digitally records the image of the prepared tooth and stores it in the memory of a computer. The image data can be retrieved immediately to grind a metal, composite or ceramic prosthesis by computer control from a solid block of the chosen material. The prosthesis can be fabricated within minutes and placed on a prepared tooth and bonded in the mouth of the patient within one hour.

So technology is an integral component of modern dentistry. Application of the principles of physics has ushered in an era of new dentistry.

The Future

The ongoing contribution of fundamental and applied sciences to the steady advancement of contemporary medicine is going to usher in a new era of excellence in this millennium.

Mathematics, Physics and Chemistry form the sheet anchor of any science including Medical Science. The award of Nobel Prizes in Physiology or Medicine and in Chemistry in 2003 is again a glaring example. Mathematical precision is the core of all medical assessments to be perfect and flawless. The Hardy – Weinberg law (equilibrium) formulated independently by the English mathematician Godfrey Harold Hardy (1877 – 1947) and the German physician Withelm Weinberg in 1908, established the mathematical basis for studying heredity in population. Influence of heredity is, of course, recognised since prehistoric times.

The development of Magnetic Resonance Imaging (MRI) is a breakthrough in medical diagnosis and research. Atomic nuclei in a strong magnetic field rotate with a frequency dependent on the strength of the field. When such nuclei return to their previous energy levels, radio waves are emitted. For discovery of nuclear magnetic resonance in solids, Felix Broch (1905-1983) and Edward Mills Purcell (1912-1997) of U.S. were awarded jointly the Nobel Prize in Physics in 1952. Magnetic resonance was initially used mainly to study the chemical structure of substances. In recent years it is used successfully in medical imaging and for this, two physicists – Paul C Lauterbur (1929- ?) of U.S. and Peter Mansfield (1933 - ?) of England were jointly awarded the Nobel Prize in Physiology or Medicine in 2003.

They took a chemists' technique to study solutions and developed it in a way to image the body, which, contrary to appearance, is mostly water (about 70%). Unlike CAT (Computerised Axial Tomography) scanner which employs radiation, Magnetic Resonance Imaging (MRI) examines the body only with magnetic fields and radio wave pulses and has replaced invasive techniques for examining joints, the brain and other vital organs. The technique is so sensitive that it can locate the site where different mental tasks are performed in the brain by essentially tracking the extra blood flow to the active regions. Lauterbur obtained spatial information to build an image of the molecules arranged in a structure. Mansfield supplied a major step to make Lauterbur's concept a practical reality. He showed how to speed up the imaging process by developing new mathematical techniques to analyse the information from rapidly varying magnetic fields.

Humans consist of about 70 per cent salt water. Transport of salt (ions) and water out of and into the cells of the body is very important in understanding many disease processes in the body. For detailed study of potassium land water channels in cell membranes by standard genetic techniques, medically qualified Roderick Mackinion and biochemist Peter C Agre, both of U.S. were jointly awarded Nobel Prize in Chemistry in 2003. Their work has immense implications in understanding the diseases of kidney.

Bioinformatics (use of computers in solving information related to problems in the life sciences) involves creation and analysis of extensive databases on genomes and protein sequences. It is crucial to acquire massive biological data sets. This includes protein structure data, protein – protein interaction data, protein – DNA interaction data, data on enzymatic and biochemical pathways, webs of neurological structures and pathways, population – scale data, large scale gene expression data, ecological and environmental data, etc, etc.

Biological modelling (Biotechnology), used in solving any problems in biology, require mathematical modelling and computer simulation. Modelling techniques can be helpful in proposing and testing hypothesis in molecular biology, such as inferring biological function, in drug – designing and testing remote protein relationship.

Biomedical Engineering is getting more and more dependent on computer hardware and software such as in modern pacemakers, some artificial limbs and implanted instrumentation in the muscles of paralytic patients. Modern radiology, is, in fact, applied biomedical engineering fully dependent on computer hardware and software as used in ultrasonography, laparoscopy, scanning, x-ray, etc. Other fields are tele surgery, tomography, virtual anatomy and other medical visualisation. Tele medicine, a big promise in future health care, also uses computers and Internet extensively.

Biometrics is another exciting area. It is an automated method of identifying a person with his or her unique physiological or behavioural characteristics such as finger printing, hand geometry, ear contour, hand writing, iris, retina, vein, voice and DNA.

Algorithm is a process or a set of rules used for calculation or problem – solving especially with a computer. Genetic Algorithm can evolve Cellular Automata which describes an n – dimensional space divided into regular cells. Each cell is characterised by one or several state variables. The cells synchronously change state based on information from the neighbouring cells.

Molecular biophysics, nanolithography and electron lithography constitute biomolecular electronics, a promising development in Information Technology (IT). Analysis of an array of protein molecules has given rise to the idea of development of computing chip containing billions of protein molecules, offering the possibility of developing very small but an extremely fast computer. A biochip would be able to perform thousands of biological reactions such as decoding genes, in a few seconds.

A self-assembled single metallo-protein transistors should be able to operate at room temperature and its performance is expected to be superior to those of single electron transistor based on semi conductors.

Nanotechnology is the building of devices on a molecular scale – micro-machines such as gears smaller in diameter than a human hair. A robot small enough to travel through the blood stream and into organs of the body, inspecting or removing diseased tissue is under development. The scanning electron microscope can be used to see and position single atoms and molecules, and to drill holes a nanometer (billionth of a metre across a variety of materials including human body).

Bio-electromagnetics is concerned with the effect of use of cell phones on human body. It is a new hazard to youngsters among whom cell phones are a "status complex" all over the globe.

With the advances in genetic engineering technology, large number of macromolecules from various sources – plants, etc. have been identified to have therapeutic properties. However, the development of dosage forms for such molecules and their penetration into the site of intended action inside the body (bio-availability) is a formidable challenge for the pharmaceutical industry. Transdermal Iontophoresis is a technique (by using low intensity electric current) that can facilitate the delivery of such molecules through the skin. A drug reservoir is placed on the skin upon which an electrode is placed. The basic principle involved is electro-repulsion. The drug ions get repelled by the electrode and are driven into the skin. Hence a positive drug ion should be repelled by an anode (anodal Iontophoresis) and a negative drug ion by a cathode (cathode Iontophoresis).

We seem to be advancing towards the centre of the mystery of health and disease. Only time will tell. Over-optimism today may land us in the den of disappointment tomorrow. A word of wisdom from Max Karl Ernst Ludwig Planck (1858-1947), Nobel Laureate in Physics, 1918 is relevant:

"Science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are part of the nature and therefore part of the mystery we are trying to solve".

Let us be optimistic. But we should always remember our limitations.

Secondly, in spite of spectacular progress so far, the message of modern medicine has not yet reached every hearth and home on this planet; the vast rural world

(80% of population live there) is still beyond its reach. It is a formidable task in this century. It is the main medico-socio-moral obligation to each and every one of more than 6 billion souls on this planet. Health cannot be allowed to become a purchasable private commodity in a globalise economy.

Thirdly, the cardinal principles of medical ethics in medical treatment – autonomy, beneficence, non-malfeasance ("do no harm") and justice, cannot be universally applied at present in the developed, developing and underdeveloped worlds because the North-South socio-politico-economic divide is so wide. This gulf of difference needs to be eliminated first.

The Epilogue

The contribution of physics and other basic sciences to modern medicine is immense. It has gathered pace with the march of centuries. Throughout our contemporary era, the science of medicine is inseparable from the science of physics and some of the other natural sciences.

We have come a long way – but still longer to go. The contemporary state of affairs is best expressed in the poetic words of the famous poet – Thomas Stearns Eliot (1888-1965), Nobel Laureate in Literature in 1948:

'Dust in the air suspended

Marks the place where a story ended'

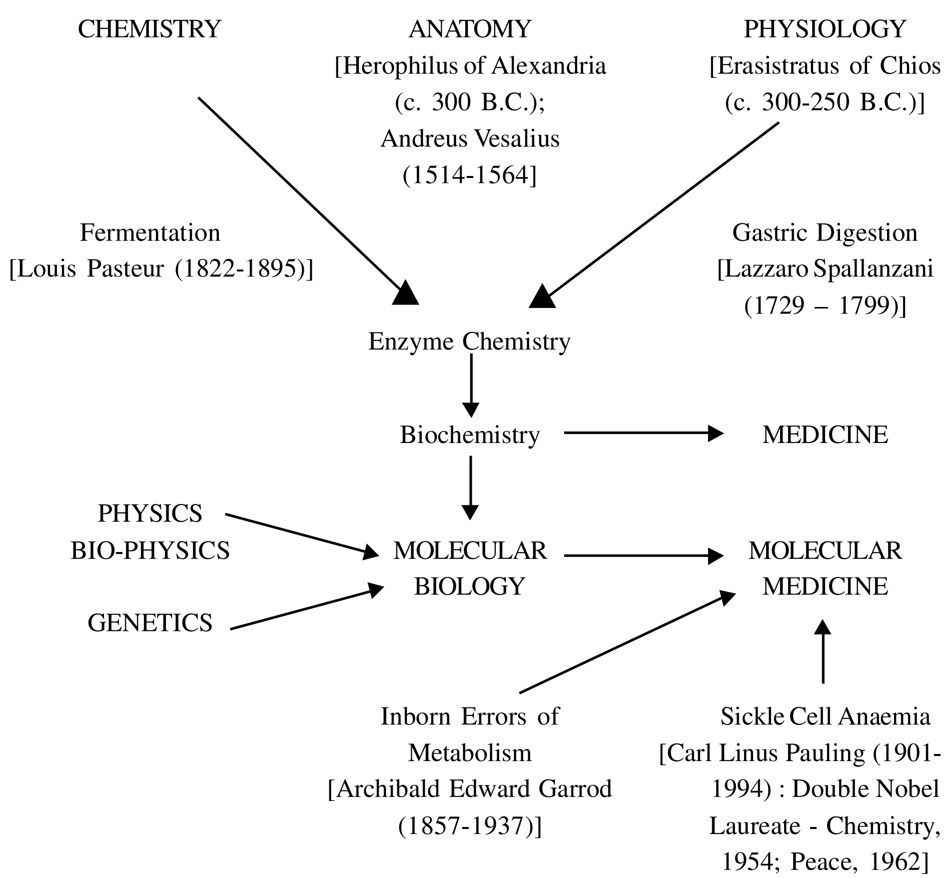
(Little Gidding (1942), Four Quartets, Part II)

But the past supplies the key to the present and to the future. The long march is on. Litterateur – Statesman – Winston Leonard Spencer Churchill (1874-1965) Nobel Laureate in Literature in 1953, has already infused a ray of optimism for all of us while addressing the Royal College of Physicians in March 1944:

'The longer you can look back, the further you can look forward'.

ANNEX - I

HISTORY OF DEVELOPMENT OF MODERN / RATIONAL MEDICAL SCIENCE [HIPPOCRATIC (c460-370 B.C.)]



सारांश

आयुर्विज्ञान की उन्नती में भौतिक शास्त्र की योगदान

शिशिर के मजुमदार

आयुर्विज्ञान की उन्नती गणित शास्त्र, भौतिक शास्त्र एवं रसायन शास्त्र जैसे बुनियादी शास्त्रों के प्रगति पर है ही निर्भर है, और रहेगी। यह सच है की मूलभूत विज्ञान का परिवर्तन प्रयोगविज्ञान में तुरंत नही हो सकता। यह विषय सदा कारीगरों की खोज एवं तकनीकी उपलब्धियों पर आधारित है।

आधुनिक निदानात्मक रसायन प्रयोगशाला में व्याधिनिर्धारण के लिए जो संसाधन, यन्त्र एवं उपकरणों का प्रयोग होता है उनके निर्माण एवं विकास में भौतिक शास्त्र का ही सम्पूर्ण योगदान पाया जाता है।