Evolution of Physics and its Impact on Society

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- “The goal of physics is not only to observe nature but to understand it. Mathematics is often the most suitable way to formulate natural laws, but theoretical systems of concepts are more essential, and these often must be adapted as science progress”.

(Heisenberg)

- Modern science is relatively new; its roots date back to the 17^{th} Century. Galileo is regarded as its father. In contrast to science, technology is very old. The pyramids in Egypt are one example of ancient technology. Before Galileo, there were two periods which we must mention in relation to the development of science.
- Ancient Greeks made remarkable contributions to human civilization: (philosophy, mathematics, science) introduced deductive method.
- From axioms which they regarded as a priori, they deduced results in self consistent manner. Eucledian geometry is one example of a perfect system. For them, pure thought was much superior than work with hands. However, Archimedes' law on floating bodies was based on experiment. Greeks also made remarkable contributions to Astronomy. Aristotle argued that orbit of a planet must be a circle because circle is a perfect curve.

- When Europe was in dark ages, the Muslim Civilization was aware of Greek knowledge.
- In the West, the access to Greek knowledge came through Muslims. [Ibn Sina (Avicenna), Ibn Rushd (Averros), Ibn al Haitham, Khawarizmi, Al Baruni, Omer Khayam].
- But Muslim Civilization could not sustain development of science for a simple reason that although they were better experimentalists than Greeks they did not go beyond observations. In general, they did not deduce scientific principles from observations (a notable exception is derivation of laws of reflection and refraction in optics by Ibn al Haitham). They were more interested in practical applications rather than building a scientific edifice.

- To build a scientific edifice, it is essential to go beyond the existing thought. The ruling class was not prepared to tolerate any thought which would initiate departure from orthodoxy prevalent at that time. They have no problem with practical use of technology avoiding rational and intellectual aspects of science and knowledge. As a consequence, the Muslim contribution to human civilization declined so rapidly that since 13^{th} century they had hardly made any contribution to secular human knowledge.

- For two thousand years, no body challenged the authority of Aristotle. His law of falling body that a stone weighing for example 100 gms would fall 10 times faster than a stone weighing 10 gm, was first challenged by Galileo. He performed a simple experiment. He went up to the top of the leaning Tower of Pisa, dropped two stones weighing 10 and 100 gms and demonstrated that the two stones fell to the ground practically simultaneously. From this experiment he deduced the law of falling bodies. All bodies fall at the same rate in a vacuum and at the end of a given time, have velocity proportional to time and distance proportional to square of the time.

- Galileo did not perform the experiment in vacuum but in air and he went beyond observation when he enunciated the law of falling body by adding the word vacuum. The deduction of scientific law from observations and experiments is basic to science. Since Galileo was first to do that, he is rightly regarded as father of modern science. Galileo also came into trouble with the Church, when he concluded that Earth is not at the Centre of Universe. Earth is one of the planets which revolves around the sun. To save his skin he renounced his theory and when he came out of prison, he said “but it still moves.”

- At about the same time, Kepler from large amount of astronomical data, formulated his famous three laws: the planetary orbit forms an ellipse (again Aristotle was wrong); equal areas are swept in equal times; the time to go around varies as $a^{3/2}$, where a is the semi major axis of the ellipse. The year Galileo died, Newton was born.
- He formulated his three laws of motion in a precise form. As Weinberg put it, the profound cultural effect of the work going back to Newton is that nature is strictly governed by impersonal mathematical laws. Newton’s Law of gravitation is the first dynamical law. As every student of physics knows Kepler’s three laws of planetary motion and Galileo’s law of falling body are just consequence of Newton’s law of gravitation. The terrestrial phenomenon of gravitation was unified with celestial gravitation.

- Newtonian mechanics is a perfect system, where-ever it is applicable it gives precise results. But it has its limit of applicability; it breaks down for bodies travelling with high velocities comparable to velocity of light and at microscopic level involving atoms and elementary particles. The formulation of Newtonian mechanics by Lagrange and Hamilton was crucial for the development of quantum mechanics. We will come to this point later.

- The development of calculus, essential for describing the motion was developed both by Newton and Leibniz. Leibniz's method was superior to that of Newton. The following observation of Bertrand Russel is pertinent for the development of science and society: "The English was misled by patriotism into adhering to his where they were inferior to those of Leibniz, with the result that after his death English mathematics was negligible for hundred years. The harm that in Italy was done by bigotry, was done in England by nationalism. It would be hard to say which of the two proved the more pernicious."
- In 19th century two great conceptual revolutions associated with Darwin (theory of evolution by natural selection) and Maxwell (unification of electricity and magnetism) took place.
- Electric environment is manmade. In nature, electricity is seen in lightening. Certain stones called magnetite exhibit magnetic properties. Nothing seems to be common between them.

- Basic laws governing electromagnetic phenomena were formulated (Coulomb, Ampere, Faraday) in 19th century. Faraday's law of electromagnetic induction is a discovery of great importance as it made possible to generate electricity directly from mechanical energy.
- Electric energy has a great advantage that it can be transported to homes and is used in numerous ways.
- We live in an environment created by electricity; entered into the first phase of domestication of technology.
- Maxwell expressed the basic laws of electromagnetism in terms of four differential equations. These equations encompass the whole of electromagnetic phenomena. It shows the power of mathematics.

- A consequence of Maxwell’s equations is that electric and magnetic fields propagate through space as waves with speed of light.
- Hertz experimentally demonstrated the existence of electromagnetic waves. His work gave stimulus for practical applications of Maxwell’s equations.
- This is how electronic communication was born: One of the far reaching impact of Maxwell’s equations is to give birth to a powerful tool in the form of electronic media for entertainment, to shape the opinion of the people for political aims or ideological indoctrination or for marketing of products especially by multinationals.

- In order to appreciate how a discovery become useable, I would like to quote from a play. The Swiss dramatist Friedrich Durrenmatt has written a play called “Physicists.” The plot as I understand is as follows:
- A physicist who is a genius made a discovery of great importance. But has a fear that his discovery may be used for destructive purpose.
- To escape from the madness of sane people; he pretends to be insane and takes refuge in an asylum. Later on two more physicists are admitted in the same asylum. In actual fact they are not insane but pretend to be so; they are spies sent by two governments to spy on the first physicist. One of the spies called himself Newton. When the nurse attending him was about to find out that he is a fake, he murders her.
- When police came to investigate, the following conversation takes place between the police inspector Richard and Newton.

- Newton: When you work that switch by the door, what happens, Richard?
- Inspector: The light goes on.
- Newton: You establish an electric contact. Do you understand anything about electricity, Richard?
- Inspector: I am not a physicist.
- Newton: I do not understand much about it either. All I do is to elaborate a theory about it on the basis of natural observation. I write down this theory in the mathematical idiom and obtain several formulae.
- Then the engineers come along. They don’t care about anything except formulae. They simply exploit it. They build machines – and a machine can only be used when it becomes independent of the knowledge that led to its invention.

- So any fool now-a-days can switch on the light or touch off the atomic bomb. (He pats the inspector’s shoulders). And that’s what you want to arrest me for, Richard. It’s not fair.
- At the end of the 19th century and beginning of the 20th century some remarkable experimental discoveries were made which have a profound effect in the future development of science and technology.
- Roentgens discovered X-rays in 1895.
- Radioactivity was discovered by Becquerel in 1896. Radioactivity was extensively studied by Marie and Pierre Curie, Rutherford and Soddy.
- In 1897, J.J. Thomson discovered the electron – the first elementary particle.
- The discovery of atomic nucleus was announced by Rutherford in 1911.

- Neutron was discovered by Chadwick in 1932. Radioactivity is the only nuclear phenomenon which is found on the earth. Nuclear environment exists in star. With the development of nuclear reactors and nuclear weapons an environment is created by human being", which is alien for earth.
- By the turn of 20^{th} century, the basic structure of physics, in which theories are formulated in terms of differential equations, predicting the future behavior in terms of states at a given instant of time was well-established. For the observable phenomena, the law of causality holds.
- Lord Kelvin pointed out in the basic structure there are "two clouds at the horizon", one is failure to detect the existence of ether by the Michelson – Morley experiment and the other is inability to use existing theory to explain energy distribution of black body radiation.

- These two clouds led to two conceptual revolutions
- Theory of Relativity and Quantum Mechanics
- The credit for the first revolution goes to Einstein. It changed our concept of space and time.
- The second revolution, Quantum Theory (Heisenberg, Schrodinger, Dirac) was more profound.
- It changed our way of thinking not only in physics but also in chemistry, biology and philosophy.

(Freeman Dyson)

- Determinism of classical mechanics is replaced by uncertainty principle i.e. when events are examined closely, uncertainty prevails; cause and effect become disconnected; causal relations hold for probabilities; waves are particles and particles are waves; matter antimatter are created and destroyed (vacuum polarization); chance guides what happens.
- By unifying special theory of relativity with quantum mechanics, Dirac predicted the existence of antimatter.
- The unification of terrestrial and celestial gravity by Newton; the unification of electricity and magnetism by Maxwell; the unification of geometry with gravity by Einstein, the unification of special theory of relativity with quantum mechanics by Dirac were hallmark of physics.

- In the same context the unification of electromagnetism with radioactivity was achieved by Glashow, Salam and Weinberg in the late 1960’s.
- Basics of electroweak unification are:
- Edifice of particle physics is built on following principles:
- Chiral Fermions: Left handed – Right handed fermions belong to different representations of gauge symmetry group, to take into account that weak interactions distinguish between left and right.
- Local Gauge Invariance: To find appropriate gauge symmetry group
- Spontaneous breaking of gauge symmetry
- Renomalizability

- Abdus Salam has made significant contributions in all these fields.
- Gauge Invariance:
- Electric charge is not only conserved, but it also determines the strength of electromagnetic interaction.
- The salient features of local gauge invariance are: Irrespective of nature of particle, the strength of electromagnetic interaction is determined by the electric charge.
- Electromagnetic interaction is mediated by photon, the quantum of electromagnetic field. Photon is massless and has spin 1 with only transverse polarization.

- Underlying gauge symmetry group U (1)
- Fundamental constituents of matter are leptons and quarks (spin ½).
- Understanding of fundamental constituents of matter and their interactions lies in discovering a gauge symmetry group.
- Both electromagnetic current and weak currents are vector in character, the weak current being V-A to take into account the violation of discrete symmetries C and P.
- Underlying gauge group for electro-weak Unification (Standard Model), proposed independently by Salam. Weinberg and Glashow, is non-Abelian group SUL (2) x UY (1).
- The gauge vector bosons which mediate the electroweak interactions are photon Aμ, charged vector bosons $W^{\pm}_{\mu}$ and a neutral vector boson Z_{μ} which mediates the neutral weak interactions. This was a crucial prediction of the Standard Model of particle physics.

- All these vector bosons are massless to start with, as gauge symmetry does not allow the mass term. Since weak interactions are short range, to give masses to the weak vector bosons the gauge symmetry is spontaneously broken so that weak vector bosons $W^{\pm}_{\mu}$ and Z_{μ} acquire masses, leaving photon massless as electromagnet gauge symmetry is exact.
- The masses of vector bosons $W^{\pm}_{\mu}$ and Z_{μ} are generated by spontaneous breaking of the gauge symmetry by the Higgs mechanism which leaves the photon massless.

- The year 1978 saw a remarkable set of experiments confirming the existence of neutral weak interaction as predicted by the electroweak theory. Salam, Weinberg and Glashow were awarded Noble Prize in 1979 for their work.
- The crowning verification of electroweak theory was achieved in 1980's, when the vector bosons $W^{\pm}$ and Z with masses 80-90 times proton mass were discovered at CERN.
- Discovery of spin zero particle viz Higgs boson (discovered at LHC in 2012) necessary for spontaneous symmetry breaking near 125 GeV is a land mark discovery-providing the last missing link of electroweak theory.
- The masses of vector bosons $W^{\pm}_{\mu}$ and Z_{μ} are generated by spontaneous breaking of the gauge symmetry by the Higgs mechanism which leaves the photon massless.

We conclude evolution of physics with the following remarks:

- Human beings are endowed with two remarkable qualities – conceptual thought (language including mathematics) and capacity to invent and use tools. Both concepts and tools have played an indispensible role in evolution of physics.
- Unlike goal oriented project, basic research is an unending project – going from one generation to another generation.
- It is shared by whole mankind
- With tremendous advance in technology, new tools became available to explore the universe at large and at small scales.

- Often hidden mysteries of nature are uncovered
- Deciphering of these mysteries lead to new insight in understanding the behavior of nature. This is the way science progresses.
- In the present century, exploration of the universe at large scale has uncovered two mysteries the dark energy and the dark matter.
- To resolve these mysteries, new insight is needed about the fundamental constituents of matter and their interactions.

Impact on Society:

- C.P. Snow in his book “Two Cultures” divides the industrial revolution in these phases.
- The first phase which began with the invention of steam engine at the end of 18^{th} century was mainly created by handy men as C.P. Snow calls them.
- In the second phase of industrial revolution: chemistry played a major role. Giant chemical companies were established in Europe and USA.
- In the third phase of industrial revolution atomic particles like electrons, neutrons, nuclei atoms, atomic and nuclear radiations played a crucial role. This revolution is based on physics of 20^{th} century. The birth of quantum theory in the 20^{th} century had a tremendous impact on future development.

- It is hard to imagine that without quantum mechanics, transistors, computer chips and lasers would have been invented.
- Physicist Freeman Dyson calls the fourth phase of revolution tool driven revolution. Scientists develop new tools and computer software.
- The craftsmanship used in their tools may initiate new technologies. Two examples: X-rays and nuclear magnetic resonance -> Computed Axial Tomography (CAT), Magnetic Resonance Imaging (MRI).

- The scanning technology revolutionized diagnostic techniques in medicine.
- It may also lead to some landmark discoveries in basic sciences. A prime example is the use of X-rays crystallography to study biological molecules.
- Such a study lead Crick and Watson to unfold the structure of DNA – the genetic code-perhaps the greatest discovery in biology after Darwin.
- The subsequent developments in DNA testing, genetic engineering and bioinformatics had made an enormous impact on human society.
- Another example is the World Wide Web (WWW) developed at CERN for basic research, which has revolutionized the information technology. These developments resulted in culmination domestication of technology in terms of internet, computer games and mobile phones.

- On the other hand tremendous progress in space technology has been used to put the probe in outer space to study the structure of universe.
- We conclude that science has not only made an enormous impact on human intellect but has also drastically changed human living.

- Prof. Salam has on many occasions made a passionate appeal to develop the scientific base to sustain the modern technologies. Knowledge is not static; one of the most important purpose of a university is to keep pace with development of knowledge. This is best done if one is a part of this process even if the participation is on a modest scale. Take as an example, the training of a physicist. a physicist is trained to observe, to take data; and in taking data to minimize the errors. He must be aware of the degree of accuracy and limitation of his data.

- He is trained to present data in a graphical or functional form to see any pattern in it, analyze it and draw inference. Sometime his data may contradict a known law, he must reexamine it to see that he may have made some errors in his measurements or whether the deviation is significant or it is just due to systematic and statistical errors. He also learns to plan and handle experimental apparatus. He is well versed in applicable mathematics.

- In theoretical physics, the most difficult part is to express a vague idea in a concrete mathematical form. Very few problems can be solved exactly; one is trained to make appropriate approximations and to discard some of the parameters which may not affect the results significantly. Modern day physicist is well trained to use computer, to solve some of the problems numerically, to modify the known programmes or to write a new programme.

- The basic training of collecting and analyzing the facts and then to draw conclusions from them using self consistent and tenable assumptions is useful whether we adapt or develop modern technologies based on modern science. In short education is a training of mind. But this training must be first rate whether it is imparted by an “irrelevant” high energy physicist or by some “relevant” physicist. There is no substitute for the quality.

- Riazuddin was also conscious of strong academic and intellectual base for research and development and for positive change in the fabric of the society. In Islamabad University (QAU) and NCP, (in the establishment of which he played a pioneering role), he tried to make them vibrant centers for teaching and research with strong emphasis on understanding and analytical thinking.
- To conclude: Modern technologies cannot be sustained without an indigenous scientific base. Social and human capitals are needed to exist as a free nation. Social capital creates an environment in which science and technology, art and literature, music and other cultural activities can flourish. It enhances our vision and makes us sublime. It keeps darkness in human soul in a dormant state.

- Human capital is needed to manage and develop scientific, technological and economic enterprises. There is no way except through education to generate this kind of capital.
- Without minimizing the importance of primary education, higher education and research in the universities must be strengthened.
- Only in this way, we can come out of intellectual and economic colonialism.

- I will end my talk with verses from Iqbal:

تو شب آفريدي چراغ آفريدم   سفال آفريدي اياغ آفريدم

بيابان و كهسار و راغ آفريدي   خيابان و گلزار و باغ آفريدم

من آنم كه از سنگ آئينه سازم

من آنم كه از زهر نوشينه سازم

Thou didst create night but I made the lamp
Thou didst create clay, but I made the cup
Thou didst create the deserts, mountains and forests
I produced the orchards, gardens and groves
It is I who make the glass out of stone
And it is I who turn a poison into an antidote

(Piyam-i-Mashriq)