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THE CENTURY OF THE ELECTRON

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It was in the year 1909, Lenin, living in exile, wrote an important tract on the philosophical implications of the new discoveries of physics that had shaken the basic foundations of the Newtonian ideas. The most profound discoveries, that had shown that not all was well with physics, were the discovery of the electron and that of radioactivity. Lenin concluded that these revolutionary discoveries in modern physics would show to the philosophers of the idealist school that “nature is infinite and infinitely exists”. The twentieth century revolution in science, which has given rise to a revolution in every sphere of human experience, came primarily in the attempt to resolve the crisis in the realm of human thought. The crisis had first appeared in the area of physics but soon embraced chemistry and then biology. Man’s conception of nature was completely overhauled in the process and the technological breakthrough profoundly changed the course of science itself on the one hand and human life in general on the other.

How encompassing this revolution has been can be judged from a simple experiment. If we ask an intelligent layperson as to what is his or her general perception of the twentieth century revolution in science, various answers can be expected. Some will say: it is the atomic age. Some will say that it is the era of electronics, or of communication or biotechnology, nuclear sciences or material sciences. Some will say that it is the space age. None of these answers are wrong, though none of them can describe the twentieth century revolution in science in totality. If one looks back, one observes that the proliferation in scientific knowledge that we perceive in the twentieth century can be traced back to a trigger given by a single event i.e. the discovery of the electron. It is not that the structure of science was ‘crisis free’ before the electron was discovered, but that the discovery of the electron made the crisis mature, so that the old physics had to give way to a new one. In some sense, the twentieth century has been the century of the electron. This overhauling, however, did not make the old science as wrong, but established the new limits of its applicability and became the special case of a more generalized knowledge that the twentieth century revolution threw up.

The discovery:

The British scientist Sir J.J.Thomson reported the discovery of electron on 20th October 1897, though evidence of the same was first seen by him about six months ago. The discovery of the electron, in fact, came as a shock to many. This is because, even in the 1890’s the atomic theory of matter had not been unanimously accepted by the physics community. To say at that time that even the atom is divisible was a matter of bold initiative on the part of the discoverer. The opponents of atomism were a group of philosophers who called themselves Machists i.e. the followers of the German mathematician-physicist Ernst Mach. They propounded a hypothesis that the world is to be represented in terms of sensations. Since sensations did not permit the “feeling” of an atom, they rejected atomism, which in turn led them to the rejection of materialism (if oppression is not felt, does it cease to exist?). Lenin’s battle against established Machists and some self styled Marxists, (but veiled Machists), requires a different essay. But the defeat of Machism came in the area of science itself, which we describe below.

To know how it came about, a knowledge about the late nineteenth century physics is essential. The great advance in eighteenth century physics took place in the area of electricity and magnetism. The industrial revolution had yielded high efficiency pumps, which could create high vacuum in gas filled tubes. By passing electric discharge through such tubes, it was seen that “something” travels from the negatively charged plate (cathode) to the positively charged (anode) one. These “somethings” were called “cathode rays”. These “somethings” could be deflected electromagnetically. By these electromagnetic deflections, Sir J.J.Thomson tried to find the ratio between the charge (e) and the mass (m) of these “something” in the cathode rays. He found the particles to be negatively charged and that the value (e/m) to be the same no matter whatever was the gas that he filled the cathode ray tube with and in every case the value was 1840 times more than what he had anticipated for hydrogen. He arrived at a bold conclusion: This object must be present in <u>all atoms</u> and is <u>negatively charged.</u> Moreover, it must be <u>subatomic</u> since such high (e/m) value can come only if m is extremely small i.e. if its mass is (1/1840) of the mass of the hydrogen atom. This meant that the smallest atom, i.e. even that of hydrogen must contain this particle. Atom is thus divisible.

The first prediction of the electron was, however, made by Stoney, who had theoretically calculated the charge of the electron, by using Faraday’s laws of electrolysis. As is described above, the path of the discovery came through an entirely different route, and was impossible without the machines and instruments that the industrial revolution in England had thrown up. A mention of this fact ought to be made, in order to meet headlong the revivalist’s (the saffron brigade in particular) oft made claims that everything that modern science has given man were known to our ancient forefathers. In the interest of objectivity, it ought to be advanced that discoveries of a certain kind are really characteristic of the era. Discovery of the electron in the pre-industrial revolution phase is an absurdity. It is indeed true that scientific discoveries often do come about through accidents. But these accidents too are perceived only by mature scientific minds in relation to the scientific knowledge known at that era. Likewise, the discovery of the electron or of radioactivity that followed, can appear only at 19th century scientific laboratories and impossible at the seminaries of advaitavada or of mayavada, as is exemplified below in the context of Machism.

The discovery of the electron was equally shocking to the Machist's for here was something, which to their sensation would not allow to be perceived and yet it was there! And that it was not the "manifestation of ether" (a mystical object) as Machists had described the cathode rays to be, but REAL MATTER. It further proved that matter too does not get exhausted with the atom but can exist as "subatomic" particles as the existence of the electron showed it to be. This inexhaustibility of matter that electron discovery established, was a crushing blow from which Machist's never recovered.

But it was in fact the influence of Mach that had delayed the discovery of the electron. X-rays that were discovered by Rontgen in 1895, we know are caused by electronic processes. In 1896, Alfred Zeeman discovered the Zeeman Effect. Its explanation as we know today, is based on the movement of electrons inside the atom when a magnetic field has been applied. But these scientists could not stick their necks out and declare the discovery of the electron, as J.J.Thomson did, in view of two factors. Firstly, their evidence was indirect. Secondly, the influence of Mach in Europe being too strong, they pondered, hesitated and even doubted what they knew. England was relatively free from the influence of the Machists and hence J.J.Thomson's boldness had fewer impediments. The discovery of the electron was the last great discovery of the nineteenth century science. With the arrival of the electron, the twentieth century science really did arrive and with every succeeding yea the old world of physics tumbled.

Crisis matures:

The crisis became even deeper when radioactivity was discovered the next year. It was found by Becquerel and the Curies that many substances spontaneously send out charged particles, (the alpha particle, beta particle) and highly penetrating radiation, called the gamma rays. This occurred, even without pumping energy from outside (electrons had to be taken out from atoms, when electric discharges were passed, as in Thomson's experiment), indicating that the center of the atom was a storehouse of motion and energy! This was the beginning of nuclear physics, the existence of the nucleus being conclusively proved by Rutherford in 1910.

Electron discovery was indeed not the beginning of the crisis. The crisis in physics was already there. Firstly, there was the surprising experimental result due to Michelson and Morley. If two people move along a line with some velocities (v_1 and v_2) their relative velocity is $v=(v_1+v_2)$ if they move towards each other and $v=(v_1-v_2)$ if they recede from each other. This does not apply in the case of light, it was seen experimentally. If one of them carries a torch light in hand. the velocity of light appears to be the same c=300,000 km/sec, no matter whether we measure it while approaching the light source or while receding from it. It was an enigma.

The other concerns the black body radiation i.e. objects when heated first turn red and finally turn white. This problem was solved in 1900, by Max Planck by introducing the quantum hypothesis i.e. radiation comes out of a heated surface in a distinct amount E_n=hn in every step. These discrete energy packets are called quanta, renamed as photons by Einstein. Further, radiation emitted by atoms, when viewed through a prism showed up dark lines in the spectrum. The discovery of the electron compounded the crisis even further. If the atom had electrons, there must also be a positive charge in it to maintain the charge neutrality. Then why do not the electrons collapse on the positive charges? The crisis was too deep to be solved by Newtonian methods.

It was the resolution of this crisis that led to the revolution by opening up conceptual breakthroughs in two different directions namely by the discovery of (a) the theory of relativity and (b) quantum mechanics. It is not the aim of this essay to deal with the philosophical stand points of these revolutionary ideas vis-à-vis our conceptualization of nature. The scientific progress that followed was also not unidirectional. This idea can be best expressed by a flow chart, even that looks quite formidable. It has not been my idea to put an exhaustive list of the scientific developments that took place in the twentieth century. To describe the events the best way would be to use a film with flashbacks, inside flashbacks or to put them in a CD and go back and forth by different routes by clicking the mouse. This short account will show how the proliferation and diversification into different fields has taken place., at the same time the emerging fields have also reinforced each other. Here too we choose only a few selected examples. The journey here though one dimensional is not actually so. It is the constraint of space which restricts us to such a narration and it is hoped that articles on similar subjects will be forthcoming in future by other authors too. .

Revolution in chemistry, biology and solid state physics

The crisis in atomic physics got resolved by the 1930's, with the discovery of the theory of relativity and quantum mechanics and finally by a master stroke by Dirac which combined the two. But the crisis in physics was a crisis in chemistry too. Nineteenth century chemistry was already based on atomic concepts. The biggest problem for the chemist was now to explain the concept of valency in terms of electrons in atoms. Such a picture looked ridiculous in terms of classical physics, because if every atom has an electron cloud, the electron clouds from two neighbouring atoms must repel each other, thus preventing molecule formation. The resolution of the crisis in atomic physics in "one stroke" solved the problem of molecular physics and gave a new life to chemistry, particularly by elucidating the question of chemical bonds. These understandings have also helped science to conceive of newer materials , and was the key to the invention of the transistor.

An important feature of the twentieth century science has been that the resolution of the crisis in one area of science has its impact on some other branch of science – the developments in biology and solid state physics are used here as illustrative points. In the beginning of the twentieth century, biology was crisis free. Important questions arose from the 1920's, as to whether a peculiar organization of matter contained the key to the question: what is life? The question that these scientists asked was, as to how the structure determines the function? In other words, do the structures of important molecules like, water, proteins, carbohydrates and the DNA, determine the functions that they perform in sustenance and replication of life? It was in this quest that the newly found technique of x-ray crystallography became an invaluable tool for observation of the structure, while the theory of electron bonding created the theoretical framework to understand and even predict the structure and formation of molecules. It was this progress that finally led to the recognition that the DNA is the molecule that holds the key to the replication of life. These concerted attempts led to the discovery of the DNA structure, which forms the cornerstone of modern technology.

A major success of modern physics has been in understanding the nature of the solid state. The atoms in a solid are formed by the chemical bond, arising out of the interaction between the electrons. It is this interaction that modern quantum chemistry elucidated and finally led to the understanding of the problem as to what happens when perfect crystals like germanium or silicon are doped with impurities, in proportion close to parts per million. It turns out that addition of such tiny levels of impurity does have profound changes in the electrical properties of the solid and forms the basis of the modern transistor.

Technology: communications, computers, miniaturization, biotechnology, information technology etc:

As has been mentioned before, the revolution in 20th century science came about due to crisis in the realm of knowledge and not because of the social pressures as such. But the revolution, when it appeared gave rise to technologies, whose impact on the society was extremely profound. But not all technologies that appeared in the last century required the resolution of the crisis to be completed. A major nineteenth century discovery that really matured in the last century was that of radio communication. The theorists knew that radio waves can propagate in space, but were not sure whether their intensity will thin out if the propagation distance be large. Physicist-engineer turned aspiring industrialist Marconi, proved that radio waves could actually travel across continents. It was just a conjecture, on the part of our irrepressible engineer, but turned out to be correct. This showed that the earth is surrounded by a mirror like shield of charged particles, which reflect the radio waves back to earth. The transmission of information across the globe was thus shown to be possible. What role the technological breakthrough finally had in globalization, nearly a hundred years later, must be a subject of serious study in the context of sociological impact of science on society.

It is here we also ought to recognize, that though the above advance was based on 19th century electromagnetism of Ampere, Faraday and Maxwell, for its transformation into a technology and finally into an industry, it was the knowledge of the motion of the electron that was absolutely essential. The crisis in atomic physics took nearly thirty years to be resolved i.e. from 1897-1930, but we always have people, who are not so interested in theoretical or conceptual niceties. Having seen that electrons do exist, they wanted to know about what to do with them, even though the conceptual foundations of physics were still shaky. It was seen that electrons from metals could be knocked off by heating the metal. This principle was utilized in building the electronic valve, i.e. a device that can control the direction (and magnitude) of the electron flow. It was indeed a combination of a 19th century technology i.e. high vacuum that acted as a back up for a new technology, emerging from a 20th century breakthrough that had just appeared. The appearance of the electronic vacuum tube (valves) were thus the first major 20th century technology. The British inventor John A Fleming's success in building the first vacuum tube, that could detect radio signals gave a major impetus in this direction. The American inventor Lee De Forest's success in 1907 in building the vacuum tube amplifier showed that the radio industry was on the throes of an imminent emergence.

It is here again that we see how a 19th century artifact, when suitably modified with new components added to it can become capable of performing qualitatively new operations. That is what happened when the TV picture tube first appeared., whose basic structure was still the Crooke's tube or the cathode ray tube with which Sir J.J.Thomson had discovered the electron. The radio allowed voices to be transmitted but with the TV images could be transmitted. The qualitative difference is there for all to see and the impact is understandable, for 85% of the brain's capacity is for the processing of visual information, while the rest 15% is to be shared by all other senses. The effect of mass scale proliferation of the radio and the TV gave a new direction to the entertainment industry. Big money came in to it, just as it had gone to the print media. On the positive side, world news came to the common man as never before. "Culture" entered people's homes, even working class homes. For even those who could not pay concert tickets could now hear them or watch them from their homes. But along with entertainment also came propaganda. The media industry, print, radio or the audiovisual, being under the control of powerful corporations, the freedom and independence of these media is indeed limited to the well known situation “one who pays the piper sets the tune”.

Miniaturisation:

Invention of transistors in 1947 made miniaturization possible. The bonding theory of electrons in molecules showed that it was possible to replicate the electron dynamics in electric valves in a solid state matrix if calculated quantities (parts per million) of certain impurities like Boron or Phosphorus be added to pure crystals of Germanium or Silicon. The main advantage of such devices is that they have an extremely small size and negligible power consumption. Thus, while the older version of the valve radio needed a 230 volt power supply, the transistor radio needs only a battery, i.e. a 19^{th} century device,(battery) when put in conjunction with a 20^{th} century device, became a product for house-hold consumption. We may look for another parallel. The 19^{th} century was the era of steam power, but the steam power cannot be transmitted. Every user of steam power must have his or her boiler. Electricity is easily transmitted through wires. Thus while steam power got held up in factories or on railway engines, electric power could enter our homes. Likewise, the smallness in size and low power consumption helped solid state devices to displace the vacuum tubes from the market. Needless to say, large corporations control these industries.

The next steps involved further miniaturization of devices. It is now possible to put millions of transistors in a tiny crystal of Silicon,- of the size of a nail. The design and fabrication of such devices are closely guarded secrets that are held only by large multinationals. It is here that the US has the virtual monopoly,-which they acquired by their pre-eminence in Silicon technology (one of the factors, business strategies, curbs etc are not discusses here). Many others lost out because they were concentrating on Germanium. Preeminence of modern technology does not necessarily come from specialization in the area aimed at but also on the knowledge and skills on many related areas, whose back up is essential e.g. Solid state physics, wafer design capabilities and chemical engineering, when it comes to microelectronic device technology.

Information science and computers:

For the proliferation of personal computers, that we see today, the technology had to wait till the early 1970s, i.e. till the miniaturization of (active) electronic components (like, solid state diodes, transistors etc.) could reach the desired maturity. The large scale application of the digital computer has been made possible due to their versatility (i.e. different users can find different uses of it), due to their small physical size, affordability in terms of cost, simplicity in terms of operation and due to the ability to exchange information between different computers by transmission of data between telephone lines. How the industry has grown can be exemplified from a few numbers. The first commercial digital computers were built in 1950’s and by 1960 there were 10,000 computers in operation, which rose to 100,000 over the next ten years. By the year 1990,there were a hundred million data processing computers in operation world wide,- of which nearly half were in operation in the United States, while for the same year the US computer industry’s revenue amounted to 100 billion dollars. It was expected at that time that in terms of annual revenue, the computer industry will be second only to agriculture in the next twenty years. The era since the 1990’s has often been referred to as the IT era. The main feature here, in which the technology played its role was in making information processing very fast, equipment cheap and the information mobile. The entry of lasers as tools in this technological drive has been extremely valuable. The role that the IT sector has played in the process globalization, ought to be a matter of interest for the readers of this magazine and may be handled by a more competent authority.

Biotechnology:

By the beginning of the twentieth century biology had already witnessed a revolution, i.e in the triumph of the theory of evolution. No other crisis appeared in the sky to give the warning of the coming revolution. Emergence of biotechnology has a direct link with the scientific revolution in the 20^{th} century. The real transformation of biology took place with the discovery of the double helix structure of the DNA fifty years ago. It opened up methods to ‘tamper’ with “life” at the molecular level. These gave means at the hands of the industries to produce patentable biological objects. Biotechnology has potential applications in medicine, agriculture and industry, e.g, with the use of genetically modified microbes it is possible to manufacture a wide range of products including new materials used for industrial manufacturing processes. A detailed discussion of this potential is required. But what twentieth century biology has shown vis a vis the dynamics within the scientific community, is an unprecedented mobility of the trained scientific manpower. No other field of science has shown such a propensity to attract scientists from other disciplines. The rise in “opportunities” in biological research is also to with the fact that for industrial exploitation, the costs are lower , while the returns are higher and the product range too looks quite unlimited.

The inexhaustibility of matter again:

This has been established all through the developments in science that we have witnessed ever since the discovery of the electron. The diversification of knowledge that we have seen since then is something that has never happened before. While this has given rise to a multiplication of disciplines, the disciplines in science have also got interconnected and interdependent. No wonder, therefore, the 2003 Nobel prize in medicine and physiology goes to a group of scientists, who modified and adopted technique in physics for medical diagnostic purposes (MRI), needless to mention the extremely useful role that the x-rays have played in medicine. It is also to be mentioned that the revolution in physics that we witnessed, also owes its success to the mathematicians, who kept all the tools ready for the physicists to exploit. The interdependence of disciplines is growing faster

We go back to the issue that we began with, the impact of the discovery of the electron to the 20^{th} century science and life in general. This was recognized very early in the history of the 20^{th} century science, as was first expressed by Lorentz in his Nobel lecture in 1905 and later by G.P.Thomson in 1938 that the discovery of the electron and the revolutions that ensued were indeed unthinkable. We have mentioned Lenin's comments on the discovery of the electron, in 1909. Had he waited four more years, he would have come across the discovery of superconductivity in mercury by Kammerling Onnes,- a phenomenon in which metals at very low temperatures lose their electrical resistance. This means that electrons move in a "co-operative way", all of them together, without losing any energy. The 2003 Nobel in physics had to do with a theoretical understanding of superconductivity I have personally seen such electric coils in which current has been flowing in an uninterrupted way, for the last 20 years, without any power supply ! It is not my intention to attribute any "mystical property" to this smallest indivisible particle that nature has given us i.e. the electron. But the discovery of the electron began the process that has shown us the inexhaustibility of matter and the motion of matter at different physical scales, whether in the discovery of elementary particles like the proton, neutron, meson etc i.e. in the micro scale to that in macro scales as seen in the motion of galaxies or stars. Here too, two important features are to be noticed. The discovery of the electron ushered in a revolution in science, which revolutionized technology. That in turn has given man more accurate and sensitive tools to probe nature deeper(the radio telescope, the electron microscope, for example). It also has given man the theoretical framework to look at and understand nature. It is no wonder, therefore, that the electron, which resides in the interior of atoms also plays a role in maintaining the equilibrium in stars, e.g. their ionization equilibrium as discovered by M.N.Saha or the mechanical equilibrium as discovered by S.Chandrasekar! Shows again the unity and diversity in the physical world!

The scientists' world:

An important point is that all these advances were possible through concerted human activity. One may of wonder as to how man’s outlook has changed and how the world has changed since the time the electron was discovered. I recommend an exercise to the reader. Think of the year 1897 and 1997 and see the change. Think of the year 1897 and 1797 and see the change. Next think of the year 1797 and 1697 and see the change. It is clear that the difference is widening in an ‘explosive way’, as we come to the modern era, both in terms of the knowledge of the physical world as also of the social life on earth. It is to be recorded that the twentieth century is also the era of social experiments. It has also given rise to social debates as to how science can be used for the social advance of mankind. It was shown that science can be planned. How a coordinated social activity, on the part of the scientific community on the one hand and the social support to science can lead to social development and scientific advance simultaneously, was witnessed in the former Soviet Union. Notwithstanding the limitations in their execution, this experience will ever remain a glorious chapter in the annals of history.

In every society in the world today, scientific activity is no longer an individual activity, but entirely social, being supported either by the industry or by the state. The freedom of an individual scientist is thus limited by the above situation in which he or she operates. It has been argued that emancipation of science can come from the emancipation of the society as a whole. In advancing this, the scientists have an important role to play, which is to understand the forces that determine the social dynamics and also the dynamics within their profession. Likewise, it is no less important for the social activists, e.g. the vanguard and its leadership to understand the dynamics that is inherent to science in the realm of knowledge or in terms of social relations. It is their duty to understand that we live in an era in which the transition from a concept to usable product has become extremely short. That science, which can wipe away many of the miseries of man are in fact used by the ruling classes to accentuate the misery. That, while in the past, steam power was used to replace human labour, the modern technologies are being used to replace human skills. While understanding and defending against these tendencies, it is also necessary to understand the philosophical issues that modern science throws up. This too needs a concerted effort in the form of a battle in the realm of thought. It also needs planning. It may be recalled that to write his manuscript on Empirio Criticism, Lenin had not only scanned the libraries in Switzerland (where he lived in exile) but traveled to England to consult the British Museum and the scientific experts. Absence of such a challenge would have meant a tame acceptance of the positivists i.e. surrender to any nonsense till the senses sense them (as Bernal opines)! The task before that exemplary revolutionary was to understand the dynamics of matter better, in order to understand materialism better. The task is no less important a hundred years later.