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This year the world is commemorating the centenary of the November Revolution that occurred in Russia between the 7th and 17th of November 1917 and led to the birth of the world's first socialist state. On this occasion, economists and social scientists all over the world are evaluating the successes of socialism in eradicating social inequality, unemployment, and various social evils. For the scientific community the natural question is, what was the status of science in the socialist society that resulted from the revolution?

** The serial "A Brief History of Science" will be continued in the next issue.*

When Spirituality Masquerades as Science

Saji K P *

The condition of a genuine researcher in India now is bleak. With research funding going down, the means of doing science on what one thinks to be a socially relevant topic are met with uncertainties. However if you are planning to carry out a research programme or to organize a conference on themes like 'science and spiritual values', 'science of ancient India' or 'science in Sanskrit texts,' etc., you are certain to get recognition and to get comfortable funding. So we see a lot of conferences on similar themes, sprouting in almost every nook and corner of our nation.

It is true that parallel to the main line of scientific activities, there have been enterprises internationally, interweaving science and spirituality, though in subtle forms. But the recent activities in India surpass all. It has become fashionable to convene such conferences and workshops in colleges and universities not barring IITs and other central institutes. It is now discernible that the target audience comprise students and young researchers.

To get a feel of where things are going, let us take a look at some of the events. On August 26 and 27, 2016, Sri Chaitanya Saraswat Institute, Bengaluru, Karnataka, in collaboration with Department of Life Sciences, Bangalore University, organised a two-day International Conference on "Is Science able to explain the Scientist? (Science and Scientist – 2016).

On 4-5 February 2017, the Bhaktivedanta Institute and the Bharatiya Vidya Mandir have jointly organized a conference on "Quantum Theory and Consciousness" in Kolkata. With illustrious figures like Dr. V. K. Saraswat, Ex Director General, DRDO, Dr. Bikash Sinha, ex-Director of the Saha Institute of Nuclear Physics, Dr. B. N. Gangadhar, Director, NIMHANS, Bangalore, among the speakers, the objective of this conference was "to serve as a mediator to merge the now-trending science of quantum physics and the age old science of consciousness as propounded quite vividly in our ancient spiritual texts." Dr. Bernard Heish, author of the book "The God Theory", and Dr. Gerard Scroeder, the author of books like "The science of God" and "Hidden faces of God" were also among the speakers.

The 10th All India Students' Conference on Science and Spiritual Quest (AISSQ-2016) was held at Hindustan College of Science and Technology, at Mathura in Uttar Pradesh, on 8-9 October 2016. The purported claim of the organizers was to 'bring together a number of leading experts from all over the world on a common platform to present and outline their vision for the benefit of the humanity in search for deeper questions of life, its origin and purpose.' In the past, the AISSQ conferences have been organized in IIT Kharagpur (2015), Delhi (2011), NIT Allahabad (2010), etc.

These are a few among umpteen such events. The Bhakti Vedanta Institute, Sri Chaitanya Saraswati Institute etc. are a few among the organizers of such conferences.

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In addition to all these, there are vast number of invited talks and lectures linking science with spirituality, specifically aiming the students of IITs and NITs.

The topics are also very curious: 'Science of Consciousness', 'Body, Mind and Consciousness', Bioinformatics and Consciousness', 'Vedantic view of life', 'Failure of Biologism or Biological Determinism', 'Quantum Physics and Life', 'Science of Spiritual Biology' to list a few. AISSQ-2016 had as its theme "Life: Origin $\rightarrow$ Meaning $\rightarrow$ Purpose". One claim is "The purpose of the present conference is to examine seriously the deeper insights of life and its origin through the inter-disciplinary approach of science and spirituality/theology incorporating the religious principle that life is a spiritual particle. Also a part of the purpose is to carefully examine the scientific data from the religious viewpoint and to generate some new research projects for the scientific study of life, its meaning and purpose, consciousness, and God." Another one says "This topic explores mind from both Neuroscience and age old Vedantic perspectives."

Yet another demands much more. "Quantum physicists have proposed many theories to explain consciousness using quantum states. Some models link quantum processes and brain function. Some leading quantum physicists try to explain the collapse of the wave function through some interaction of the mind and consciousness. Researchers hope that quantum uncertainty and non-locality could be linked to complex brain states and thus could possibly provide an explanation of our free will. The topic shall attempt to deal with these thoughts and understand the mystery behind life from both Quantum Physics and Vedantic perspectives."

Thus, in larger perspective, the actual objective of these conferences is to provide 'Vedantic' explanations to some of the findings of modern science, or attributing scientificity to our age old 'traditional knowledge'. This is not new! It started with the 'orientalism' of the nineteenth century and had flourished after calls of leaders of freedom movement to be proud of our great heritage in an attempt to instill patriotism in the fight against British imperialism. But the increased enthusiasm behind the present arguments may be due to current political, social patronage.

Apart from sadhus, sanyasis and heads of mutts, professors and scientists from Indian as well as foreign universities and research institutes participate in these conferences. It is not uncommon that sadhus are invited to attend scientific conferences if they have some scientific credential. But we hear from the conglomerations of these peculiar mixtures of participants, arguments against many of the established and accepted theories of science. We also hear scientific-sounding explanations to what are preached in ancient texts.

Again it is not unjustifiable to question accepted theories. In fact science always calls for questioning its theories, and encourages one to be sceptical. What we need to do is to evaluate each claim through a critical assessment process. The history of science has already given a time tested tool for this. The touch-stone with which these claims are to be verified should be the method of science, where each claim is thoroughly tested against objective reality by performing observations and experiments. Only this method of science allows us to obtain reliable answers.

It is difficult here to do the same within the limits of this article, as the topics ranges from origin of life, to quantum nature of consciousness, to Darwinian theory of evolution, so on and so forth.

Science claims that everything, every

phenomenon in the natural world has a cause, and that cause is to be found in material processes and phenomena — not in anything supernatural. Science asserts that the material world exists independent of our consciousness. If one can start from a diametrically opposite standpoint, by claiming that material processes or phenomena are caused by a supernatural entity, that will be anything but science. The latter is the standpoint of the philosophical current called idealism. Science has grown by rejecting this idealistic philosophy. So at the outset we have to discard attempts to tie together science and various shades of personal beliefs.

Science starts with careful observations and questions generated from them. A preliminary hypothesis is then put forth to answer the question. Experiments are then designed and performed to test the hypothesis, which leads the scientist to establish or modify or discard it. Then it is left for peer review and verification by repeated experimentation by other scientists. A scientific proposition is accepted as theory through these long processes. Again once it is accepted it is not deemed as final and unchangeable. In the light of new observations it is open for modification or rejection.

Another point to be noted is that ideas produced by man are subject to the limits imposed by space and time. No man, however great, can produce anything surpassing the limit set by the objective conditions pertaining in his time. That is why we do not fault Jesus, Buddha or Confucius for not being able to develop the concepts of democracy, which had to wait for centuries. That is not a shortcoming of these historical personalities but a historical limitation. Knowledge always evolves and develops unidirectionally. It develops into higher and higher forms with the passage of time. That is why it is equally wrong to claim that eternal knowledge can be created at one point of time. The claim by the proponents of 'ancient Indian heritage' that all of modern science was there in Vedas or the ancient scriptures is thus historically unacceptable.

The strategy and tactics these groups employ are also manifold. They denigrate modern science for its materialistic outlook, for its inability to provide eternal values. But since their political counterparts in power cannot but use modern scientific and technological innovations, they argue that what is claimed in modern science was already there in our great Indian heritage.

It is also worth noting that the so called ancient Indian knowledge system is not a monolithic entity. We see divergent systems of knowledge in it. We see materialistic enquiries and answers to day to day problems in the Rig Veda and Vedanga Jyothisha texts. Then it gradually turned idealistic and Brahminic in content, as the political and social structure changed. At every point of time opposite views prevailed in the ancient Indian system of knowledge. The strong school of materialistic philosophy that existed in the Siddhantic period was gradually pushed into oblivion by the politically strong idealistic school. Detailed accounts of these have been given in earlier volumes of Breakthrough. (Refer to the article on History of Indian Science by Prof. Soumitro Banerjeein in Vol.17. No.3. and the article on Materialistic Philosophy in Ancient India by Subrata Gauri in Vol.18 No.1&2).

Before reincarnating into written form, all these creations had passed through many generations orally, continually experiencing changes. The written texts also changed in each rewriting and translation. The great Mahabharata scholar V. S Sukthankar, who compiled a history of the Mahabharata, had collected more than a thousand manuscripts of the text from various Indian languages and had observed that each differed considerably from the others, even in the main story line. So what is termed 'ancient Indian knowledge' by the present day pundits is a political construct. The predominantly idealistic, religious teachings are now forcefully propagated as great traditional knowledge.

Have the ways of religion anything to do with that of science? Obviously, it does not. The Hindu religious system assumes an omnipresent apriori consciousness: a 'Brahma'. It denies the existence of the material world. What we see or experience as the material world is, according to the Vedanta philosophy, an illusion or 'maya'. It emphasizes the primacy of idea over matter and is thus pure idealism.

Science, on the other hand, has to be materialistic and has been so historically. Otherwise the technological and conceptual developments we see today would not have been possible. No idealistic philosophy could ever produce a steam engine, a television set, a hydrogen bomb, or an aeroplane — though they chant hymns on 'varunastra' and 'pushpakavimana'. Unlike science, religious teachings are not falsifiable, and are not prone to continual development. They are stagnant, claimed as eternal. Life as such, evolves to greater and newer heights and complexity. The issues and problems of life are ever developing, as are the answers. So it is futile to expect that religious prescriptions can solve all the ever increasing demands of life.

J.V.Narlikar in his essay 'Science and Religion: Approaches Towards a Synthesis' comments "If Galileo found that the speed of a stone dropped from the Leaning Tower of Pisa grew in proportion to time after drop, the same result would have to be obtained by any Tom, Dick or Harry performing the same experiment. But with religious experiences it is a different story. When Krishna showed Arjuna his Universal Form he told him:

> Neither by the Vedas,
> (nor by) sacrifices nor by study
> nor by gifts nor by ceremonial rites
> nor by severe austerities
> can I with this form be seen in the
> world of men by anyone else but thee,
> O hero of the Kurus (Arjuna).
> — *Gita* 11.48

Thus only Arjuna was privileged to see the Universal Form. No scientist can similarly get away by saying, 'Only I have seen the proton decay. Others cannot see it happen.'

This is the main contrast between science and religion in their perception of truth: the objectivity insisted on by the scientist versus the subjective personal realizations of the religious. Conflicts arise when scientists are asked to believe these unique experiences of the select few. They obviously will not believe what they cannot themselves observe or experience. On the other hand, a deeply religious follower of a seer who has had that experience sincerely believes that the experience is real. Indeed, he may consider scientists obdurate in their disbelief.

Another aspect worth scrutiny is that these types of activities seen in India are not local phenomena. For instance see the advertisement of a conference to be held in San Jose, California in the USA. "Join Science and Non-Duality Conference (SAND) for a 5-day immersive experience where leading scientists, philosophers and spiritual teachers gather to explore a new understanding of who we really are, both as individuals and as a society. Join us for 2 days of pre-conference workshops followed by a 3-day conference filled with talks, panel discussions, meditation, performances, music and dance. Attempts to fuse science and spirituality are quite widespread, though with characteristics of each country.

The matter needs to be evaluated from a wider perspective. Internationally there developed a movement in the seventies of the last century, against what we call modernity, specifically against the outcomes of renaissance. 'Post-modernism', labeled as the cultural logic of late capitalism by Frederic Jameson, is a conglomeration of divergent viewpoints, but united against the philosophical standpoint of objective truth and Renaissance concepts. As a by-product, a spectre is haunting the academic centres in the West now. A spectre of so-called science studies 'which constitutes the beating heart of postmodernism' writes Meera Nanda , 'for it aims to deconstruct natural science, the very core of a secular modern world view'. Science studies do not attribute any prominence to scientific truth. It does not take serious note of the scientific method even. It rejects the distinctiveness of scientific knowledge as against the other bodies of knowledge. It demands symmetry between modern science and other local knowledges, i.e., it sees modern science as much a social process as any other local knowledge. Being 'social constructs', modern science and ideas generated in any other local culture with different social background, historical period or geographic location, regardless of whether they are true or false, rational or irrational, successful or not, all stand on equal footing.

One argument goes to the extent of claiming that if modern science gets any predominance, that is because it was a product of the dominantly 'male', 'white', 'colonial' and powerful 'West' which imposed it on other cultures. So they argue that science of modern Western societies is not any more 'true' or 'rational' than the beliefs generated in other cultures. In the postmodernist viewpoint, the 'scientific method' does not enjoy any superiority in the production of knowledge.

According to Meera Nanda, "··· there was a dangerous convergence — unintended for sure, but not entirely coincidental – between the social constructivist views of science routinely taught in science studies, women's studies, post colonial studies and allied disciplines, and the views of those who defend creation science, Islamic science, or, as in the case of India, Vedic Science".

So all religious fundamentalists, internationally, find a suitable philosophic ally in post-modern viewpoints. We see various off-shoots from this stem. Research progammes and institutes have sprung up defending every miracle and every superstition as science. On the one side, frauds like 'urine therapy' (both human and cow!) is spreading. 'Ganesha idol drinking milk' gets media coverage and authenticity. Arguments like intercontinental air travel ten thousand years ago are presented in prestigious Indian Science Congresses (we need not pinch ourselves to believe). A Prime Minister boasts about ancient Indian medicine which could carry out cloning, organ transplant and what not! It goes on and on.

But on the other side, carefully constructed and more subtle arguments are produced and propagated which confuse the so-called educated middle class. They now wear the cloak of modern science to claim their case. Creationism now wears the cloak of "intelligent design theory", seeing the hand of God in the anatomical design of the bodies of different species. Vedic science proponents now see the hand of God in the collapse of wave function in quantum mechanics. They look for words resembling "relativity" to claim that Einstein's theory was there in sacred ancient texts.

Claims from still higher planes are also worth mentioning. See for instance the case of the 'quantum healing' of Deepak Chopra. He claims that the human body can heal itself by setting right imbalances using quantum mechanical means. It claims to fall under the category of alternative medicine and boasts to draw from various streams like quantum mechanics, philosophy, neurophysiology and psychology. Different concepts of quantum mechanics like energy, vibrations, dual nature of matter and virtual particles are all freely used.

Another case is that of Subhash Kak, an Indian engineer in US who claims that the Rigveda contains all advanced astronomical findings in a coded form. He argues that the structure of fire altars in 'yagnas' are actually codes which tell the distance between the sun and the Earth, the lengths of solar and lunar years, the speed of light and other things. If we ask how they found out these, the answer is, through deep introspection. No painstaking processes of the scientific method were required! No need of formulating and solving any differential equations! Considering the limit on the length of this write-up, all such arguments cannot be outlined here. The readers are requested to go deep into such fashionable arguments and to arrive at reasonable conclusions.

To conclude, we see from history that occasionally such deviations from science occurred, in various cultures, in various epochs. Whenever such deviations happened, knowledge production and development of human race faced serious setbacks. The dark Middle Ages in Europe was the outcome of the society as a whole pursuing untested beliefs and customs. The decline of knowledge production in India in the second millennium reveals similar factors being operative. Acharya P C Ray critically examined it and attributed the philosophical shift towards 'maya' philosophy to be a major contributing factor. But the present rhetoric is not simple and innocent. When life becomes problem-ridden and suffocating, common people will strive for a solution. Scientific knowledge is the natural weapon at their disposal, to unravel the truth and tread forward. History proved that students and youths were in the forefront of all these movements. If they are lacking clarity in matters of societal development, if they are kept in darkness or in confused state, they will be unable to lead any social change. So the spread of obscurantism and anti-science ideas are not without any purpose. It is the duty of science loving people to stay together in fighting against the spread of unscientific ideas in the name of science. □

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Science under Socialism in the USSR

This year the world is commemorating the centenary of the November Revolution that occurred in Russia between the 7th and 17th of November 1917 and led to the birth of the world's first socialist state. On this occasion, economists and social scientists all over the world are evaluating the successes of socialism in eradicating social inequality, unemployment, and various social evils. For the scientific community the natural question is, what was the status of science in the socialist society that resulted from the revolution? The Editorial Board of Breakthrough *takes a look at this issue.*

AFTER THE November Revolution, the victorious working class proceeded to create a new society where the means of production would be socially owned, so that there would be no exploitation of man by man. This gigantic experiment that the emergent Soviet state undertook depended on science to create and multiply the productive forces, including industry and agriculture, that would be the bedrock of the new socialist economy. That demanded heavy investment in science and technology, building up a system of scientific institutions, training of scientific personnel, and bringing the results of scientific investigation quickly to the service of the people.

It was urgently necessary for the survival of the emergent socialist state to remove backwardness in all fields, in terms of material as well as intellectual production. For this, the educational level of the masses had to be raised, and the semi-literacy that was a legacy of the past had to be wiped out. Educational institutions of every type — schools, colleges, and universities—had to be created in large numbers. Teachers and professors had to be trained to man the educational institutions and laboratories. Productivity had to be increased as rapidly as possible, and for that, the means of production had to be improved and new productive forces had to be sought out and brought into use. So science was in great demand.

The socialist state inherited a scientific tradition on which the new edifice was to be built. Let us take a brief look at the status of science in Russia before the November revolution.

Status of science before the November Revolution

Russia, being a European country, had cultural links with the rest of Europe. The intelligentsia of the Czarist period was exposed to the developments of science in Europe. But there was no patronage for science, practically no scientific institution. Science learning in the universities was also meagre.

But Czar Peter 1 (1672-1725) had imbibed the spirit of Enlightenment and was exposed to the tumultuous change that was taking place in the science and technology scenario of Europe. He understood the value of scientific development, and founded the St. Petersburg Academy of Sciences in 1725. Under his reign, modern science had its beginning in the Russian soil, which soon saw the emergence of many renowned scientists. Lomonosov was the first to demonstrate the law of conservation of mass in a chemical reaction, Lobachevsky developed hyperbolic non-Euclidean geometry, Chebyshev made seminal contributions to the theory of probability and statistics, Mendeleev proposed the periodic table and gave a theoretical basis to chemistry, Pavlov experimentally investigated the higher nervous activity in animals (and received the Nobel Prize in 1904 for his work on the mechanism of digestion).

But these were isolated efforts of individual scientists, carried out without state support or patronage, because the Czars after Peter-I failed to appreciate the worth of scientific development and were preoccupied with palace intrigues, conquest of other lands, and exploiting their own people. To the Czarist government, universities and scientific institutions were little more than centres for supplying the necessary teachers, professors, and engineers. Scientific research was regarded as the scientist's private affair, not as an essential part of his profession. Neither proper equipment nor the necessary auxiliary personnel were available for scientific work.

In 1910 there was a student protest in Moscow University, and as a reprisal, the police invaded its premises. Many professors and scientists resigned in protest. They received massive public support and continued to teach and to do research with the meagre means the general public could afford. In this period, experimental physicist Lebedev continued to work in the basement of an apartment house, Lyapunov did brilliant work in analytical mechanics, and Andrey Markov did seminal work in statistical physics while teaching in a high school. This public-supported scientific research system continued up to the time of the November Revolution.

Science in the initial years after the November Revolution

Soon after the November Revolution, it became clear to scientists in Russia that the state was willing to put its weight behind scientific development. In the socialist state, scientific effort was no longer dependent on private initiative or people's personal contributions. It became an affair of the state, a matter of the greatest importance to the Soviet government.

One of the first manifestations of this changed approach was the rapid organization of large numbers of research institutes, sponsored by the state. The first few years of Soviet rule brought into being an entirely new network of scientific institutions—specialized research institutes. The Institute of Physics and the Central Aerohydrodynamics Institute (TSAGI) were established in Moscow, the Physico-Technical Institute and the State Optical Institute came up in Petrograd.

Immediately after the revolution, Lenin correctly realized the potential of electricity in large-scale industrialization and in unleashing productive forces. He called for large-scale electrification, saying "Communism is Soviet power plus the electrification of the whole country." But at that time there was no electrical power industry in Russia, and very few people had the required know-how. To overcome the problem, the All-Union Electro-Technical Institute was built in Moscow.

Big research institutes soon began to appear in other fields of science as well—chemistry, biology, geology. All these institutes were organized and equipped with amazing speed with adequate budget provisions. A distinctive feature of the new institutes was the close contact they maintained, through the people's commissariats and the plants and factories, with the problems of national economy. They became an important link between science and the needs of industry and agriculture. For example, the Central Aerohydrodynamics Institute laid the groundwork for the huge Soviet aviation industry. The State Optical Institute rendered great assistance in the development of the optical industry and the improvement of its output. The All-Union Electro-Technical Institute paved the way for a national electrical industry. The work of the Karpov Chemical Institute, in Moscow, promoted the development and consolidation of various branches of the chemical industry. The Institute of Plant Breeding worked on the problems of increasing agricultural output.

The 'Academy'

We have seen earlier that the St. Petersburg Academy of Sciences was founded by Peter the Great in 1725. But in the period preceding the revolution its activity was very limited. After the November Revolution, the leaders of the Academy realized the potential for science unleashed by the socialist state. They approached the Soviet government, expressing their readiness to participate in scientific planning of the reconstruction of the economy. Accepting this offer, the Council of People's Commissars resolved to provide the necessary assistance to the Academy.

The Academy was called upon to set up a number of committees of experts to draw up, as quickly as possible, a plan for the reorganization of industry and economic revival in Russia. This plan was to provide for large scale industrialization (including recommendations on locations of the proposed factories) from the point of view of proximity of indigenously available raw materials, energy sources, labour, and points of use of the products. Particular attention had to be given to the electrification of industry, mechanization of transport and agriculture, and the utilization of water power and the poorer grades of fuel (peat, low grades of coal) to produce electric power with the minimum expenditure on the extraction and transportation of fuel.

The Academy took up the challenge in right earnest.

With active support from the Soviet state, the Academy, formerly at the head of little more than deserted museums, archives, and libraries, was transformed into a broad association of a large number of research institutes, well-staffed, equipped and active, pursuing clearly defined aims in clearly defined fields.

Thus, the old physics laboratory of the Academy became the Institute of Physics and Mathematics. As it expanded further, it was reorganized into three separate institutes: the Lebedev Institute of Physics, the Steklov Institute of Mathematics, and the Seismological Institute. An Institute of Physical and Chemical Analysis was set up. I. P. Pavlov's physiological laboratory grew into a big Physiological Institute.

Soon the results began to appear. In the years following the revolution, because of the hostile encirclement and civil war, no new scientific equipment could be imported. In spite of such problems, scientists undertook a thorough investigation of a magnetic anomaly observed in the region of Kursk, which led to the discovery of enormous deposits of iron ore, hitherto unknown. A geological survey of the Kola Peninsula brought to light large apatite deposits.

Particularly worth mentioning was the famed GOELRO (abbreviation for "State Commission for Electrification of Russia") plan made by engineers belonging to the Academy at the instruction of the government: an elaborate plan for economic reconstruction including the electrification of the whole country. It was implemented over a 10 year period. It was a feat of unheard-of dimension that laid the foundation of industrially advanced socialism in the Soviet Union.

In 1925, on the occasion of the bicentenary of the Russian Academy of Sciences, it was renamed as All-Union Academy of Sciences. Congratulating the scientific community on behalf of the Soviet government, M. I. Kalinin said "Socialist society, more than any other form of society, urgently requires the broad development of both the abstract and the applied sciences; and it is the first form of society to create for scientific thought and labours genuine freedom and fruitful contact with the masses."

Scientific academies and societies are there in most advanced countries, whose main activities are to organize conferences, to publish research journals, and to honour scientific achievements. They do not run or administer research institutions themselves. In the USSR, the Academy of Sciences grew into the apex body that managed most scientific research. The Academy's activities covered not only the scientific disciplines, but also history, philosophy, linguistics, economics, etc., that is, all fields of human enquiry. The Academy's major function was to manage scientific laboratories and to advise the government on scientific matters. In 1945, the Academy managed 57 institutes, 16 laboratories, 15 museums, 31 commissions and committees, 35 research stations, and 7 societies. Its annual budget was 200 million roubles, which dwarfed the defense budget of most advanced countries.

The Academy was not a governmental body: it was an autonomous body of eminent scientists. In 1945 it had 139 members (they were called 'Academicians') and 198 corresponding members. It was considered far more difficult to become an Academician than to become a Fellow of the Royal Society of London. The Academicians were elected solely on the basis of their scientific eminence, and the Soviet government played no role in their election. Once elected, the Academicians received a large salary and many other perks that made their life comfortable, and their prestige in society was far higher than that of their counterparts in capitalist countries.

Even though the Academy was not formally a government body, it was responsible for implementing the Soviet government's ambitious programme of promoting science and to bring science to the service of the people. By being attached to the government this way, it had access to enormous funds, land, equipment, and other resources. It could plan and carry out ambitious programmes that demanded hundreds of scientific workers.

Apart from the Academy of Sciences, most ministries also had scientific establishments of their own. For example, in 1945, the Ministry of Agriculture maintained 100 research Institutes and 865 experimental stations with a staff of around 14,000 scientific workers. The other ministries also ran institutes and experimental stations with focused research objectives. This way, Soviet Russia built a gigantic machinery for scientific research with no equivalent anywhere in the world.

In Soviet science there was a definite emphasis on practice: It had close contact with the national economy and the problems to be attacked were often set by government departments and by branches of industry. Such problems often demanded intricate and laborious research, to be undertaken through collective effort of scientists and technologists of different specializations. For this, a mechanism was evolved where much of scientific pursuit was not individual but collective, undertaken by a group of scientists, usually headed by a prominent specialist in the field. In this way science could play a major role in the development of productive forces.

However, emphasis on these practical activities did not diminish the support for theoretical work not directly connected with agriculture or industry, which also brought splendid results. Soon after Einstein published his general theory of relativity, the Soviet scientist A A Friedman made important contributions to the theory. Mathematical work in the Soviet Union was revered all over the world. I P Pavlov developed his theory of first and second signal systems, A F Joffe made fundamental contributions on the character of crystals, and S V Lebedev produced the first synthetic rubber.

The state of science, 1925 to 1942

Around 1925 the nascent socialist state had regained the production levels of the pre-revolution period. But this was clearly insufficient to save the socialist state encircled by hostile powers. In the 14th Congress of the CPSU, Stalin gave the call for all-out industrialization: "The conversion of our country from an agrarian into an industrial country able to produce the machinery it needs by its own efforts—that is the essence, the basis of our general line."

This meant that the country had to build up heavy industry—and if the USSR was to be independent of the capitalist world, it had to have the capability to manufacture big machines, iron and steel had to be produced in large quantities, electrical machinery and equipment had to be produced to generate and use electrical power, and new sources of energy had to be found and put into use. Coal and oil output had to be increased and huge dams and other hydroelectric projects had to be built. More importantly, the knowledge-base needed for these had to be created within the country.

In order to be self-sufficient in food production, agricultural productivity had to be stimulated, which was not possible with land owned by hostile landlords. In December 1927, the government adopted a decision calling for collectivization of agriculture. This resulted in an extraordinary increase in the demand for agricultural machinery, particularly tractors. Huge tractor plants had to be built to satisfy this need.

All these societal developments threw up great challenges before the scientists. The Academy again took up the challenge in right earnest.

The decisions on the industrialization of the country and the collectivization of agriculture were the precursors of the Five Year Plans. A further decision adopted by the 15th Party Congress called upon the State Planning Commission to draft the First Five Year Plan for the national economy.

In April 1929 the First Five Year Plan was approved and adopted. "The fundamental task of the Five Year Plan," wrote Stalin "was to create such an industry in our country as would be able to re-equip and reorganize, not only the whole of industry, but also transport and agriculture—on the basis of Socialism." The plan was grandly conceived. And it was carried out, not in five years, but in four. It was followed by a second Five Year Plan, and a third. With their accomplishment, a solid basis for socialism was built.

During this surge for rapid industrialization and introduction of mechanized agriculture, the demand for trained scientific and technological manpower increased manifold. There were only 91 universities and colleges in pre-revolutionary Russia.

Over the first three decades after the revolution, the number continuously rose, and on the eve of the 2nd World War, in 1941, there were some 800 universities and colleges in the Soviet Union. In the course of the three Five Year Plans, the Soviet Union's college and university student body multiplied almost four times over.

Scientific developments of this period

Due to the contribution of mathematicians like Chebyshev and Lobachevsky, Russia had a prominent position in the world of mathematics even before the revolution. After the revolution, it did not remain the individual efforts of isolated geniuses. Cultivation of mathematics became a collective effort where a large number of mathematicians worked together in big Institutes and exchanged ideas. Some of the fields in which original and seminal contributions came from Soviet mathematicians are: (a) modern analytical number theory by I M Vinogradov, (b) probability theory by the Soviet school of probability theorists like S N Bernstein, A N Kolmogorov, A Y Khinchin and many others, (c) theory of differential equations by I G Petrovsky, S L Sobelev, V I Smirnov, and (d) geometrical topology by P S Alexandrov.

Mathematicians contributed to industrial growth also. The young Leonid Kantorovich (1912-1986), after finishing studies in mathematics, was given the task of optimizing production in a plywood industry. In 1939 he came up with the mathematical technique now known as linear programming. It proved to be so useful in practice that it became a standard practice in industrial planning all over the world, and Kantorovich got the Nobel Prize in economics in 1975.

The concept of surface states proposed by the physicist Igor Tamm (1895-1971) in 1932 proved to be important for the development of MOSFETs, an important electronic device. The idea that the neutron has a non-zero magnetic moment, suggested by Tamm and Semen Altshuller in 1934, was met with scepticism at that time, as the neutron was supposed to be an elementary particle with zero charge, and thus could not have a magnetic moment. The same year, Tamm coined an idea that proton-neutron interactions can be described as an exchange force transmitted by a yet unknown massive particle, this idea was later developed by Hideki Yukawa into a theory of meson forces. The approximation method for many-body physics now called the Tamm-Dancoff approximation was first developed in Soviet Russia by Tamm in 1945.

Lev Landau (1908-1968), the celebrated Soviet physicist, made fundamental contributions to many areas of theoretical physics. His accomplishments include the independent co-discovery of the density matrix method in quantum mechanics (alongside John von Neumann), the quantum mechanical theory of diamagnetism, the theory of superfluidity, the theory of second-order phase transitions, the Ginzburg-Landau theory of superconductivity, the theory of Fermi liquid, the explanation of Landau damping in plasma physics, the Landau pole in quantum electrodynamics, the two-component theory of neutrinos, and Landau's equations for S matrix singularities. The books written by Landau and Lifshitz are still standard textbooks used all over the world.

There was also an effort to bring home Soviet scientists who were working abroad. When the physicist Pyotr Kapitsa (1894-1984), who worked with Ernest Rutherford in the famous Cavendish Laboratory of the University of Cambridge, returned to the Soviet Union in 1934, he was given a whole Institute—the "Institute for Physical

Cover Article

The "systems" of science under advanced capitalism and socialism

In the current state of the world, there are two distinct societal systems—capitalism and socialism—running in parallel. From the point of view of science, the natural question is: How does science fare under these two systems of society? To review this, let us take two representative examples: the United States of America as an example of advanced capitalism, and the USSR as an example of a socialist state.

In the United States most scientific research is conducted in the university system. There are a few national laboratories (like the Los Alamos National Laboratory, the Argonne National Laboratory, National Institute of Health, etc.) and a few laboratories supported by private companies (like the AT&T Bell Labs). But the volume and extent of research conducted in these laboratories are nowhere close to that in the Universities. So, in analysing the system of American science, let us focus on how research is conducted in the universities.

There is little governmental support for the universities in US. There are a few State Universities which receive a small amount of support from the states, and the vast majority of private universities receive none. As a result, all running expenses are raised from students' fees, which are exorbitantly high, and private donations. Most Americans cannot dream of sending their children to university. The students who manage to get there, start their lives with a huge educational loan. In contrast, in the Soviet system, education up to the highest level was free, every deserving student had access up to the highest level, and all the universities were fully funded by the government.

In the US, a few governmental bodies have been established to disburse funding for scientific research, most important of them being the National Science Foundation (NSF). All faculty members have to obtain external funding to support their research—either from industries or from funding agencies like the NSF. The success rate of research proposals submitted to the NSF is only about 5%. There is cut-throat competition to obtain funding, and so the scientists have to tune their research plan according to what are perceived as the "thrust areas" by the industries and funding agencies. And the thrust areas are often set by the national priority: Defense-related research receives the maximum support. During his Presidency, Ronald Reagan started the so-called "Star Wars" programme: a plan to fight wars from space. There was huge financial outlay for the programme, and scientists scrambled for pieces of the cake, no matter what their true scientific interests were. Why? Because they can survive in the university system only by doing that.

In contrast, in the Soviet system individual faculty members trying to obtain external funding was unheard of. A faculty member had to plan his/her research work a year in advance, had to estimate the equipment or manpower needed, and had to submit the budget to the institute he or she belonged to. That would be included in the budget of that institute, which would in turn be included in the budget of the whole Academy. *(Continued to the next page)*

Problems"—to carry on his research, but was not permitted to leave the country. The Soviet Government bought Kapitsa's equipment at Cambridge for 30000 British pounds, and Rutherford arranged to transfer these to Soviet Russia. Kapitsa made full use of the opportunity offered to him, and devoted his energy to the study of properties of matter at very low temperatures. In 1937 he discovered the phenomenon of super-fluidity—a strange behaviour of Helium at a temperature below 2.17 K—for which he was awarded the Nobel prize much later in 1978. During the war years, he was the head of the oxygen industry—a crucial requirement at war-time—and

There is an allegation, often circulated in popular media, that in the socialist system individual scientists do not have freedom to pursue research as per their own desire. The above shows that this is in fact more true in the US system. In contrast, in the socialist system there was a conscious attempt to bring science to the service of the people and so problems posed by the necessities of people's life and social progress were placed before the scientific community, and individual scientists could choose what to work on. Theoretical research and abstract mathematics were equally encouraged; in fact the Soviet Union stands out in terms of contribution to these areas.

In the US, all faculty members are inducted into the university system as temporary employees—the so-called "tenure-track" positions. They have to publish research papers in scientific journals, in sufficient numbers over a period of 5 to 10 years, in order to get a permanent position, that is, to get "tenured". For that they have to bring funds to support doctoral and postdoctoral students, and to buy the necessary scientific equipment. Thus a lion's share of their productive time is spent in writing research proposals, and in defending these before the funding agencies. If they fail to obtain funding and to publish papers in sufficient numbers, their tenure would be terminated. This is the "publish-or-perish" policy followed in American universities. Naturally, most of the scientists quickly move to areas where money is available.

Such pressure has its advantages: it ensures that all faculty members are productive in research, and that the total volume of research output is high. Suffice it to say that most of the Nobel Prizes in science have been bagged by American (or more accurately, those who emigrated to America) scientists.

But it ensures that scientists do research in the areas supported by the "system". It becomes difficult for scientists to attempt out-of-the-box thinking and truly path-breaking (and hence risky) research. Nobel Laureate Prof. Peter Higgs, who theorized the existence of a particle now named after him, once commented that such academic expectations would likely have prevented him from both making his groundbreaking research contributions and attaining tenure. "It's difficult to imagine how I would ever have enough peace and quiet in the present sort of climate to do what I did in 1964," he said. "Today I wouldn't get an academic job. It's as simple as that. I don't think I would be regarded as productive enough" (The Guardian, 06 Dec 2013). He was commenting on the academic atmosphere in Britain, which is similar to that in the US.

A noticeable feature in all capitalist countries is the dwindling support for basic science and increased focus on military technology.

In contrast, the socialist system guaranteed employment to all its citizens (in fact, right to employment was recognized as a fundamental right in its Constitution), and so all scientists had permanent positions from the beginning of their career. One might argue that that reduces the motivation to excel, but as we have seen earlier, the facts speak otherwise. There was a system of criticism and self-criticism, publication of successes and failures of research groups in newspapers, and of recognizing research accomplishments which ensured that scientists tried their best to be in service of the society.

developed a new technique for liquefaction of air for large-scale application. After the war, he headed the scientific team that developed the atom bomb, without which the imperialist countries would have been able to dominate over the whole world with the threat of nuclear warfare.

After Kapitsa's discovery of super-fluidity, Lev Landau developed the mathematical theory explaining the phenomenon (for which he received the Nobel Prize in 1962), and experimental confirmation of the implications of this theory was obtained by V P Peshkov. V L Ginzberg developed a phenomenological theory of superconductivity in collaboration with Landau (the Landau-Ginzberg theory). A A Abrikosov explained how magnetic flux can penetrate a class of superconductors. He was a co-recipient of the 2003 Nobel Prize in Physics, with Vitaly Ginzberg and Anthony Leggett, for theories about how matter can behave at extremely low temperatures. Soviet physicists and mathematicians like Kolmogorov, Arnold, Filippov, and others made basic contributions to the study of non-linear oscillations. The works of L I Mandelstam, N D Papalexy, A A Andronov, N M Krylov, and N N Bogolyubov, led to important developments in radio engineering and mechanics.

In 1934, while working under S I Vavilov, P A Cherenkov observed the emission of blue light from a bottle of water subjected to radioactive bombardment. This phenomenon proved to be of great importance in subsequent experimental work in nuclear physics, and for the study of cosmic rays. Igor Tamm and Ilya Frank theoretically explained the phenomenon, for which Cherenkov, Tamm, and Frank together got the Nobel Prize in 1958.

Chemistry also developed, and produced a number of works of the greatest moment, both theoretical and practical. The works of A E Favorsky and S V Lebedev paved way for the establishment of the synthetic rubber industry in the USSR. The investigations of A N Nesmeyanov threw a new light on the important field of organometallic compounds. In physical chemistry, N N Semyonov discovered the mechanism of chemical transformations, for which he was awarded the Nobel Prize in 1956. A N Terenin discovered the photo-dissociation of diatomic molecules.

The science of geochemistry was founded by Vladimir Vernadsky and Alexander Fersman. Pioneering work in theoretical petrology and chemical thermodynamics was done by Dimitri Korrzhinskii, which is lauded world over. In other branches of Earth Sciences also, Russian scientists made important contributions, e.g., in seismology (Grigory Gamburtsev), oceanography (Leonid Brekhovskikh) and marine geology (Maria Klenova). The collective style of work which became a feature of Soviet science was particularly notable in the huge geological investigations conducted under the Five Year Plans. It was these investigations, seeking and discovering oil, metal ores, and other minerals in various parts of the Soviet Union, that charted Soviet industry's raw material base.

Science during war-time

Early in the war—in the spring of 1942—Stalin wrote in a telegram addressed to the president of the Academy of Sciences: "I am confident that the Academy of Sciences, despite difficult wartime conditions, will keep pace with the increased requirements of the country."

In a second telegram to the president of the Academy, Stalin wrote: "I hope that the Academy of Sciences will head the movement of innovators in science and industry, will become the centre for progressive Soviet science in the struggle which has been launched against the most malignant enemy of our people and of all other freedom-loving peoples—German fascism."

The Academy of Sciences lived up to his expectations.

The war was a test for Soviet science. On the one hand, science was called upon to solve entirely new and often extremely intricate problems in every conceivable field, set before it urgently by the front, the war industries, and the national economy as a whole. On the other hand, it was compelled to work in unaccustomed conditions, often involving great hardship. Soviet science

The Soviet Nobel Laureates in science. Top row: Nikolay Semyonov (1956, Chemistry), Igor Tamm (1958, Physics), Ilya Frank (1958, Physics), P. A. Cherenkov (1958, Physics). Middle row: Lev Landau (1962, Physics), Nikolay Basov (1964, Physics). Alexander Prokhorov (1964, Physics), Leonid Kantorovich (1975, Economics). Bottom row: Pyotr Kapitsa (1978, Physics), Zhores Alferov (2000, Physics), Vitaly Ginzberg (2003, Physics), Alexei Abrikosov (2003, Physics). It is notable that many of the scientists who received the Nobel Prize after Stalin's demise (1953), like Kapitsa, Landau, Semyonov, Ginzberg, Tamm, etc., did their most significant scientific work during the Stalin era.

proved to be up to the task. In fact, towards the end of the war, Soviet industry was able to produce technically superior fighter planes, tanks, artillery cannons, and other weapons, for which the science and technology was generated by the vibrant Soviet science.

Noticeable is the fact that all the leading scientific periodicals in the Soviet Union continued publication throughout the war, and the majority of the universities and colleges continued to function. Early in 1943, at the time of the decisive fighting at Stalingrad, the Soviet scientists observed the tricentenary of the birth of Isaac Newton. This celebration at the height of war was a striking demonstration of the strength and vitality of Soviet science.

The 220th anniversary of the foundation of the Academy of Sciences of the USSR was celebrated in June 1945, when the banner of victory was floating over the Reichstag in Berlin. Scientists from all over the world came to Moscow to congratulate the Soviet scientists for their role in saving the world from the fascist menace.

After the war

The vast infrastructure and the tradition of research remained even when the socialist system in Soviet Russia was declining after the late 1950s. By the 1950s, a batch of scientists educated and trained in the Soviet Union had emerged on the scene. Thus Soviet science was flourishing even when the leadership of the country fell in the hands of those who were following policies that led to a reversal of the socialist ideal, and the political-economic system was on a decline. Many works of great importance were done in this period. Scientists all over the world are still discovering work done by Soviet scientists in the 1950s and 1960s, that were reported only in Russian journals and were unknown to the Western world.

In space exploration, Soviet Union was ahead of the rest of the world: in 1957 it launched the first artificial satellite and put the first living animal, a dog named Leika, in orbit. In 1959, its Luna missions discovered what is known as “solar wind”, and took photos of the far side of the moon. The first human space-flight was by Yuri Gagarin in 1961, and the first woman in space was Valentina Tereshkova, in 1963.

Weaknesses of Soviet science

Like all systems, the Soviet science system also had its drawbacks. Due to the difficult and often stressful conditions in which the socialist system in Soviet Russia had to build its scientific establishments, weaknesses, too, cropped up. After the civil war ended, the nation had to build a large network of scientific research institutions within 5-6 years. The state provided the money for it, and the physical infrastructure was built up. But where would it get the scientifically equipped manpower to do the research? Czarist Russia did not produce even a fraction of the necessary number of scientists.

Under that condition, the Soviet state was constrained to engage people of lesser competence to run these institutions. A formula was worked out in which research teams were set up, each with well-defined goals and methodology to achieve the targets, each one headed by a competent scientist. This formula worked remarkably well, especially in areas that demanded painstaking data collection or repeated experimentation. But the shortfall of competent scientists compared to the necessity led to a situation where the senior and eminent scientists were over-worked, often one person having to serve as Director of many research organizations. Thus their time for productive science would be severely constrained, with more time spent on administrative work. The time available to train and mentor the next generation of scientists also became limited. This situation has the danger of people of lesser calibre or those proposing wrong theories rising to commanding positions by manipulating the system.

In the Soviet intellectual circle there was a serious cultivation on philosophical aspects of science and a conscious effort to study how the concepts in dialectical materialism were vindicated by scientific discoveries. A movement was released to propagate among the people a materialist view of nature and society, and many of the scientists tried to follow a true materialist approach in scientific research. But there were people who, either from wrong understanding or from unscrupulous motive, vulgarised the teachings of dialectical materialism and used to brand the scientific propositions of their opponents as idealist and anti-Marxist and hindered the objective pursuit of research.

Such situation occurred in the field of linguistics, where Academician N Y Marr rose to prominence by creating a school of so-called "Marxist linguistics" which claimed that language has class character, and that thought can exist without language medium. The use of politically laden verbiage in scientific discourse helped him to confuse a section of the political system and to earn favour, so that he managed to get those opposed to his theory removed from prominent positions in the linguistics institutes all over the Soviet Union. In the end, Stalin personally intervened, not by any administrative fiat, but by writing an essay on linguistics where he showed that Marr's ideas are theoretically incorrect, and that they had no relation with Marxist theory.

"Language, as a means of intercourse", wrote Stalin "always was and remains the single language of a society, common to all its members; The 'class character' of language formula is erroneous and non-Marxist." Stalin also showed that "Whatever thoughts arise in the human mind and at whatever moment, they can arise and exist only on the basis of the linguistic material, on the basis of language terms and phrases. Bare thoughts, free of the linguistic material, free of the 'natural matter' of language, do not exist."

After that, the linguists sidelined by Marr were reinstated in their positions.

Similar situations happened in the fields of political economy, philosophy, and biology, which stunted the growth of research in these disciplines. These cases, however, should not be taken as representative of Soviet science, for the successes far outweighed the failures—the victory over fascism stands testimony to that.

Public awareness of science

From the very outset, popularization of science was undertaken on a wide scale. Besides the extensive publication of popular scientific literature and the organization of lectures, this included such methods as the despatch of train wagons, fitted up with graphic displays aimed to popularize various branches of science, to all parts of the country. With the advance of radio, the government received still another powerful instrument for the propagation of scientific ideas.

Science also had a prominent position in the state-run newspapers and other media. The activities and successes of each laboratory were regularly reported in newspapers, and failures to meet the planned research goals were criticized publicly. Before the election of prominent scientists into the Academy, reviews of the research of each candidate were published in newspapers. Popular science articles reporting important discoveries inside as well as outside the Soviet Union also were published regularly. These were part of the Soviet government's conscious effort to improve the scientific consciousness of the people. As a result, industrial workers and farmers were also exposed to the contributions of Galileo, Newton, Darwin, and others.

All Union Conferences were regularly organized in different branches of science. The daily proceedings of the conferences were extensively reported in the newspapers and the people, not just the scientists or intellectuals, followed the deliberations with interest. These helped to create a scientific temper and curiosity about issues in science among common people.

It is sad that this system of doing science broke down after capitalism recaptured power in the Soviet Union in 1991. The social prestige of scientists diminished, as did their remuneration, so much so that most scientists found it difficult to make both ends meet. Financial support for science hit rock bottom and many able scientists fled to the West. That is a glimpse of the damage wreaked in the field of science and education caused by the switch from a production system that put the interest of society first to one driven by blind profit motive.

Despite this setback, the emergence of a state—which was one of the most backward states in Europe at the turn of the 20th Century—as a superpower by the mid 1950s, with achievements in every field of human endeavour, has made a very sizable section of world's population to draw inspiration from Soviet history. The history of Soviet Science (and Technology) is only a part of that history.

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On the Significance of Faraday and Maxwell's works

N R Sree Harsha and D P Kothari *

In this article, we shall see the importance of the works of two physicists that changed the world and the way we live. In a way, all modern technological revolutions like the electrical generator, cellular mobile phone, television, computer, etc., have their origins in the brilliant attempts done by these two scientists to understand the nature of the electric and magnetic forces.

Introduction

ON 29TH NOVEMBER 1999 , a survey was conducted by the *Physics World* to determine "which scientists have made the most important contributions to physics" [1]. More than 400 physicists took part in the survey and they have voted that Sir Isaac Newton had made the most contribution in the field of physics. Albert Einstein was voted second for his discovery of the special and general theories of relativity. Third in the list was James Clerk Maxwell, who unified electricity and magnetism within a single framework called "electromagnetism". Michael Faraday was listed in the 9th position for his "experimental researches in electricity". Faraday is widely regarded as one of the greatest experimental physicists. Unfortunately, Maxwell and Faraday are not well known to the general public. In this article, we shall see the significance and the genius of their work. But, before can we do that, we need to understand the history of classical electromagnetism.

Even before the formulation of theoretical foundations of electromagnetism, people knew about it in the form of lightning, static electricity, and frictional electricity. In the early 19th century, electricity was already a very widely researched field. In 1780s a military engineer named Charles Coulomb had discovered what later Ampére called "electrostatics". He posited two kinds of charges, positive and negative and formulated the inverse square law by means of his torsion balance. Later in 1812, a polytechnician named Simeon Denis Poisson developed the theory by introducing what is now known as a scalar electric potential. Coulomb and Poisson's theory fitted well with the Laplacian scheme, which dominated physics of their time. They sought to reduce every phenomenon into the central force scheme introduced by Newton to explain the phenomenon of gravitation. In this view, the underlying formalism was the so-called "action at a distance".

Let us understand what "action at a distance" means with the following simple example: consider two point particles of mass m labeled as A and B. Let the

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distance between the two particles be r. Then, we know that the magnitude of the gravitational force of attraction F between the two particles is given by

$$F = G\frac{m^2}{r^2}$$

Let us now change the distance from r to R instantaneously. Then the magnitude of the new gravitational force of attraction F_{new} between the two particles is given by

$$F_{\text{new}} = G\frac{m^2}{R^2}$$

Now, according to Newton's "action at a distance" formalism, the two particles A and B will see the change in the force from F to F_{new} almost instantaneously. It is as if the space between them did not matter. Due to the enormous success of Newton's theory in explaining the physical world around us, physicists of those days sought to explain the electric and magnetic phenomenon through "action at a distance" formalism. But, it was a self-taught genius named Michael Faraday who seriously challenged this formalism.

Michael Faraday

Michael Faraday was born on 22nd September, 1791 in Surrey, England. His father, James Faraday, was a blacksmith who often fell ill and was incapable of working steadily. Michael Faraday was one of the four children and they were a rather poor family. Faraday later recalled being given one loaf of bread that had to last him for a week [2]. At the age of 14, Michael Faraday became an apprentice to George Riebau, a bookbinder and bookseller. During this seven-year apprenticeship, Faraday read many books that were brought in for binding. He developed a passion for science, and for chemistry in particular. Later, Faraday became a laboratory assistant to Sir Humphry Davy at the age of 20. Sir Humphry was then a prominent chemist who discovered that chemical changes were largely responsible for the electrical action of a battery. Faraday eagerly learnt every piece of knowledge Davy deemed to impart.

Figure 1: Michael Faraday (1791-1867)

In July 1820, a Danish Professor named Hans Christian Oersted discovered that an electric current in a wire would cause a nearby compass needle to deflect, if it is placed parallel to the wire. He also discovered that the magnetic needle turned in circles around the current carrying conductor. He discovered, as he had anticipated, that there is a deep connection between electricity and magnetism. A self-taught French Physicist named André-Marie Ampère [6] heard of this discovery of Oersted through a demonstration given by his friend named Francois Arago to the Paris Academy of Sciences on 11th September 1820. Ampère improved Oersted's results by eliminating the effects of the Earth's magnetic field. He did this by inventing an astatic compass needle. It was Ampère, not Oersted, who discovered that the compass needle points at 90° to the current carrying wire. Ampère also found that the currents flowing through the voltaic battery and the wire are equal and thus formed the concept of the "circuit", in which electric current was closed. In order to detect the electric currents in a wire, he also invented the so-called "galvanometer". The contributions of Ampère were so important to the formulation of the electromagnetism that Maxwell regarded him as "the Newton of electricity" [3].

The experiments of Oersted and Ampère created a flurry of research throughout Europe. Richard Phillips, who was a friend of Michael Faraday and the editor of the Annals of Philosophy, asked Faraday to write a comprehensive review on the history of electromagnetism. Michael Faraday wrote an article [4], which eventually got him interested in the theory of electricity and magnetism [5]. The consequence of this was to change the direction of physics forever and to make him the architect of field theory that now dominates the modern physics.

Ampère tried to develop electromagnetism in close analogy with the theory of gravitation. He wanted to explain the interaction between currents in terms of current elements that were analogous to the central force scheme. Faraday, on the other hand, meticulously noted his experimental results and suggested that there were "lines of force" around a current carrying conductor. He also noted that a hypothetical magnetic pole would move along these lines of forces created around a current carrying wire. Thus, he did not employ field concept just as a mathematical tool to explain his experiments. He believed that the space filled with the electric and magnetic fields was different from the empty space. Later Einstein [7] remarked that

Figure 2: James Clerk Maxwell (1831-1879)

"It is fascinating to muse: Would Faraday have discovered the law of electromagnetic induction if he had received a regular college education? Unencumbered by the traditional way of thinking, he felt that the introduction of the "field" as an independent element of reality helped him to coordinate the experimental facts."

But, owing to lack of mathematical tools to support his claims, Faraday largely resorted to experimental demonstrations. It was another genius named James Clerk Maxwell who formulated Faraday's ideas into a rigorous mathematical framework.

James Clerk Maxwell

Unlike Faraday, Maxwell had a very good education in mathematics. James Clerk Maxwell was born on 13th June 1831, in Edinburgh, Scotland. He was born in a comfortable middle class family and was a mathematical prodigy. At the age of 14, he wrote a paper on the geometrical character that was read before the Royal Society of Edinburg by Prof. Forbes. He later went to Peterhouse, at University of Cambridge and later moved to the Trinity College [8]. He graduated as the Second Wrangler in Mathematical Tripos, which were extremely difficult applied mathematical problems.

Michael Faraday had the greatest influence on Maxwell. Maxwell, after reading the Faraday's account on electricity, wrote his first paper on electromagnetism at the age of twenty-three. This paper was titled "On Faraday's lines of force" and was read to the Cambridge Philosophical Society on 10th December 1855. Maxwell later developed his theory from 1861 to 1862 in a series of four papers while at King's College London. In these papers he used mechanical models and analogies like the cylindrical vortices and idle wheels to develop the mathematics. It was while developing the model that he completed the electromagnetic theory by adding a term called "displacement current". Maxwell then left his professorship at King's College London and worked independently at his estate in Glenlair. It was there he wrote his famous "Treatise on electricity and magnetism", which was published in 1873. Maxwell removed his "mathematical scaffoldings" in his Treatise.

Maxwell had originally used a set of twenty equations to describe electromagnetism. Later, Oliver Heaviside mastered the Faraday-Maxwell approach to electromagnetism and reduced the Maxwell's original set of twenty equations to four equations, which are widely known today as the Maxwell's equations. Maxwell also noted that his equations gave rise to wave like disturbances that can propagate as the electric and magnetic fields. He calculated the speed with which such disturbances travel and found that it almost exactly matched the speed of light, hence concluding that light was an electromagnetic wave. Another peculiar property of these electromagnetic waves is that they do not depend of the frame of reference. This led Einstein to develop the Special Theory of Relativity and establish the foundation for Modern Physics.

Conclusion

We conclude this article by saying that the impact of Faraday and Maxwell is well regarded in the scientific community but unfortunately, is not well recognized among the general public. Suffice it to say that perhaps no other theory has made such technological revolutions as the classical electromagnetic theory, which was largely formulated by Faraday and Maxwell. For further developments and modern understanding of electricity and magnetism please refer [9].

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Neutrinos: A Tale as old as Time

Radha Pyari Sandhir *

1. Introduction

The neutrino; arguably the most alluring elementary particle we have confirmed exists. Without neutrinos, the sun wouldn't shine, and the universe would be far different from what we know it to be. Neutrinos are ancient particles: they've been around since the birth of our known universe. At around 50 billion per electron in the universe, neutrinos are also the most abundant.

The nature of this enthralling elementary particle lies in its name, given by Italian physicist Enrico Fermi. The origin 'neutro' implies a neutral subatomic particle. With the added Italian suffix '-ino', the word translates to a perfect description of the particle: little neutral one. Neutrinos rarely interact with other matter, and are unaffected by the strong force that holds nucleons together; thousands of trillions of neutrinos pass through us each second without us realising it. They're produced in the cores of stars and nuclear reactors; neutrinos from our own sun travel millions of kilometres undeviated just to reach and pass through us.

Neutrinos come in three flavours, named after the particles that are produced on the rare occurence of a collision: electron, muon, and tau. Antineutrinos follow suit. These fascinating tiny particles were originally assumed to be massless, as per the Standard Model, but since then we've found that they do have a tiny mass, though the exact value is unknown to us. They harbour a spin of $\frac{1}{2}$.

In this article, we follow the fascinating scientific journey behind this elementary particle.

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2. History

Like many scientific discoveries, the neutrino was originally conceived as a solution to an anomaly – specifically involving beta decay – and then detected by experiments searching for it. Before we get into the discovery of the neutrino, let's establish what beta decay is.

2.1 Beta Decay

Some radioactive nuclei emit high speed electrons or positrons. This happens when a neutron spontaneously converts to a proton or vice versa. High speed electrons or positrons are called "beta particles" or "beta rays". An example of such a decay is the nuclear transmutation of the Carbon isotope $C-14$. In order to stabilise, one of its neutrons emits an electron to become a proton, resulting in the element Nitrogen. The neutron to proton decay can be written explicitly as:

$$n \rightarrow p + e^- \tag{1}$$

where n represents the neutron, p the proton and e^- the electron, with negative charge. As per this information, the nuclear transmutation of $C-14$ can be written as:

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + e^- \tag{2}$$

There were two issues involving beta decay that puzzled scientists in the 1920's. Firstly, English physicist, James Chadwick, established that the spectrum[1] of beta decay is continuous – something that wouldn't be possible according to conservation of energy if beta decay was simply the release of a beta particle. The spectrum would be marked by discrete energy values of the beta particles if that were the case. Secondly, the conservation of momentum appeared to be violated. As an example, we refer again to the decay of $C - 14$ into Nitrogen and an electron (e^-), as given by Equation 2. Spin is an integral number for nuclei of even mass number and a half-integral number for nuclei of odd mass number. That means there's a discrepancy of spin of $\frac{1}{2}$ between the before and after of the reaction; adding up the spins on both sides just don't match!

2.2 The Neutrino as a Solution

German physicist, Wolfgang Pauli (Figure 1), in order to explain these anomalies, conceived the notion of the neutrino: a neutral particle of spin $\frac{1}{2}$. The continuous nature of the spectrum emerges due to the combined varying energies of the beta particle and neutral particle, thereby preserving energy. Momentum is preserved through its spin. The correct beta decay equation for $C - 14$ is given in Eq. 3.

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + e^- + \bar{\nu_e} \tag{3}$$

where $\bar{\nu_e}$ is an electron antineutrino. He proposed this concept in a famous letter on December 4, 1930, addressed to scientists in the radioactive community at the time. Interestingly, he proposed the name 'neutron' for this particle, though this name was withdrawn when the discovery of the neutron was made, as it seemed more appropriate for the neutron. Figure 2 is a translation of this letter, which was originally written in German.

[1]A spectrum is the intensity of a particle beam as a function of particle energy.

Figure 1: German physicist Wolfgang Pauli, who originally conceived the notion of the neutrino. [2]

Thus began a decades-long journey of discovery. Over the years, a number of experiments involving iron and water based detectors lead to the detection of neutrinos and gave rise to even more puzzles, which was not surprising for such a mysterious particle. A timeline of these events, up to the 2015 Nobel Prize in Physics is given by Figures 3 and 4. It was awarded to Takaaki Kajita and Arthur B. McDonald for the confirmation of neutrino oscillations; an important discovery which indicates that neutrinos have mass.

3. Neutrino Oscillations

The discovery of neutrino oscillations was a remarkable one, for it put the Standard Model into question. The Standard Model assumed neutrinos to be massless, which is now confirmed to not be the case due to these oscillations. In order to understand neutrino oscillations, we must first look at solar neutrinos.

Copy

Physics Institute
of the ETH
Zürich

Zürich, Dec. 4, 1930
Gloriastrasse

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, because of the "wrong" statistics of the N- and Li-6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" (1) of statistics and the law of conservation of energy. Namely, the possibility that in the nuclei there could exist electrically neutral particles, which I will call neutrons, that have spin 1/2 and obey the exclusion principle and that further differ from light quanta in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event not larger than 0.01 proton mass. - The continuous beta spectrum would then make sense with the assumption that in beta decay, in addition to the electron, a neutron is emitted such that the sum of the energies of neutron and electron is constant.

Now it is also a question of which forces act upon neutrons. For me, the most likely model for the neutron seems to be, for wave-mechanical reasons (the bearer of these lines knows more), that the neutron at rest is a magnetic dipole with a certain moment μ. The experiments seem to require that the ionizing effect of such a neutron can not be bigger than the one of a gamma-ray, and then μ is probably not allowed to be larger than e • (10^{-13} cm).

But so far I do not dare to publish anything about this idea, and trustfully turn first to you, dear radioactive people, with the question of how likely it is to find experimental evidence for such a neutron if it would have the same or perhaps a 10 times larger ability to get through [material] than a gamma-ray.

I admit that my remedy may seem almost improbable because one probably would have seen those neutrons, if they exist, for a long time. But nothing ventured, nothing gained, and the seriousness of the situation, due to the continuous structure of the beta spectrum, is illuminated by a remark of my honored predecessor, Mr Debye, who told me recently in Bruxelles: "Oh, It's better not to think about this at all, like new taxes." Therefore one should seriously discuss every way of rescue. Thus, dear radioactive people, scrutinize and judge. - Unfortunately, I cannot personally appear in Tübingen since I am indispensable here in Zürich because of a ball on the night from December 6 to 7. With my best regards to you, and also to Mr. Back, your humble servant

signed W. Pauli

[Translation: Kurt Riesselmann]

Figure 2: Translation of letter written by Wolfgang Pauli proposing his idea of a neutral particle with spin $\frac{1}{2}$ to solve the beta decay anomalies dealing with energy and momentum.[3]

3.1 Solar Neutrinos

Thermonuclear fusion reactions taking place in the core of the sun produce energy, and along with it, electron neutrinos.

The main mechanism is the fusion of Hydrogen (H) to Helium (He). In this process, protons combine to form Hydrogen, which in turn form Helium, releasing positrons and electron neutrinos. The complete fusion process can be summarised as:

$$4p \rightarrow 2(^2H + e^+ + \nu_e) \rightarrow {}^4He + 2e^+ + 2\nu_e. \quad (4)$$

Secondary reactions in the sun involving

Figure 3:

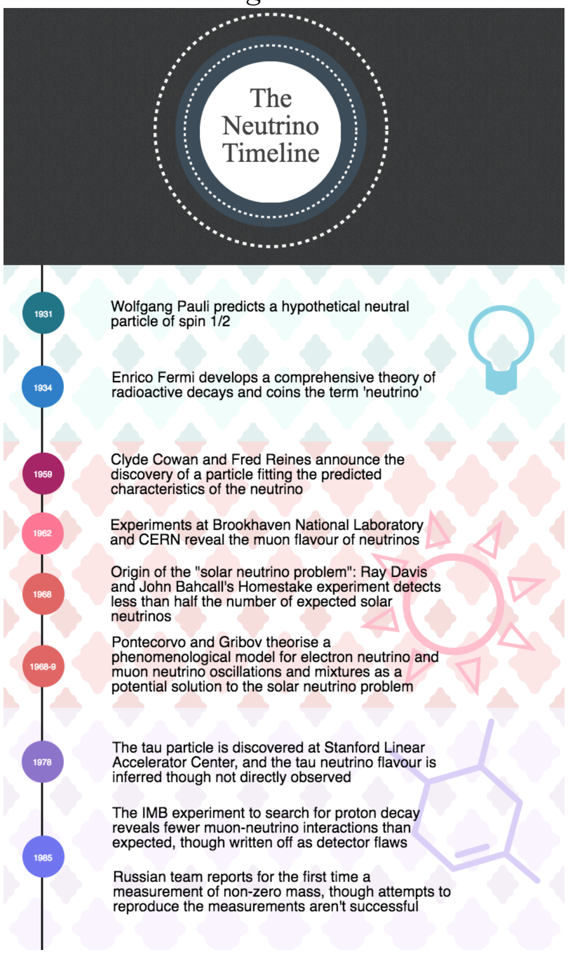
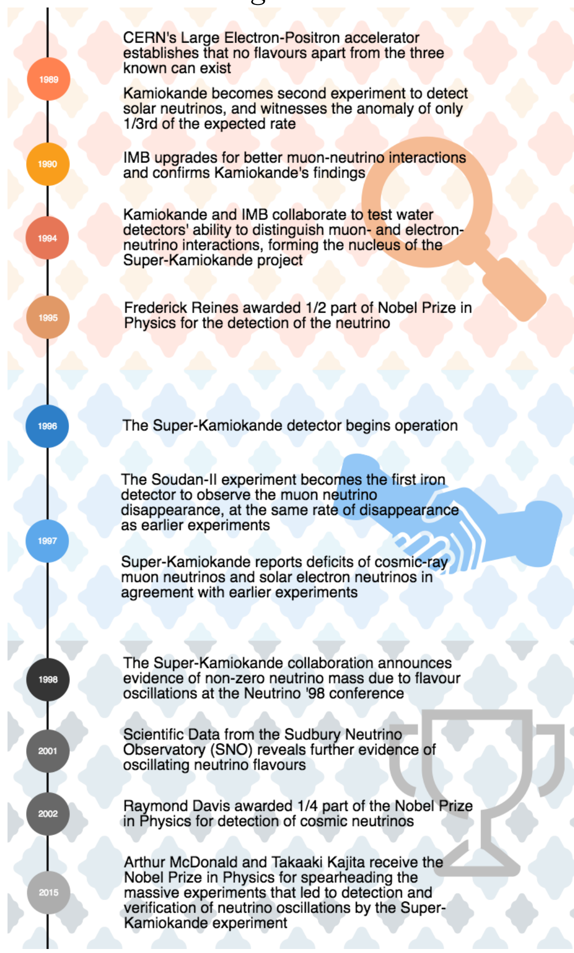


Figure 4:



electron capture by Beryllium and the beta decay of Boron produce neutrinos as well.

As neutrinos very rarely interact with matter, once they're produced at the solar core they move straight through the various solar zones and leave the sun. Based on this knowledge a prediction of electron neutrino flux – the amount passing through a surface – can easily be made. However, in the late 1960's, Ray Davis's and John Bahcall's Homestake experiment (shown in Figure 6) detected a deficit of less than half the expected amount of electron neutrinos reaching us from the sun. This was the origin of the solar neutrino anomaly, a problem that continued for a little over three decades, till Sudbury Neutrino Observatory gave evidence of neutrino oscillations. The total amount of all flavours of neutrinos matched the expected amount – what was happening was electron neutrinos were switching over to muon neutrinos. This is possible if at least two of these neutrino flavours have mass – a stark contrast to what the Standard Model expected.

Not only did the discovery of neutrino oscillations tell us that neutrinos have mass, it provided us with a sense of relief as well. The detected number of electron neutrinos originating from reactions in our sun was only one-third of what was expected. Photons from reactions that take place at the sun's core fight their way to the surface over thousands of years due to random walks and constant interaction with the layers they move through. Therefore, the brightness we see at the surface tells us about reactions that took place all that time ago. However, neutrinos tell us about the nuclear reactions that are happening at the core *right now*, since they can pass through the sun's shells virtually untouched. When the number of electron neutrinos detected was just a third of what was expected, it was thought that perhaps the sun's core was slowly dying out, i.e., the nuclear reactions in the core were decreasing over time – something that would eventually be catastrophic for us. Thankfully, that isn't the case.

Figure 6: The Homestake mine tank: diameter - 20', length - 48', capacity - 100,000 gallons of perchloroethylene, location - 4,900' below ground surface.[12]

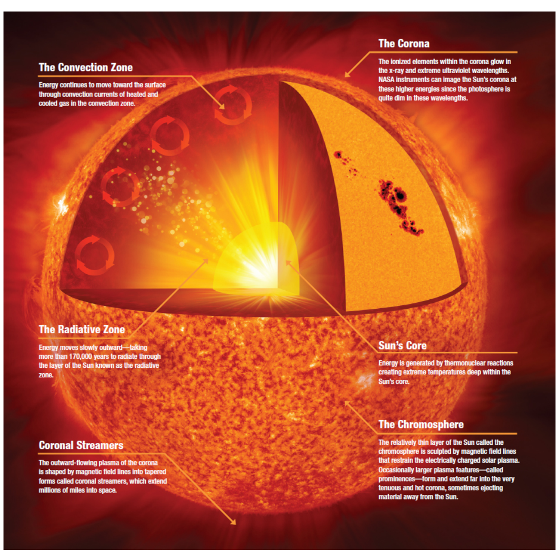


Figure 5: The three major zones in the interior of the sun.[8]

3.2 Theory Behind Neutrino Oscillations

We now get a little more technical and take a look at the theory behind neutrino oscillations. Neutrinos can be classified in two ways: 1) in terms of 'flavour' and 2) in terms of mass (Figure 7)[2]. Moreover, flavour and mass eigenstates[3] cannot be determined simultaneously.

Each flavour of neutrino is a weighted mixture of the three mass categories, as shown in Figure 8. In the figure, a larger shape indicates a larger contribution from that particular mass category.

[2]Specific values of these masses have not been determined, only their differences.

[3]Eigenstates are the states a particle can be in. To determine the flavour of a neutrino is to determine its flavour eigenstate.

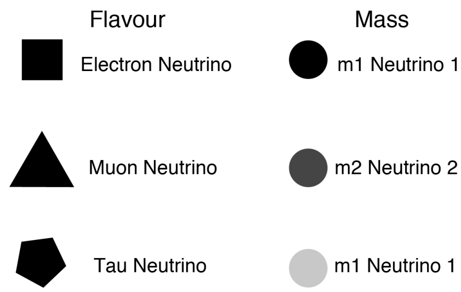


Figure 7: Neutrino classifications in terms of flavour and mass. [16]

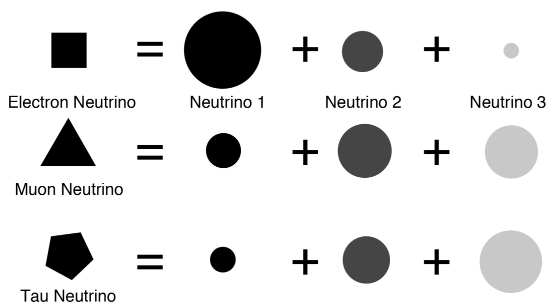


Figure 8: Neutrino flavours in terms of mass-classified neutrino mixtures. [16]

Like any other quantum particle, neutrinos act both as particles and as waves. And like any other wave, each mass eigenstate travels at a certain frequency. Since the flavour of a neutrino is a superposition of these mass eigenstates (neutrinos 1, 2, 3 in Figure 8), it is a wave packet that has its own frequency, giving rise to oscillations between flavours as shown in Figure 9.

These neutrino oscillations were first discovered in 1998 by the Super-Kamiokande experiment. A picture from inside the detector is shown in Figure 10.

The experiment measured the muon neutrinos generated through collisions between cosmic rays and Earth's atmosphere both above and passing through the earth. It was found that the muon neutrinos passing through the earth turn into tau neutrinos. This discovery verified that neutrinos do indeed harbour a tiny but finite mass, thereby requiring a modification to the Standard Model. While individual mass values have not been established as yet, the square differences of the masses have been found.

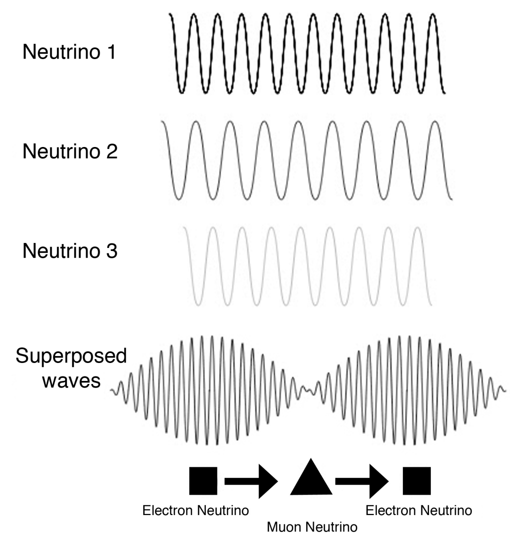


Figure 9: A superposition of the waves associated with the different mass eigenstates gives rise to flavour oscillations. [16]

4. The Future

The journey to learn about the mysterious neutrino is far from over, though many leaps have been made. We still don't know why their mass is so small – a million times smaller than that of an electron. Neutrinos also violate something called 'CP-symmetry': a pair of symmetries involving particles and their antiparticles, and mirror symmetries. These symmetries were accepted to be real until observations of symmetry violations by neutrinos shattered this belief. Moreover, their difference of

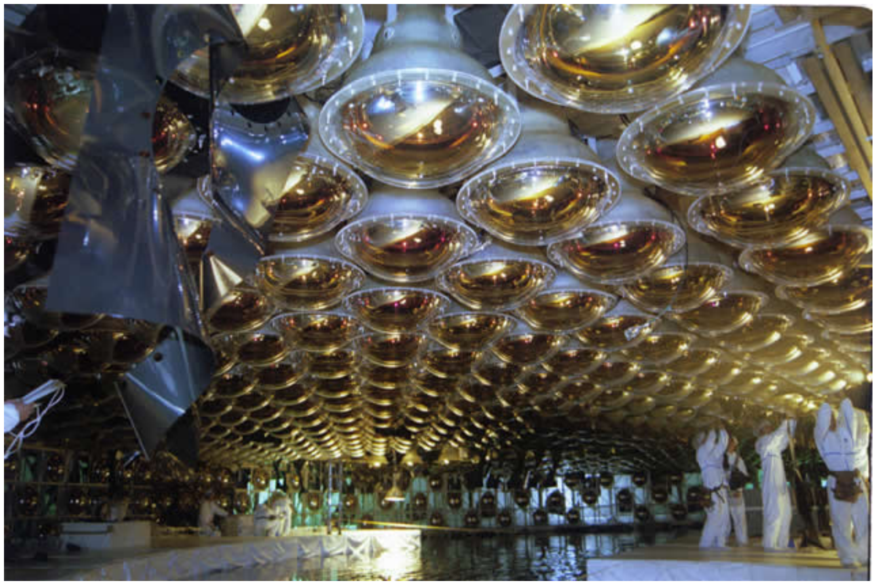


Figure 10: Array of photomultiplier tubes inside the Super-Kamiokande detector. [17]

behaviour from other quantum particles like quarks leaves gaps in the Standard Model. Some think that a unified theory will shed light on these discrepancies, and so, further study of neutrino oscillations may lead to a unified theory. Whatever the case may be, we should expect illuminating results in the future of neutrino physics.

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Analysis of the Real: Part II

Sarosh Ali *

ANALYSIS is that part of mathematics which tries to bring forth the intricacies of cause and effect relation between phenomena, to develop a more profound understanding. In the last issue, we dealt with functional dependences between two quantities, and analyzed the character of such functions. In the present issue we deal with sequences and series.

1. Sequences and Series

A 'map' is a derived object y from a set of value x. The set which provides the value of the independent variable x is called the domain of the map. And the collection of all the values of the dependent variable y is called the range of the map. Prior to studying the map it is sometimes not clear what the actual range of the function is and so a larger set is chosen. This is called the co-domain, and so the range $\subset$ co-domain. For a map of range $=$ co-domain, the map is called a onto map or a surjective map. Further, if for each value of x, there is a unique y then the map is called one-to-one $(1:1)$ or injective map. A map which is both surjective and injective is a bijective map.

If the map involves continuum of values of x then it is called a 'function' over a continuum, which we saw in the previous issue. However, if the map takes the independent variable from a countable set then we can think of the function values being indexed by discrete x. In this case it is called a sequence: $A = \{a_1, a_2, \cdots, a_n, \cdots\}$.

The terms in a sequence may approach a certain value as we keep increasing the index n. This value is called the limit of the sequence and is represented as $\lim_{n\to\infty} a_n$. Related to this is the concept of series which is a sequence of the sum of the first n values: $s_n = a_1 + a_2 + \cdots + a_n$.

This value s_n may also converge at a certain value for larger and larger n: $s = \lim_{n\to\infty} s_n$.

Let us consider the sequence of reciprocals of natural numbers $\frac{1}{1}, \frac{1}{2}, \frac{1}{3}, \cdots, \frac{1}{n}, \cdots$. What happens to the series associated with this sequence?

$$s_n = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{n}$$

In order to analyze this series let us also consider another series.

$$s'_n = 1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{4} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \frac{1}{8} + \cdots$$

In the new series we have replaced the values added before a power of 2 by that value which is smaller. Clearly, $s'_n < s_n$. But s'_n can also be written as

$$s'_n = 1 + \frac{1}{2} + \frac{1}{2} + \frac{1}{2} + \cdots \to \infty$$

and so s_n also diverges. Each infinite series has infinite terms in it. In order to compensate for this, each term must keep decreasing and become arbitrarily small for the series to be finite. Even if this is the case, it is not always guaranteed that the series converges as in the previous example.

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The series we have seen is a $\zeta(1)$ that is the value of Riemann zeta function at $x = 1$. Riemann zeta function is defined as

$$\zeta(x) = \frac{1}{1^x} + \frac{1}{2^x} + \frac{1}{3^x} + \cdots + \frac{1}{n^x} + \cdots$$

This function diverges at $x = 1$. The value for $x = 2$ is,

$$\zeta(2) = \frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{3^2} + \cdots = \frac{\pi^2}{6}$$

The transcendental nature of this series makes it a little difficult to prove here whether it converges or diverges.

Series are maps over a discrete set. Their analysis can be later extended to functions over the continuum. That is why it is important to study series first. The idea behind a series can be used to express certain 'integrals'. This is because as the size of the interval becomes infinitely small, it can be regarded as a continuum at a larger scale.

One of the key series in mathematics, which is of a very important nature, is the geometric series $s_n(x) = 1 + x + x^2 + \cdots + x^n$. It can be shown that it is equal to $\frac{x^{n+1}-1}{x-1}$, in this case it can be easily seen that

$$\lim_{x\to\infty} s_n(x) \to \begin{cases} \infty & : x \geq 1 \\ \text{oscillating divergence} & : x \leq -1 \end{cases}$$

in either case it is divergent. It is interesting to note that when $|x| < 1$ the series is convergent: $\lim_{n\to\infty} s_n(x) = \frac{1}{1-x}$.

This can also be proved by extending the binomial theorem for non-natural number powers:

$$\begin{aligned}(1+x)^r &= 1 + \frac{r}{1!}x + \frac{r(r-1)}{2!}x^2 + \cdots + \\ &\quad \frac{r(r-1)(r-2)\cdots(r-n+1)}{n!}x^n + \cdots\end{aligned}$$

For the case of $r = -1$,

$$\begin{aligned}(1-x)^{-1} &= 1 - \frac{(-1)}{1!}x + \frac{(-1)(-2)}{2!}x^2 + \cdots + \\ &\quad (-1)^n \frac{(-1)(-2)(-3)\cdots(-n)}{n!}x^n + \cdots \\ &= 1 + x + x^2 + \cdots + x^n + \cdots\end{aligned}$$

One of the salient features of this infinite series is its simple closed form ($\frac{1}{1-x}$). It helps a lot in the comparison test where we can check the convergence of any series if it is bounded by the geometric series within its region of convergence (for that matter any convergent series will do). This can be achieved if the terms are less than another convergent series beyond a particular value of n.

The precise condition for the convergence of a series s_n to a value s is that given an arbitrarily small ϵ then $|s_n - s| \leq \epsilon$ for $n > N$ (some value, no matter how large). This suggests that whatever the behaviour of the series s_n for small values of n, and given a small region around the limiting value s, one of the times the series enters this region it stays in it for all larger values of n. This is a general principle of convergence of a series. We notice the clause that a series must remain in the arbitrary small region implies that the series be incremented by smaller and smaller values which must tend to zero.

A weaker condition is absolute convergence given an arbitrary small value ϵ, then $||s_n| - |s|| \leq \epsilon$ for all $n > N$ (some large value).

The paradox of Achilles and Tortoise may be resolved by thinking of each step as a new addition to the sequence of steps. As more and more steps get added, the increment in distance keep getting smaller and smaller, and the series converges to a fixed value of the total distance.

We now discuss a few tests that might determine whether a series is convergent or not. The convergence or divergence of the series depends on the behaviour of the sequence a_n for higher values of n. This is because the major cause of divergence of a series is the infinite number of elements getting added. Thus, if the series doesn't go to infinitesimal values fast enough, the series is divergent.

1.1 Tests

• **Comparison test :** Given the sequences a_n and b_n, if for all $n > N$ (some) if $|a_n| \leq |b_n|$, then if Σb_n converges then so does Σa_n.

• **Ratio Test :** If $\lim_{n\to\infty} |\frac{a_{n+1}}{a_n}| = r < 1$ for all $n > N$ (some N) then the series Σa_n converges. In order to prove this we notice that $|a_{n+1}| < |a_n|$. When $r < r' < 1$,

$$\begin{aligned}\Sigma_{n=N+1}^{\infty}|a_n| &= \Sigma_{i=1}^{\infty}|a_{N+i}| \\ &< \Sigma_{i=1}^{\infty}r'^i|a_{N+1}| = |a_{N+1}|\frac{r'}{1-r'}\end{aligned}$$

Thus, the series is convergent for $r < 1$, divergent for $r > 1$ and the test is inconclusive for $r = 1$. For $r = 1$, the behavior of the infinite series depends on the high n behavior of the sequence.

• **Root Test :** Let a_n be a sequence such that $\lim_{n\to\infty} \sqrt[n]{|a_n|} = r$. For $r < 1$ the series converges, for $r > 1$ the series diverges and for $r = 1$ the test is inconclusive. This result can be proved analogously to the proof of Ratio Test.

There are many more tests for checking the convergence of a series and the student is encouraged to find the same in a more elaborate book on Analysis.

We present below some examples of popular and interesting infinite series:

$$\begin{aligned}1-\frac{1}{2}+\frac{1}{3}-\frac{1}{4}+\frac{1}{5}+\cdots &= \ln 2\\ 1-\frac{1}{3}+\frac{1}{5}-\frac{1}{7}+\frac{1}{9}+\cdots &= \frac{\pi}{4}\\ \frac{1}{2}+\frac{1}{3}+\frac{1}{5}+\frac{1}{7}+\frac{1}{11}+\cdots &\to \infty\\ \frac{1}{0!}+\frac{1}{1!}+\frac{1}{2!}+\frac{1}{3!}+\frac{1}{4!}+\cdots &= e\\ \frac{1}{1}+\frac{1}{4}+\frac{1}{9}+\frac{1}{16}+\frac{1}{25}+\cdots &= \frac{\pi^2}{6}\\ \frac{1}{1}+\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{5}+\cdots &= \psi \approx 3.36\end{aligned}$$

Notice that the 3rd one has reciprocals of prime numbers, the 5th one has reciprocals of squares or $\zeta(2)$, and the 6th one is composed of reciprocals of Fibonacci Numbers.

If we look at the values then it seems that many transcendental and algebraic irrational numbers come to the fore, the proof of which shall only come through techniques in the method of integration.

2. Limits of Functions

From maps over the set of integers, let us move on to maps over continuum. Such maps are generally called functions. But, the meaning of functions varies with the context. Functions take value from one set called the domain, runs its machinery, and produces a new value in a second set called the co-domain. The set of all the new values, which is a subset of the co-domain is called the range of the function.

Consider the following example. A body is tossed upwards with an initial velocity of 10 m/s. What is the maximum height achieved by the body? Let us now attempt at the solution of this problem in a systematic manner.

Initial velocity is $u = 10$ m/s. Final velocity is $v = 0$ m/s. Acceleration due to gravity is $g = -10$ m/s^2. Let h be the maximum height. Relevant formula is $v^2 = u^2 + 2gh$ which gives $h = (v^2 - u^2)/2g = 5m$.

Now let us analyze what we did here. We labelled all the attributes like velocity, acceleration, heights by english alphabets and used the kinematic equation relevant to these attributes. We then churned the mathematical machinery and got a simplified result of the required quantity in terms of the other given quantities. At first sight there may not seem anything extra ordinary about this method; like the concept of wheel which we see all around us. However, after four thousand years of organized mathematics, it was only in the 16^{th} century that the use of symbolic representations of quantities started. But, this was as revolutionary as the wheel, because it allowed everybody to explore the natural sciences in a mathematical language. If we look at the previous solution, we notice that all relevant quantities have been labelled as particular symbols. The reason behind this is that, let us say, we want to change the value of a given quantity, the machinery still works. For example, let us throw the body upward with a different initial velocity u or we do the experiment on a different planet, so that the value of g changes, $h = (v^2 - u^2)/2g$ still works.

The need for symbolic representations arose when it was necessary to analyze data (a sequence of values). For various numbers of independent variables given, the values of the dependent variable varies. This is an example of a map (even though discrete). This set of data can be used to achieve a relationship between the independent variable x with the dependent variable y. This may be written as $y = f(x)$.

Now the y value for any value of x maybe determined once we find out about the above function. One can think of the data as being a sequence and the resulting function as an approximation to the sequence, such that its value for the intermediate points may also be computed. Functions are not just important to generalize data, but they arise in various situations in natural sciences, and most scientific laws are expressed in equation on how one dependent variable depends upon an independent variable.

For functions over a continuum there is a value of y for each value in the domain of x. These pair of values, each belong to a subset of **R** (real numbers). $y = f(x)$ is generally represented as $f : \mathbf{R} \to \mathbf{R}$. For all those x's for which a y does not exist are not in the domain of x. For example, if we consider a function $y = \sqrt{x}$, the negative reals are not a part of the domain of x. Further, a function is continuous at a point x_0 if $\lim_{x\to x_0^+} f(x) = \lim_{x\to x_0^-} f(x)$, which means if the limit of the value of the function approaching from both sides of x_0 are the same. If this is the case for all values in the domain of x, then the function is called a continuous function. For a continuous function, the graph of y vs. x is connected for all x. Examples of continuous function are: finite degree polynomials, $\sin x$, $\cos x$, $\sec x$, cosec x, $|x|$, $\ln x$, e^x etc,. Examples of discontinuous functions are: sgn(x), $\tan x$,$\cot x$,$\frac{1}{x}$, etc. We can see the nature of these functions much better through their respective graphs.

If we want to further our knowledge of limits of functions, we would need to learn how to evaluate these values of limits. For this we need to understand some identities. First we consider the value of $\lim_{x\to 0}(1+x)^{\frac{1}{x}}$. This is of the form 1^∞. If the argument of the power is slightly increased from 1 then the limit diverges. If, subsequently, the power is made finite, the value converges to a finite value no matter how large. What is its limit? Let us use the binomial equation and try to find out.

$$\begin{aligned}
\lim_{x\to 0}(1+x)^{\frac{1}{x}} &= \lim_{x\to 0}(1 + \frac{\frac{1}{x}}{1!}x + \frac{\frac{1}{x}(\frac{1}{x}-1)}{2!}x^2 \\
&\quad + \frac{\frac{1}{x}(\frac{1}{x}-1)(\frac{1}{x}-2)}{3!}x^3 + \cdots) \\
&= \lim_{x\to 0}(1 + \frac{1}{1!} + \frac{1(1-x)}{2!} \\
&\quad + \frac{1(1-x)(1-2x)}{3!} + \cdots) \\
&= (\frac{1}{0!} + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \cdots) \\
&= e
\end{aligned}$$

How were we able to evaluate this limit? We started with a binomial expression which had a power that goes to a larger number ($\frac{1}{x}$). The argument $(1 + x)$ is slightly greater than 1. If we take the limit as $x \to 0$ we find that the argument tries to keep the value near 1, whereas $1/x$ power tries to make the value large. The result of this competition is the value $e = 2.71828\cdots$, which is a constant that appears in mathematics time and again. The number is the sum of inverse factorials, is a transcendental number. This makes us wonder, whether this number would be the same in an alternative existence. This is same as the question whether the mathematics that we discover is a property of the universe we live in, or is the physics of the universe a result of the omnipresent mathematics?

The next example we consider is $\lim_{x\to 0}\frac{\sin x}{x}$. Consider a unit circle with center at A. Draw two points B, C that subtend an angle x at the center. Drop a perpendicular from C at a point E on the radius AB. $CE = \sin x$. Now let us slide point C on the circle closer and closer to point B so that the arc-length (or angle in radians x) tends to 0. We see that the distance CE gets smaller and smaller with respect to the radius AB. Let the small distance EB = ϵ. Then,

$$\begin{aligned}\sin x = CE &= \sqrt{AC^2 - AE^2}\\ &= \sqrt{1-(AB-EB)^2}\\ &= \sqrt{1-(1-EB)^2}\\ &= \sqrt{2\epsilon-\epsilon^2} = \sqrt{2\epsilon}(1-\frac{1}{4}\epsilon)\end{aligned}$$

And,

$$\begin{aligned}x &= arc(BC)\\ &\approx BC \text{ this needs a more rigorous proof}\\ &= \sqrt{BE^2+CE^2}\\ &= \sqrt{AC^2-(AB-EB)^2+CE^2}\\ &= \sqrt{2EB} = \sqrt{2\epsilon}\end{aligned}$$

Thus,

$$\lim_{x\to 0}\frac{\sin x}{x} = \frac{\sqrt{2\epsilon}(1-\frac{1}{4}\epsilon)}{\sqrt{2\epsilon}} = 1$$

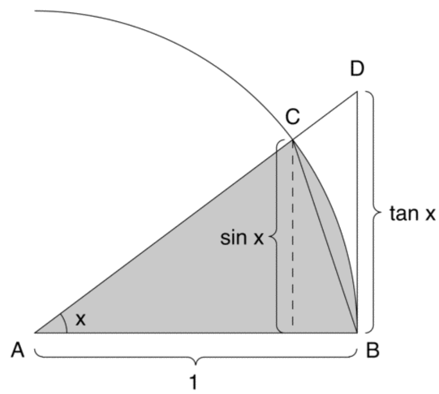

Figure 1: $\lim_{x\to 0}\frac{\sin x}{x}$

The crux of the evaluation of $\sin x/x$ limit uses the properties of a circle in its given proof. Once the reader has absorbed the contents of this whole chapter, they can try and prove this result in quite a number of ways. One thing one must retain from this proof is that the higher the power of a small quantity the more suppressed is its value and can be neglected as compared to other terms in the zero tending limit.

The example of $(1+x)^{\frac{1}{x}}$ was a non trivial limit of the form 1^∞. If we take natural logarithms it becomes of the type $\infty\dot{0}$ type. The $\frac{\sin x}{x}$ was a $\frac{0}{0}$ type of limit. Thus we see that the non-trivial limits appear when the actual value is of an indeterminate form. A general form of limit which matches this criteria is when given a smooth function $y = f(x)$, and we take the limit $\lim_{x\to x_0}\frac{f(x)-f(x_0)}{x-x_0}$. The reason why this is relevant is that as $x \to x_0$, then for normal functions $f(x) \to f(x_0)$ and this limit if of $\frac{0}{0}$ type. The functions that do not have this property have mathematical pathologies such as discontinuity, discontinuous tangents etc,. This limit is a very important property of the function f and shall be the next topic of discussion. □

(To be continued)

distance between the two particles be r. Then, we know that the magnitude of the gravitational force of attraction F between the two particles is given by

$$F = G\frac{m^2}{r^2}$$

Let us now change the distance from r to R instantaneously. Then the magnitude of the new gravitational force of attraction F_{new} between the two particles is given by

$$F_{\text{new}} = G\frac{m^2}{R^2}$$

Now, according to Newton's "action at a distance" formalism, the two particles A and B will see the change in the force from F to F_{new} almost instantaneously. It is as if the space between them did not matter. Due to the enormous success of Newton's theory in explaining the physical world around us, physicists of those days sought to explain the electric and magnetic phenomenon through "action at a distance" formalism. But, it was a self-taught genius named Michael Faraday who seriously challenged this formalism.

Michael Faraday

Michael Faraday was born on 22nd September, 1791 in Surrey, England. His father, James Faraday, was a blacksmith who often fell ill and was incapable of working steadily. Michael Faraday was one of the four children and they were a rather poor family. Faraday later recalled being given one loaf of bread that had to last him for a week [2]. At the age of 14, Michael Faraday became an apprentice to George Riebau, a bookbinder and bookseller. During this seven-year apprenticeship, Faraday read many books that were brought in for binding. He developed a passion for science, and for chemistry in particular. Later, Faraday became a laboratory assistant to

Figure 1: Michael Faraday (1791-1867)

Sir Humphry Davy at the age of 20. Sir Humphry was then a prominent chemist who discovered that chemical changes were largely responsible for the electrical action of a battery. Faraday eagerly learnt every piece of knowledge Davy deemed to impart.

In July 1820, a Danish Professor named Hans Christian Oersted discovered that an electric current in a wire would cause a nearby compass needle to deflect, if it is placed parallel to the wire. He also discovered that the magnetic needle turned in circles around the current carrying conductor. He discovered, as he had anticipated, that there is a deep connection between electricity and magnetism. A self-taught French Physicist named André-Marie Ampère [6] heard of this discovery of Oersted through a demonstration given by his friend named Francois Arago to the Paris Academy of Sciences on 11th September 1820. Ampère improved Oersted's results by eliminating the effects of the Earth's magnetic field. He did this by inventing an astatic compass needle. It was Ampère, not Oersted, who discovered that the compass needle points at 90° to the current carrying wire. Ampère also found that the currents flowing through the voltaic battery and the wire are equal and thus formed the concept of the "circuit", in which electric current was closed. In order to detect the electric currents in a wire, he also invented the so-called "galvanometer". The contributions of Ampère were so important to the formulation of the electromagnetism that Maxwell regarded him as "the Newton of electricity" [3].

The experiments of Oersted and Ampère created a flurry of research throughout Europe. Richard Phillips, who was a friend of Michael Faraday and the editor of the Annals of Philosophy, asked Faraday to write a comprehensive review on the history of electromagnetism. Michael Faraday wrote an article [4], which eventually got him interested in the theory of electricity and magnetism [5]. The consequence of this was to change the direction of physics forever and to make him the architect of field theory that now dominates the modern physics.

Ampère tried to develop electromagnetism in close analogy with the theory of gravitation. He wanted to explain the interaction between currents in terms of current elements that were analogous to the central force scheme. Faraday, on the other hand, meticulously noted his experimental results and suggested that there were "lines of force" around a current carrying conductor. He also noted that a hypothetical magnetic pole would move along these lines of forces created around a current carrying wire. Thus, he did not employ field concept just as a mathematical tool to explain his experiments. He believed that the space filled with the electric and magnetic fields was different from the empty space. Later Einstein [7] remarked that

Figure 2: James Clerk Maxwell (1831-1879)

"It is fascinating to muse: Would Faraday have discovered the law of electromagnetic induction if he had received a regular college education? Unencumbered by the traditional way of thinking, he felt that the introduction of the "field" as an independent element of reality helped him to coordinate the experimental facts."

But, owing to lack of mathematical tools to support his claims, Faraday largely resorted to experimental demonstrations. It was another genius named James Clerk Maxwell who formulated Faraday's ideas into a rigorous mathematical framework.

James Clerk Maxwell

Unlike Faraday, Maxwell had a very good education in mathematics. James Clerk Maxwell was born on 13th June 1831, in Edinburgh, Scotland. He was born in a comfortable middle class family and was a mathematical prodigy. At the age of 14, he wrote a paper on the geometrical character that was read before the Royal Society of Edinburg by Prof. Forbes. He later went to Peterhouse, at University of Cambridge and later moved to the Trinity College [8]. He graduated as the Second Wrangler in Mathematical Tripos, which were extremely difficult applied mathematical problems.

Michael Faraday had the greatest influence on Maxwell. Maxwell, after reading the Faraday's account on electricity, wrote his first paper on electromagnetism at the age of twenty-three. This paper was titled "On Faraday's lines of force" and was read to the Cambridge Philosophical Society on 10th December 1855. Maxwell later developed his theory from 1861 to 1862 in a series of four papers while at King's College London. In these papers he used mechanical models and analogies like the cylindrical vortices and idle wheels to develop the mathematics. It was while developing the model that he completed the electromagnetic theory by adding a term called "displacement current". Maxwell then left his professorship at King's College London and worked independently at his estate in Glenlair. It was there he wrote his famous "Treatise on electricity and magnetism", which was published in 1873. Maxwell removed his "mathematical scaffoldings" in his Treatise.

Maxwell had originally used a set of twenty equations to describe electromagnetism. Later, Oliver Heaviside mastered the Faraday-Maxwell approach to electromagnetism and reduced the Maxwell's original set of twenty equations to four equations, which are widely known today as the Maxwell's equations. Maxwell also noted that his equations gave rise to wave like disturbances that can propagate as the electric and magnetic fields. He calculated the speed with which such disturbances travel and found that it almost exactly matched the speed of light, hence concluding that light was an electromagnetic wave. Another peculiar property of these electromagnetic waves is that they do not depend of the frame of reference. This led Einstein to develop the Special Theory of Relativity and establish the foundation for Modern Physics.

Conclusion

We conclude this article by saying that the impact of Faraday and Maxwell is well regarded in the scientific community but unfortunately, is not well recognized among the general public. Suffice it to say that perhaps no other theory has made such technological revolutions as the classical electromagnetic theory, which was largely formulated by Faraday and Maxwell. For further developments and modern understanding of electricity and magnetism please refer [9].

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