Contents

Breakthrough, Vol.18, No.4, July 2016

Book Review

Science in Saffron — by Meera Nanda

Pritesh Ranadive 4

General Articles

Genetically Modified Mustard — A Trojan Horse For Introducing GM Food Crops in India

Safique Ul Alam 6

Water Crisis

Pradip K Datta 17

Series Article

A Brief History of Science
Part-13: The development of quantum mechanics

Soumitro Banerjee 23

This installment of the series article discusses one of the most exciting phases in the history of science, when our conception of the micro-world underwent a revolution through the development of quantum mechanics. This development also gave rise to important questions regarding the nature of physical reality and debates regarding its interpretation, which are yet to die down.

Students' Section

Analysis of the Real

Sarosh Ali 34

Organizational News

- Felicitation of scientists involved in the discovery of gravitational wave
- Observation of Transit of Mercury, 9 May 2016 39

Book Review:

Science In Saffron — by Meera Nanda

Pritesh Ranadive *

Science in Saffron, a book by Meera Nanda, may be said to have arrived on the scene at an apt time, when a large section of Indians, not limited to any specific political or religious persuasion, is engaged in glorification of the ancient Indian culture with exalted claims of extraordinary scientific prowess. The book endeavours to present a clear picture on the chronology of the development of ideas across cultures, with evidence and detailed justifications. It also emphasizes how the past needs to be viewed, not with a competitive but a comparative stance, and with a viewpoint not centred on any particular culture.

The author is a historian, with training in science as well as humanities, enabling her to analyse issues from a broader perspective. The book explains how anachronism, i.e., *reading the past with the vocabulary of the present*, as the author puts it, is damaging the very fabric of history and development of the human understanding of various concepts in science and mathematics. The book, though a bit repetitive at times, is very well referenced and helps remove the glasses of nationalism and renders a new objective view of how ideas evolved in the past. The book compares the claims made about the extraordinary Indian scientific history, with achievements and progress of science, or natural philosophy as it was then called, in contemporary civilizations.

The book consists of a set of four essays dealing with ground realities concerning four different claims made by various people in the country, especially politicians. The author first deals with the Pythagoras theorem, clarifying that the ancient Greeks, Mesopotamians (inhabitants of what is now Iraq) and Indians all used mathematical/geometrical techniques efficiently. She notes that the emergence of the Pythagoras theorem was not the subject of a race, and insistence on renaming the theorem, as sought by some, is pointless in the overall context.

Likewise, the claims about Zero and decimal system having originated in ancient India, have been very thoroughly examined in the light of archaeological evidence and researches in the history of science. Credit has been given to ancient Indian scholars for their fully evolved decimal place value system together with concrete symbols for numbers. It is highlighted that ideas in mathematics transcended the physical boundaries as they evolved in the ancient times, and in this process India was not just a giver but also a receiver of ideas.

Various claims made by politicians about the advances in genetic research and plastic surgery in ancient India, are drawn from mythology, and are not credible from a historical viewpoint, which calls for critical analysis and clear insight into the workings

*The author is a Scientific Assistant, Astronomy Olympiad Cell, HBCSE – TIFR. Email: astroprit@gmail.com. The article first appeared in a Marathi daily Loksatta, under 'Loksatta Bookmark' page on Saturday 14th May 2016.

of the societies. In fact the religious establishment of the time held back the development in medical sciences in ancient India, as seen from the case of “Sushruta”. The *Sushruta Samhita* (some centuries BCE), which is the first ever written record of surgical procedures, describes, in particular, procedures for reconstruction of nose, ear and lips etc. The procedures are simple and elegant, and were indeed applied successfully over a period. This text was later translated into Arabic and Chinese. However, the practice of the techniques did not flourish in India for long, at least as far as the historical records go.

The reason for this lies predominantly in the caste system. On account of caste related taboos surgeries were performed, in the later period, not by learned Vaidyas (the Ayurvedic physicians), but by illiterate men, lacking in the knowledge of anatomy and the rationale for the sequential steps involved in the procedures. Similarly with regard to dissection of human body to study anatomy the practice involved, as the author puts it, *“see but don’t touch”* approach, which hampered the progress of anatomical and medical studies considerably. Caste based prejudices also considered medical practitioners to be *impure*, and obliged them to undergo rituals for purification. Despite all these, and many more such restrictions, the ancient scholars thirsted for knowledge and made progress in the field, putting their limited freedom to best use.

In the context of scientizing the yoga, the author cautions the reader about correctly finding the demarcation between science and pseudo-science, which has been obliterated today by various nationalistic elements.

The book narrates how development of ideas in the past crossed all geographical and other boundaries, and led to the overall progress of humankind. In this the Indians undoubtedly contributed a major share, but it can not be said that they achieved the developments single-handedly or that they were the pioneers or competitors. Science in ancient India was held back due to its social hierarchy and superstitions, which is also something to learn from the book, to avoid it now and in the future.

Use of tall claims about fantastic scientific developments in ancient India, for nationalistic and political purposes, has been thoroughly challenged in the book, with meticulous arguments. □

Form 4 (vide rule no. 8)
Declaration of proprietorship and other information

1. Place of publication: Kolkata
2. Periodicity of publication: Quarterly
3. Printer’s name: Ashok Lithographing Co.,
   Nationality: Indian
   Address: 128 Keshab Chandre Sen St., Kolkata-700009
4. Publisher’s name: T. K. Naskar
   Nationality: Indian
   Address: 9 Creek Row, Kolkata-700014
5. Editor’s name: D. Mukhopadhyay
   Nationality: Indian
   Address: 9 Creek Row, Kolkata-700014
6. Ownership: Debashis Ray
   Nationality: Indian
   Address: 9 Creek Row, Kolkata-700014

I hereby declare that the above information are true to the best of my knowledge and belief.

Date: June 2016 Publisher (T. K. Naskar)

Genetically Modified Mustard — A Trojan Horse For Introducing GM Food Crops in India

Dr Safique Ul Alam *

Introduction

India has so far officially approved only GM cotton as a non-food genetically modified (GM) crop for commercial cultivation in the country in 2002, and that too only after it had been already sown illegally in Gujarat virtually through subterfuge by a seed company. Trials on several GM food crops have been going on subsequently. In 2009, the Genetic Engineering Appraisal Committee (GEAC, which was initially called as Genetic Engineering Approval Committee and subsequently renamed) — the apex regulatory body for GMOs (Genetically Modified Organisms) under the present Ministry of Environment, Forests & Climate Change (MoEF&CC) in the Government of India — approved Bt brinjal for commercial cultivation. But, the then minister in charge of the said ministry, Sri Jairam Ramesh, overturned the regulators' approval on 9th February, 2010 and placed an indefinite moratorium on the commercial release of Bt brinjal after a series of public consultations and a nationwide debate.

While moratorium on Bt brinjal is still going on, an Indian mustard (Brassica juncea) hybrid developed by a public sector institution, Centre for Genetic Manipulation of Crop Plants (CGMCP) of Delhi University, has now been apparently lined up for approval for commercial cultivation. If this GM crop is finally approved, then it will likely open the doors to many other GM food crops like GM maize, GM rice, GM brinjal, etc., of several MNCs like Monsanto, Syngenta, Bayer, Du Pont and Dow Agri Sciences, etc.

The CGCMP of Delhi University under the guidance of Dr Deepak Pental has developed a genetically modified Indian mustard (rai) hybrid and named it Dhara Mustard Hybrid 11 (DMH11). The Government of India is contemplating to approve the commercial cultivation of this hybrid GM mustard. But, amid public pressure to disallow commercialization of genetically modified (GM) mustard in the country, the present environment minister, Sri Prakash Javadekar, has lately assured that the government will not impose GM mustard on the people and a final decision will be taken only after due deliberations. However, if approved, GM mustard will be the first GM food on our plates in India.

This is the first time in about six years that a GM food crop is being considered for commercial cultivation in India after the moratorium on GM Brinjal. However, this is not the first time that a proposal for commercial cultivation of GM Mustard has come up before the government. In 2002, the then Union government rejected a proposal for commercial cultivation of a private sector seed manufacturer, Bayer's transgenic mustard plants.

The GEAC is the statutory authority that

*Dr. Alam is an Agricultural Scientist and Member of All India General Council of Breakthrough Science Society.

appraises proposals for field trials and commercial release of GM crops but its views are not binding on the government. The final decision on such clearances lies with the Union Minister for Environment, Forests and Climate Change.

Mustard in Indian Cuisine

Mustard belongs to the family Cruciferae (now renamed as Brassicaceae) and popularly used in Indian cooking in various ways. Mustard oil is one of the chief cooking oils in India and it contains the lowest amounts of saturated fatty acids among common edible vegetable oils. It also contains adequate amounts of linoleic and linolenic fatty acids. Mustard seed contains normally 33 % oils. The oilseed cake (about 67% of seed weight) is used for cattle feed as well as manure in agricultural fields for enhancing soil fertility. Mustard seed is also used as condiment in the preparation of vegetable dishes and curries. The young mustard leaves are used as green leafy vegetable. Split and powdered mustard seeds and oil are used for pickling. Rapeseed and mustard are the third most important edible oilseed crops of the world after soybean and oil palm. Mustard oil is preferred as a cooking medium particularly by the people of West Bengal, Assam and other East and North-Eastern states of the country.

Some of the documented health benefits of mustard are – alleviating symptoms of asthma, prevention of gastro-intestinal cancer, aiding in weight loss, relieving arthritic and muscle pain, slowing aging, lowering cholesterol and stimulating hair growth.

Mustard Productivity and Production in India

India is a major mustard producing and consuming countries in the world. It is cultivated as Rabi crops (planting season is October- November) in India. Total area under mustard and associate crops (rape, toria, brown sarson, yellow sarson, rai, karan rai, gobhi sarson, black mustard and taramira etc.) in India for the year 2013-14 is 71.30 lakh hectares [1 hectare = 10,000 sq meter = 2.5 acre (approx)] and total production of mustard seed and associate crops in India for the year 2013-14 is 73.00 lakh tonnes. Average yield for the year 2013-14 is 1023 kg/hectare.

In 2013-14, the three largest rapeseed-mustard producing states were Rajasthan (48.12% of all-India production), Madhya Pradesh (11.31%) and Haryana (11.06%). Together, they account for more than 70% of India's production. Other important mustard growing states include Uttar Pradesh, West Bengal, Gujarat, Assam, Bihar and Punjab.

Development of GM Mustard Hybrid using Bar-Barnase-Barstar Transgene System

Hybrid varieties are F1 generation produced from a cross between two dissimilar strains/varieties of a same crop. For development and production of hybrid seeds of a crop in mass scale, a male sterile female parent (strain/variety/line) is needed, otherwise self pollination will occur in female parent and it will contaminate the F1 seeds. The seeds produced on female line (through cross fertilization by pollen from male parent) are used as F1 seeds for production of commercial crops in the next season. The two parental lines/varieties are so chosen, that the F1 seeds produced by crossing between them exhibit a very good heterosis/hybrid vigour and give good yield in farmers' fields.

The parental lines (to be used as female and male parents in hybrid seed production programme) are also to be maintained separately so that they can be used regularly for production of hybrid seeds year after year. So, for commercial mass production of F1 (hybrid) seeds, the female line should be male sterile and the pollen to fertilize the eggs in the ovule of female line (leading to setting of seeds in female parent) must come from another dissimilar male parent of the same crop. If the two parents are different and dissimilar with respect to some features, then the hybrid vigour of F1 generation will be more pronounced. The seeds produced by crossing between two plants of same strain/variety are not considered as hybrid seeds, genetically this is called inbreeding, which is quite different from heterosis.

For some crops, a female line with natural Cytoplasmic Male Sterility (responsible genes are situated in mitochondria and plastids and not in nuclear chromosome) and a male line with a dominant restorer gene (situated in nuclear chromosome) that can overcome the cytoplasmic male sterility of female parents in F1 generation (produced from crossing between them) are available naturally. When crossing takes place between these two types of parents the restorer gene present in the male line (restorer gene is present in male parent in homozygous state and is also maintained in homozygous state through self pollination) overcomes the cytoplasmic male sterility of female parent. This Cytoplasmic-Genetic Male Sterility system is used in mass production of hybrid seeds in crops where it is available naturally — such as maize, rice, cotton, sunflower etc. In crops, where this type of natural cytoplasmic male sterility and nuclear fertility restoration system are not available, transgenes are now being used to produce Genetic Male Sterile line (not cytoplasmic male sterility as described above) which is a dominant character (dominant characters are always expressed in bearer if the concerned gene is present either in homozygous or in heterozygous state). In the F1 generation (crops raised by farmers using F1 hybrid seeds), the male fertility is to be restored so that all F1 plants can produce seeds/crops through self-pollination or pollen from other F1 plants in the same field and the farmer can get good economic yield of the crop.

The CGMCP has used the bar, barnase and barstar transgene system for the development and production of DMH11 hybrid mustard variety. Using this approach male sterile lines and their restorer line were developed incorporating barnase and barstar genes from Bacillus amyloliquefaciens and bar gene from Streptomyces hygroscopicus in Brassica juncea varieties. The barnase gene disturbs the developmental steps specifically required for production of functional and viable pollen from the microspore or for the development of any somatic tissues supporting the microspores. Microspores are haploid cells produced from pollen mother cell through meiosis or reduction division inside the anther and mature into pollen grains through thickening of their walls.

The gene barnase encodes a Ribunuclease enzyme (RNase), that kills the cells in which it is expressed by degrading RNA. If RNA is degraded in a cell, it will not be able to produce any protein needed for its development and normal physiological functions and the cell will die in due course. The expression of barnase was confined to tapetum tissues of anthers by integrating it with the promoter pTA29 (collected from tobacco plants, here p means promoter) which can only express itself in tapetum tissues (the gene construct is pTA29-barnase). The tapetum is a specialized layer of nutritive cells found within the anthers of flowering plants, where it is located between the sporogenous tissue (which contains pollen mother cells) and the anther wall. Tapetum is important for the nutrition and development of pollen grains and it is a source of precursors for the pollen wall formation. A gene construct is an artificially constructed segment of nucleic acid (collection of genes along with promoter DNA sequences) that is going to be transferred into a target cell. A promoter is a region of DNA that initiates transcription of a particular gene. Promoters are located near the transcription start site of genes and transcription is the first step of gene expression in which a particular segment of DNA (gene) is copied into RNA (mRNA) and the second step in gene expression is translation where a protein is synthesized using the synthesized mRNA as template.

When the gene construct pTA29-barnase was transferred and expressed in mustard, the tapetal cells of anthers were destroyed, and so there was no functional pollen development. However, there was no effect on female fertility. As the male sterility due to barnase is a dominant trait, the male sterile plants are always heterozygous (barnase/–, the '–' sign indicates the absence of barnase gene in the homologous chromosome; homozygous barnase/barnase plants are not possible to produce as there will be no self fertilization in male sterile barnase/– plants). So, the male sterile line is to be maintained by crossing to any normal, non-transformed (and non-transgenic) homozygous male fertile line (–/–) (barnase gene absent). Only 50% of the progeny from such crosses will be male sterile (barnase /–), while the rest 50% will be male fertile (– / –), The gene segregation is similar to monohybrid cross.

In a hybrid seed production programme, the male fertile plants present in the male sterile line must be readily identified and easily eliminated from the field, otherwise they will pollinate and contaminate the F1 (hybrid) seeds produced in male sterile plants and reduce the quality of F1 (hybrid) seeds so produced. This has been done by linking the barnase gene with the bar gene from a bacteria Streptomyces hygroscopicus. The bar gene confers resistance to the herbicide glufosinate. Herbicides are chemicals that kill plants especially weeds. The gene construct is pTA29-barnase + p35S-bar simply depicted as barnase-bar (p35S is a promoter collected from Cauliflower Mosaic Virus). These two genes are combined together along with respective promoter DNA sequences in final gene construct and transferred to target Brassica juncea varieties. These two genes in the developed transgenic variety act as linked genes and are inherited together. Crossing over does not occur between these two transgenes and they behave as a single heritable unit (barnase-bar).

When such heterozygous male sterile (barnase-bar /–) plants are maintained by crossing with normal homozygous male fertile plants (–/–), all the male sterile progeny (barnase-bar/–) generation are resistant to the herbicide, while all the male fertile plants (–/–) are herbicide (glufosinate) susceptible. This male sterile line and the male fertile maintainer line are similar in all aspects except that the former contains only barnase-bar genes in its genome in heterozygous condition and the maintainer line lacks only these two genes. The male fertile plants (–/–) are, therefore, easily eliminated by spraying of glufosinate (a herbicide) at an early stage of growth in concerned crop (female parental line in hybrid seed production program). The survived plants (barnase-bar /–), resistant to the herbicide (glufosinate) are retained in field as seed producing female parent in the hybrid seed production programme.

The male fertility of barnase male sterile line (female parent) is restored (in F1 generation) by another gene, barstar, collected from the same bacterium B. amyloliquefaciens and transferring it to the male parent. The gene barstar encodes a specific inhibitor of RNase produced by barnase gene. The barstar product (Barstar) forms a highly stable 1:1 non-covalently bound complex with the barnase RNase. This reaction provides protection to the bacterial cells (where both these genes barnase and barstar are simultaneously present) from their own RNase product.

Transgenic plants expressing barstar gene (to be used as male parent in hybrid seed production programme) are male fertile without any phenotypic effect of its own, and are easily maintained in the homozygous state (barstar/barstar) by self-pollination. No other maintainer line is needed for maintenance of this male parental line in hybrid seed production programme. When a homozygous barstar male fertile line (barstar/ barstar, as male parent) is crossed with a barnase-bar male sterile line (barnase-bar/– , as female parent), all the F1 progeny plants (that may be raised by farmers' in their fields using F1 hybrid seeds produced from such cross) are male fertile since barstar gene product effectively inhibits the barnase RNase in heterozygous barnase-bar-barstar plants (barnase-bar-barstar/–, '–' sign indicates absence of barnase, bar and barstar genes in homologous chromosomes). However 50% of F1 seeds so produced do not contain barnase-bar genes (they are having genotype barstar/– only), but all the F1 seeds contain one copy of barstar gene. So 50% of F1 plants will not exhibit tolerance to glufosinate in F1 generation. However, glufosinate need not and should not be applied in commercial production of crops using the hybrid seeds so produced. During commercial production of hybrid (F1) seed, male and female lines are sown in rows in specific ratio (normally 2 rows female : 1 row male).

This male sterility-fertility restoration system has shown commercial promise in rapeseed (and also in maize). These lines are stated to be stable and provide a complete and usable male sterility-restorer system for commercial production of hybrid (F1) seeds to be used by farmers for growing crops during next season. These transgene complexes are used in the development of Dhara Mustard Hybrid 11.

So the main purpose integrating concerned transgenes in DMH-11 rape mustard hybrid and use of herbicide (glufosinate) is mass production of the male sterile female parent/line to be used for production of hybrid seeds commercially. For the transgenic variety DMH-11 Biosafety Research Level (BRL)-II trials in Rabi 2014-15 season have reportedly been completed, which is the penultimate research stage, before it is considered for release for commercial cultivation. The project was funded by the Department of Biotechnology, Government of India from 1994.

Supposed benefit and reasons for introducing GM Mustard

Dr Pental claimed that his transgenic mustard hybrid variety gave a 30 per cent higher yield than other varieties without applying any additional inputs like water or fertilizer. He also claimed that the costs for the hybrid seed would be considerably lower. It is otherwise also reported that the yield comparison has been made against non-hybrid seeds. Some other non-transgenic hybrids also give similarly higher productivity. As the research on mustard has been funded entirely by the department of biotechnology and National Dairy Development Board (NDDB), hybrid seed should reach the farmers at a very reasonable price.

Why commercial cultivation of GM Mustard should not be permitted

Developers of GM mustard hybrid DMH-11 have claimed that the yield of mustard can be increased by allowing commercial cultivation of the variety. Ordinarily the yield of mustard or any other crop can be improved to some extent by using hybrid varieties (F1 seeds). So, if hybrids are to be seen as an option, then non-transgenic hybrids, if available in the market, shall be the option for commercially introducing the same. GM mustard is not needed in the first instance. Many review committees in the country have already recommended time and again that transgenic option should be considered only if no other option is available or feasible.

But, Indian regulatory authorities have entertained the applications for various field trials prior to commercialization of DMH-11 at each stage without adequately assessing the bio-safety parameters. Various national and international policy directives and frameworks have clearly been flouted while conferring consent for going ahead. Required trials and safety parameters needed at various trial stages for introducing a GM crop variety are not adhered to. Hybrid producing GM technology will benefit seed manufacturers more than the farmers. The farmers cannot save seeds from a hybrid crops for cultivation in the next season and he has to purchase seeds each time he wishes to cultivate the crop.

This DMH11, like other GMOs, may have objectionable health and environmental impacts, going by the experience of other similar GMOs like GM canola in other countries. No results of any rigorous long-duration epidemiological studies have been released in the public domain. Super weeds are a real problem in places where herbicide tolerant GM crops have been introduced, in addition to health impacts of herbicides used on such crops. Super weeds are naturally developed as a direct consequence of the huge increase in herbicide use. Eventually spread of cultivation of herbicide tolerant crops will lead to increased use of the concerned herbicide and development of herbicide resistant super weeds will aggravate the situation leading to the use of ever increasing quantity of different herbicides to counter the resistance.

Contamination of other varieties of mustard with transgenes and promoter DNA sequences of bacterial and/or viral origin is inevitable. This will have serious implications given that India is a Centre of Diversity for mustard. The potential for contamination by Herbicide Tolerant (HT) mustard is particularly high as it is a cross-pollinated crop. So, even small scale field trials may become much deleterious let alone large-scale commercial cultivation. Approval of DMH11 in large-scale field trial also amounts to Contempt of the Supreme Court Order regarding the requirement of “no contamination” criterion for introducing GM crops.

Under the PPVFRA (Protection of Plant Varieties & Farmers’ Rights Authority, India), established under Protection of Plant Varieties & Farmers’ Rights Act, 2001, no national law allows toxins to be put in foods/food crops and seeds. The PPVFRA expressly refuses registration of such injurious’ seeds. Thus, DMH 11 should doubly be banned for seed registration under the PPVFRA for being “injurious to life (produce toxin that kills cells)” and for being a GURT (using sterility trait, Genetic Use Restriction Technology).

Moreover, higher yields in DMH11 mustard are not the result of these particular transgenes. It is due to hybrid vigour manifested in F1 generation as a result of hybridization of two dissimilar parents of the same crop. In some crops like maize particularly, natural male sterile lines are found, and hybrid maize varieties have been developed incorporating these natural sterility traits and it has nothing to do with genetic engineering. These are presently widely used in maize production. However, neither Bt nor HT GM crops have traits for yield enhancement. Bt is a trait for toxin (pesticides) production and HT for pesticides (herbicide) tolerance. The use of the term hybrid seems to be a deliberate ploy to camouflage the yield attributable to hybrid and assign it to the GM crop instead. Many independent studies have shown that GM food is not safe for us. Indian government is aware of such studies. Many concerned scientists/institutions have pointed to the dangers of GM foods time and again, and even the Technical Expert Committee set up by the Supreme Court of India itself has also expressed the same opinion. GMOs are part of the package of industrial agriculture that is chemically intensive, loaded with toxins, loaded with pesticides.

It is not clear whether adequate safety studies on the effect of non-target organisms such as butterflies, moths, other insects, fishes, reptiles, amphibians and soil biology have been conducted or not. Yet, it is not possible through measurements of toxicity in a few species of non-target organisms to get a sufficient view of the possible harm to complicated ecosystems, which may vary from place to place in India.

GM crops will foster the dependence on corporate seed supply. So, farmers and consumers lose control over seeds, agriculture and food. GM crops require higher inputs not matched by yield. And, loss and contamination of biodiversity means loss of food and food security. As the GM seeds are patented, costs of seeds will be much higher, thereby increasing costs of cultivation.

The Herbicide Glufosinate — some documented detrimental effects

Glufosinate is registered for use as an herbicide in many countries including India and it is associated with big MNCs like Bayer. It is a persistent, mobile and broad spectrum herbicide applied after the weeds have emerged (post-emergence application). Sometimes, it is used as pre-emergence herbicide in vegetable fields also. It is also used for total vegetation control on land not used for cultivation. Its half life varies from 3 to 70 days depending on the soil type and organic matter content. Its residue was found to be present in spinach, radishes, wheat and carrots that were planted 120 days after the treatment of the herbicide. It is also reported to exhibit neurotoxic and teratogenic (birth defects) effects. It is also found to have caused adverse health effects in animal studies and is likely to leach into drinking water sources. It can increase nitrate leaching, and is toxic to beneficial soil micro-organisms and terrestrial plant species. The introduction of glufosinate resistant crops will lead to its higher use in agricultural fields and a greater exposure to glufosinate increases the likelihood of these harmful effects in animals, humans and the environment. Both the Environment Protection Agency of the USA (EPA) and the European Food Safety Authority have confirmed that glufosinate poses a risk to mammals and a number of studies have indicated that glufosinate is toxic to beneficial insects that naturally suppress crop pests and to pollinators. EPA has also stated that glufosinate is expected to adversely affect non-target organisms.

Lack of Transparency

Notwithstanding the many concerns over genetically modified foods, GEAC has refused repeatedly to divulge bio-safety and other information related to the commercial trials of GM mustard. In a RTI response accessed and reported by the dna, an English broadsheet daily from Mumbai (www.dnaindia.com), GEAC has refused to disclose the same and referred to "commercial confidence trade secrets or intellectual property, the disclosure of which would harm the competitive position of third party". This is against the Supreme Court 2008 directives that clearly stated that people should know the details of agricultural product safety trials much before commercial approval of the same.

The Central Information Commission (CIC) in 2009 also opined, "(the) toxicity and allergenicity of any product to be put on large scale field trial is a matter of overriding public interest" and that existing data had to be provided to public domain before any massive field trial.

According to the minutes of the 121st meeting of the GEAC, the CGCMP plea for large-scale trials, called BRL (Biosafety Research Level)-II trials, was considered and approved on July 18, 2014. Field trials have two levels, viz. BRL-I and BRL-II. While the former is done to take up a set of studies and to generate data, the second is an advanced commercial level trial. The agenda notes circulated to members at the meeting said, "The CGMCP has completed safety studies as per the prescribed guidelines". It also mentioned that the Committee appreciated the compilation of the bio-safety dossier. Lately, Dr Deepak Pental, developer of the GM mustard seed at Delhi University submitted an application to the Genetic Engineering Appraisal Committee (GEAC) for the approval for commercial cultivation of hybrid mustard crop in September, 2015.

As an application moves from BRL-I to BRL-II, and from BRL-II to commercial cultivation, regulators should be presumed to make data-based decisions on whether permission should be accorded or not. Concerned scientists in the country should also be in a position to peruse such data and make effective representations if and where needed. Such data cannot be withheld on any grounds.

The quality of mustard trial is also a major concern. The dna on September 22, 2015, revealed that for the period from 2008 to 2014, only 39 of the 133 GM crop field trials were properly monitored. In 2014, three GM mustard trials of Delhi University were taken up – at two sites in Punjab and one in Delhi – during the rabi season. There is enough evidence to suggest that there were no post-harvest foolproof monitoring in these cases.

The issue of bio-safety data of Bt brinjal that has been brought into public domain, was a decisive turning point in its fate. Subsequent analyses by international scientists pointed out its lack of safety measures.

Jairam Ramesh, the then environment minister who placed Bt brinjal under an indefinite moratorium, took note of allegations of conflict of interest in the regulatory body. It is interesting to note that GEAC at this point of time has the presence of a member from CGCMP, the same Centre from where GM mustard has emerged.

In a move which may bring transparency in the decision making process on the fate of transgenic mustard of Delhi University in India, the Central Information Commission (CIC) on 7th April, 2016 has directed the GEAC to verify and make public all non-confidential bio-safety dossier of GM mustard before April 30, 2016 [1].

[1] At the time of publication of this article, the GEAC has not yet made any non-confidential or other bio-safety data regarding GM mustard public.

Bio-safety issues

DNA in a living cell is a very delicate material. During the process of transfer of external genes, wide spread mutations occur within the inserted gene, near its insertion, and in hundreds or thousands of locations throughout the genome of the concerned cell. This creates a sort of genetic imbalances in the developed transgenic plant varieties. This leads to reduction of photosynthetic activity and productivity of the concerned variety. No GM crop has ever been developed whose yield is higher than the parent variety in which foreign genes have been incorporated. If commercial cultivation of GM seeds is allowed, this instability will spread to other local and high yielding varieties through pollination which is practically unavoidable. In course of time all the available varieties of the concerned crop will eventually exhibit this genetic instability. Also, during gene transfer some undesirable gene may get inserted in the newly developed GM crop varieties whose presence could not be ascertained primarily. But later on this gene can be expressed and produce a toxin protein that leads to various health problems in animals or even human beings feeding on the concerned GM food and also to some detrimental environmental consequences. Once the GM crop is introduced, the farmers and the consumer will have no choice but to produce and consume transgenic crops and foods.

GMOs destroy the natural web of life, threaten biodiversity and the environment, and are a potential scourge for human health and society. Large-scale field trials may only be conducted when a crop has comprehensively cleared all bio-safety protocols in rigorous independent long-term testing and appraisal. However, this has not been done in the case of DMH11 GM mustard. Official regulators have even hidden all data from the public and the independent scientific community, which is against constitutional provisions and the orders of the Hon'ble Supreme Court. This indicates that, the mandatory rigorous biosafety protocols have not been carried out or adhered to, and the data pertaining to DMH 11 therefore needs to be concealed.

Indian regulatory authorities are using sneaky means to introduce GM crops into Indian agriculture. There appears to be no place for science or transparency in this process, which will inevitably contaminate India's mustard diversity. Dr Pental said it was up to the government to decide if it wanted to disclose the bio-safety data in public domain or not.

Government Stand

Amid public pressure to disallow commercialization of genetically modified (GM) mustard in the country, environment minister Prakash Javadekar lately assured that the government will not impose GM mustard on the people and a final decision will be taken only after due deliberations. He, however, said that the progress of science could not be stopped and that India's population of 1.25 billion people could not be allowed to starve. Javedekar stated that the decision will not be taken at the cost of people's health.

Mr Javadekar also stated that emphasis shall be given on science, development, productivity and increased production; but at the same time, we have to be scientific and not risk the lives of our people. A number of farmer unions and many scientists from across the country had urged Mr Javadekar not to accord permission to GM mustard and to put all bio-safety data regarding GM mustard in public domain for scientific scrutiny.

Kavitha Kuruganti of Alliance for Sustainable and Holistic Agriculture (ASHA), which is a nationwide informal network of more than 400 organizations drawn from 20 states in India opined "It is indeed unacceptable that despite so many objections from citizens and even state governments, GEAC is going ahead with its secretive processes in a business-as-usual manner. This is all the more surprising given that the government talks about transparency, accountability, good governance and federal polity constantly. Our point is that this technology is a risky, irreversible, living technology".

She added "On top of that, our regulators have proven themselves to be untrustworthy of protecting citizens from the risks of modern biotechnology. Given a combination of both, should we not have a policy directive on the subject that ensures that we don't adopt such risky technologies when we have other alternatives?"

Conclusion

One should try to improve agriculture by holistic means and not by the piecemeal introduction of highly toxic inputs that poison a region's food supply. After the failure to prove the safety of transgenic technology in the case of Bt brinjal, the current attempt is to bring in this GM mustard as the Trojan horse for introducing transgenic technologies in food crops in India. The argument that is being put forward is that this GMO is from the public sector and therefore, will not be expensive or monopolistically controlled. It is also being argued that with this GM mustard being brought in, India's oilseed/oils import reliance will come down. The promoters also claim that this is safe and similar to GM canola in Canada. But, various studies revealed that all the claims around Bt cotton have been proven to be false and incorrect, as the experience for past 14 years in India shows. Agrochemical use has increased in cotton in India (both pesticides and fertilizers) with the per-hectare use of pesticides reaching 0.9 kg/ha, similar to what prevailed during the early 2000s in the pre-Bt cotton era. Farmer suicides continue unabated, and Bt cotton farmers account for most of them. Leading cotton scientists/experts are now talking about the need to promote non-GM Indian cottons as a solution to the agrarian crisis around cotton.

We cannot allow the government to take decisions about the food we eat in this obscure and underhand manner. It is now the case with mustard, we all use it, we cannot avoid using it. If permitted, we might have no choice but to use harmful, unhealthy GM Mustard. But, GM crops have not been proven safe. On the contrary, GM crops are inherently harmful. The regulatory framework was hopelessly flawed from the start. It was based on an anti-precautionary approach designed to expedite product approval at the expense of safety considerations. Jeffrey M Smith in his book 'Documented Health Risks of Genetically Engineered Foods' (2007) clearly showed that GM crops affects animal and human body adversely on 65 counts and practically all organ systems are damaged in some way or the other.

Regulators should have applied the recommendations and taken precautions that have come out from the judiciary-based, parliamentary and executive inquiry and study processes into the subject of GM crops, all of which recommended against introduction of crops like this GM mustard.

We also demand that the regulators put out all the biosafety information on this GMO for public scrutiny, as laid down by CIC and Supreme Court Orders in the past. The MOEF&CC should also ensure that the minutes of GEAC meetings are not put out of public domain.

The Government should, under no circumstances, approve this GMO, and the choices of farmers and consumers must not be violated by the introduction of an unsafe, irreversible and uncontrollable GM technology. The regulators should not process this application for commercial release of DMH11 mustard. The regulators have time and again substantiated their incapability, conflict of interest, lack of transparency, indifference to public interests while taking decisions for allowing various preliminary and advanced level trials and commercial introduction of GM crops.

The case surrounding GM mustard in India is evidence of unremitting regulatory delinquency. It all raises the question — why the rush to by-pass the proper procedures and regulations to push GMOs into the food chain of the country?

Finally, we add that genetic engineering undoubtedly signals a great leap in scientific achievement, and has opened up the vista of using this new science for the benefit of mankind. However, utmost caution must be exercised in applying this technology, particularly for food-crops meant for human consumption. Apart from the possible effect on environment and biodiversity, extra care needs to be taken to ensure that there is no long term toxic effect from the consumption of the modified food product. All relevant tests and epidemiological studies must be made available in the public domain, so that the people can make an informed decision. Often this is not done, and the seed companies and corporate houses act in a hush-hush manner and take recourse to many a underhand practice in introducing GM products. As concerned scientists we forcefully raise this demand that GM food crops are not to be introduced without thorough independent environmental assessments and independent rigorous toxicity and epidemiological studies and that all the results must be put in the public domain so that the right decision may be made on basis of scrutiny and informed public debate. □

References:

1. Briefing Paper on Delhi University's GM Mustard Prepared by the Coalition for a GM-Free India (www.indiagminfo.org), July 2015 (Revised).
2. GM Crops – The Toxic Truth published by One India One People Foundation, 2016 available at www.oneindiaonepeople.com
3. Understanding Gene and GMOs, Stephen Nottingham, Zed Books Limited, London and New York (2007)
4. Genetic Modification, Issues – 87, Independence, Cambridge, England (2004)
5. Plant Breeding — Principles and Methods, B D Singh, Kalyani Publishers, Ludhina, 2005.
6. Text Book of Field Crop Production, ICAR, New Delhi, 2002
7. Websites and webpages:

   http://www.plantbiotechnology.org.in/issue13.htm

   http://www.thehindu.com/2002/12/04/stories/2002120400341000.htm

   http://www.i-sis.org.uk/Teminator_Mustard_Must_Not_be_Released.php

   http://infochangeindia.org/agriculture/features/after-bt-cotton-its-gm-mustard.html

   http://www.dnaindia.com

   http://www.indiatogether.org/agricuture

   http://www.fbae.org/

WATER CRISIS

Pradip K. Datta *

1. Introduction

Water is a precious natural resource. It is essential for human survival and well-being and important to many sectors of the economy. The scale of global water consumption is having a dramatic impact around the world. Scarcity of fresh water poses a serious and growing threat to sustainable development and protection of the environment. It is estimated that in 2030, 47% of the world population will be living in areas of high water stress.

Water resources are irregularly distributed in space and time and the amount of fresh water on this globe is very limited. Only 3% of the Earth's water is fresh water to sustain human, plant, and animal life and 97% is saline (sea water) [1]. But most of the fresh water is in ice-caps and glaciers (69%) and groundwater (30%), while all lakes, rivers and swamps combined only account for a small fraction (0.3%) of the Earth's total freshwater reserves.

Today throughout the world, many factors such as urbanisation, population growth, increased living standards, growing competition for water, pollution, climate change and variations in natural conditions are reducing available water resources whereas the demand for water is increasing. According to a United Nations Press Release [2], world's population is expected to rise to 9 billion by 2050, with most of the increase taking place in developing countries that already suffer water stress.

In 2007 the International Water Management Institute, Sri Lanka conducted an assessment of water management in agriculture sector to see if the world had sufficient water to provide food for its growing population [3]. It found that a fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity where there is not enough water to meet all demands. One third of the world's population (more than 2.3 billion people) does not have access to clean drinking water.

Water crisis occurs when the available potable, unpolluted water within a region is less than that region's demand. Water scarcity is driven by two phenomena: growing freshwater use and depletion of usable freshwater resources. Water scarcity can be a result of two mechanisms: physical (absolute) water scarcity and economic water scarcity. Physical water scarcity is a result of inadequate natural water resources to supply a region's demand. Economic water scarcity is a result of poor management of the available water resources.

According to some reports, water crisis may reach such a dimension that disputes over water would be a source of future wars [4]. For example, the former Secretary-General of the United Nations, Boutrous Ghali, said, "The next war in the Middle East will be fought over water, not politics"; another former Secretary-General of the United Nations said in 2001, "Fierce competition for fresh water may well be-

*Dr. Datta is a retired Reader and Head of the Department of Physics, Presidency College, Kolkata-700073 e-mail : dattapradip@gmail.com

come a source of conflict and wars in the future" and the former Vice President of the World Bank, Ismail Serageldin said, "The wars of the next century will be over water unless significant changes in governance occurred." But economic criteria and political considerations still tend to drive water policy, whereas science and best practice are rarely given adequate consideration. When managing water resources, more attention should be paid to increasing existing natural resources and reducing demand and losses. Despite repeated calls from world experts, we are a long way from an approach to the management of water resources.

In this article we shall discuss water resources, water stress and its causes, uses of water, water conflicts and other related issues.

Water Resources

Sources of water that are useful or potentially useful are called water resources. The world's water exists naturally in different forms and locations: in the air, on the surface, below the ground, and in the oceans. The sources of fresh water are: surface water, ground water, frozen water, atmospheric water, etc. About 97 percent of all water is in the oceans. Only three percent of all Earth's water is fresh water. The majority, about 69 percent, is locked up in glaciers and ice-caps, mainly in Greenland and Antarctica. Remaining freshwater is ground water. Of all the freshwater on Earth, only about 0.3 percent is in rivers and lakes. One estimate [1] of global water distribution is shown in Table 1.

Basic water requirements

It is estimated that 8% of worldwide water use is for household purposes [4]. These include water for drinking, bathing, cooking, washing, laundry, gardening, etc. Basic household water requirements have been estimated by Peter Gleick5 at around 50 liters per person per day, excluding water for gardens.

The minimum drinking water requirement for human survival has to be determined considering the amount of water lost from the body due to normal activities. This loss must be regularly restored. The amount of water loss depends on surrounding environmental conditions and personal physiological characteristics. Humans may feel thirst after a fluid loss of only one percent of the body fluid and a fluid loss of nearly ten percent may cause death. Minimum water requirement for fluid replacement has been estimated as 3 litres per day per person under normal weather conditions. Gleick [5] has recommended that the minimum water requirement per day per person for bathing is 15 litres. The water requirement for cooking is different in different regions and it is estimated that 10 litres per day per person will meet the basic needs.

In addition to this, water is required for growing food and in industry. It is estimated that 70% of worldwide water is used for irrigation. It takes around 2,000-3,000 litres of water to produce enough food to satisfy one person's daily dietary need. It is estimated that 22% of water in the world is used in industry.

Water stress

More than one in every six people in the world is water stressed, because they do not have access to potable water. Most of them live in developing countries. The situations where the amount of available water is not enough for all uses has been termed as water stress by the World Business Council for Sustainable Development.

According to the Falkenmark Water

Table 1: An estimate of global water distribution

Water source	Water volume (Km^3)	Percent of fresh water	Percent of total water fresh water
Oceans, Seas, & Bays	1,338,000,000	–	96.5
Ice caps, Glaciers, & Permanent Snow	24,064,000	68.7	1.74
Groundwater	23,400,000	–	1.7
– Fresh	10,530,000	30.1	0.76
– Saline	12,870,000	–	0.94
Soil Moisture	16,500	0.05	0.001
Ground Ice & Permafrost	300,000	0.86	0.022
Lakes	176,400	–	0.013
– Fresh	91,000	0.26	0.007
– Saline	85,400	–	0.006
Atmosphere	12,900	0.04	0.001
Swamp Water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological Water	1,120	0.003	0.0001
Total	1,386,000,000		100

Stress Indicator, when annual per capita renewable freshwater availability is less than 1,700 m^3, a country or region is said to experience periodic or regular "water stress". Below 1,000 m^3, water scarcity begins to hamper economic development and human health and well-being.

Water stress is usually evaluated by comparing the volume of renewable water resources per capita at a national level. In 2006, about 700 million people in 43 countries were living below the 1,700 m^3 per person threshold.

Water stress is ever intensifying in China, India, and Sub-Saharan Africa. The world's most water stressed region is the Middle East with averages of 1,200 m^3 of water per person. Much of the water stressed population currently live in river basins where the usages of water resources greatly exceed the renewal of the water source.

Causes of Water Crisis

Some of the causes of water crisis may be summarised as follows:

1. As a result of increase in world's population the amount of available fresh water per person per year is decreasing. The amount was about 9,000 m^3 and 7,800 m^3 respectively in 1989 and 2000 and is expected to fall to 5,100 m^3 in 2025 [6].
2. The demand for water is increasing due to urbanization, economic development, growing more food for the people, etc., while the basic amount of fresh water supply provided by the hydrological cycle is not.
3. Fresh water is not evenly distributed throughout the globe, throughout the seasons or from year to year.
4. In the developing countries, the fresh water supply comes in the form of seasonal rain. For example, in Asia and

India the rainy season lasts for about 4 months and the remaining 8 months get very little rain.

5. There is lack of efficiency in storing the rain water.
6. Waste water from factories, sewage, garbage and even toxic pollutants are discharged into rivers and lakes and this pollutes the rivers and lakes. As a result, the amount of fresh water is decreasing.
7. The amount of available freshwater is decreasing due to climate change. Climate change has caused receding glaciers, reduced stream and river flow, and shrinking lakes and ponds.
8. The depletion of aquifers due to over-drawing of water for production of high yielding crops which need a large amount of water.
9. In many places arsenic is found in groundwater and has become unsuitable for drinking.
10. Lack of investment in infrastructure or technology to draw water from rivers, aquifers or other water sources.

Virtual Water

The amount of water needed to produce food or any commodity is called virtual water. For example, on an average 1,600 cubic meters of water is required to produce one metric tonne of wheat and if one metric tonne of wheat is exported 1,600 cubic meters of water is also exported with the wheat. In order to reduce water crisis, some countries import food and other commodities instead of producing them in their own country and thereby save the water needed to produce the food and commodities in the country.

Effects of Water Crisis

Some of the effects of water crisis are:

1. Due to want of safe drinking water water-borne diseases cause death of many people, particularly children below the age of five. According to the World Bank, 88% of all waterborne diseases are caused by unsafe drinking water, inadequate sanitation and poor hygiene [7]. In low- and middle-income countries, 38% of health care facilities lack any water source, 19% do not have improved sanitation and 35% lack water and soap for hand washing.

2. Water scarcity has many negative impacts on the environment, including lakes, rivers, wetlands, and other fresh water resources. During the last 100 years, more than half of the Earth's wetlands have been destroyed and have disappeared. The wetlands are the habitats of various inhabitants such as mammals, birds, fish, amphibians and invertebrates. These wetlands also support the growing of rice and other food crops as well as provide water filtration and protection from storms and flooding.

   Freshwater lakes have also suffered. For example, the Aral Sea in Central Asia, which was once the fourth largest freshwater lake, has lost more than 58,000 km^2 of area only in three decades. It is now as salty as an ocean due to the excessive pollution and the diversion of water for irrigation and power generation. As the sea has retracted, it has left polluted land. This ecological catastrophe has created food shortages and resulted in a rise in infant mortality and a decrease in life expectancy for the nearby population [8].

Water Conflict

Water crisis has most often led to conflicts at local and regional levels. The conflict between countries, states, or groups over access to water resources is termed as water conflict. A wide range of water conflicts have appeared throughout history. These conflicts occur over both freshwater and saltwater and both between and within nations. Freshwater resources being limited and unevenly distributed, conflicts occur mostly over freshwater.

During history there has been much conflict over use of water from rivers such as the Tigris and Euphrates Rivers. Another highly politicized example is Israel's control of water resources in the Levant region since its creation, where Israel's securing its water resources was one of several drivers for the 1967 Six Day War.

The Pacific Institute has developed a Water Conflict Chronology [9]. The conflict between India and Bangladesh over Tista water has not yet been resolved. Within India disputes on river water have occurred. For example, the sharing of waters of the Kaveri River has been the source of a serious conflict between the states of Karnataka and Tamil Nadu. The dispute still persists. The Government of India had to set up two separate Tribunals in 1969 to adjudicate disputes among the river basin states of interstate rivers Godavari and Krishna on the sharing of river water utilization disputes under the provisions of Interstate River Water Disputes Act, 1956.

The Dublin Statement

A meeting of experts on water related problems was held on the 31st January, 1992 at the International Conference on Water and the Environment, Dublin, Ireland. The Dublin Statement on Water and Sustainable Development recognised the increasing scarcity of water as a result of the different conflicting uses and overuses of water. The declaration sets out recommendations for action at local, national and international levels to reduce the scarcity, through the following four guiding principles:

Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.

Principle 3: Women play a central part in the provision, management and safeguarding of water.

Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good.

Principle 4 was criticized by a number of organisations because it states that "Water has an economic value" rather than considering water as a universal right. However, in November, 2002 the UN Committee on Economic, Social and Cultural Rights adopted General Comment in which water is recognised not only as a limited natural resource and a public good but also as a human right. This is a decisive step towards the recognition of water as universal right. On 30 September, 2010 the 15th Session of the UN Human Rights Council passed Resolution reaffirming an earlier General Assembly resolution (64/292 of 28 July 2010) which recognized the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights [10].

Conclusion

Thus we see that the available fresh water resource in the world is very limited and that too is unevenly distributed. Further, already many regions are water stressed and the annual per capita renewable freshwater availability is decreasing. Governments should develop national water management policies that will help to improve supply as well as manage demand better. Governments in water stressed regions have to deal with acute freshwater shortages and resources. When managing water resources, more attention should be paid to making better use of existing natural resources, increasing existing natural resources and reducing demand and losses. Previously rising demand for water was to store surface water in reservoirs, divert flow to dry regions and withdraw groundwater. Now these methods are increasingly being supplemented by water reuse, desalination and rainfall harvesting. The efforts to conserve water and reduce demand are not only useful in water stressed regions, but in other regions also.

References

1. http://water.usgs.gov/edu/earthwherewater.html
2. United Nations Press Release POP/952, 13 March 2007.
3. Molden, D. (Ed). Water for food, Water for life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan/IWMI, 2007.
4. https://en.wikipedia.org/wiki/Water_resources
5. Peter H. Gleick, Water International 21, 83-92 (1996)
6. Freshwater lifeblood of the planet. peopleandplanet.net (11 November 2002)
7. "All About: Water and Health". CNN. 18 December 2007.
8. http://www.worldwildlife.org/threats/water-scarcity
9. http://worldwater.org/water-conflict
10. https://en.wikipedia.org/wiki/Dublin_Statement

A Brief History of Science
Part 12: The development of quantum mechanics

Soumitro Banerjee*

Introduction

BY THE 1890s, the pillars of physics — the Newtonian theory of gravity and dynamics that explained the motion of bodies, Maxwell's theory of electromagnetism that explained all electrical and magnetic phenomena including the nature of light, and thermodynamics which explained the phenomena resulting from exchange of heat — were on firm footing. Physicists grew complacent and believed that there was nothing more to be done in this field.

"All that remains is to dot a few i's and cross a few t's", commented the physicist John Trowbridge of Harvard University. Albert Michelson of Chicago University (a future Nobel Laureate) said in a lecture, "The future truths of physics are to be looked for in the sixth place of decimals."

Yet in the next 30 years physics saw a revolution that completely changed our perception of the material world. Two path-breaking theories made their appearance— the theory of relativity and quantum mechanics. This happened in the intellectual atmosphere of struggle between positivism and materialism. In this instalment we shall discuss the history of development of quantum mechanics.

The realization that the knowledge of the time cannot explain the material world came mainly with two discoveries: black-body radiation and radioactivity. We have discussed the former in the last issue. So let us start with radioactivity on our way to quantum mechanics.

Radioactivity

In 1895, Wilhelm Conrad Roentgen discovered the x-ray, and captured the image of the bones of his hand on photographic plates. To publicize the event, he mailed the photographs to a few eminent scientists. That created a sensation, and within three weeks the new technique of x-ray was being used by medical practitioners to set broken bones.

Becquerel knew about the phenomenon of phosphorescence, that some materials glow in the dark after absorbing energy from the sun during daytime. He guessed that in phosphorescence, the materials emitted x-rays. As a test, he exposed a phosphorescent material, potassium uranyl sulphate, in the sun, and then covered it with black paper and put it on a photographic plate. The plate, when developed, turned black. He thought that this material was emitting x-rays just like Roentgen's rays.

The next few days were cloudy, and so Becquerel put the whole contraption in his drawer. A week later, when the

*Dr. Banerjee is a Professor at the Indian Institute of Science Education & Research, and General Secretary of *Breakthrough Science Society* .

sun came back, he intended to resume his experiment. But instead of putting the potassium uranyl sulphate out in the sun, he first wanted to test how good the photographic plates were, and so he developed one of them. Surprise: It turned black, meaning that it has been exposed to radiation even though the material had not absorbed sunlight. The discovery was serendipitous, but the importance of such chance factors can be grasped only by a trained mind. Becquerel did systematic investigation for a few months and established that the material was emitting the rays all by itself. He showed that the rays contain energy—because substances that absorbed the rays became heated. He showed that dry air, which normally does not conduct electricity, became conducting in presence of these rays—the extent of which can be measured with electroscopes.

At this point of time, Marie Sklodowska Curie, a young student from Poland, was looking for a suitable problem to do her research. Becquerel's discovery attracted her attention as it posed a few questions.

I shall discuss Madame Curie's method of investigation in some detail because today's research students can learn many things from it regarding the method of scientific research. Any scientific research starts with a question. So she asked the question: Is radioactivity a property of a compound or of an element? To seek answer to this question, she prepared a few compounds of the same mass, but in which the quantity of uranium was different. By measuring with an electroscope, she found that radioactivity in these compounds were different, but was proportional to the amount of uranium in each compound. Thus she concluded that radioactivity is a property of the element uranium.

Then she asked the question: Is radioactivity a property of only the element uranium, or do other elements have the same property? She took various compounds that contain different elements and measured the radioactivity of each. This way she examined all the elements discovered till that time, and found that another element, thorium, is also radioactive.

Then she argued that the minerals found in nature should exhibit radioactivity if they contain uranium and thorium, and should not exhibit radioactivity if they don't contain these two elements. She examined hundreds of minerals and checked that the hypothesis was indeed true. Then she did something strange: she argued that in the minerals that contain uranium and thorium, the radioactivity due to these two elements individually should add up to give the radioactivity of the mineral. So she measured the quantities of uranium and thorium in these minerals, and checked if the radioactivity of the mineral is a simple sum of the radioactivity of the uranium and thorium present in the mineral. She found that this is true for most minerals, but in the mineral called pitchblende she found that its radioactivity exceeds that expected by considering its uranium and thorium contents individually.

She hypothesized that pitchblende contains a hitherto unknown element that is highly radioactive. Why was it not detected in her chemical analysis? That is because it occurs in minute quantities. She needed to isolate this substance. Since her research opened such an exciting possibility, her husband Pierre joined her pursuit. They painstakingly isolated each element in the mineral, and measured the radioactivity of each. To their surprise they found that not one but two elements that are known to be non-radioactive—bismuth and barium—are exhibiting radioactivity. They realized that pitchblende contains not one but two new radioactive elements, the chemical

Pierre Curie (1859-1906)
and Madame Curie (1867-1934).

properties of the first are similar to that of bismuth and the properties of the second are similar to that of barium. They named one as 'polonium' and the other 'radium'. The reader may note how Madame Curie made use of John Stuart Mill's ideas on operational causality (see Part-9 of this essay) in designing her experiments to answer the question "what causes radioactivity"?

The story does not end there. They now faced the task of isolating these two new elements and measuring their atomic weights. It was a herculean task since these elements occur in trace quantities. So they would need an enormous quantity of pitchblende, which is an expensive mineral. How would they get such money?

They found a solution: there were companies that extracted uranium and thorium from pitchblende and threw away the remaining material. They realized that the elements they were looking for must be contained in this leftover substance.

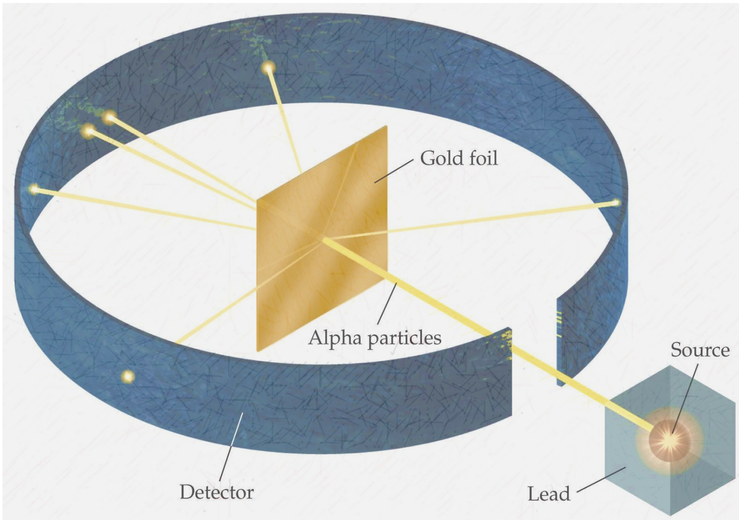
So they arranged to get a thousand kilograms of this material, and started the painstakingly laborious process of processing one kilogram each day to isolate bismuth and barium from the substance, and subject these to further processing to extract the two new elements. They were finally able to isolate polonium and radium in sufficient quantities to measure their atomic masses. Along with Henri Becquerel, they were awarded the Nobel Prize in 1903.

Radium turned out to be highly radioactive—its radioactivity is a million times that of uranium. And so it turned out to be the ideal source if one wanted to experiment on radioactivity. It is also extremely rare. By 1916 the world's store of radium was less than half an ounce. But Madame Curie parcelled out small amounts of the new element to whoever wanted to experiment on it.

Looking inside the atom

When J J Thomson discovered the electron through the study of cathode rays, there was considerable reluctance in the scientific community to accept it. "It is difficult to grasp how startling the notion of a subatomic particle was to the nineteenth century physicists, many of whom did not believe that atoms existed, let alone they had constituent parts" [1]. But the study of radioactivity was increasingly revealing that there must be things inside the atom. It was found that the beta rays emitted by radioactive substance were nothing but electrons. If there are negatively charged electrons inside the atoms, there must be something positively charged also, because the atoms are neutral.

Ernst Rutherford, sitting in distant McGill University in Canada, obtained a bit of radium generously parcelled by Curie, and proceeded to investigate the character of alpha rays. He measured the



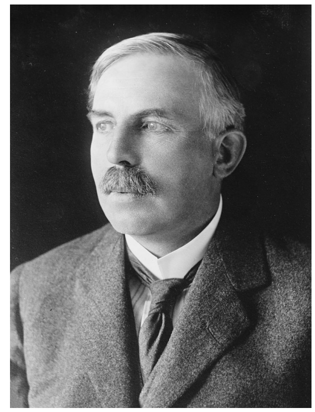


Illustration of Rutherford, Geiger, and Marsden's experiment and Ernest Rutherford (1871-1937).

charge-to-mass ratio of the alpha particles and concluded that these were positively charged helium atoms. But he noticed that observations of the alpha particles are extremely difficult because the particles are constantly scattered by everything in the laboratory, including air. Unable to reduce the scattering in spite of repeated attempts, he decided to focus on scattering itself. By then, he had moved to Manchester in England. In 1908, he asked his students Hans Geiger and Ernst Marsden to observe the scattering when alpha particles fell on a thin metal foil.

By that time, in spite of the positivists' objections, people had started to believe in the existence of atoms (after Einstein's arguments, see part 12 of this article), and the discovery of radioactivity indicated that atoms were made of smaller constituents. The mental picture of the time was that negatively charged electrons were embedded in a ball of positively charged substance, much as pieces of fruit are embedded in a fruit-cake. It was called the "plum-pudding" model.

Geiger and Marsden's experiment revealed that the alpha particles are scattered mostly around the direction of travel, but one in eight thousand particles would rebound right back in the opposite direction. This puzzled Rutherford, because the result was not expected from the existing plum-pudding model of the atom. After many repetitions of the experiment and much groping in the dark, around 1911 he found the answer: the observation indicates that the positive charge of the atom is concentrated in a tiny blob at the centre of the atom, while the electrons are whizzing around this 'nucleus'. This gave rise to a solar system like mental picture of the atom.

Very few physicists paid attention to Rutherford's proposition regarding the structure of the atom, because it had a serious flaw: according to the theory of electromagnetism, an electron going round a nucleus (which is an accelerated motion) would continuously radiate energy and would drop into the nucleus in a fraction of a second. The 'solar system' like atom,

Niels Bohr (1885-1962)

therefore, cannot be stable. Yet we do see stable matter all around us!

In 1911, a twenty five year old Danish physicist named Niels Bohr was visiting Thomson's Cavendish laboratory in Cambridge and Rutherford's laboratory in Manchester. There he heard of Rutherford's idea about the structure of an atom, and took it seriously. Earlier the idea of light quanta (the fact that light comes not as a continuous stream but as discrete 'packets' of energy) had been proposed by Planck in 1900, and Einstein had demonstrated in 1905 that light is emitted and absorbed in similar 'packets' (see Part 12 of this article). Bohr guessed that the light quanta as proposed by Planck and Einstein were in some way responsible for the stability of atoms.

He postulated that electrons in atoms can move only in certain stable orbits and can jump from one to another by absorption or release of a quantum of energy. Assuming circular orbits of the electron, the laws of classical mechanics and the above 'quantum' postulate, Bohr managed to show that absorption and emission of light by hydrogen can happen only at certain frequencies. It was known that the spectrum of light passing through hydrogen shows a few dark lines corresponding to the frequencies that are absorbed by hydrogen, and the mathematician Balmer had given a formula for these frequencies. Bohr's prediction exactly matched Balmer's formula, and by that, his postulate explained why the Balmer lines occur in the hydrogen spectrum.

The paper published in 1913 caused quite a stir, because, for the first time scientists had an explanation of the spectral lines. But it was soon found that, while Bohr's theory obtained the correct values of the frequencies of the spectral lines of hydrogen, it shed no light on the intensities of these spectral lines. Moreover experimentalists found that there were faint lines around the major spectral lines, and Bohr's theory provided no explanation for that. Arnold Sommerfeld (1868-1951) tried to overcome this weakness by assuming elliptical orbits, but it was soon found that the Bohr-Sommerfeld line of approach cannot predict the spectral lines of anything other than hydrogen—the simplest atom.

Physicists groped in the dark for quite some time, trying to reconcile the well-known laws of classical physics and electromagnetism with the new experimental findings of atomic phenomena, but with no success. Then from 1924, things began to move really fast.

The solution

Earlier Einstein had demonstrated that light, which is known to be of wave character (recall interference and diffraction), also has a particle character. In 1924 Louis de Broglie postulated, in a similar vein, that what were known as particles (electrons, protons, etc.) also have a wave character. G P Thomson (son of J J) in England and

Davisson and Germer in the United States experimentally demonstrated in 1927 that streams of electrons passing over obstacles exhibit diffraction pattern, a sure sign of wave character. But waves of what? That question was yet unresolved.

In July 1925, the young Werner Heisenberg took a shot at the hydrogen spectrum in a different way. Bohr had postulated that absorption or emission of radiation from an atom can happen only when an electron jumps from one level to another. Assigning numbers 1, 2, 3 $\cdots$ to the different levels, Heisenberg arranged the possible transitions and the associated energies and other variables in square arrays and proceeded to manipulate such arrays to obtain useful results. Now we know that such arrays are matrices, but in the 1920s matrices were unknown to physicists. Max Born first realized that these are matrices, and in a paper that appeared in September 1925, he and his student Pascual Jordan proceeded to apply the rules of manipulation of matrices that were given by mathematicians.

They soon realized that there was a problem: while two ordinary numbers can be multiplied in any order and the result is always the same (i.e., $a \cdot b = b \cdot a$), in the multiplication of matrices the order matters. So if these matrices in some way represent the physics of the microworld, that physics would be quite different from the physics of classical mechanics and electromagnetism. In particular, they found that if the position q and momentum p of a particle are represented by such matrices, then $p \cdot q$ is not equal to $q \cdot p$, that is, in modern language, these two variables do not commute. This result had a far-reaching implication that was to be revealed later.

While Bohr, Heisenberg, Jordan, and others were working out this 'matrix mechanics', in 1926 Erwin Schrödinger approached the problem from a completely different direction. It was known that the common perception of 'ray of light' is only a mental construct: the line perpendicular to the propagating wave front. For long-wavelength radio waves, such 'rays' lose meaning the way we do not talk about 'rays' of sound. Thus the straight line propagation of light is only a consequence of its wave nature. Schrödinger added to this de Broglie's assertion that particles also have wave character. He guessed that the propagation of a particle could, in some way, be explained by the evolution of its associated wave, and proceeded to construct a theory of micro-particles based on the well-known theory of waves.

Louis de Broglie (1892-1987)

In fact, another clue led him in this direction. In 1924, half the globe away from the centre of activity, in the University of Dacca (now in Bangladesh), Professor Satyendra Nath Bose was teaching Planck's derivation of the black body radiation curve to his students. He did not like Planck's approach and derived it on his own. He then wrote up his derivation as a paper and sent it to Einstein with a request that, if he approved it, he may kindly get the manuscript translated into German and get it published. Einstein realized that Bose had made a major discovery, and promptly got it published.

In his derivation, Bose had made a daring assumption that photons are indistinguishable from each other, and had built his statistics on that basis. Einstein then went a step further and assumed a 'gas' composed of particles that are indistinguishable. In a paper published in 1925, He showed that such a gas would undergo a qualitative change in character at low temperatures—a phenomenon now known as 'Bose-Einstein Condensate' [1]. Using this knowledge, Schrödinger argued that, if light behaved as waves as well as particles, and if Einstein could use the same kind of statistics to atoms that actually apply to photons, why not take it a step further and try to construct a wave theory of particles?

He assumed that there is a quantity, denoted by the Greek character Ψ (psi), that embodies this wave character, i.e., goes up and down in a wavelike manner. He wrote down an equation that captures this variation of Ψ (called the Schrödinger equation). When he applied the equation to a particle bound by some kind of force (say, an electron tied to an atom) and solved the differential equation, the discrete or 'quantized' values of energy emerged as a natural consequence of the wave nature—in a way similar to the common observation that strings tied at the two ends can produce only certain notes, i.e., discrete values of frequency. And for the hydrogen atom, the discrete energy values that emerged matched exactly the observed ones.

Thus, there was a peculiar situation: two

Werner Karl Heisenberg (1901-1976)

different mathematical formalisms—Heisenberg's matrix mechanics and Schrödinger's wave mechanics—seemed to account for the observed facts, both successful in their own ways. Finally, Schrödinger solved the quandary by showing that these two approaches are in fact equivalent, two sides of the same coin. One could use either of them to arrive at the correct answers. Slowly scientists found, through their practice, that Schrödinger's method is easier to use, and now science has practically forgotten Heisenberg's matrix mechanics.

But what was this Ψ? What is its physical interpretation? Schrödinger took a shot at this question, but his answer turned out to be incorrect. Then Max Born showed that Ψ is related to probability—the probability that the particle exists in a certain location is given by the square of the magnitude of Ψ evaluated at that location. Thus the statistical interpretation of quantum mechanics was born.

The statistical interpretation said that it is impossible to pinpoint the position of a

[1]The Bose-Einstein condensate was experimentally observed by Eric Cornell, Carl Wieman, and co-workers on 5 June 1995.

particle and we can only get a probabilistic estimate of where it could be. It has different probabilities of being in different positions, which is given by the wave function Ψ. The evolution of the wave function, in turn, is governed by the Schrödinger equation. It turned out that the momentum of a particle also has to be specified in probabilistic terms, i.e., we cannot say what the momentum of a particle exactly is, but we can calculate the probability of having a momentum lying between two specific values.

Then Heisenberg showed in March 1927 that the 'spreads' in the probability distributions of position and momentum cannot both be arbitrarily small. If the standard deviations of the distributions of position and momentum be Δx and Δp respectively, then $\Delta x \cdot \Delta p$ should be greater than $h/4\pi$, where h is the Planck's constant. This is the celebrated uncertainty principle of Heisenberg. Note that this is a mathematical result, not a result of our attempts to observe the position and momentum of a particle, nor is it a matter of efficacy of our instruments. In fact, all the pairs of variables that do not commute (for example, the angular momenta in the x and y directions) have this property.

All these developments happened over a brief period from 1924 to 1927. The basic formalism of quantum mechanics was laid out within these three years. After this period, major contributions were made by Wolfgang Pauli (the exclusion principle), Paul Dirac (quantum electrodynamics) and many others that opened up the new branch of particle physics.

But the development of quantum mechanics created intense controversy regarding its interpretation and philosophical implication. Let us now turn our attention to that.

Max Born (1882-1970)

The controversies

There were basically two central issues on which the scientists of the time could not agree with each other. The first concerned the probabilistic nature of reality. Classical physics was based on strict determinism: a given initial condition of a body necessarily leads to a specific final state after a lapse of time, and classical physics provided the tools by which the evolution from the initial state to the final state could be exactly calculated. In contrast, quantum mechanics enabled one to calculate only the probabilities of various possible outcomes starting from a given initial state. Some scientists, including Einstein, contended that this probabilistic description is on account of our ignorance of the exact position and momentum, and there is a fundamental reality behind the quantum probabilities, which quantum mechanics has not grasped. When the missing pieces are assembled, the probabilistic nature will disappear and we'll again have a deterministic description of microscopic phenomena.

A conference, called the Fifth Solvay

Box-1: The postulates of quantum mechanics
(for the mathematically inclined reader)

- The state of a particle is given by the wave function $\Psi(x,t)$ which has different values at different points in space, and varies with time. Ψ is in general a complex number.
- The probability of finding the particle in the range between a to b is given by $\int_a^b |\Psi(x,t)|^2 dx$. Since the particle must be *somewhere*, $\int_{-\infty}^{\infty} |\Psi(x,t)|^2 dx = 1$.
- When a particle of mass m is subjected to a potential function $V(x)$, the wavefunction evolves deterministically according to the Schrödinger equation

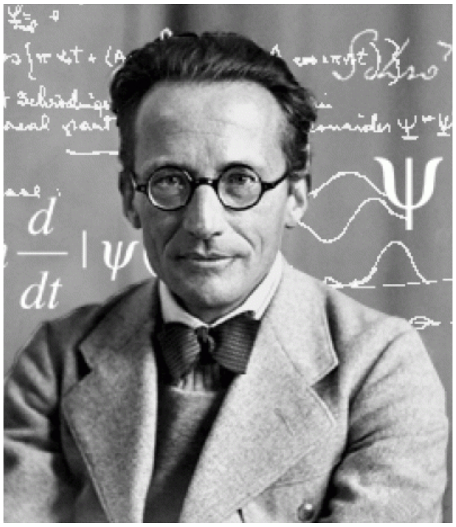
$$i\hbar \frac{\partial \Psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + V(x)\Psi(x,t) \quad \text{where } \hbar = h/2\pi.$$

- We cannot observe the state of the system, but can measure the 'observables'. The observables are given by *operators*. For example, 'multiplication by x' is the operator for position, $-i\hbar\frac{\partial}{\partial x}$ is the operator momentum, etc.
- Every measurement of an observable yields one of the eigenvalues of the corresponding operator.
- If the operator corresponding to an observable (say, energy) has n eigenvalues, we cannot say which energy value will be observed in a measurement. But we can state the probability of observing the i-th eigenvalue, which is given by

$$p_i = \left| \int_{-\infty}^{\infty} \psi_i^* \Psi(x,t) dx \right|^2 ,$$

  where ψ_i is the corresponding eigenfunction.
- A measurement causes the wave function to jump discontinuously to an eigenstate of the dynamical variable that is being observed.
- The average or 'expectation' value of an observable (represented by the operator $\hat{O}$) is given by $\int_{-\infty}^{\infty} \Psi^* \hat{O} \Psi dx$.
- If $\hat{A}$ and $\hat{B}$ are two operators that commute, i.e., $\hat{A}\hat{B} - \hat{B}\hat{A} = 0$, then the corresponding variables can be simultaneously measured with infinite precision. But if they do not commute, the corresponding variables cannot both have precise values at any point of time.

International Conference on Electrons and Photons was convened in October 1927 at Brussels, where the world's most notable physicists met to discuss the newly formulated quantum theory. In this conference, Einstein raised a few objections about the statistical interpretation, especially about the uncertainty principle, in his characteristic style—by proposing thought experiments and demonstrating that these would lead to contradictions. Scientists would spend sleepless night trying to find answers to the questions Einstein had raised, and the next morning Bohr would come forth with the appropriate logic to show that there would be no contradiction. The same thing continued in the Sixth Solvay Conference in 1930. Finally Einstein and other opponents (like Planck, de Broglie, etc.) conceded that quantum theory is a correct theory, at least as far as its mathematical methodology is concerned.



Erwin Schrödinger (1887-1961)

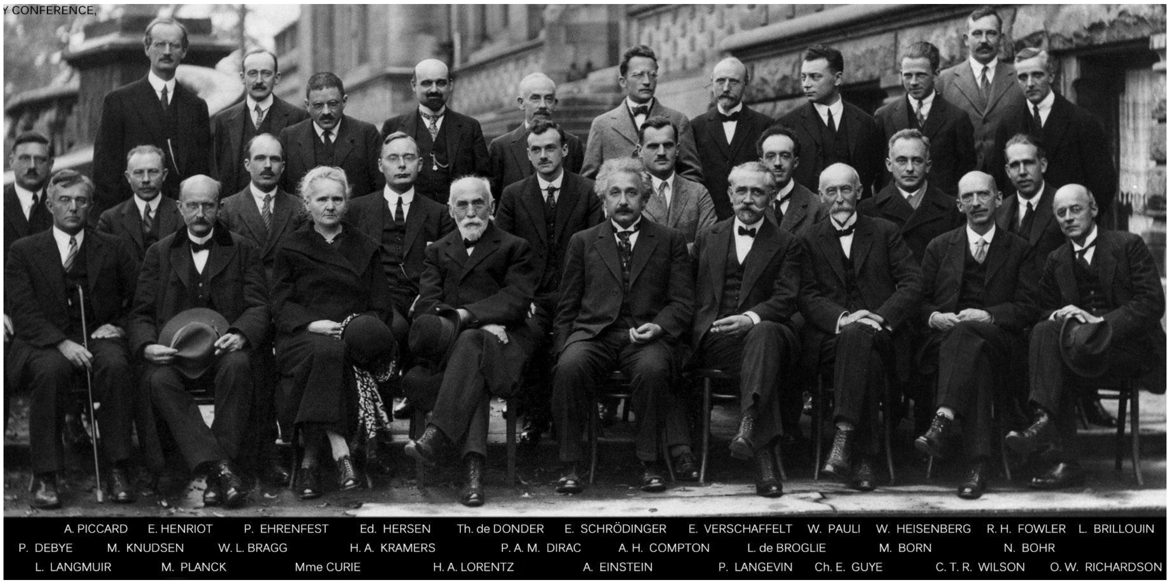
But Einstein never changed his second point of objection. What was it?

In order to understand the nature of the controversy, we need to see how the theoretical structure of quantum mechanics was interpreted. The most prevalent one is known as the Copenhagen interpretation, which was developed mainly by Niels Bohr and Werner Heisenberg. It contended that the real character of the micro-world is not amenable to experimental investigation because any attempt to observe it will invariably disturb what we are trying to observe. Therefore, we should abandon all attempts to know the character of physical reality and instead should only focus on what are observable. They went a step further and said that physical reality does not exist until we observe it. In the language of Heisenberg, "Atoms or elementary particles are not real; they form a world of potentialities or possibilities rather than one of things or facts." When an observation is made, say, on a particle's position, we force the particle to take a decision: out of the many possible positions, one actualizes. In the language of the physicist Pascual Jordan, "Observations not only disturb what has to be measured, they produce it ⋯ We compel [the electron] to assume a definite position ⋯ We ourselves produce the results of measurements." Thus, according to them, conscious intervention creates reality. There is no reality existing independent of our consciousness. It is clear that this line of argument comes from a positivist philosophical position.

Einstein could never accept this interpretation, and firmly stuck to his belief in a physical reality existing independent of our consciousness. And in that sense he held that the theory of quantum mechanics, in spite of all its successes in explaining various physical phenomena and predicting the outcome of experiments, is still an incomplete theory. The completion will come only when it throws light on the nature of physical reality.

In 1935, Einstein teamed up with Boris Podolsky and Nathan Rosen to publish a paper in which he demonstrated how the prevailing ideas of quantum mechanics led to a paradox (now called the EPR paradox): a pair of particles would be able to instantly communicate with each other over long distances.

The same year, Schrödinger published a paper to demonstrate the absurdity of supposing that a system can stay in an "undecided" state until we observe it. He proposed a thought experiment in which a cat is enclosed in a box that contains a radioactive element. When the radioactive element decays, an instrument detects the radiation and opens a vial containing a lethal poison that kills the cat. Now, according to the Copenhagen interpretation of quantum mechanics, the radioactive atom will be in an "undecided" state – a superposition of the 'not decayed' state and the 'decayed' state – until we observe it.



A group photograph of the participants of the 1927 Solvay conference

Schrödinger asks: Will the cat also be in a superposition of the 'alive' state and the 'dead' state until we open the box and observe it?

Most scientists shoved these objections under the rug and proceeded with their business.

Towards the end of his life Einstein became increasingly isolated as the Copenhagen interpretation became 'mainstream', with a generation of scientists being taught to use quantum mechanics to calculate without bothering about its philosophical implication. Yet he stuck steadfastly to his materialistic views. Einstein's biographer Abraham Pais observed "We often discussed his notions on objective reality. I recall that during one walk Einstein suddenly stopped, turned to me and asked whether I really believed that the moon exists only when I look at it."

Since the 1980s there has been a resurgence of interest in the foundations of quantum mechanics. Though all the experiments performed so far confirm the predictions of quantum mechanics, many scientists now feel that the question is still wide open, almost nine decades after it was raised. The famous physicist and mathematician Roger Penrose who wrote in the foreword of the book *Einstein's miraculous year* : "Why, when Einstein started from a vantage point so much in the lead of his contemporaries with regard to understanding quantum phenomena, was he nevertheless left behind by them in the subsequent development of quantum theory? ⋯ Many would hold that Einstein was hampered by his 'outdated' realist standpoint, whereas Niels Bohr, in particular, was able to move forward simply by denying the very existence of such a thing as "physical reality" at the quantum level of molecules, atoms, and elementary particles. Yet it is clear that the fundamental advances that Einstein was able to achieve in 1905 depended –

Continued to page 38

Analysis of the Real

Sarosh Ali *

NATURE IS ABOUND by examples of certain things dependent of certain other things. For example, the elevation of sun and the time of the day. Or electricity generated by a wind-mill and the speed and direction of wind. On certain occasions these 'cause and effect' relations are simple to fathom. But many a times the pattern seems to be complicated. And every time that a more complex phenomena surfaces, of which the time is ripe to require a more precise understanding, mathematics evolves. And that part of mathematics which tries to bring forth the intricacies of such cause and effect, for a more profound understanding, is called 'Analysis'.

Analysis is a branch of mathematics in which we break down a problem into tiny constituents and then infer the results. For example, it can be used to measure the length of a curve by breaking down the curve into tiny straight lines and then adding them all up. This method of solving a problem is the key to the natural sciences. The most important pioneering contributors to the field of analysis are Newton and Leibniz, and it is because of this they are considered as patriarchs of modern science. So let us begin with this interesting story.

1. The Continuum

Cantor showed that real numbers are a greater infinity than rationals and algebraic numbers (roots of algebraic equations with rational coefficients) put together. The number of reals in any small interval are equivalent to the set of all real numbers. Not only this, but on the number line, every point represents a real number, unlike the integers or rationals or even algebraic numbers. Thus, reals are aptly named as 'the continuum'.

Take the interval $(-1, 1)$. We can expand it to $(-2, 2)$ by taking the map $f(x) = 2x$; and we can keep changing the map to derive larger and larger sets. In fact we can generate the whole number line by an appropriate map of $(-1, 1)$. Given a continuum one can always expand it into a larger sized continuum.

It is my guess that humankind first encountered this mystery around the time when Zeno (of the Eleatic school) came up with his paradoxes. The first paradox says the following. Consider the trajectory of the tip of an arrow that has been shot. At any single instant of time (taking a snapshot) the arrow is at a fixed position and thus is stationary. Then, how can it move to change positions?

There is another paradox by the name 'Achilles and the Tortoise'. It says that, whenever Achilles is chasing the tortoise, for Achilles to reach the tortoise it must first reach where the tortoise had started. However, in that much time the tortoise has moved a little further. If this keeps going on it will take infinite steps for Achilles to reach the tortoise and thus Achilles can never reach the tortoise.

*The author is a theoretical physicist and a mathematics enthusiast. He is a freelance writer.

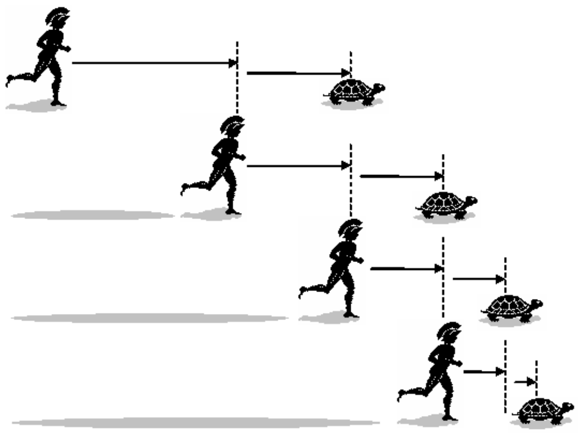


Figure 1: Achilles and the tortoise

The resolution of these paradoxes, as given by Zeno, was that all motion or all change is illusory and the world is actually in a static state where nothing changes. However, this is a very pessimistic point of view. The resolution of this lies in the mystery of continuum.

Let us first consider the arrow. The single position of time that Zeno talks about is a point on the number line. However, when we microscopically look at this point, it no longer remains a point, but becomes a small interval. This is manifestation of the fact that every measuring apparatus has a least count and thus an uncertainty associated with it. If we look at the snapshot of the arrow, the shutter speed can only be increased upto a certain value. Now if we notice the image of the arrow on a tiny scale, we still get a blurred image of motion of the tip of the arrow within an interval. This uncertainty is due to the limitation of the process of measurement and not of fundamental nature like the 'quantum uncertainty'. This can be minimized arbitrarily by improving the resolution. And as we zoom in more and more, the inaccuracy of the result also gets truncated more and more.

The 'point' and the 'single instant' are just idealizations. In reality, as much as we try and approach this idealization we only encounter smaller regions of the continuum. These smaller regions constitute the motion and change we see about us.

Now if we look at the second paradox, its resolution also lies in the nature of continuum. As Achilles tries to reach the tortoise, it takes him infinite number of steps as expressed in the paradox. However, the time interval of each step also gets smaller and smaller infinitely. Thus the added sum of infinitely many of the infinitely small gives a finite answer.

In both these paradoxes the mystery of the continuum (something that could be pushed down under the rug) comes to the rescue. However, after crossing a particular scale we must modify or even overhaul our description of the given system.

2. Functions

The world we see around us is mostly understood as a dialectic of cause and effect. Invariably, all phenomena are understood by the relation between a dependent and an independent variable. For example, consider the projectile motion. We release the projectile into an upwardly forward direction and start the stopwatch. The time passing now is the independent variable and the position of the projectile is the dependent variable. This relation is given by $x \propto t$ and $y \propto t^2$. As another example consider a piston and cylinder apparatus. By changing the weights on the piston one can change the volume of the ideal gas inside. The pressure in the cylinder depends on the volume by the ideal gas law as $P \propto \frac{1}{V}$.

Functions or Maps are just mathematical ways to express the relationships between two variables. It is usually denoted as

$y = f(x)$ where y is the dependent variable and x is the independent variable. The most convenient and enlightening way to visualize this is to take a piece of graph paper, call the vertical axis as y-axis, the horizontal axis as x-axis, choosing the appropriate scale (providing a value to the unit of measurement), and plotting all data in form of y versus x. Thus, drawing graphs is a neat way to describe the nature of the phenomenon vis-a-vis the given mathematical relationship. So, let us look at the graphs of some elementary and not so elementary relationships.

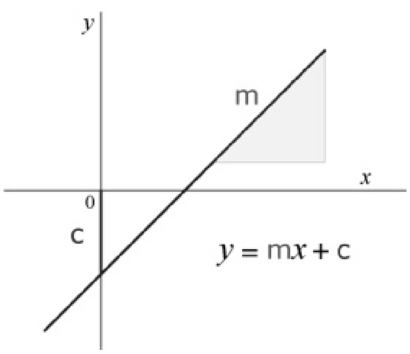


Figure 2: A straight line

- $y = mx + c$ (a straight line). This is a monotonically increasing or decreasing ($m > 0$ or $m < 0$) function such that $m = \tan\theta$.
- $y = ax^2 + bx + c$ (a parabola): This curve has a minimum around which the curve becomes completely flat (parallel to x-axis) – it is monotonic on either sides of the minima. The new thing in this function was the quadratic term. The rest of the lower order coefficients just shift the curve to a new position, which can be easily determined by completing the square ($y = a(x + \frac{b}{2a})^2 + (c - \frac{b^2}{4a})$). As we get away from the minima, the rate at which the function increases or decreases becomes faster and faster.

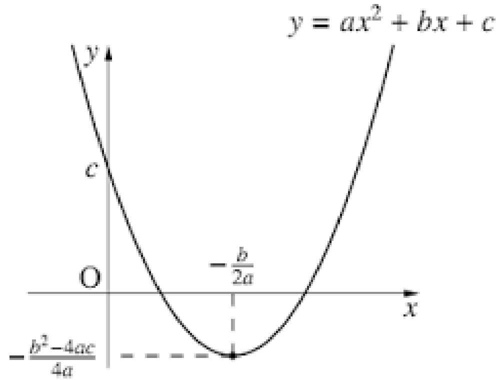


Figure 3: A parabola

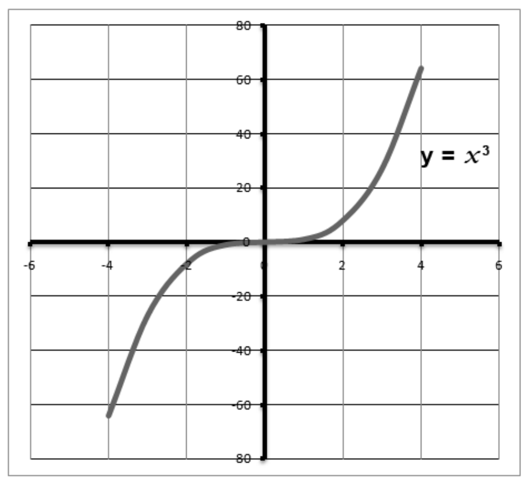


Figure 4: A cubic

- $y = ax^3$ (a cubic) (lower order terms are left out without loss of generality): The curve becomes flat at the origin. At the origin, the curve goes from being convex from the top (bulging upward) to concave from the top (bulging downward). Such a point is called a point of inflexion.
- $y = \sin x$ and $y = \cos x$ (the sine and cosine): These are periodic circular functions, for which everything (maxima, minima, roots etc,.) repeats at an interval of 2π. Their values vary from -1 to 1. The

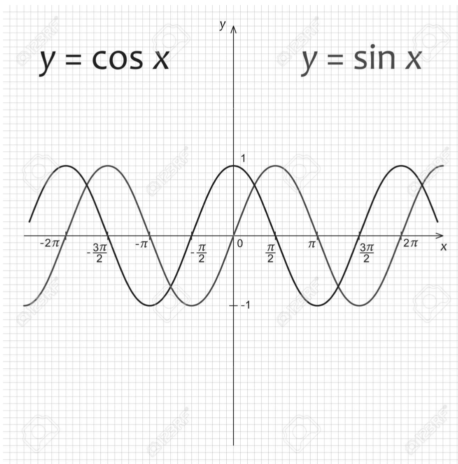


Figure 5: The sine and cosine

cosine lags in phase by $\pi/2$ from the sine. In all other aspects they are the same.

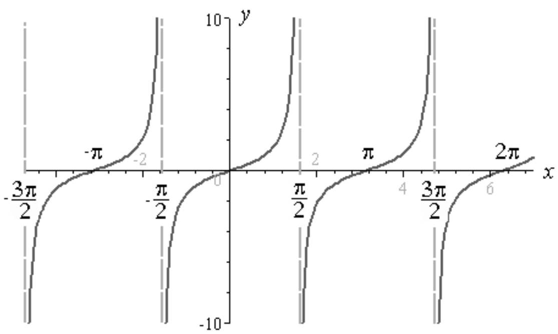


Figure 6: The tangent

- $y = \tan x$: It is a periodic function with period π. It asymptotically approaches the line $x = \frac{\pi}{2}$ at which its value diverges. Similarly, in the other direction it approaches the line $x = -\frac{\pi}{2}$ at which it is $-\infty$.
- $y = \sin x/x$: This is an oscillating function, the amplitude of which decreases as we move away from the origin.
- $y = e^x$ (the exponential): This is a positive definite monotonically increasing function. The magnitude of the function

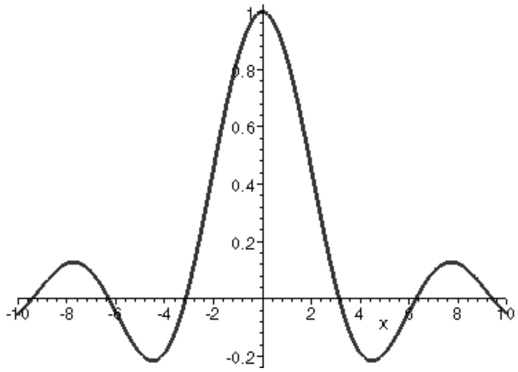


Figure 7: $\sin x/x$

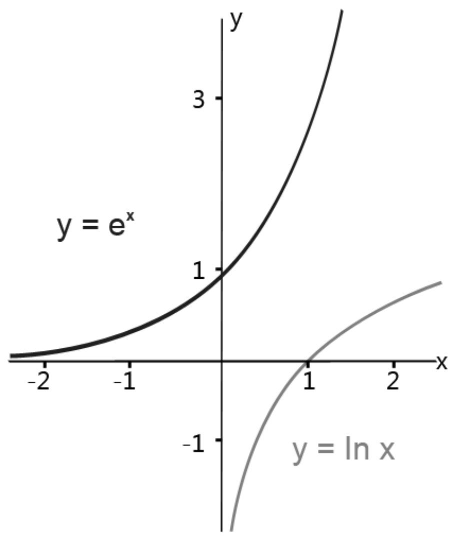


Figure 8: The exponential and the logarithm

increases faster than any power law relationship.

- $y = \ln x$ (the natural logarithm) : This is the inverse function of the exponential. It is also a monotonically increasing function. It increases in value slower than any power law relationship.
- $y = \begin{cases} 0 & : x < 0 \\ e^{-\frac{1}{x}} & : x \geq 0 \end{cases}$: This is a two piece function. The boundary between the two pieces lie at $x = 0$. At this

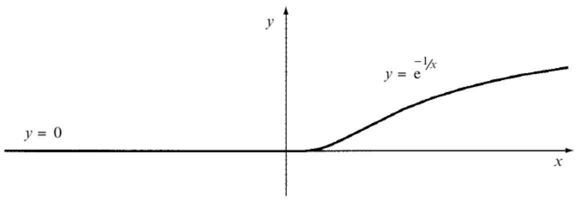


Figure 9: A two piece function that is smooth

point (and all other points) the function is continuous and infinitely differentiable which essentially means that the function is smooth.

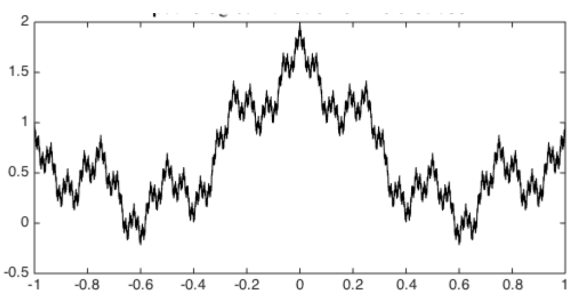


Figure 10: The Weierstrass function

• $y = \Sigma_{n=0}^{\infty} \frac{\sin(a^n x)}{b^n}$ such that $\frac{a}{b} > 1$ (Weierstrass function): This function is an oscillating function, which is continuous everywhere (one may find an arbitrarily close points in any small intervals) and differentiable nowhere (which means it is a scatter of distinct points). It is like a fractal (self similar when zoomed in or zoomed out).

These are some functions that appear in certain scientific phenomena and encapsulated in them are some important features that are generally studied while analyzing mathematical relationships. □

Continued from page 33 —

crucially on his robust adherence to a belief in the actual reality of physical entities at the molecular and sub-molecular levels." Penrose continues to add "Can it really be true that Einstein, in any significant sense, was as profoundly 'wrong' as the followers of Bohr might maintain? I do not believe so. I would, myself, side strongly with Einstein in his belief in a sub-microscopic reality, and with his conviction that present-day quantum mechanics is fundamentally incomplete." Penrose is not alone in this conviction, evidenced by the fact that the foundations of quantum mechanics is still an active area of research that draws inspiration from Einstein's philosophical arguments. □

References

1. Robert P Crease and Charles C Mann, "The Second Creation", Collier Books, New York, 1986.
2. G. Venkataraman, "Quantum Revolution-I: The Breakthrough", "Quantum Revolution-II: The Jewel of Physics", and "Quantum Revolution-III: What is Reality?", Universities Press, Hyderabad, 1994.
3. Albert Einstein and Leopold Infeld, " The evolution of physics", Indian Edition: Universal Book Stall, New Delhi, 1995.
4. Mario Bunge, "Philosophy of Physics", D. Reidel Publishing Co., Boston, USA, 1973.
5. Max Planck, "The philosophy of physics", George Allen & Unwin Ltd., London, 1936.
6. Otto Frisch, "What little I remember", Cambridge University Press, 1979.
7. S. Körner (editor), "Observation and interpretation in the philosophy of physics", Dover publications, New York, 1957.
8. Werner Heisenberg, "Physics and philosophy: The revolution in modern science", Harper & Row, New York, 1958.

* Past installments of this article are available in our homepage www.breakthrough-india.org in the link → Breakthrough magazine → Archive.

Organizational News

Felicitation of scientists involved in the discovery of gravitational wave

Kolkata, 18 June, 2016: Breakthrough Science Society, West Bengal Chapter organized a program to felicitate Dr Rajesh Kumble Nayak and Ms Anuradha Samajder of Indian Institute of Science Education and Research, Kolkata (IISER) who were involved in the discovery of gravitational wave. The program was held on June 18 at Meghnad Saha Auditorium, Rajabazar Science College, Calcutta University. Prof. Dhrubajyoti Mukherjee, President of BSS presided. Prof. Soumitro Banerjee, General Secretary of BSS was also present. Prof. Amit Ghosh of Saha Institute of Nuclear Physics delivered a popular talk on General Theory of Relativity. Dr Rajesh Nayak explained about the discovery of gravitational wave by LIGO and their contribution in the project. After the talks, Dr Rajesh Nayak and Ms Anuradha Samajder were presented with a felicitation certificate. The auditorium was full with students, teachers and professors.

Dr. Rajesh Kumble Nayak is being felicitated by the President of *Breakthrough Science Society* , Prof. Dhrubajyoti Mukherjee.

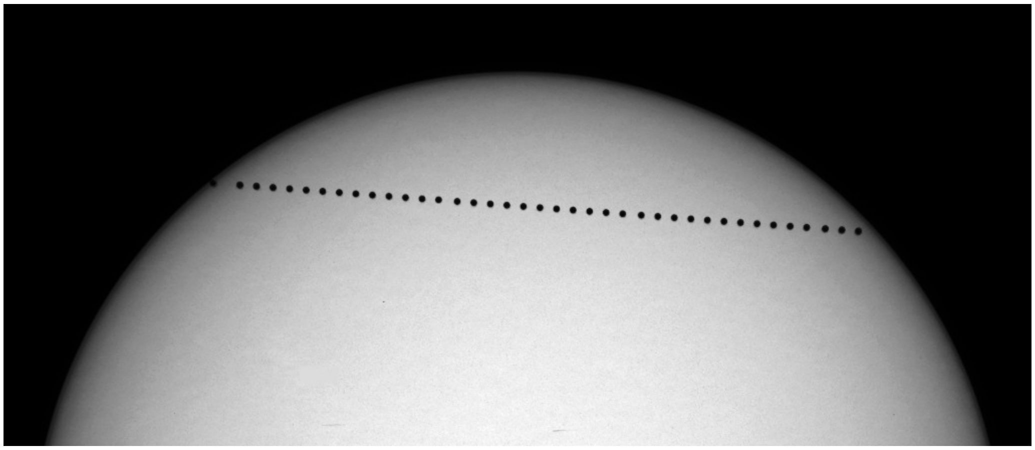
Observation of Transit of Mercury 9 May, 2016

— Report by Prof. S A Mohan Krishna

The Transit of Mercury (ToM) over the disc of the Sun took place from 16 h 42 m 19 s on May 9 to 00 h 09 m 11 s on May 10. The transit was visible from most of Asia, Africa, Europe, Greenland, North and South America, Atlantic and Pacific oceans. In India, the beginning of the event was visible from all places but the ending was not observable from any place as the same took place after sunset.

Transits of Mercury can happen in May or November. November transits occur at intervals of 7, 13 and 33 years; May transits occur at intervals of 13 and 33 years. The previous transits were in 1999, 2003 and 2006. The beginning of the transit is marked by ingress and exterior contact, which were visible in India since it occurred after sunrise. The ending of the transit comprising egress and interior contact were not visible from any part of India since it occurred after sunset.

The Breakthrough Science Society and many other amateur astronomy societies and planetariums organized public viewing



The path of Mercury on the disk of the sun

of the event. Here is a brief report of the programmes organized by *Breakthrough Science Society* .

Karnataka

The people of Mysuru (Mysore) were fortunate to witness the rare celestial spectacle on May 9 from 4.42 pm to 6.10 pm. TOM viewing program was arranged at Excel Public School by science teacher and amateur astronomer Mr. Kiran Prasad. They were supported by Mr. G B Santosh Kumar, Mr. Kesari, Prof. S A Mohan Krishna and Mr. Ashwin Ganesh.

Gujarat

The Universe Science Forum made arrangements for viewing the Transit of Mercury in Ahmedabad and Baroda.

On May 8, a discussion was organised on the Transit of Mercury event in Ahmedabad. Mr Dilip Satashiya explained the phenomenon with slide show and discussed the scientific and historic significance of the event. Shri Prashant Joshi spoke on Science and Scientific Temper. Shri Uttam Surapati spoke on the life struggle of Geonardo Bruno. A good number of people participated in the discussion very enthusiastically.

Ahmedabad Science City arranged telescope viewing of the ToM and invited people to observe the event. A team of science activists from Universe Science Forum joined the viewing program.

Universe Science Forum Baroda chapter made arrangements for viewing the ToM with the help of a telescope in Gotri Area in association with Satva flats residents. Later the phenomenon was explained to the people who gathered, through slide show and an interactive session.

Observation of Transit of Mercury at Baroda, Gujarat.

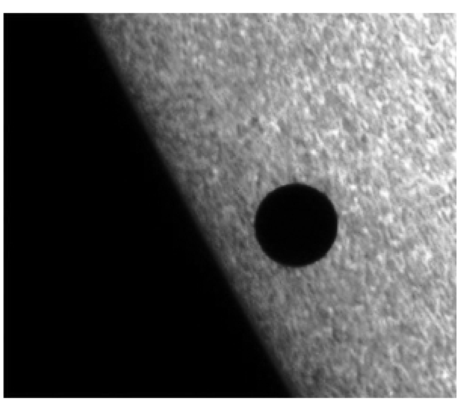
Observation of Transit of Mercury at Jamalpur, Bihar.

Bihar

Einstein Science Club, Jamalpur, organized public viewing of the Transit of Mercury. The program was held at Jamalpur Sports Association ground. Students and teachers of various institutions and schools participated in the viewing program.

West Bengal

A central ToM observation camp was held at Kolkata Maidan from 4pm to 6pm. Dr Tapan Si and Dr R Konar conducted the camp and showed ToM through telescope to the general public.



The Transit of Mercury.

At Nimta, the Galileo Science Forum organized ToM observation camp at Belghoria Ramkrishna Mission School playground from 4pm to 6.30pm. Students, teachers and science loving people enthusiastically gathered to observe the celestial event. Nirmal Duari and GSF members conducted the camp.

A camp was held at Panskura Banamali College of Purba Medinipur district. This was organised by BSS, Panskura Banamali College Chapter. More than 100 students, professors and staff observed the ToM through telescopic projection.

Four-day summer camp in Jharkhand

A four day long Summer camp was organised at Chandrapura, Bokaro, from 7 to 10 June, 2016. Delegates enjoyed the different activities such as Learning Science through Experiments, yoga and exercises, drama class, movies, first-aid course, mind games, discussions and magic. Mr Vijay Kumar conducted the experiment demonstration, yoga classes and magic. Mr B K Mahapatro conducted the first aid classes. Mr Sanjay Chohan conducted the drama classes. The participants eagerly took part in all the activities and enjoyed the camp life.

On March 5, 2016, A talk on “Ethics of Science” was organised by Einstein Club, Ghatsila, Jharkhand. Mr Kanay Barik was the main speaker. He spoke about the necessity to imbibe the noble ethics of science as practised by great scientists such as Madam Curie. More than 150 college students participated in the programme.

Environmental Day was observed by Einstein Club, Ghatsila on June 10. A Seminar on the topic “Environmental Pollution and it’s solution” was organised on this occasion. About 80 college level students participated in the seminar.