ISASINDIA *Newsletter*

Vol 21, No. 4 *October-December, 2021*

From Editor's Desk

Namastay to all ISAS members

It gives me immense pleasure in bringing out the October -December issue of ISAS newsletter. Ajadi ka Amrit Mahotsav is being celebrated with great enthusiasm. On this occasion special articles have been compiled. DAE contribution has been comprehensively described by Chairman Atomic Energy , Shri K.N. Vayas.

Union minister of state for science and technology Jitendra Singh has rightly said that India's future growth depends on a science-driven economy. ISAS recognizes the contribution in science of Acharya Prafull Chandra Ray, also known as the Father of Chemistry in India and regarded "master of nitrites". To whom British called " revolutionary in the garb of scientist". His famous inspiring quote is, "*Science can afford to wait but Swaraj cannot*…" . Author of *"The History of Hindu chemistry"* *which glorifies ancient chemistry of India.* He has set up India's first pharmaceutical company, Bengal Chemicals which has been licensed by to produce the much-needed hydroxychloroquine (HCQ) during the Covid-19 situation. It is matter of pride that India has participated in Mega Science Project Large Hadron Collider (LHC) at CERN , Geneva. In the 1990s, The Raja Ramanna Centre for Advanced Technology (RRCAT) at Indore delivered hardware for Large Electron-Positron Collider (LEP), and the Indian High-Energy Heavy Ion Physics Team contributed to the construction of the Photon Multiplicity Detector for the WA93 experiment at the CERN-SPS. In recognition of its contribution to the LHC construction, India was awarded the status of an Observer State in 2002. More than 150 Indian scientists and students from India participate in various experiments at CERN. Also at CERN 'Ghost Particles' (neutrinos) were Detected at the Large Hadron Collider for the First Time during an experiment called FASER. A new state of matter—Electron quadruplets has been experimentally found. NASA's Parker Solar Probe has reached out to our star and touched its atmosphere. it became the first spacecraft to enter the upper atmosphere of the sun, called the corona. For the First Time, generation a Vortex Beam of Atoms and Molecules have been reported. Researchers from the Weizmann Institute of Science, have created, for the first time, vortices made of a single atom. Scientists have detected a quantum effect that blocks atoms from scattering light . In an ultracold, dense cloud of atoms, a quantum effect dictates whether atoms scatter light. If the quantum states are fully occupied, the atoms cannot change quantum states and the light isn't scattered. Photonic Chip Breakthrough Opens a Path toward Quantum Computing in Real-World Conditions. ISAS members are encouraged to contribute their articles in newsletter.

Dr. Pradeep Kumar

Vice President and Chief Editor ISAS.

Message from Vice President ISAS

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I am happy that October - December issue of the ISAS newsletter is ready to be released. The dedication of the Editor is praise worthy in maintaining the unstinted pace of trimonthly issues of the news letter with quality articles.

During pandemic, ISAS fraternity was quite active with its series of seventy five webinars commemorating Amrit Mahotsav of the country, opening of new chapters Jaipur, Belagavi and Pune. The News letter was quite active in reflecting the events.

On the occasion, I convey my best wishes to Members of the Society!

Dr. Raghaw Saran

Vice President , ISAS

India‘s Future Growth Depends on Science-Driven Economy

19 October, 2021 | by PTI

Source website links: **https://www.hindustantimes.com/india-news/indias-future-growth-depends-on-science-driven-economy- 101634647792152.html**

Singh added that Indian coastal areas should utilise the vast oceanic resources the country possesses as the "blue economy" offers extensive socio-economic opportunity

Union minister Jitendra Singh commended the "Deep Ocean Mission" and said it "heralds yet another horizon to harness various resources to enrich the "Blue Economy". (PTI Photo)

Union minister of state (independent charge) for science and technology Jitendra Singh said on Monday that India‘s future growth depends on a science-driven economy.

—While India commemorates 75 years of independence, it is also an occasion to plan for the next 25 years with the conscious realisation that science and technology are going to be the main currency for the inclusive growth of India,‖ he said at an event organised by the ministry of health sciences. He emphasised the importance of planning ahead for successful growth. Singh added that Indian coastal areas should utilise the vast oceanic resources the country possesses as the —blue economy offers extensive socio-economic opportunity. He said it aids the production of goods and services that have clear linkages with economic growth, environmental sustainability, and national security.

Singh commended the —Deep Ocean Mission‖ and said it —heralds yet another horizon to harness various resources to enrich the —Blue Economy.‖ The —Deep Ocean Mission‖ was approved in June by the Modi-led government to work towards the deep exploration of the ocean for resources and develop deep-sea technologies for sustainable use of oceanic resources .

Acharya Prafulla Chandra Ray

By Dr. Pradeep Kumar,

Senior Nuclear Scientist,

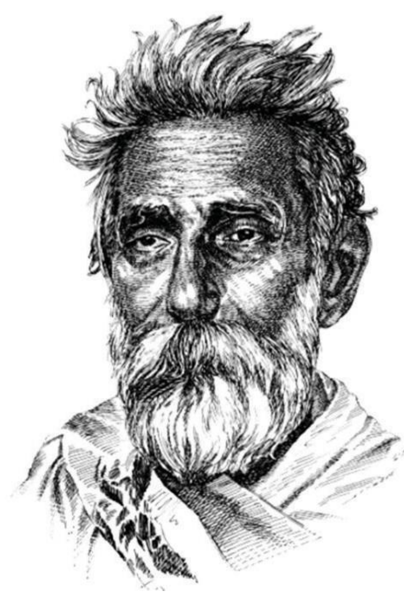
Bhabha Atomic Research Centre,

Trombay &

Vice President and Chief Editor , ISAS

Acharya Prafull Chandra Ray, also known as the Father of Chemistry in India. Also regarded "master of nitrites". British called him " revolutionary in the garb of scientist". A simple living Chemistry professor, whose discoveries and experiments attracted the world towards India. His famous inspiring quote is, "*Science can afford to wait but Swaraj cannot*…" -

He wrote "The History of Hindu chemistry which glorified ancient chemistry of India.

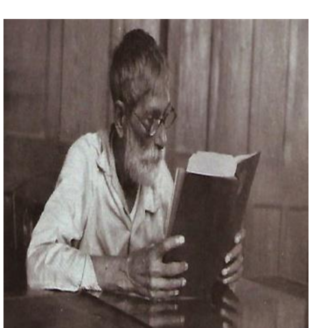


P. C. Ray's Laboratory, University College of Science and Technology, Calcutta, Telegraph file picture

Prafulla Chandra was born on August 02, 1861, in the village of *Raruli-Katipara*, Jessore district , now in present day Bangladesh. His father Harish Chandra Ray was a zamindar who appreciated education, supported learning, had liberal views, and had set up an extensive library at home. rafu lla Chandra had his early education in the school founded by his father. In 1870, Ray's family shifted to Calcutta and Prafulla was admitted to Hare School. After clearing the entrance examination in 1879, Prafulla Chandra took admission at Metropolitan Institution (nowVidyasagar College) founded by Pandit lswarchandra Vidyasagar. Metropolitan College had great teachers like Surendranath Banerjee and Prasannakumar Lahiri, who strongly influenced the nationalist feelings of Prafulla Chandra. Prafulla Chandra along with one of his close friends, set- up a mini laboratory at home and reconducted the experiments taught to them in the college. Halfway through his BA studies, he won the Gilchrist scholarship of Edinburgh University (1882). Only two students were selected from India, Prafulla Chandra Ray and a Parsee student Bahadurji. Ray completed his B. Sc. in 1885 and at the age of 26, was awarded a D. Sc. in Inorganic Chemistry (1887) for his thesis, *'Conjugated Sulphates of Copper Magnesium Group: A study of /somorphous Mixtures and Molecular Combination.'* His thesis was judged the best thesis and got 'Hope Prize' which allowed him to carry on research for one more year. He was elected the Vice-President of the Edinburgh University Chemical Society in 1887, as his colleagues and teachers held him in high esteem because of his disciplined life, work ethics and simplicity.

"He is also a real organiser and a real teacher", **I heard a European saying, *"If Mr. Gandhi had only been able to create two more Sir P. C. Rays he would have succeeded in getting Swaraj within this year."***

Correspondent, Manchester Guardian



There are occasion that demanded that I should leave the test tube to attendto the call of the country...". **- P. C. Ray (Rowlatt Act, 1919)**

P C Ray during hisstudy sessions

Contribution to Chemical Research

Prafull Chandra Ray began his research in India in the field of detection of adulteration of edible fats and food items. He was very worried about the regular deterioration in quality of food items available in Bengal. He conducted chemical examinations of adulterants in fats, oils and ghees available in the market and published his findings in the Journal of Asiatic Society of Bengal in 1894. His aim was to create standards for food items and put the identified adulterants being used in Bengal in public domain. P. C. Ray began analysis of certain rare Indian minerals in his quest to discover some new elements to fill the gaps in Mendeleev's Periodic table. He travelled far and wide all through India collecting samples of compounds and mineral ores. By 1894, he had built up an extensive library of samples with the aid of his friend Thomas Holland of Geological Survey of India. He soon reported the first ever synthesis of the *previouslyunknown compound of Mercurous Nitrite* Hg/ N0)$_{2}$• He narrates in his autobiography, "the discovery of mercurous nitrite opened a new chapter in my life". This compound of mercury was a fascinating example of two relatively unstable ions combining to form a stable substance. He received congratulatory messages from eminent chemists like Victor Meyer, Volhard, Berthelot and his teachers. On his discovery, Alexander Pedler, his former teacher said, "Dr. P. C. Ray, by his discovery of the method of preparation of this compound, has filled up a blank in our knowledge of the mercury series".

Prafulla Chandra was a synthetic inorganic chemist with active interest in organic molecules and reactions; especially into the chemistry of thio-organic compounds. His initial work which made him famous was based on the chemistry of inorganic and organic nitrites. He was regarded as *'Master of Nitrites'*. British Chemist, Henry H. Armstrong stated: 'The way in which you have gradually made yourself 'master of nitrites', is very interesting and the fact that you have established that as a class they are far from being the unstable bodies, chemists had supposed, is an important addition to our knowledge.' He continued his work on related compounds and thereon shifted to organic thio-compounds and their metal complexes. The metal which particularly fascinated him was mercury, maybe because it has an extensively important role in Indian medicine system of Ayurveda.

The formation of mercurous nitrite, Hg/ N0) 2 2 was an accidental discovery, while he was trying to react excess mercury with cold dilute nitric acid to synthesize mercurous and mercuric nitrates, Hg/ N0 3\ and Hg(N0 3\ . During the course of reaction, he noticed the appearance of a yellow crystalline solid on the sides which on analysis revealed to be the unknown mercurous nitrite. The nitrite ion probably was the result of initial reduction of nitric acid by mercury. The pertinent point to be noted here is that stable mercury(!) complexes are very few in existence, even today, owing to the instability of mercury(I) towards disproportionation to mercury(II) and metallic mercury in solution.

$$Hg\ (excess) + dil.\ HNO_3 \longrightarrow Hg_2(NO_2)_2$$

This discovery was first published in the *Journal of Asiatic Society of Bengal* (1896), and immediately noticed by *Nature* magazine, which mentioned the work in its issue of May 28, 1896, "A paper by Dr. P.C. Ray on mercurous nitrite, that is worthy of note ". Eminent chemists of the time like Volhard, Victor Meyer, Berthelot sent him congratulatory letters on the discovery. Subsequent series of work by Ray and his students, led to establishing the foundation of the first research school of modern Chemistry in India. He published numerous significant research papers on nitrites and its related derivatives. Now with advances in analysis techniques, the compound has now been structurally analyzed using X-ray crystallography techniques (1985, 1986, 2011).

In 1912, he presented this work at Chemical Society, United Kingdom before a distinguished audience including Noble Laureate William Ramsay. In its issue, the Nature magazine mentioned the work as, "...a *further accomplishment in determining the vapour density of this very fugitive compound."*

His major work contributions has been in the field of coordination chemistry, specially metal nitrites, ammonium nitrites and their derivatives, organic thio-compounds and their complexes. Almost seventy percent of his research publications from Presidency College in major journals belonged to the field of nitrite chemistry.

P. C. Ray had published 158 research papers. 60% of his papers were published in famous journals like Nature (8 papers) and the Journal of the Chemical Society (65 papers). He was also greatly appreciative of research being carried out in Germany and published many papers in German language, many of them in Zeitschrift fuer anorganische Chemie. He was equally dedicated towards his contribution in Indian journals (nearly 50 papers) like Journal of the Asiatic Society of Bengal (12 papers) and Journal of the Indian Chemical Society.

Some of the luminaries who learned the art of scientific investigation and undertook research with him and spread across the country in different universities were: Jnan Chandra Ghosh (Director of IISc, Bangalore and founding Director of IIT, Kharagpur), Panchana Niyogi (founding Principal of Raja Monindra Chandra College in Calcutta), Nil Ratan Dhar (Allahabad University), Priyada Ranjan Ray (Calcutta University), Biresh Chandra Guha (founder of Biochemistry Research in India), prominent scientist Shanti Swarup Bhatnagar was a student of Prof. Atul Chandra Ghosh, who was in turn a student of P. C. Ray. Eminent Indian scientists like Satyendra Nath Bose (Bose-Einstein statistics) and Meghnad Saha, (Saha equation) were also part of his extended group.

Establishment of Indian Chemical Society

P. C. Ray took the initiative to create Indian Chemical Society (1924). He along with Shanti Swarup Bhatnagar (student), J. N. Mukherjee and J. C. Ghosh had always felt the strong need of a chemistry society of India and the Indian Chemical Society was founded and registered on 9 May, 1924. P. C. Ray consented to be the Founder-President for the first two terms. The establishment of the new chemical society and its journal was well received in academic circles in India and abroad. The London Chemical Society sent this message, *"Hearty congratulations and warm wishes to the newly formed Indian Chemical Society".*

In the initial days, the society didn't have its own office and functioned from the office of Dr. J N Mukherjee (Secretary). Prafulla Chandra Ray felt that proper accommodation was needed and so he gifted ten thousand Rupees to Calcutta University requesting space for the society. Thus, in 1933, the construction of three large rooms started on the second floor of the Sir Taraknath Palit Building of the University College of Science and Technology, Calcutta. The address 92, Acharya Prafulla Chandra Road, Kolkata- 700009 remains its registered office still.

This society published the first research journal of India, The Journal of Indian Chemical Society, under his leadership in November, 1924. Nature magazine welcomed it with a congratulatory note, *"The great work in chemistry which has occurred in the Indian Empire during the past ten years, had led to the establishment of an Indian Chemical Society, the first number of the quarterly journal of the Society has now appeared. There are thirteen papers, and only one of these is published under the English names. The remaining papers are published by Indians and come fromall parts of the Indian Empire. Four of these emanate from the College of Science, Calcutta, and this is as it should be, because for many years past, this Institution has been the back-bone of chemical research in India."*

He believed that problems being faced by a common Indian can best be understood by an Indian and there was a need for national regeneration using science. To achieve this, he, along with Meghnad Saha, established Indian Science News Association (ISNA), with the purpose of spreading and informing achievements in the scientific domain and initiating the young scientists to devise solutions for the problems present in the society. P. C. Ray was the founder President of ISNA and he guided in starting the journal - *Science and Culture* in 1935.

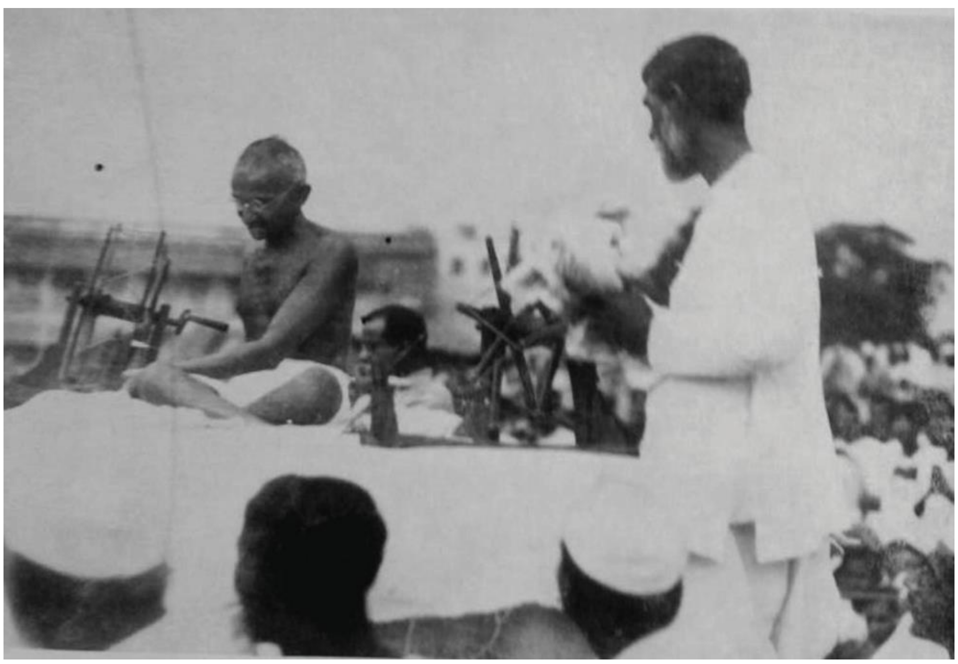
P.C Ray, S.N. Ghosh, Meghnad Shah and other prominent Scientists of India

Revolutionary Scientist ofIndependence Movement

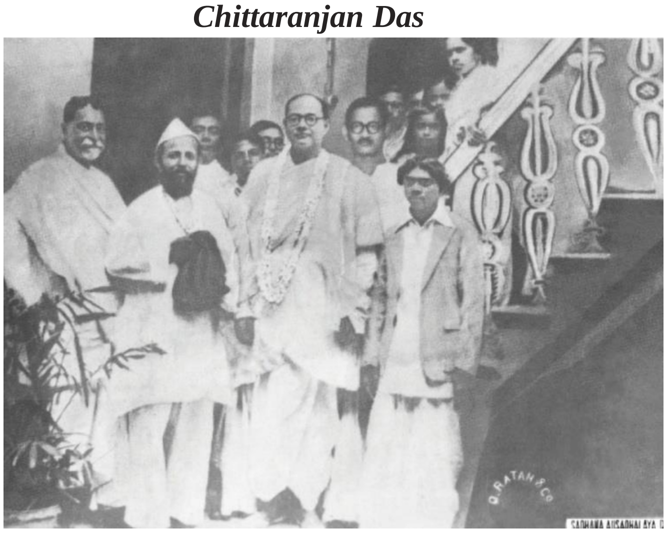
Indian scientists were constantly feeling the requirement for a system of scientific self-reliance to be created in India, which will be managed and run by Indians. He established the first research laboratory at Presidency College from scratch and that became the cradle of chemistry research for the whole country. He realized that our country needs a hand of highly educated and capable researchers dedicated to the service of sciences.

P.C. Ray was always irked by the absence of research studies in the academics of Calcutta University and therefore, he was fully supportive of a teaching system gaining roots in Bengal at that time. He closely affiliated himself with National Council of Education (NCE), a pedagogic organization based upon the swadeshi spirit with science, technology and industrialization as its foundation. NCE was founded by Satish Chandra Mukherjee along with Sri Aurobindo. In the year 1921, the council planned expansion in the syllabus of engineering studies. Under the chairmanship of P. C. Ray, a syllabus revision committee was set up to introduce new streams. The new curriculum introduced Chemical Engineering besides Mechanical and Electrical. Later on, Ray was made the President of National Council of Education, Bengal. He was of the opinion that Indian students should learn new skills and techniques and mere getting degrees will not suffice the modern era dawning upon the world. He inspired students to become self-reliant entrepreneurs and not keep running for academic degrees to get a comfortable government job.He believed in the principles of Gandhi and was a practising Gandhian in daily life. When Mahatma Gandhi visited Calcutta in 1901, on the invitation of Gopal Krishna Gokhale, Prafulla Ray actively participated in making arrangements for Gandhi's first public appearance in Calcutta. In the book *My Experiments with Truth* (Part 3, Chapter 17), Gandhiji writes, *"Of these the one who stands foremost in my memory is Dr. (now Sir) P. C. Ray. He lived practically next door and was a very frequent visitor.This is how he introduced Dr. Ray: 'This is Prof Ray, who having a monthly salary of Rs. 800, keeps just Rs.* 40 *for himself and devotes the balance to public purposes. He is not, and does not want to get, married.'* During the decade of 1920's, Ray participated in the freedom movement and was attached with political fronts. Although he did not take part in active politics, he could not keep himself aloof from the freedom struggle sweeping through the nation at that time. In the 1920's, during the peak of the Non-cooperation Movement, he delivered the famous inspiring quote, "*Science can afford to wait but Swaraj cannot…*" - When British rulers introduced the norm of separate election of Hindus and Muslims (*Indian Councils Act, 1909 or Minto-Morley Reforms*) to the legislative forms, Congress remained indifferent to it but Prafulla Chandra opposed nationalism on the basis of religion. He criticized the opportunist policy of then Congress leadership which he believed could lead to communal divide. Being a righteous person and despite being a practising Gandhian, he severely criticized Gandhiji for his blunder in Khilafat Movement (1919), "*We must not allow our loyalty to the mother country to be swamped by the wave of extra-territorial patriotism. India must not be a spoke in the Khilafat gyrated from Istanbul. The Swaraj of India must be our one all-compelling goal…*".Ray was vociferous in his support for Subhash Chandra Bose, when the Congress was divided on the election of Netaji to the President's post the second time in 1938.

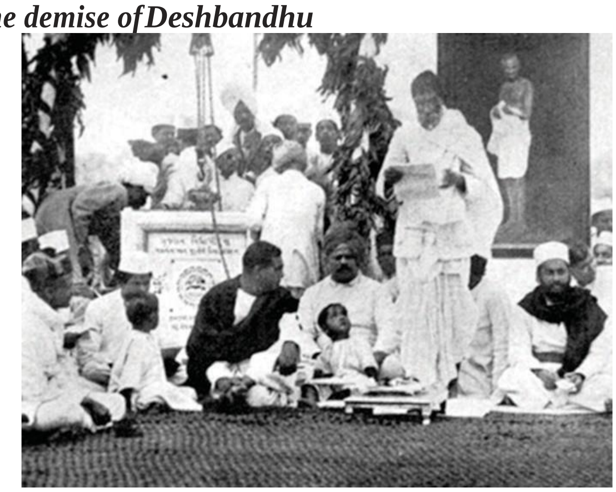
During World War II, when Nazi Germany attacked Russia in 1941, Acharya Prafulla Chandra Ray along with prominent Indians, issued a manifesto urging Indians to express full "*Sympathy and solidarity with USSR*". Acharya P C Ray was the first signatory to the statement. He was also sympathetic towards the revolutionaries and would make arrangements for their shelter and food at his factories. After his death, many revolutionaries and his colleagues mentioned his indirect support and help in manufacturing explosives. The Government records of that time mention him as a "*Revolutionary in the garb of a Scientist.*"



Prafulla Chandra with Gandhi at the memorial meeting after the demise of Deshbandhu Chittaranjan Das



Prafulla Chandra Ray, Netaji Subhas Bose atSadhana Aushadha/aya (1924)



P C Ray inaugurating Gujarat Vidyapeeth University established by Mahatma Gandhi

In later decades, Ray heavily criticised British for their failure to understand the nationalist feelings of Indians, the progressive needs of young Indians and cautioned the British that this would lead to inevitable anger against their administration. The political and economical mayhem that they have created will cost them dearly. He was right in his observation as can be seen from the fact that India gained independence within the next 10 years.

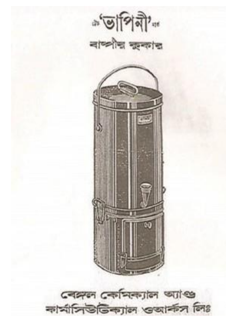
Visionary Startup Industrialist

'In Europe, industry and scientific pursuits have gone hand in hand … one helping the other… The gigantic progress in industry achieved in Europe and America is a history of the triumph of research in the laboratory. These thoughts were weighing heavy on me at the very threshold of my career at Presidency college. How to utilize the thousand and one raw products which nature in her bounty has scattered in Bengal? How to bring bread to the mouth of the ill fed…' - P. C. Ray

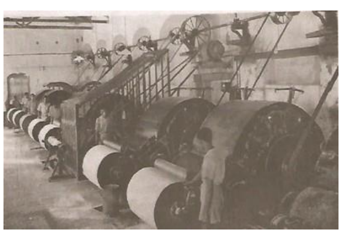
This dependency on imports made the existing local industry slow with no growth and innovation. With increasing unemployment levels in Bengal, he took up to himself to revive the industrial economy using the latest scientific knowledge and putting it to industrial use. With an initial investment of Rs. 700, in the year 1893, he set up India's first pharmaceutical company, **Bengal Chemicals,** now known as the **Bengal Chemicals and Pharmaceutical Works Ltd (BCPWL).** The company is now in prominence during the Covid-19 situation, as it has been licensed by Government of India to produce the much-needed hydroxychloroquine (HCQ). With establishment of this industry, he was able to achieve his dream definition of Swadeshi, self-reliance in research leading to the development of swadeshi industries. BCPWL. was set up with an in-house research facility for development of alternate and cost- efficient processes for production of imported chemicals like Tincture of Nux Vomica, Spirit of Nitric Ether, Syrup Ferri lodidi. The products manufactured at Bengal Chemicals were displayed at the Indian Medical Congress, His industry also started manufacturing basic necessary reagents like sulphuric acid, which were a necessary part of the chemical processing industry. Gradually his industry moved towards manufacturing of various other products like soaps, paper pulp, fertilizers and oils. P. C. Ray along with his students established many other industries like Acharya Prafulla Chandra Cotton Mills, Bengal Salt Manufacturing Company, Bengal Potteries, Bengal Enamel Works, Bengal Steam Navigation, Bengal Paper, Bengal Canning and Condiment, National Tanneries, Chuckervertty, Chatterjee & Company Ltd (Publishing House) and Bharati Scales and Engineering Company. Even today many of us are using the products of industrial legacy established by Ray in the form of common sanitization products like naphthalene and phenyl bottles.

Many Indians from various walks of life like Leaders, Scientist and Doctors gradually started supporting him in his endeavours. People like Subhash Chandra Bose, Chitranjan Das, Dr. Amulya Charan Basu, Radha Gobinda Kar, Kulbhusan Bhaduri, Chandra Bhusan Bhaduri, Suresh Prasad Sarbadhikari stepped in to help his initiatives achieve success.

Bengal Chemicals & Pharmaceuticals Limited Kolkata



Pressure Cookerdesigned manufactured by Bengal Chemical



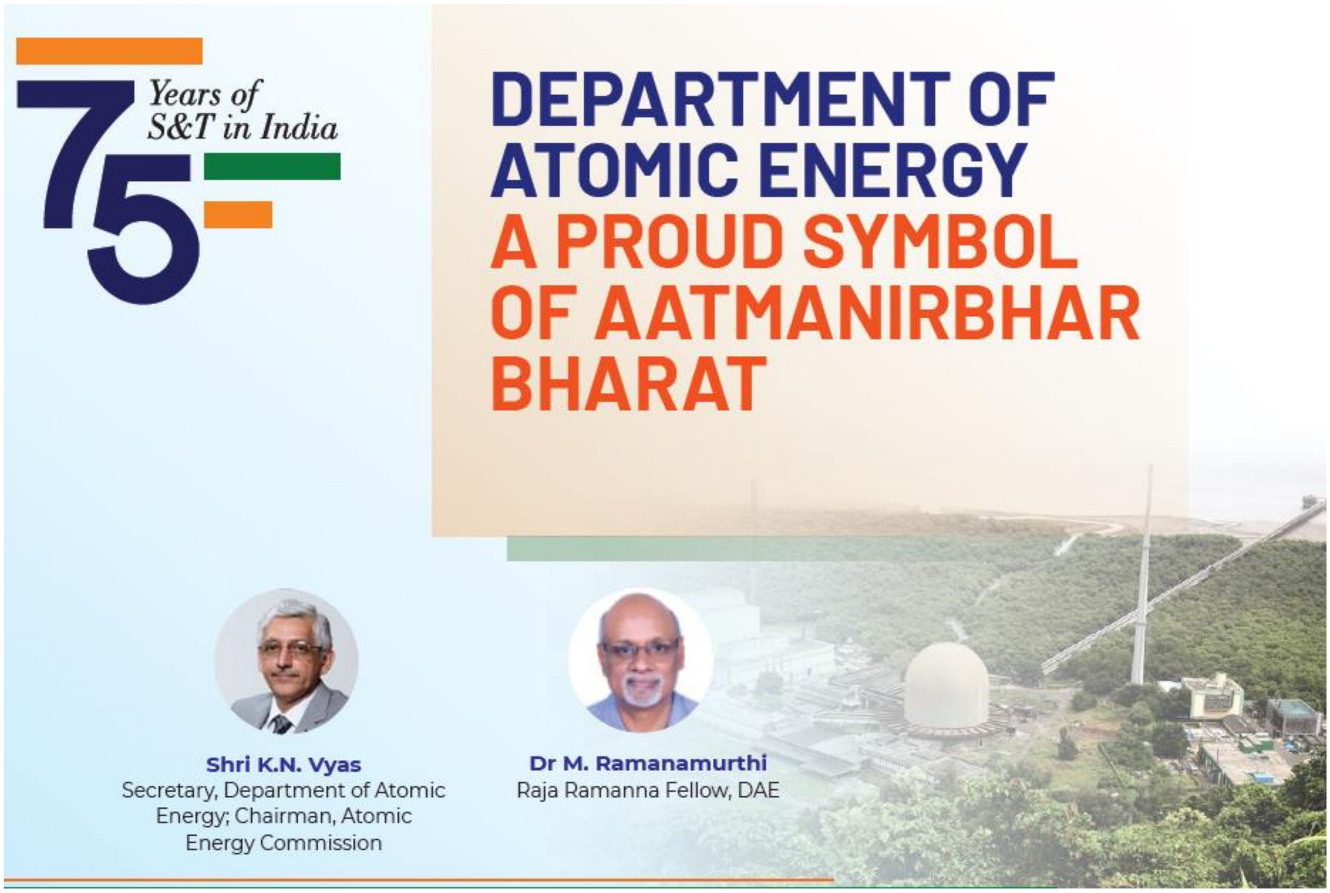
Manufacture ofSurgical Cotton

Manufacture of Fine Chemicals at Maniktala

The Book World: THE HISTORY OF HINDU CHEMISTRY

For many years, he continued studying various Indian texts of *Susruta*, *Charaka* and explored the world of Indian science developed hundreds of years ago. He learnt the languages like Sanskrit and Pali from eminent scholars like Pandit Nabakanta Kavibhusana and Acharya Brajendranath Sil. Pundit Nabakanta Kavibhusan worked with him in searching ancient manuscripts in various temple libraries of Benares (present Varanasi). They collected many volumes and texts of books in Sanskrit language which contained processes, techniques, methodology, characteristics and other details about use of chemical knowledge and involvement of concepts of Chemistry in ancient India. He studied ancient Indian medical and chemical encyclopaedia like *'Materia Medico of the Hindus'* by Udoychand Dutt, *'Indian Materia Medico and Indigenous Drugs of India'* by Kannai Lal Dey. He took guidance and help from Kavirajs, the traditional scholars of Indian system. He carried out many of the experiments to prove and verify their exactness like preparations with Kurchi *(Holarrhena antidysenterica)*, Kalmegh *(Andrographis paniculata)*, Vasaka syrup *(Adhatoda vasica)* etc. the languages like Sanskrit and Pali from eminent scholars like Pandit Nabakanta Kavibhusana and Acharya Brajendranath Sil. Pundit Nabakanta Kavibhusan worked with him in searching ancient manuscripts in various temple libraries of Benares (present Varanasi). They collected many volumes and texts of books in Sanskrit language which contained processes, techniques, methodology, characteristics and other details about use of chemical knowledge and involvement of concepts of Chemistry in ancient India. He studied ancient Indian medical and chemical encyclopaedia like *'Materia Medico of the Hindus'* by Udoychand Dutt, *'Indian Materia Medico and Indigenous Drugs of India'* by Kannai Lal Dey. He took guidance and help from Kavirajs, the traditional scholars of Indian system. He carried out many of the experiments to prove and verify their exactness like preparations with Kurchi *(Holarrhena antidysenterica)*, Kalmegh *(Andrographis paniculata)*, Vasaka syrup *(Adhatoda vasica)* etc.

source: Internet and study material for VVM.



Source: Science Reporter August 2021.

AS the country approaches the 75th Anniversary of her independence, it is indeed an occasion to celebrate and rejoice in her growth, progress, triumphs and achievements. Much has been accomplished in this long march after her rebirth, rising from the ashes of a fledgling and impoverished nation to become one of the largest economies of the world.

This task of nation-building has been a multi-pronged effort, facilitated by a sustained pursuit of growth across agricultural, infrastructural, energy, industrial, health and educational sectors amongst many others. The green revolution has made the nation self-sufficient in food grain production and visionary infrastructural developments have made it an industrial powerhouse. The nation today generates surplus electricity and a vast network of educational institutions have created a large pool of trained and expert human resources in science, technology, arts, social sciences, management, humanities and many other domains.

Science and technology have played a pivotal role behind every facet of the growth and transformation of the nation over the last 75 years. Realising that the socio-economic progress of the nation hinges upon a robust science and technology infrastructure, a large spectrum of science and technology institutes and centres, including the Department of Atomic Energy (DAE), were set up across the country covering a gamut of domains requiring rapid progress, in order to propel the nation forward on a path of growth and development.

The Birth of DAE

Atomic Energy Commission was constituted in 1948 soon after independance and the Department of Atomic Energy was established in 1954. The mission statement of DAE is "To harness the power of the atom towards enhancing energy security, health security, food security and national security and to carry out developments and innovations in the use of Nuclear and Radiation Technology leading to economic and social benefits to the nation and a better quality of life to its citizens".

Dr Homi Bhabha during the construction phase of AEET

"As of today, it is estimated that the use of nuclear energy avoids carbon emissions roughly equivalent to removing one-third of all cars from the world's roads."

Panoramic view of research reactors CIRUS and DHRUVA

Right since its inception, the visionary founder Dr Homi Jehangir Bhabha had the foresight to realise that the nation would need to be self-reliant in this sphere in order to gain complete mastery over the technology and forge an independent path. However, the foundations for science and technology R&D were poorly developed in the country at that stage. DAE, therefore, embarked on R&D programmes in numerous disciplines to support its programmes and has today emerged into a distinctive organisation, not only as a hub for R&D in all aspects of the nuclear fuel cycle but also for carrying out pioneering cutting-edge research work in associated areas of relevance. Over the decades, this blend of activities and disciplines has led to the creation of several world-class institutes and units of DAE, comprising a vast network of 30 research centres, public sector units, aided institutes and service organisations around the country, having footprints spanning across multiple sectors such as energy, healthcare, agriculture, food preservation, drinking water, environment, etc. A few salient aspects of our diverse contributions shall be touched upon in this article to provide glimpses of our vast range of activities and achievements.

Reactor Technology

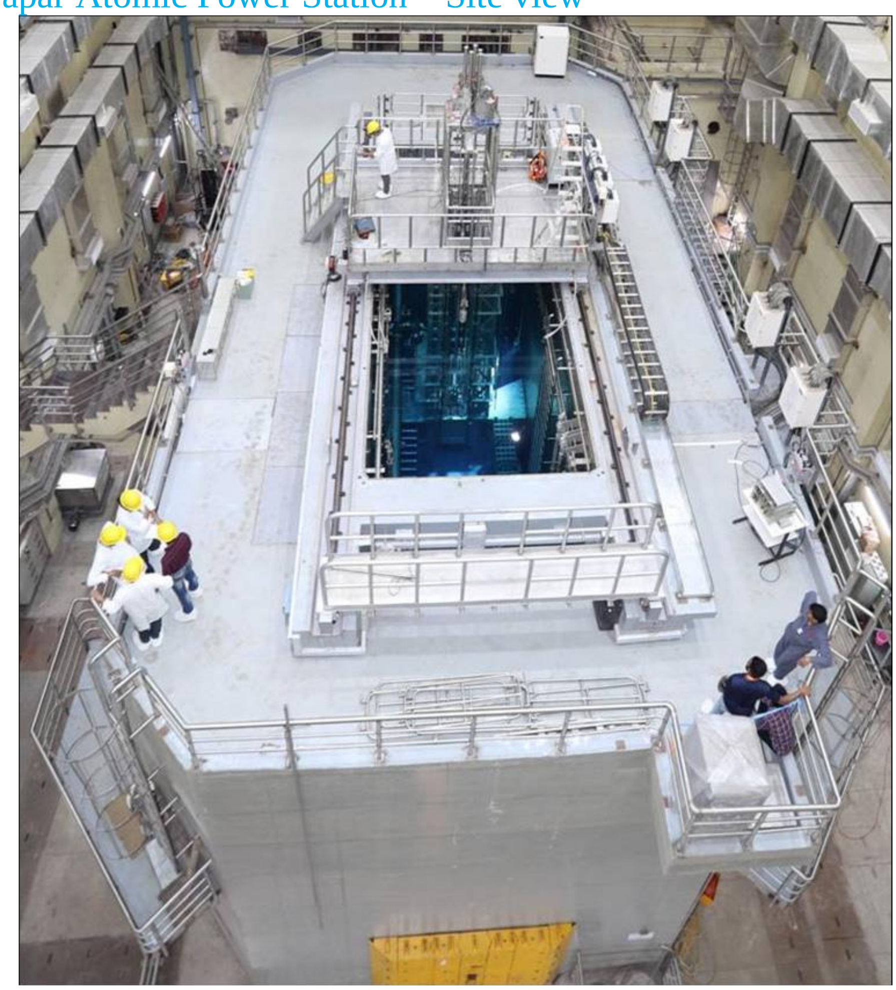
Electricity is one of the foremost requirements to run the engine of growth. In the early days of the nuclear energy journey, many nations understood the importance of this powerful source of energy and embarked on nuclear energy programmes on a massive scale. India too decided to include nuclear energy in the energy basket of the nation to augment electricity production in the country.

The journey to master the technology began in right earnest with the setting up of the first research reactor in India and Asia – the Apsarareactor at Trombay in 1956. Built in a short span of one year, this reactor gave the confidence, set the tone and provided the thrust for sustained growth of the Indian nuclear sector thereafter. A second research reactor CIRUS was built in 1960 and two power reactors were commissioned at Tarapur soon after. Two more research reactors Dhruva and Apsara-U as well as 22 power reactors have since been constructed, commissioned and being operated by DAE. Six power reactors are under construction and several more are in the pipeline.

Radioisotopes produced in research reactors Dhruva and Apsara (U) are the key requirements in almost all applications of radiation technology – healthcare, agriculture and food preservation. Dhruva is the workhorse for the production of radioisotopes in the country. In addition to radioisotope production, material irradiation and neutron radiography facilities in the research reactors support the power programme towards material characterisation and diagnostics.

It is important to mention that nuclear power plants produce no greenhouse gas emissions during operation, and over the course of their life-cycle, they produce only 33% of the emissions per unit of electricity when compared with solar and 4% when compared to thermal power plants. As of today, it is estimated that the use of nuclear energy avoids carbon emissions roughly equivalent to removing one-third of all cars from the world’s roads.

Kakrapar Atomic Power Station – Site view



APSARA (U) during the stage of final commissioning

Healthcare

There is minimal awareness of the enormous contributions being made by DAE in the healthcare sector of the country. Nuclear Medicine is a branch of medicine requiring the use of specialised pharmaceuticals known as radiopharmaceuticals, which are drugs tagged with radioactive elements and used for diagnostic as well as therapeutic purposes. Millions of procedures are being carried out every year using radiopharmaceuticals.

Table 1: Recently developed Radiochemicals/ Radiopharmaceuticals/Freeze-dried kits

Sl. No.	Product Name	Application
1.	^{99m}Tc-Hynic-TOC/HYNIC-TATE	Neuroendocrine tumour imaging
2.	^{99m}Tc-HSA-Nanocolloid	Detection of sentinel nodes in breast and other cancers
3.	^{99m}Tc-UBI (29-41)	Infection imaging
4.	^{99m}Tc-HYNIC-[cyclo(RGDfk)]$_2$	Malignant tumour imaging
5.	^{18}F-FDG	Cancer diagnosis
6.	Na^{18}F	Bone imaging
7.	^{18}F-FLT	Tumour proliferation marker
8.	^{68}Ga-DOTA-TOC/DOTA-TATE/DOTA-NOC	Neuroendocrine tumor imaging
9.	^{68}Ga-PSMA-11	Prostate cancer imaging
10.	^{64}CuCl$_2$	Cancer imaging & ^{64}Cu-radiopharmaceutical preparation
11.	^{131}I-Lipiodol/^{188}Re-DEDC-Lipiodol	Liver cancer therapy
12.	^{188}Re-HEDP/^{177}Lu-EDTMP/^{177}Lu-DOTMP	Bone pain palliation
13.	^{177}Lu-DOTA-TATE	Neuroendocrine cancer therapy
14.	^{177}Lu-Hydroxyapatite/^{90}Y-Hydroxyapatite	Radiation synovectomy
15.	^{177}Lu-PSMA-617	Prostate cancer therapy

The diagnostic procedures produce functional imaging of the organ after the radiopharmaceutical is administered. This is akin to an online live image of the functioning organ such as heart, brain, kidneys, liver, etc., enabling precise pinpointing of the malfunctioning segment of an organ, aiding in accurate diagnosis and therapy. Nuclear medicine procedures can diagnose abnormalities in the early stages of diseases such as cancer, neurological disorders and heart ailments, facilitating timely commencement of treatment. Just as novel drugs for better outcomes are being continuously developed by the pharma industry, DAE is involved in the development of novel organ and disease-specific radiopharmaceuticals for improved outcomes. DAE formulates radiopharmaceuticals, coordinates clinical trials, creates harmonised protocols and provides imaging services at its centres.

"The cost for eye and liver cancer treatment in the country is expected to be considerably lowered with the availability of these new-age procedures at an affordable cost."

Cancer therapy is an important wing of DAE operations. Tata Memorial Centre (TMC) under the aegis of DAE is a pioneer in cancer research and treatment in the country. Radiation therapy, as well as radiopharmaceutical formulations, are extensively used at these and other cancer centres of DAE and more than 5 lakh patients receive treatment every year.

"All diagnostic and treatment procedures at DAE centres are provided at a fraction of the cost incurred at privately run establishments, making them affordable to a large section of the society."

Radiation therapy is carried out with external beams of radiation – usually from a 60Co source as well as by placing sealed radiation sources close to the tumour sites to facilitate higher radiation dose deliveries. This type of internal beam radiotherapy is known as Brachytherapy (*Brachy* in Greek means 'short distance'). Therapeutic radiopharmaceuticals are designed to deliver doses of ionising radiation to specific disease sites and are used extensively in treatments of thyroid and neuroendocrine tumours as well as for bone pain palliation. The radiochemical moiety makes the drug molecule more potent and helps in reducing the cycles of cancer treatment required to be administered, alleviating patient distress.

Eye Plaque developed for the treatment of eye cancer

The development of Ruthenium-106 plaques for the treatment of eye cancer and Yttrium-labelled glass microspheres (named BhabhaSphere) for the treatment of liver cancer are two recent noteworthy developments. The production of Ru-106 eye plaques and Yttrium labelled glass microspheres require specialised skills and expertise making them expensive in the international market. These are low-cost import substitutes, costing about one-tenth of the equivalent imported products. Their use has been cleared by the regulatory authority and several patients have received treatment at TMH with excellent outcomes. The cost for eye and liver cancer treatment in the country is expected to be considerably lowered with the availability of these new-age procedures at an affordable cost.

The recent commissioning of India's largest medical cyclotron facility in Kolkata, Cyclone-30 has enhanced the capability of DAE to produce cyclotron-based radioisotopes for healthcare applications. Production and regular supply of 18F-FDG (PET detection of cancers) have been initiated from Cyclone-30 to cater to the need of this extremely important short-lived radiopharmaceutical in the eastern region of our country. Gallium-68 is being produced in the country for the first time using this medical cyclotron. Gallium-based radiochemicals such as $68GaCl_3$ (PET radionuclide used for imaging of neuroendocrine cancers, prostate cancer, etc.) and 201TlCl (myocardial perfusion imaging agent) for clinical utilisation are in the process of obtaining regulatory clearance.

Cobalt Teletherapy machine – Bhabhatron

DNA microanalysis, early-stage cancer detection equipment, teletherapy machines, a blood irradiator using Cs- 137, and a radioisotope extracted from nuclear waste have also emerged from the R&D efforts at DAE centres.

All diagnostic and treatment procedures at DAE centres are provided at a fraction of the cost incurred at privately run establishments, making them affordable to a large section of the society.

Nuclear Agriculture

Biological systems continuously undergo mutations on a very slow time scale, governed by environmental conditions or on exposure to extraneous influences. However, direct exposure to ionising radiations such as gamma rays from a radioisotope can induce accelerated mutations.

The Bhabha Atomic Research Centre (BARC) has an extensive programme on creating induced mutations in various crops, a technique known as mutation breeding. The method involves exposing seeds to controlled dose of gamma radiation, leading to favourable as well as unfavourable mutations in them. Seeds with desirable traits are selected and multiplied. Extensive field trials are carried out in collaboration with state agricultural universities like Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Dr Panjabrao Deshmukh Krishi Vidyapeeth (DPDKV), Akola and many others.

The seeds are eventually released for cultivation by the State Variety Release Committee and notified by the Central Crop Variety Release and Notification Committee, Ministry of Agriculture & Farmers' Welfare, Government of India. Forty-nine Trombay crop varieties including groundnut, rice, mustard, mung bean, and cowpea with improved characteristics like higher yield, early maturity, improved disease resistance, drought tolerance, etc., have been developed using the radiation-induced mutation breeding techniques and are cultivated extensively in the country.

In recognition of their exceptional contributions to mutation breeding programmes, the mutation breeding team of BARC has been conferred the 'Outstanding Achievement Award' by IAEA in 2021.

Table 2: Trombay varieties released & notified

S.No.	Crop	No. of Varieties Released
1.	Groundnut	15
2.	Soybean	2
3.	Mustard	4
4.	Sunflower	1
5.	Linseed	1
6.	Mungbean	8
7.	Urdbean	5
8.	Pigeon pea	5
9.	Cowpea	2
10.	Paddy	5
11.	Jute	1
	Total	**49**

Food Preservation

Pest infestation, contamination and mould infestation are major problems faced by the agricultural sector, leading to substantial losses to the extent of 20-30% of the produce. Prevention of post-harvest spoilage is, therefore, a national imperative.

Food preservation is conventionally carried out using chemical additives such as sorbates, benzoates, parabens, sulphites, nitrites, nitrates, etc. Radiation processing provides a healthy and eco-friendly solution to this problem as it eliminates the use of chemicals in food preservation. The method involves exposure of food and agricultural commodities to measured doses of gamma radiation. This process results in favourable outcomes such as disinfestation of pests, delayed ripening, inhibition of sprouting and elimination of pathogens and microorganisms causing spoilage. Radiation processing is the only method of killing pathogens in raw and frozen food.

Liquid nitrogen based Reefer undergoing road trials

> **"A recent contribution to food preservation is the development of a liquid nitrogen-based system for refrigerated transport of vegetables, fruits, seafood, etc. improving the economics and profitability for growers, farmers and traders."**

The radiation beam produces its effect by merely depositing its energy and does not lead to any radioactivity being generated in the target material. Radiation processing of food is a method approved by various organisations such as IAEA, WHO, FAO and FSSAI. DAE has developed irradiation technology for the preservation of fruits, vegetables, pulses, spices, seafood, etc. by radiation processing and transferred the technology to private entrepreneurs. Several such commercially operated facilities are available around the country.

India is the second largest fruits and vegetables and third largest fish producer in the world. However, a substantial portion of the produce gets wasted due to the spoilage caused by the lack of cold chain facilities for storage and transport. An important recent contribution to the food preservation agenda has been the development of a liquid nitrogen-based system for refrigerated transport of vegetables, fruits, seafood, etc.

Liquid nitrogen is a by-product of oxygen generation plants used extensively in industrial and medical sectors. A large untapped capacity, therefore, exists in the country for the generation of liquid nitrogen, making it relatively inexpensive. The technology is also an environmentally friendly solution since the use of diesel or CFC gases has been completely eliminated. These refrigerated vans or reefers as they are known, have been named SHIVAY (Sheetal Vahak Yantra). A significant advantage of SHIVAYs is that they possess multimodal logistical flexibility, being customisable to suit the mode of transport available at the sourcing location of the merchandise – railways, roadways or waterways.

The systems require minimum maintenance due to very few moving parts and are therefore rugged enough to be deployed even on rough road conditions. An incubation agreement has been signed with Tata Motors Limited (TML) to jointly develop SHIVAYs for vehicular applications. This technology, when extensively deployed, will substantially reduce wastage and not only improve the economics and profitability for the growers, farmers and traders but also benefit the eventual end-users. An upgraded version of the system, “SHIVAY-V”, has been designed for reaching even lower temperatures of up to -70°C and can be used for storage and transport of vaccines requiring such low temperatures. above, several other products and applications to serve the agriculture and food sector have emerged over the years, such as solar dryers, disinfectors, soil testing kits and various kinds of food processing techniques.

View of a bay in food irradiation facility

Technologies for Smart Cities

One of the objectives of the smart cities mission is to provide clean and sustainable environment through the application of ‘smart solutions’. DAE has developed a bouquet of technologies which can be deployed to meet this objective.

Sludge Hygenisation: This is a dual-purpose technology for the hygenisation of sewage sludge as well as for its conversion to organic fertiliser. Dried sewage sludge is irradiated with gamma rays to eliminate pathogens and dormant seeds. The irradiated sludge is then enriched with micronutrients by inoculation with Bio- NPK and used as fertiliser. A plant has been commissioned by the Ahmedabad Municipal Corporation.

Hybrid Granular Sequencing Batch Reactor (HgSBR) for Sewage Treatment: Wastewater contains fibrous impurities, known as floccular mass, making it difficult to purify and recirculate. DAE has developed a treatment technology for the conversion of floccular mass to granular mass (contaminants aggregated into larger particles) which settle at the bottom of the tank. Pure water is decanted and can be reused for industrial consumption. These plants incur considerably lower operational and maintenance costs as compared to a conventional sewage treatment plant. A 150 KLD plant has been recently commissioned at Kalpakkam, Tamil Nadu. A large 1500 KLD plant at Kalpakkam and a 40 KLD plant at RVNL, New Delhi, are under construction.

Nisargruna: Nisargruna (repaying our debt to nature) is an organic waste management technology for the treatment of biodegradable waste such as food waste, municipal waste, abattoir waste, dung, etc. Pathogen and weed free carbon-rich manure and biogas are useful by-products. The technology has a modular design and is, therefore, scalable from 10-100 kg/day, making it amenable for installations in small as well as large establishments generating such waste. Biogas equivalent to 2 LPG cylinders can be generated from each metric tonne of waste.

Plasma Pyrolysis: Graphite-based plasma pyrolysis system has been developed for the thermal disintegration of organic mass into hydrogen, CO_2 and lower hydrocarbons. Almost 99% of organic mass gets converted into combustible and toxic molecules are completely eliminated. Plasma pyrolysis is approved under the Gazette of India for safe disposal of Bio-Medical Waste.

Water Purification: DAE has developed low-cost water purification systems using membrane filters for ultrafiltration of impurities. These systems require no electricity and call for minimum maintenance, thereby making them rugged and versatile. Technology has been transferred to several entrepreneurs and the systems are commercially available and in wide use.

Water Desalination: A technology for the desalination of seawater has been developed using nuclear waste heat. Two such plants have been set up at Kalpakkam and are supplying potable water to the nearby township. The freshwater resources of the country are rapidly depleting due to overuse and seawater desalination technologies will be required to be increasingly deployed in the future. This technology provides a cost-effective and viable solution and can be considered as a technology for the future.

Looking Ahead

The motto of DAE is 'Atoms in the Service of the Nation' and the organisation has lived up to this mandate by delivering numerous pioneering and one-of-its-kind technologies to the nation. Work on serving and building upon this mandate continues unabated, by way of enhancing capacities and developing innovative technologies for the nuclear sector as well as for societal benefits. Increasing radioisotopes production is essential towards the expansion of several societal applications and the department is actively working towards augmenting this capacity by building reactors in the PPP mode.Eight cancer hospitals have been brought into the DAE fold and several new ones are under construction. A National Cancer Grid has been established to link major cancer centres, research institutes, patient groups and charitable institutions across India for establishing uniform norms for prevention, diagnosis and treatment of cancer, providing specialised training and education in oncology and facilitating collaborative research on cancer. This is expected to lead to a sharing of the knowledge and harmonisation of diagnosis and treatment protocols across the country.

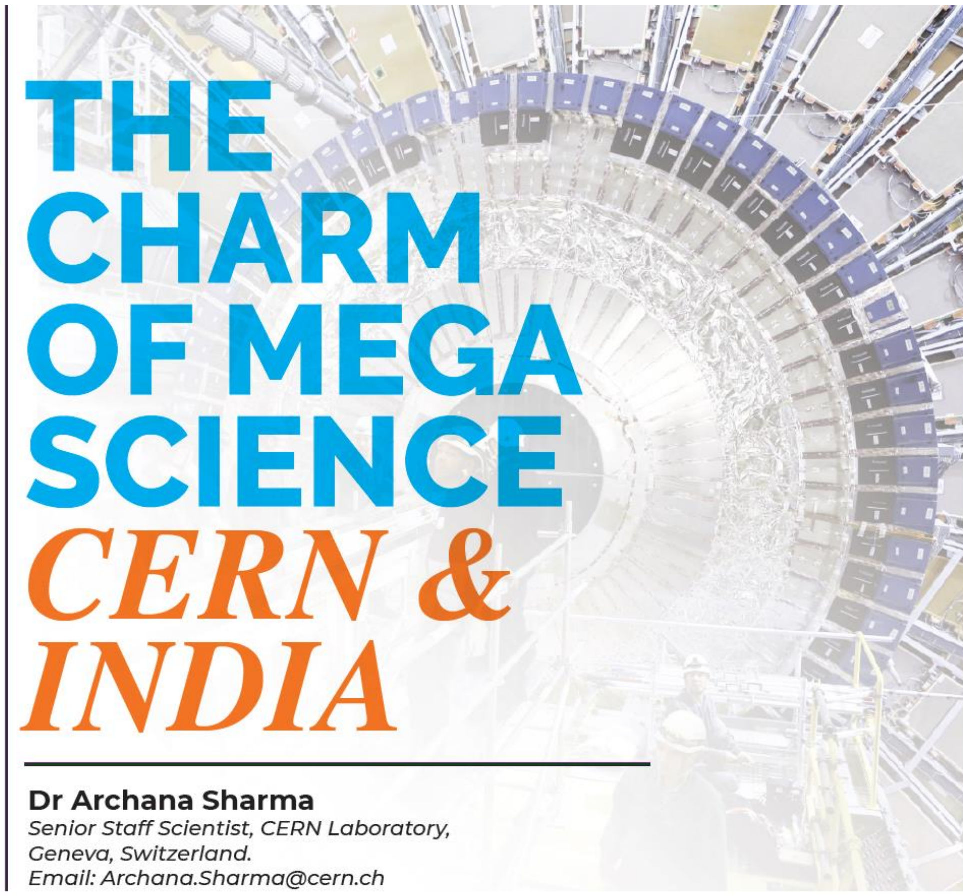
DAE has thrived over the decades by building an R&D ecosystem facilitating a continuous update of its knowledge base. The Homi Bhabha National Institute (HBNI), a 'Deemed to be University', was established under its aegis in 2005 to provide a platform for further strengthening the R&D infrastructure. HBNI is an umbrella institute of 11 DAE units and constituent institutions primarily focussing on educational, research and developmental activities in the sphere of nuclear sciences and engineering and cutting-edge basic and applied research. Within a span of 16 years, HBNI has established itself as a high-quality research institute accredited by NAAC and its research activities have yielded rich dividends towards enhancing our capabilities in several domains.

DAE has attained the stature of a premier institution in the country by the dint of hard work supported by a strong organisational culture, state-of-the-art infrastructure, motivated workforce and pathways to excellence forged over six decades of its existence and will continue to deliver yeoman service to the nation in the future.

MEGA SCIENCE PROJECTS

75 *Years of S&T in India*

It takes decades to build a once unfathomable machine like the LHC, and its experiments. India has been at the heart of it all. Mega Science projects and experiments like those at the LHC, HL-LHC and the future circular collider, among others, open avenues for other technologies and ideas to flourish.



THE CHARM OF MEGA SCIENCE *CERN & INDIA*

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IT'S cold in Geneva. Hymns of the sanctimonious Large Hadron Collider (LHC) at CERN fill the air like white noise. Time churns again and particles are set in motion. They swirl like a subtle breeze, swallowing every ounce of energy that keeps them in motion.

There's a burning sensation around, not because something is on fire but because the excitement is filling the room and our skins can feel it. All eyes on screens, lip biting happens, someone starts clicking their wrists, staring begins. The gentle sound of experimental results appears. There are moments of palpable silence and then someone declares the opening of the abyss, the chasm in the heart of the world! This is a discovery! Of course, it's not as simple as it seems, it takes decades to build a once unfathomable machine like the LHC, and its experiments.

India has been at the heart of it all. In the sixties, India had an army of high energy physicists. It was also the decade of unprecedented scientific advancement in India. India was brimming with ideas. Most of these physicists were working at the Tata Institute of Fundamental Research (TIFR). It was, and still is, one of the most important centres of theoretical studies in Physics in the East. The first collaboration of CERN with India began in the sixties and has grown to be an extraordinary example of Mega Science Collaboration with a legacy of excellence.

The Nobel Prize in 2013 for Physics was given to Peter Higgs and Francois Englert "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider". The CMS India collaboration contributed to this discovery and has continued this excellent work over the last three decades.

Science, especially Physics, is enchanted by the recurrence of ideas. We continuously reevaluate and review our ideas and opinions. It's a spiritual process of some kind and every discovery comes as intermediary enlightenment. Lo and behold, and there is light! It is perhaps of some value to admit that the obsession of humankind (mythology to modern physics) with light has not changed. It's the longest romantic relationship known to us. It has inspired us. Imagine a giant cosmic chest of drawers. Every age discovers one drawer and calls itself advanced. Well, we discovered more than ten but one must be modest. It's a gratifying thought.

The universe begins at nothing. The word oblivion, which our peers in social science departments use to indicate unconsciousness or stupefaction, physicists around the world use this word to indicate the beginning, the moment of creation. There is no agreement on the state of consciousness of the universe, we would like to think, if there's a conscious universe to which Roger Penrose would agree, the act of creation would have been a conscious decision. The befuddlement of these ideas is the pastime of lazy winter conferences of physicists and philosophers.

Since Roger Penrose was mentioned, thanks to him we know that the universe exploded from nothing. Something was created out of nothing. The speculation is that before this eruption, a minor glitch in maintaining quantum vacuum led to the creation of the first particle that expanded to maintain the action-reaction principle, and that led to everything else. Boom! You read that with a sound, didn't you? Everyone does.

India CMS Collaboration (Photo courtesy Prof. B. Choudhary)

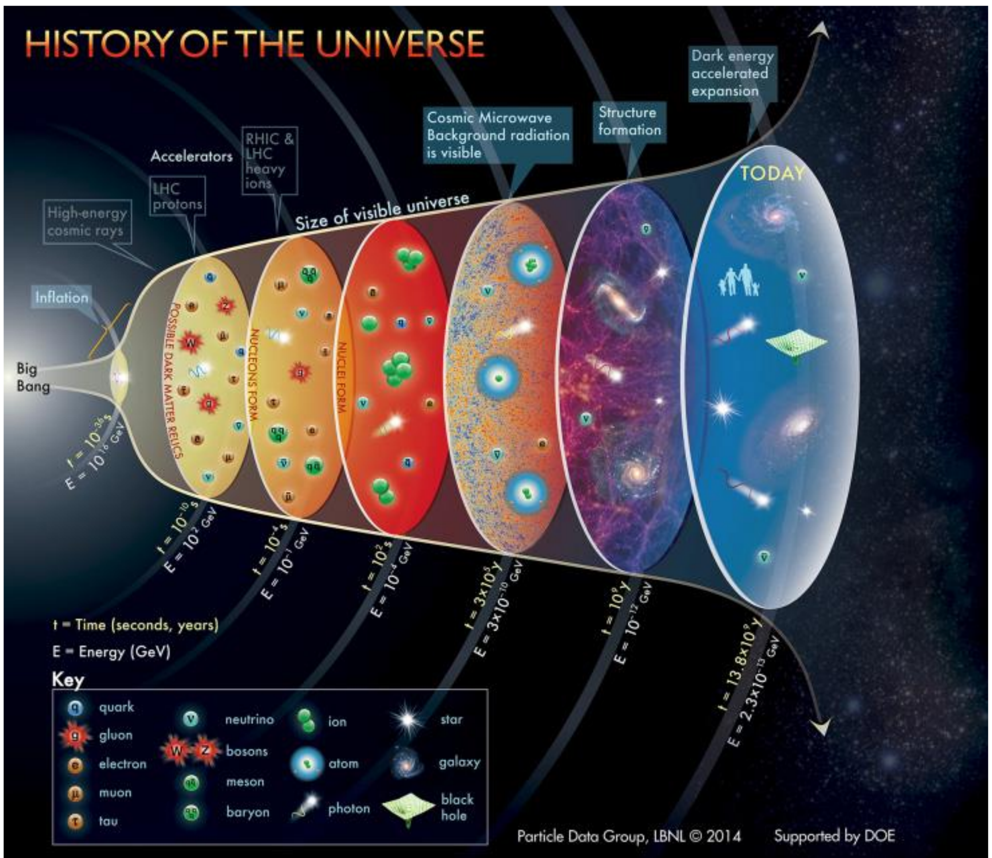
All of us recount these memories of the universe several times every day. This is a physicist's day job and at the night we astound ourselves with the vastness of it. How can something this gigantic exist? Where does it exist? Why does it exist the way it does? How did it all begin?

Autumn is in her last days; followed by winter and then mud-soaked spring. The cycle goes on. It recurs several times in our lifespan. You must know of the story of a man who used to count his age in the number of springs he had witnessed. When asked how old he was, he replied, "I am seventy-eight springs beautiful." It's a romantic thought.

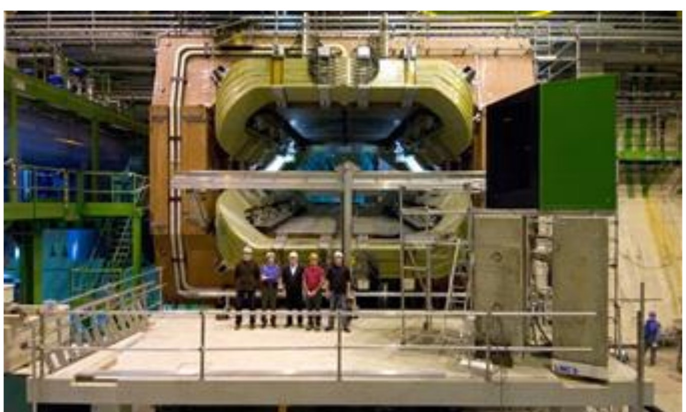
Two twentieth-century physical discoveries that changed the realm of physical reality were general relativity and quantum mechanics. We were awestruck for the first four decades of the twentieth century. In the fifties, we realized that particles can be of great help in understanding the microstructure of matter and then we discovered a dictionary worthy number of particles. One collision after another, one recurrence at a time, we started coming closer to the truth, the absolute truth (we are still far from knowing what it actually is, it sounds exciting when we say this), and then we discovered Higgs Boson! We now know what makes us heavier! You still have to exercise to lose weight; Higgs Boson can't be held accountable for the extra calories you eat.

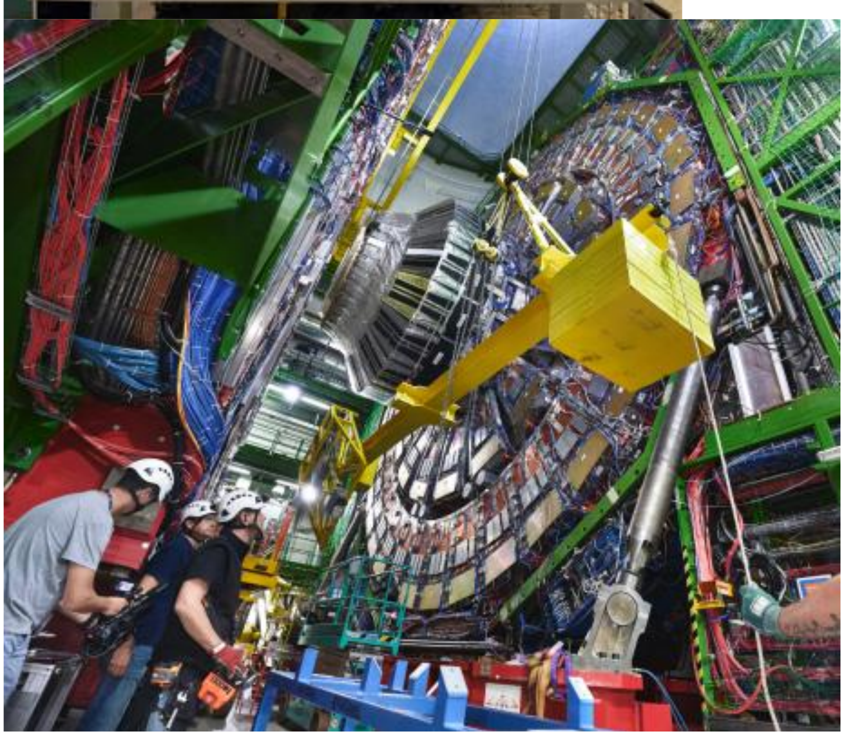
It has been a century of ideas, maybe more than that when we started peeking into the intricacies of the material world. Our vision is somewhat of a hurdle in the path of our ambition to see everything. So, we invented new pairs of glasses, microscopes, telescopes, and several other instruments that had the capability to make us observe whatever we wanted to observe.

Physicists brazenly invented an oxymoron a few years ago. 'The largest microscope' or Large Hadron Collider is an instrument that helps us see, for the lack of better words, the microcosm elaborately. The LHC, as it is abbreviated, accelerates particles (such as protons, etc.) closer to the speed

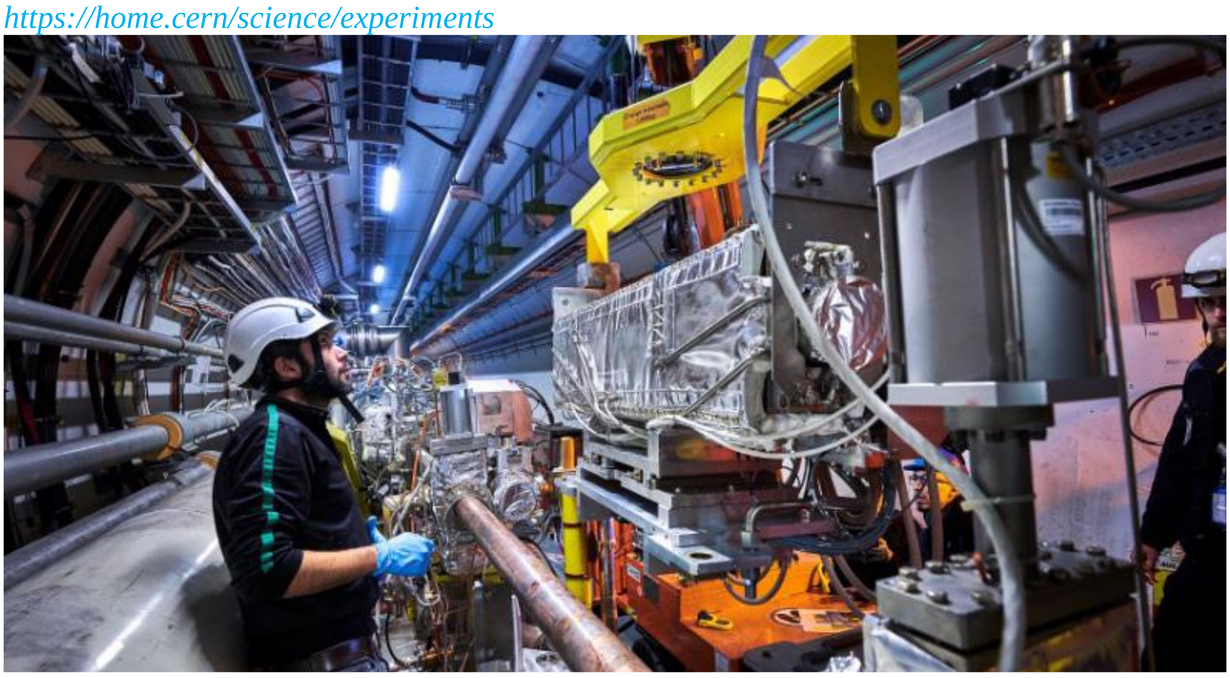


Cosmic chest of drawers: *Cartoon depiction of the universe timeline starting from the Big Bang till the present. The particle era is expected to have formed around a few microseconds. Figure courtesy Particle Data Group, LBNL: https://cds.cern.ch/record/2645860/files/Figures_Ch1_historyUniverse.png*





The Large Hadron Collider and its four major experiments, clockwise from top left: ATLAS, CMS, LHCb and ALICE *https://home.cern/science/accelerators/large-hadron-collider* *https://home.cern/science/experiments*



The High Luminosity LHC Project *(https://hilumilhc.web.cern.ch/)*

of light and then they are set on the path to collide. The rate of these collisions at LHC is about 40 million times per second!

These collisions produce billions of particles that are studied by extremely large experimental detectors that track them creating terabytes, petabytes of data. It would come as surprise but CERN has processed 99.9975% of all data produced from each collision. Computer scientists' hearts just skipped a beat. It's all right, take a breath.

This processing happens simultaneously actually. CERN's computing grid has a sophisticated code to decide which data to capture or discard that happens via constant vigilance through trigger systems that are designed to check every collision in the experiments. This cycle repeats itself when the experiments take data again.

As mentioned earlier, the realization that one could recreate the conditions of the beginning to study it in principle, led to the experimental setup of the LHC. The universe began as a hot soup of particles. It expanded to form structures, from atoms to stars were formed. Then it evolved to form large scale structures such as galaxies and superclusters. This expansion led to thermodynamic cooling and whatever we see right now is 13.8 billion years after everything began. So, the experimentalists are basically trying to traverse through time by creating that hot cosmic soup and then push the limit a bit backward in time. It's astonishing that the LHC can (and it has) reproduced that hot cosmic soup.

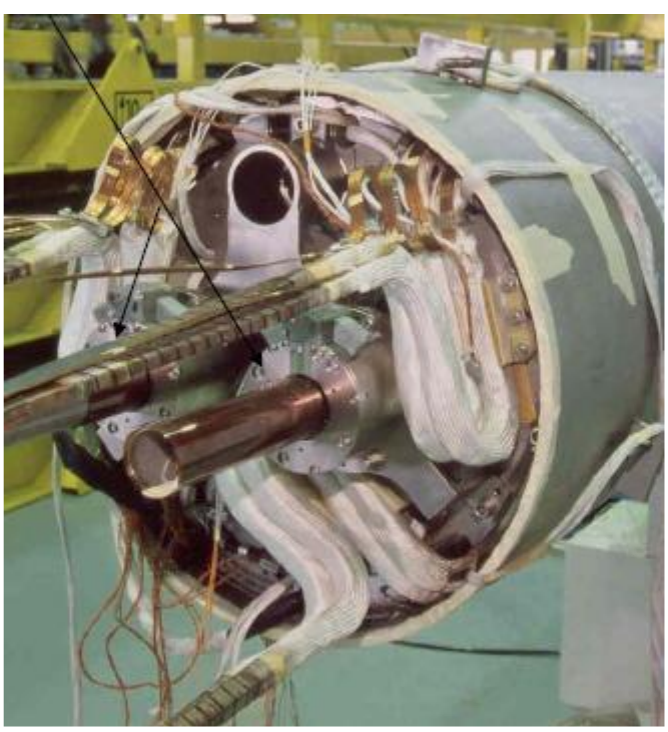
The thing about good food and good science is that we want more. The LHC will "run" (not run away) again in March 2022. That would be its third race and the stakes would be quite gigantic! We are expecting that the total number of collisions and rate will increase dramatically. This will be followed by the LHC's High-Luminosity era, which is scheduled to begin in 2027 and operate until the 2040s. This High-Luminosity era would be defined by increasing the luminosity of the machine (a measure of the focus of the crossing beams of particles at the collision point) by ten times its design value. How very droll! It is only humorous to think of the abyss stepping out of nothingness (I laugh at it sometimes), standing in front of physicists and asking for a giant cheeseburger!

Setting up and running (not running away from) these experiments is also a humbling exercise. They also serve as an important opportunity to collaborate and learn from your peers. You would be interested in knowing that the experiments that help expand the sphere of human knowledge and scientific enterprise are also pinnacles of engineering innovation and industrial advancement. It was not long ago that the internet was invented at CERN to help physicists communicate and share data around the globe. The same thing you would use to find the right song or a poem for romantic purposes. Physicists did the same. They wanted to communicate the most heart-clenching moment of their life with their peers.

Physicists from India contributed to the making of several important experimental hardware such as the endcap hadron calorimeter and the development of the core software of the L3 experiment. The teams were involved in key physics research ideas at the CERN, such as the line-shape analysis, Higgs searches, quantum chromodynamics and b-quark physics.

Experts like Som Ganguly, Tariq Aziz and Sunanda Banerjee analyzed vast amounts of such information for electroweak interactions at the Large Electron-Positron Collider (LEP). The L3 results from the TIFR group contributed to precise W and Z measurements across all LEP experiments.

In the 1990s, The Raja Ramanna Centre for Advanced Technology (RRCAT) at Indore delivered hardware for LEP, and the Indian High-Energy Heavy Ion Physics Team contributed to the construction of the Photon Multiplicity Detector for the WA93 experiment at the CERN-SPS. In



Indian “corrector magnets” installed in LHC dipole magnets

Visit of Dr R. Chidambaram, Chairman, Atomic Energy Commission, India 4 October 1999

Honourable President Kalam visiting the SM18 magnet test facility at CERN and meeting with the Indian engineers from DAE (May 2005)

1991, an International Cooperation Agreement (ICA) between the Department of Atomic Energy (DAE) of the Government of India and CERN concerning the further development of scientific and technical cooperation in the research projects of CERN was signed. These developments paved the way for the Indian AEC's (Atomic Energy Commission) decision in 1996 to take part in the construction of the LHC and to contribute to the construction of the CMS and ALICE detectors.

In recognition of its contribution to the LHC construction, India was awarded the status of an Observer State in 2002. The success of the DAE-CERN partnership in the LHC has also led to a new cooperation on Novel Accelerator Technologies (NAT), which envisioned DAE's participation in CERN's Linac-4, SPL and CTF3 projects, as well as CERN's contribution to DAE's programs. India also contributes to the

COMPASS, ISOLDE and nTOF experiments and operates two Tier-2 centers for the Worldwide LHC Computing Grid (WLCG).

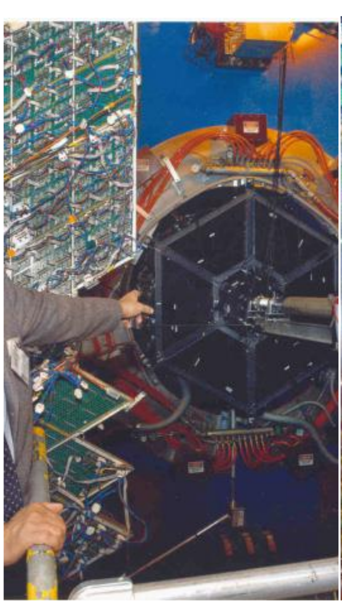
Currently, India is a significant contributor to several experiments at CERN. Several Indian universities and institutes are members of one or two of the collaborative experiments. In addition to this participation, the Indian groups have also contributed in terms of design, development, fabrication and operation of several sub-detectors or detector components used in them. More than 150 Indian scientists and students from India participate in various experiments at CERN.

From knowing the universe, to how to know the universe, and eventually what to do to keep up with the quest is a very long journey. It is uncharted territory. Hence collaboration is the only way to go for the future towards attaining sustainable development goals for our country.

India has made excellent progress by signing the Associate Membership at CERN on 22 November 2016 which consolidates the path for Indian collaboration at CERN, not only for the present generation of experiments and R&D but for the future projects that span decades. It is also an incredible opportunity for training our younger generation and create international leadership for the future.

MegaScience projects and experiments like those at the LHC, HL-LHC and the future circular collider (slated to start in 2040) among others, open avenues for other technologies and ideas to flourish. Let us talk about India. The Indian government led by Prime Minister Shri Narendra Modi has set a goal of making India a $5 trillion economy by 2024-25. In addition to infrastructure, banking and agriculture, certain sectors have been prioritized to achieve the goal and drive employment opportunities.

Industries based on physics and mega science projects generate over 16 per cent of the total turnover in Europe, Indian “corrector magnets” installed in LHC dipole magnets



Photon Multiplicity Detector (PMD) and Muon Spectrometer: Bikash Sinha Senior INSA Scientist (left) Team ALICE building the PMD (right) surpassing contributions from financial services and retail sectors. Among all physics disciplines, High Energy Physics (HEP), given the gigantic scale, complex technology, and large-scale facilities, becomes a significant contributor.

Relevant state-of-the-art technologies were initially developed for fundamental research at institutions like CERN. It has happened time and again that technologies were improved and exclusive versions of techniques were made available for social use. There are several examples. The LHC Grid Computing involves algorithms that have numerous applications in banking, finance and weather forecasts. Data quenching technology built-in high-energy physics can be used in developing teaching aids as well as in safety monitoring. High Performance Embedded Computing (HPEC) systems can be used for several applications like the US Department of Homeland Security does in the aerospace and communications industry.

Sensors from High Energy Physics (HEP) have been used for 3D imaging of the body in medical diagnostics. Radiotherapy devices deliver cancer treatment by means of particle accelerators, also using positron emission tomography (PET) scanners that contain photon detectors based on crystals. The list is huge and this tells us that the road for India to utilize the mega science enterprise is to harness its existing academic and industrial expertise and combine it with the advanced experimental setups around the world. This would not be an unusual experiment. We have precedent. We just need to take the plunge and move forward, and that is certainly the key learning of the pandemic too.

The medical sector has seen widespread adoption of developments in particle physics technologies. The more we can peer into how tiny particles zip around, the more we can utilize the same technology to peer into tiny processes in our bodies. Over 1,500 positron emission tomography scanners have been built using crystal technology from HEP by GE healthcare at a cost of $250,000-$600,000 each, with which around 1.5 million PET scans are performed every year in the US.

The Medipix chip was developed as a side project for a tracking application in particle physics. Its potential quickly realized, the second generation of chip was licensed by the company PANalytical and is at the core of the PIXcel system, of which over 500 systems are currently being deployed worldwide. Low-dose high-precision 3D imaging applications for diagnosis using sensors developed in particle physics are in use. Proton and particle therapies are used in a large number of cancer treatment centres in the world, exploiting the IP from HEP.

Given the increasing incidence of cancer in India and the surrounding region, there is massive societal impact that can be delivered. This also forms the basis for a viable commercial model. A net benefit of approximately €1.6 billion has been projected in an equivalent European cancer treatment (accelerator-based) facility, over 10 years. Of course, for commercialization to take effect, a multi-disciplinary setting is needed where particle physics engages with other disciplines involving both academia and industry, and this must be enhanced and strengthened.

There is a need for international collaborations and networks and help to young people from our field, many of whom go into industry, to develop as entrepreneurs creating spin-offs and start-ups.

Industry is looking for talent from our community — let's help them find it. Medical, industrial and research applications of particle physics technologies are located at the nucleus for the spiral of development of a strong ecosystem that will deliver a benefit to India for decades to come, creating a vibrant particle physics community that will continue to grow, innovate and contribute to the economy.

Outreach and Education is extremely important in order to raise awareness about Mega science projects among the young talent in the country, to leverage training possibilities across the board in skill-building for the future for both academia and industry. The dream is to see the Indian flag flying high in all mega science projects, veritably at CERN!

'Ghost Particles' Were Detected at the Large Hadron Collider for the First Time

26 November, 2021 | by Chris Young

Bringing us closer to uncovering the role of these 'elusive particles' in the universe.

Source website links: https://interestingengineering.com/ghost-particles-were-detected-at-the-large-hadron-collider-for-the-firsttime?utm_source=newsletter&utm_medium=mailing&utm_campaign=Newsletter-27-11-2021

Physicists from the University of California, Irvine (UCI) found never-before-seen "ghost particles", or neutrinos, in the Large Hadron Collider (LHC) during an experiment called FASER, a report from New Atlas reveals.

The FASER equipment at the LHC. UCI

Neutrinos are electrically neutral elementary particles with a mass close to zero. The reason they're known as ghost particles is that, though they are incredibly common, they have no electric charge, meaning they are difficult to detect as they rarely interact with matter.

'Ghost particles' could carry immense amounts of information

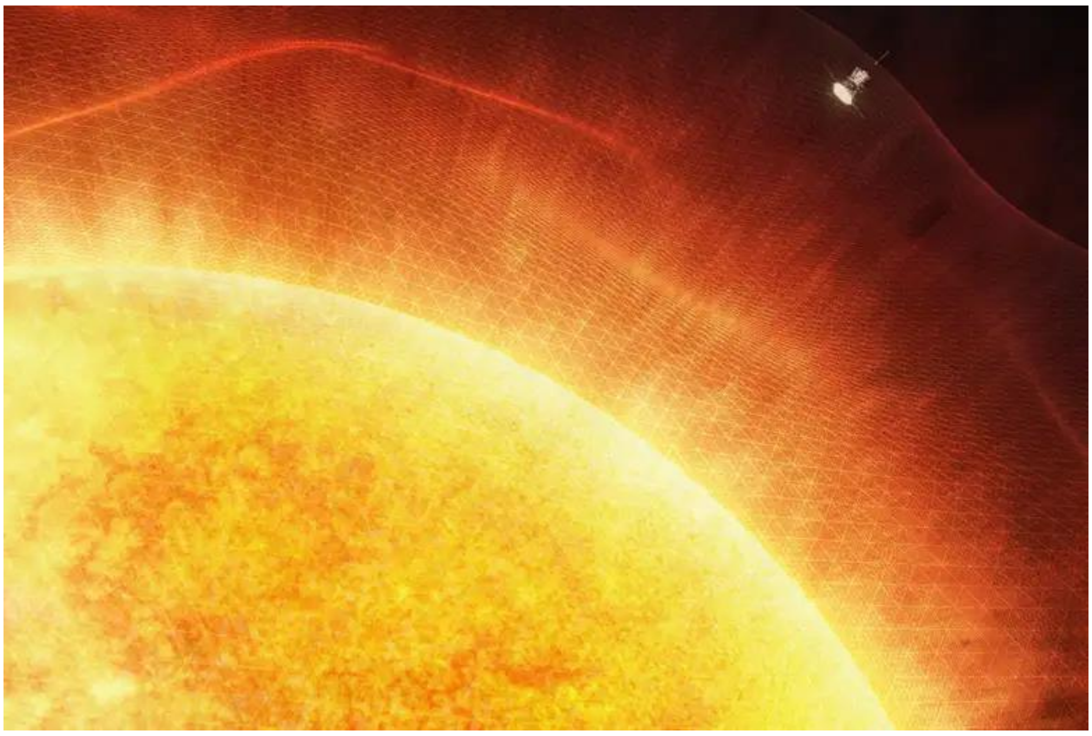
Alongside the FASER experiments at the LHC, a series of in development neutrino observatories, designed to detect neutrino sources in space, have the potential to reveal many of the universe's mysteries. Despite their name, ghost particles might actually provide a wealth of information due to the fact that they don't interact with other matter as they travel through the universe— unlike light particles, photons, which are distorted by interactions as they traverse space. The problem, so far, has been our ability to detect these ghost particles or neutrinos. Neutrinos are produced in stars, supernovae, and quasars, as well as in human-made sources. It has long been believed, for example, that particle accelerators such as LHC should also produce them, though they have likely gone undetected. Now, a paper published in the journal Physical Review D, provides the first evidence of neutrinos, in the form of six neutrino interactions, at the LHC. "Prior to this project, no sign of neutrinos has ever been seen at a particle collider," study co-author Jonathan Feng said in a press statement. "This significant breakthrough is a step toward developing a deeper understanding of these elusive particles and the role they play in the universe."

The FASER experiment will be expanded by 2022

Back in 2018, the FASER experiment installed an instrument to detect neutrinos, some 1,575 ft (480 m) down from where particle collisions occur in the LHC. The instrument uses a detector composed of plates of lead and tungsten, which are set apart by layers of emulsion. When neutrinos smash into nuclei in the metals, they produce particles that then travel through the layers of emulsion. This creates marks that are visible following a processing procedure that's somewhat similar to film photography. During the experiments, six of these marks were spotted after processing. According to Feng, the team is "now preparing a new series of experiments with a full instrument that's much larger and significantly more sensitive," so as to collect more data. This larger version will be called FASERnu. It will weigh 2,400 lb (1,090 kg) — a lot more than the first version's 64 lb (29 kg) — allowing it to detect many more of the elusive ghost particles. David Casper, another co-author of the study, says the UCI team expects FASERnu to "record more than 10,000 neutrino interactions in the next run of the LHC, beginning in 2022."

NASA’s Parker Solar Probe is the first spacecraft to 'touch' the sun

Source:www.newscientist.com/article/2301879-nasas-parker-solar-probe-is-the-first-spacecraft-to-touch-the-sun/



NASA’s Parker Solar Probe has reached out to our star and touched its atmosphere. On 28 April, it became the first spacecraft to enter the upper atmosphere of the sun, called the corona. This milestone was announced on 14 December at a meeting of the American Geophysical Union in New Orleans.

The edge of the sun’s corona is the area of space just far enough from the sun’s centre that its gravity and magnetic field are no longer dominant and cannot trap material on the star. That boundary is called the Alfvén critical surface, which is what the Parker Solar Probe crossed in April to dip into the corona.

“For centuries, humanity has only been able to observe this atmosphere from afar. Now… we have finally arrived,” said Nicola Fox, director of NASA’s Heliophysics Division, in a press conference. “Humanity has touched the sun.”

The spacecraft entered the corona on its eighth close pass of the sun, when it was only about 13 million kilometres from the centre of the star. The boundary was wiggly, though, and the spacecraft exited after about five hours, only to enter and exit the corona twice more before continuing to a more distant part of its orbit. It may have passed through again in August, but that data hasn't yet been fully analysed.

Until the probe entered the region, researchers weren't sure exactly how far from the sun the Alfvén critical surface would be or what it would be like, but they knew that its presence could be measured by changes in the magnetic field and a slowing of the solar wind below the surface. The Parker Solar Probe's measurements confirmed this, and demonstrated that the critical surface wasn't a smooth bubble around the sun, but rather a wrinkled edge.

Studying this surface could help us understand how the sun spits out charged particles that can pose issues for satellites and space explorers, and maybe even predict those outbursts. It is also a step towards understanding other stars beyond our solar system. "These are stellar phenomena, not just solar phenomena," said Parker Solar Probe team member Kelly Korreck during the press conference.

The probe is planned to continue circling ever closer to the sun well into 2025, repeatedly breaking its own records for the fastest-moving spacecraft and the closest spacecraft to the sun. Now that we have touched the star, researchers will keep working to unravel its many mysteries.

Experiments Reveal Formation of a New State of Matter—Electron Quadruplets

18 October, 2021 | by KTH, Royal Institute of Technology

Source website links: **https://www.eurekalert.org/news-releases/931832**

The central principle of superconductivity is that electrons form pairs. But can they also condense into foursomes? Recent findings have suggested they can, and a physicist at KTH Royal Institute of Technology today published the first experimental evidence of this quadrupling effect and the mechanism by which this state of matter occurs.

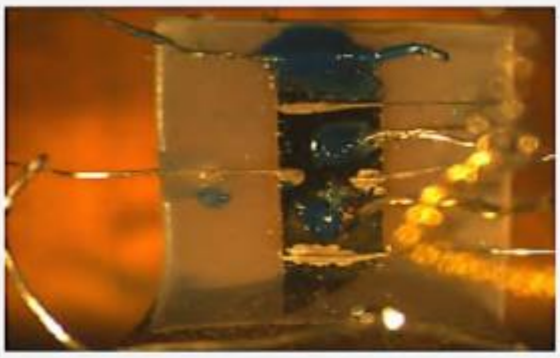


IMAGE: THE IRON-BASED SUPERCONDUCTOR MATERIAL, BA1−XKXFE2AS2, IS MOUNTED FOR EXPERIMENTAL MEASUREMENTS. view more >

CREDIT: VADIM GRINENKO, FEDERICO CAGLIERIS

Reporting today in Nature Physics, Professor Egor Babaev and collaborators presented evidence of fermion quadrupling in a series of experimental measurements on the iron-based material, Ba1−xKxFe2As2. The results follow nearly 20 years after Babaev first predicted this kind of phenomenon, and eight years after he published a paper predicting that it could occur in the material. The pairing of electrons enables the quantum state of superconductivity, a zero-resistance state of conductivity which is used in MRI scanners and quantum computing. It occurs within a material as a result of two electrons bonding rather than repelling each other, as they would in a vacuum. The phenomenon was first described in a theory by, Leon Cooper, John Bardeen and John Schrieffer, whose work was awarded the Nobel Prize in 1972. So-called Cooper pairs are basically —opposites that attract‖. Normally two electrons, which are negatively-charged subatomic particles, would strongly repel each other. But at low temperatures in a crystal they become loosely bound in pairs, giving rise to a robust long-range order. Currents of electron pairs no longer scatter from defects and obstacles and a conductor can lose all electrical resistance, becoming a new state of matter: a superconductor. Only in recent years has the theoretical idea of four-fermion condensates become broadly accepted.

For a fermion quadrupling state to occur there has to be something that prevents condensation of pairs and prevents their flow without resistance, while allowing condensation of four electron composites, Babaev says. The Bardeen-Cooper-Schrieffer theory didn‘t allow for such behavior, so when Babaev‘s experimental collaborator at Technische Universtät Dresden, Vadim Grinenko, found in 2018 the first signs of a fermion quadrupling condensate, it challenged years of prevalent scientific agreement. What followed was three years of experimentation and investigation at labs at multiple institutions in order to validate the finding. Babaev says that key among the observations made is that fermionic quadruple condensates spontaneously break time reversal symmetry. In physics time-reversal symmetry is a mathematical operation of replacing the expression for time with its negative in formulas or equations so that they describe an event in which time runs backward or all the motions are reversed.

If one inverts time direction, the fundamental laws of physics still hold. That also holds for typical superconductors: if the arrow of time is reversed, a typical superconductor would still be the same superconducting state. ―However, in the case of a four-fermion condensate that we report, the time reversal puts it in a different state,‖ he says. ―It will probably take many years of research to fully understand this state," he says. "The experiments open up a number of new questions, revealing a number of other unusual properties associated with its reaction to thermal gradients, magnetic fields and ultrasound that still have to be better understood

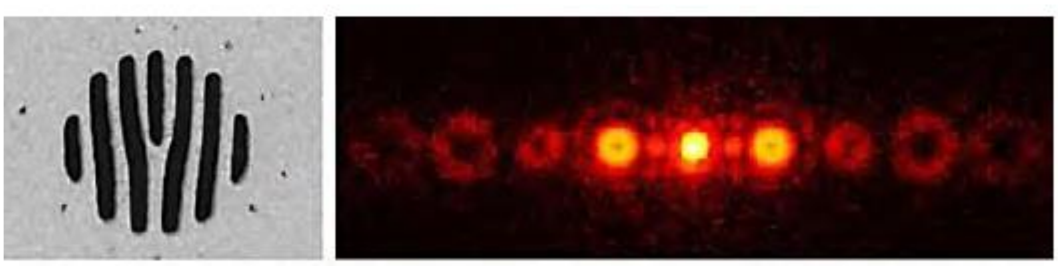
Researchers Generate, for the First Time, a Vortex Beam of Atoms and Molecules

01 December, 2021 | by Weizmann Institute of Science

Source website links: https://phys.org/news/2021-11-vortex-atoms-molecules.html

Vortices may conjure a mental image of whirlpools and tornadoes—spinning bodies of water and air—but they can also exist on much smaller scales. In a new study published in Science, researchers from the Weizmann Institute of Science, together with collaborators from the Technion-Israel Institute of Technology and Tel Aviv University, have created, for the first time, vortices made of a single atom. These vortices could help answer fundamental questions about the inner workings of the subatomic world and be used to enhance a variety of technologies—for example, by providing new capabilities for atomic microscopes. Scientists have long been striving to produce various types of nano-scale vortices in the lab, with recent focus on creating vortex beams—streams of particles having spinning properties—where even their internal quantum structure can be made to spin.

Vortices made up of elementary particles, electrons and photons, have been created experimentally in the past, but until now vortex beams of atoms have existed only as a thought experiment. "During a theoretical debate with Prof. I do Kaminer from the Technion, we came up with an idea for an experiment that would generate vortices of single atoms," says Dr. Yair Segev, who has recently completed his Ph.D. studies in the group of Prof. Edvardas Narevicius of Weizmann's Chemical and Biological Physics Department In classical physics, spinning objects are often characterized by a property known as angular momentum. Similar to linear momentum, it describes the effort needed to stop a moving object in its tracks, or rather, to stop it from spinning. Vortices—characterized by the circulation of flux around an axis—embody this property perfectly in their relentless spin.



(Left) An example of a nano-grating design with transmitting (black) and blocking (white) ...

However, the very basic property of angular momentum, which characterizes naturally occurring vortices both big and small, takes on a different twist on the quantum scale. Unlike their classical physics equivalents, quantum particles cannot take on any value of angular momentum; rather, they can only take on values in discrete portions, or "quanta." Another difference is the way in which a vortex particle carries its angular momentum—not as a rigid, spinning propeller, but as a wave that flows and twists around its own axis of motion.

These waves can be shaped and manipulated similarly to how breakwaters are used to direct the flow of seawater close to shore, but on a much smaller scale. "By placing physical obstacles in an atom's path, we can manipulate the shape of its wave into various forms," says Alon Luski, a Ph.D. student in Narevicius's group. Luski and Segev, who led the research along with Rea David from their group, collaborated with colleagues from Tel Aviv University to develop an innovative approach for directing the movement of atoms.

The four-and-a-half-meter-long experimental setup starting with the supersonic beam of...

They created patterns of nanometric "breakwaters" called gratings—tiny ceramic discs, several hundreds of nanometers in diameter, with specific slit patterns. When the slits are arranged into a fork-like shape, each atom that passes through them behaves like a wave that flows through a physical obstacle, in this way acquiring angular momentum and emerging as a spinning vortex. These "nano-forks" were produced through a nanofabrication process that was developed specifically for this experiment by Dr. Ora Bitton and Hila Nadler, both of Weizmann's Chemical Research Support Department.

To generate and observe atomic vortices, the researchers aim a supersonic beam of helium atoms at these forked gratings. Before reaching the gratings, the beam passes through a system of narrow slits that blocks some of the atoms, transmitting only the atoms that behave more like large waves—those that are better suited to being shaped by the gratings. When these "wavy" atoms interact with the "forks," they are shaped into vortices, and their intensity is recorded and photographed by a detector.

This results in a donut-shaped image constructed from millions of vortexed helium atoms that collide with the detector. "When we saw the donut-shaped image, we knew we had succeeded in creating vortices of these helium atoms," says Segev. Much like the "eye" of the storm, the center of these "donuts" represents the space where each atomic vortex is calmest—the intensity of the waves there is zero, so no atoms are found there. "The 'donuts' are the fingerprint of a series of different vortex beams," explains Narevicius.

During the experiments, the researchers made an odd observation. "We saw that next to the perfectly shaped donuts, there were two small spots of 'noise' as well," says Segev. "At first we thought this was a hardware malfunction, but after extensive investigation we realized that what we're looking at are actually unusual molecules, each made of two helium atoms, that were joined together in our beams." In other words, they had generated vortices of not only atoms but also of molecules.

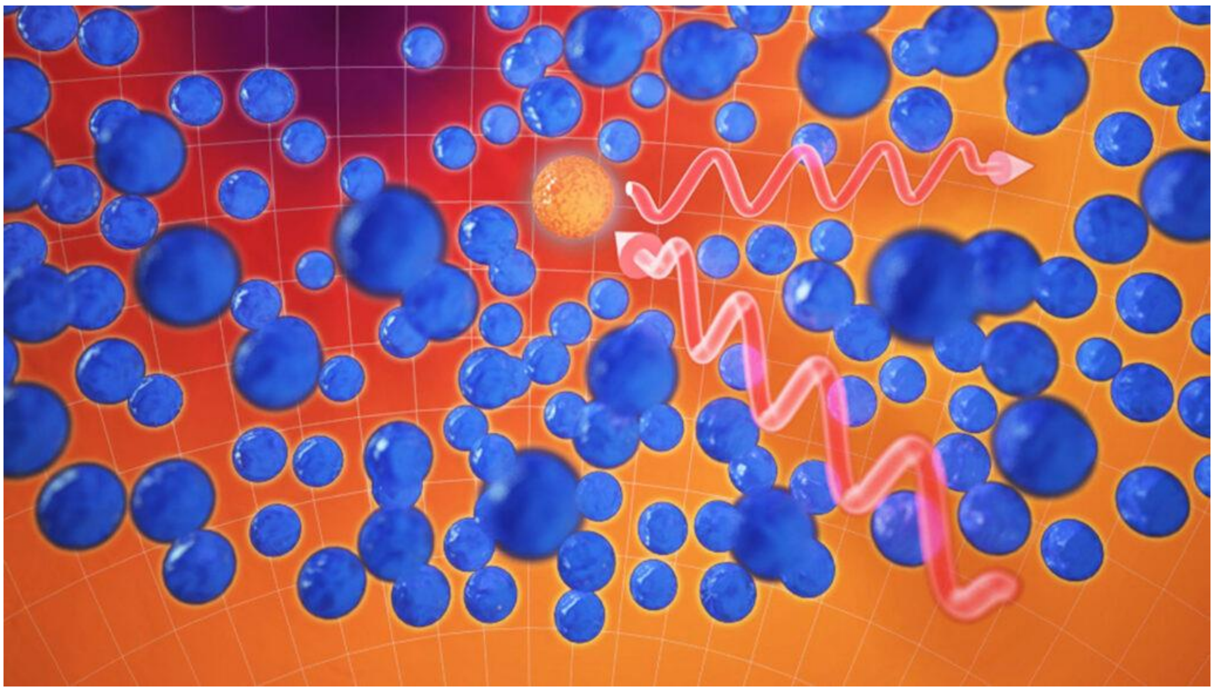
Although the researchers used helium in their experiments, the experimental setup may accommodate studies of other elements and molecules. It could also be used to study hidden subatomic properties, such as the charge distribution of protons or neutrons that may be revealed only when an atom is spinning. Luski gives the example of a mechanical clock: "Mechanical clocks are made of tiny gears and cogs, each moving at a certain frequency, similarly to the internal structure of an atom. Now imagine taking that clock and spinning it—this motion could change the internal frequency of the gears, and the internal structure could be expressed in the properties of the vortex as well."

In addition to offering a new way of studying the very basic properties of matter, atomic vortex beams might find use in several technological applications, such as in atomic microscopy. The interaction between spinning atoms and any investigated material could lead to the discovery of novel properties of that material, adding significant, previously inaccessible data to many future experiments.

Scientists finally detected a quantum effect that blocks atoms from scattering light

Source : Science News, November 22, 2021 , By Emily Conover

When all available quantum states are full, ultracold atom clouds become more transparent



In an ultracold, dense cloud of atoms (blue), a quantum effect dictates whether atoms scatter light (red arrows). If the quantum states are fully occupied, the atoms cannot change quantum states and the light isn't scattered.
Illustration by Steven Burrows/JILA

A cloud of ultracold atoms is like a motel with a neon "no vacancy" sign.
If a guest at the motel wants to switch rooms, they're out of luck. No vacant rooms means there's no choice but to stay put. Likewise, in new experiments, atoms boxed in by crowded conditions have no way to switch up their quantum states. That constraint means the atoms don't scatter light as they normally would, three teams of researchers report in the Nov. 19 Science. Predicted more than three decades ago, this effect has now been seen for the first time.
Under normal circumstances, atoms interact readily with light. Shine a beam of light on a cloud of atoms, and they'll scatter some of that light in all directions. This type of light scattering is a common phenomenon: It happens in Earth's atmosphere. "We see the sky as blue because of scattered radiation from the sun," says Yair Margalit, who was part of the team at MIT that performed one of the experiments.

But quantum physics comes to the fore in ultracold, dense atom clouds. "The way they interact with light or scatter light is different," says physicist Amita Deb of the University of Otago in Dunedin, New Zealand, a coauthor of another of the studies.

According to a rule called the Pauli exclusion principle, atoms in the experiments can't take on the same quantum state — namely, they can't have the same momentum as another atom in the experiment (SN: 5/19/20). If atoms are packed together in a dense cloud and cooled to near absolute zero, they'll settle into the lowest-energy quantum states. Those low-energy states will be entirely filled, like a motel with no open rooms.

When an atom scatters light, it gets a kick of momentum, changing its quantum state, as it sends light off in another direction. But if the atom can't change its state due to the crowded conditions, it won't scatter the light. The atom cloud becomes more transparent, letting light through instead of scattering it.

To observe the effect, Margalit and colleagues beamed light through a cloud of lithium atoms, measuring the amount of light it scattered. Then, the team decreased the temperature to make the atoms fill up the lowest energy states, suppressing the scattering of light. As the temperature dropped, the atoms scattered 37 percent less light, indicating that many atoms were prevented from scattering light. (Some atoms can still scatter light, for example if they get kicked into higher-energy quantum states that are unoccupied.)

In another experiment, physicist Christian Sanner of the research institute JILA in Boulder, Colo., and colleagues studied a cloud of ultracold strontium atoms. The researchers measured how much light was scattered at small angles, for which the atoms are jostled less by the light and therefore are even less likely to be able to find an unoccupied quantum state. At lower temperatures, the atoms scattered half as much light as at higher temperatures.

The third experiment, performed by Deb and physicist Niels Kjærgaard, also of the University of Otago, measured a similar scattering drop in an ultracold potassium atom cloud and a corresponding increase in how much light was transmitted through the cloud.

Because the Pauli exclusion principle also governs how electrons, protons and neutrons behave, it is responsible for the structure of atoms and matter as we know it. These new results reveal the wide-ranging principle in a new context, says Sanner. "It's fascinating because it shows a very fundamental principle in nature at work."

The work also suggests new ways to control light and atoms. "One could imagine a lot of interesting applications," says theoretical physicist Peter Zoller of the University of Innsbruck in Austria, who was not involved with the research. In particular, light scattering is closely related to a process called spontaneous emission, in which an atom in a high-energy state decays to a lower energy by emitting light. The results suggest that decay could be blocked, increasing the lifetime of the energetic state. Such a technique might be useful for storing quantum information for a lengthier period of time than is normally possible, for example in a quantum computer.

So far, these applications are still theoretical, Zoller says. "How realistic they are is something to be explored in the future."

Photonic Chip Breakthrough Opens a Path toward Quantum Computing in Real-World Conditions

31 August, 2021 | by University of Virginia

Source website links: https://scitechdaily.com/photonic-chip-breakthrough-opens-a-path-toward-quantum-computing-in-real-worldconditions/

The quantum computing market is projected to reach $65 billion by 2030, a hot topic for investors and scientists alike because of its potential to solve incomprehensibly complex problems.

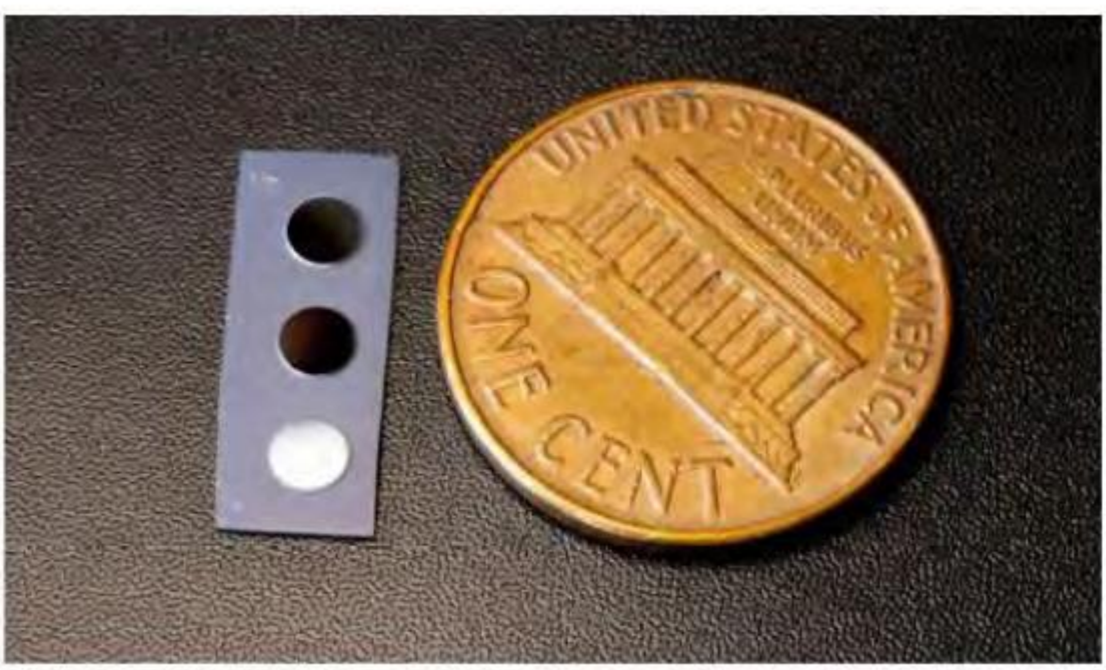
Drug discovery is one example. To understand drug interactions, a pharmaceutical company might want to simulate the interaction of two molecules. The challenge is that each molecule is composed of a few hundred atoms, and scientists must model all the ways in which these atoms might array themselves when their respective molecules are introduced. The number of possible configurations is infinite—more than the number of atoms in the entire universe. Only a quantum computer can represent, much less solve, such an expansive, dynamic data problem. Mainstream use of quantum computing remains decades away, while research teams in universities and private industry across the globe work on different dimensions of the technology.

Quantum Computing Platform Accelerates Transition from Bulk Optics to Integrated Photonics on a Silicon Chip Smaller Than a Penny

A research team led by Xu Yi, assistant professor of electrical and computer engineering at the University of Virginia School of Engineering and Applied Science, has carved a niche in the physics and applications of photonic devices, which detect and shape light for a wide range of uses including communications and computing. His research group has created a scalable quantum computing platform, which drastically reduces the number of devices needed to achieve quantum speed, on a photonic chip the size of a penny.

Olivier Pfister, professor of quantum optics and quantum information at UVA, and Hansuek Lee, assistant professor at the Korean Advanced Institute of Science and Technology, contributed to this success.

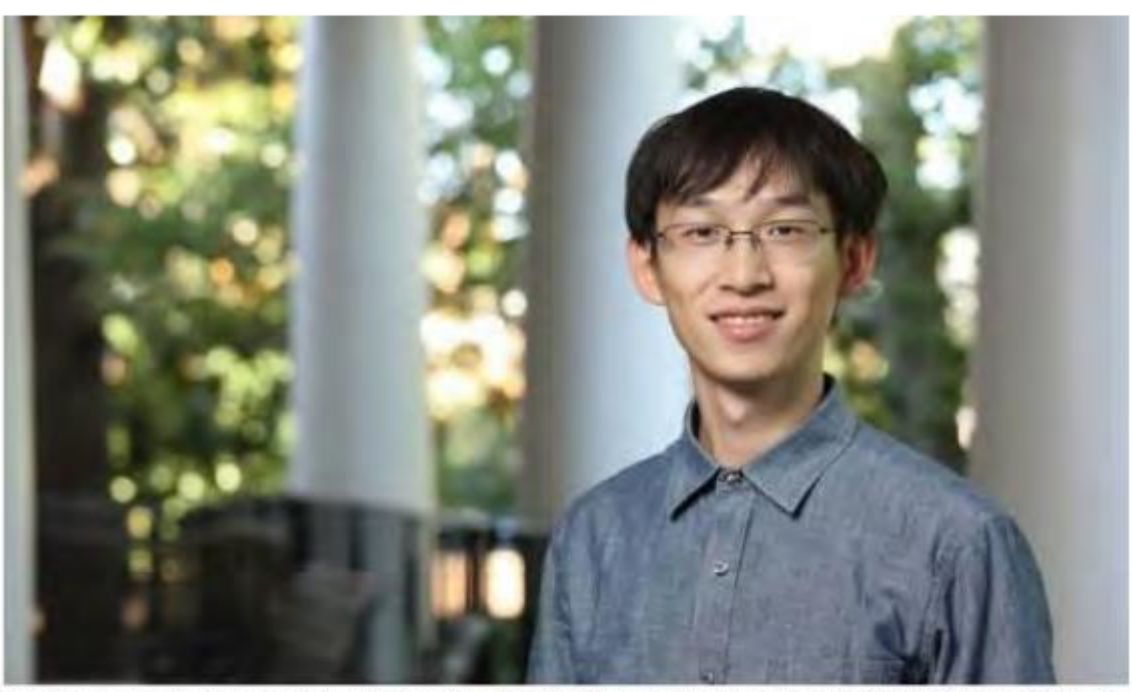
Nature Communications recently published the team‘s experimental results, ―A Squeezed Quantum Microcomb on a Chip.‖ Two of Yi‘s group members, Zijiao Yang, a Ph.D. student in physics, and Mandana Jahanbozorgi, a Ph.D. student of electrical and computer engineering, are the paper‘s co-first authors. A grant from the National Science Foundation‘s Engineering Quantum Integrated Platforms for Quantum Communication program supports this research. Quantum computing promises an entirely new way of processing information. Your desktop or laptop computer processes information in long strings of bits. A bit can hold only one of two values: zero or one. Quantum computers process information in parallel, which means they don‘t have to wait for one sequence of information to be processed before they can compute more. Their unit of information is called a qubit, a hybrid that can be one and zero at the same time. A quantum mode, or qumode, spans the full spectrum of variables between one and zero—the values to the right of the decimal point.



This silicon chip contains three optical microresonators that envelope photons and generate a microcomb to efficiently convert photons from single to multiple wavelengths. Yi's team verified the generation of 40 qumodes from a single microresonator, proving that multiplexing of quantum modes can work in integrated photonic platforms. Credit: University of Virginia

Researchers are working on different approaches to efficiently produce the enormous number of qumodes needed to achieve quantum speeds. Yi‘s photonics-based approach is attractive because a field of light is also full spectrum; each light wave in the spectrum has the potential to become a quantum unit. Yi hypothesized that by entangling fields of light, the light would achieve a quantum state. You are likely familiar with the optical fibers that deliver information through the internet. Within each optical fiber, lasers of many different colors are used in parallel, a phenomenon called multiplexing. Yi carried the multiplexing concept into the quantum realm. Micro is key to his team‘s success. UVA is a pioneer and a leader in the use of optical multiplexing to create a scalable quantum computing platform. In 2014, Pfister‘s group succeeded in generating more than 3,000 quantum modes in a bulk optical system. However, using this many quantum modes requires a large footprint to contain the thousands of mirrors, lenses and other components that would be needed to run an algorithm and perform other operations.

―The future of the field is integrated quantum optics, Pfister said. ―Only by transferring quantum optics experiments from protected optics labs to field-compatible photonic chips will bona fide quantum technology be able to see the light of day. We are extremely fortunate to have been able to attract to UVA a world expert in quantum photonics such as Xu Yi, and I‘m very excited by the perspectives these new results open to us. Yi‘s group created a quantum source in an optical microresonator, a ring-shaped, millimeter-sized structure that envelopes the photons and generates a microcomb, a device that efficiently converts photons from single to multiple wavelengths.



A research team led by Xu Yi, assistant professor of electrical and computer engineering at the University of Virginia School of Engineering and Applied Science, has carved a niche in the physics and applications of photonic devices, which detect and shape light for a wide range of uses including communications and computing. Credit: University of Virginia

Light circulates around the ring to build up optical power. This power buildup enhances chances for photons to interact, which produces quantum entanglement between fields of light in the microcomb. Through multiplexing, Yi‘s team verified the generation of 40 qumodes from a single microresonator on a chip, proving that multiplexing of quantum modes can work in integrated photonic platforms. This is just the number they are able to measure. ―We estimate that when we optimize the system, we can generate thousands of qumodes from a single device,‖ Yi said. Yi‘s multiplexing technique opens a path toward quantum computing for real-world conditions, where errors are inevitable. This is true even in classical computers. But quantum states are much more fragile than classical states. The number of qubits needed to compensate for errors could exceed one million, with a proportionate increase in the number of devices. Multiplexing reduces the number of devices needed by two or three orders of magnitude. Yi‘s photonics-based system offers two additional advantages in the quantum computing quest. Quantum computing platforms that use superconducting electronic circuits require cooling to cryogenic temperatures. Because the photon has no mass, quantum computers with photonic integrated chips can run or sleep at room temperature. Additionally, Lee fabricated the microresonator on a silicon chip using standard lithography techniques. This is important because it implies the resonator or quantum source can be mass-produced. ―We are proud to push the frontiers of engineering in quantum computing and accelerate the transition from bulk optics to integrated photonics,‖ Yi said. ―We will continue to explore ways to integrate devices and circuits in a photonics-based quantum computing platform and optimize its performance.‖