

# KARNATAKA PHYSICS ASSOCIATION (R.)

(Reg. No. DRB 2/SOR/210/2021-2022)

Website: [karnatakaphysicsassociation.in](http://karnatakaphysicsassociation.in)

KPA NEWSLETTER – 3

MAY 2024

## Editors

Prof. B. A. Kagali (Managing Editor)

Prof. Somashekar Sidiginamale

Prof. P. Nagaraju

Prof. S. P. Basavaraju

Prof. M. R. Nandan



## **Content**

**S N BOSE – THE FOUNDER OF QUANTUM STATISTICS**

**PETER HIGGS OBITUARY: THE SHY MAN WHO CHANGED OUR UNDERSTANDING OF THE UNIVERSE**

**GRAVITATIONAL WAVES – A NEW TOOL TO PROBE THE UNIVERSE**

**WORLD FAMOUS INDIAN SCIENTISTS/PHYSICISTS**

**GALILEO GALILEI – A POLYMATH**

**ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ - ಒಂದು ವೈಜ್ಞಾನಿಕ ವಿಶ್ಲೇಷಣೆ**

**WHAT IS SCIENCE AND WHO ARE SCIENTISTS?**

**PHYSICS & CHATGPT**

**Roddam Narasimha (1933-2020):  
AN ENGINEERING SCIENTIST PAR EXCELLENCE**

## S N BOSE – THE FOUNDER OF QUANTUM STATISTICS

Dr B. A. Kagali

Professor and Chairman (retd.) Department of Physics,  
Bangalore University.

Email: bakagali@gmail.com



Ever since the discovery of the Higgs Boson in 2012, the new particle has made frequent appearances in scientific and world media. Many people recognize Peter Higgs—one half of the particle's namesake, but fewer realize that the "Boson" half of the particle's name refers to the Indian physicist Satyendra Nath Bose.

Although not as well known as his contemporaries, S.N. Bose was arguably one of the most important scientists of the 20th century. His revolutionary way of viewing photon behavior and photon statistics—later known as Bose statistics—changed the field in a dramatic way. Albert Einstein played an integral role in publishing his work and also extended Bose's new statistics to atoms and predicted the Bose-Einstein condensate (BEC).

### Early life and education

Satyendra Nath Bose was born on 1 January 1894 in Calcutta, the capital of British India at that time. At the age of five, he enrolled in the Normal School in North Calcutta and completed his final years of primary education at the Hindu School in Calcutta. When he was eight, Bose demonstrated extraordinary intellect and mathematical talent. He developed an urbane, liberal and open-minded character with deep curiosity along with love of the arts. Following his studies at the Hindu School, Bose studied at the Presidency College in Calcutta from 1909 to 1915. Although he suffered from weak vision, he loved to read - his favorite poets were Tagore and Tennyson. His motivation to study science was similar to that of many of his fellow students: application of science could facilitate the advancement of and prosperity in the country.

Presidency College was the best place to study science in Calcutta, and the competition to get admission was intense; about 2,000 applicants competed for 32 seats! Bose overcame the odds and earned himself a seat. He was impressed with his science teachers and especially with the lectures and laboratory demonstrations of his physics teacher : Jagadish Chandra Bose, who had developed novel instruments to produce and detect millimetre waves. On his final examinations, Bose achieved the highest ranking among the B.Sc. students and repeated this feat on his M.Sc. examinations.

In 1914, at the age of 20 and while still an M.Sc. student, Bose married Ushabati Ghosh, the 11-year-old daughter of a prominent physician in Calcutta.

## Early professional life

In 1917, Bose became a lecturer in physics and applied mathematics at the University College of Science, Calcutta University. In 1918, Bose and Meghnad Saha published a joint paper on the kinetic theory of gases in the prestigious English journal: *Philosophical Magazine*. Subsequently they translated Einstein's papers into English so that Indian students who did not know German could read them. This work, 'The Principles of Relativity', which contained papers by Einstein and Hermann Minkowski, was published in 1919 by Calcutta University.

Bose worked at the University of Dhaka in East Bengal from its founding in 1921 to 1924. His initial post was as a Reader in the physics department. He taught courses on thermodynamics and electromagnetic theory to the M.Sc. students. For Bose, Dhaka was isolated from the European centres and thus from many of the modern developments in relativity theory and quantum theory. His colleague Debendra Mohan Bose, who returned from his doctoral studies in Germany in 1919 and gave Bose a wonderful gift: Max Planck's book :*Thermodynamik und Wärmestrahlung*.

## Bose's 1924 publications

Bose read Planck's papers on the distribution of energy in blackbody radiation in order to teach that material to his class. He was disturbed by Planck's derivation of the law with its ad hoc assumptions. In 1924, Saha stayed with Bose in Dhaka and pointed out the 1923 papers of Wolfgang Pauli, Einstein and Paul Ehrenfest and their relation to Einstein's 1917 paper. This led him to develop Bose statistics—a new method to count states of indistinguishable particles—and applied it to his derivation of Planck's radiation law. Bose wrote two papers in which he independently derived and further developed the previous work of Planck: "Planck's law and the light-quantum hypothesis," and "Thermal equilibrium in the radiation field in the presence of matter." He considered the papers as a single unit and submitted them to the 'Philosophical Magazine'. He did not receive a reply from the prestigious English journal; therefore, on 4<sup>th</sup> June 1924, he sent the first paper to Einstein, along with a letter: "If you think the paper worth publication, I shall be grateful if you arrange for its publication in *Zeitschrift für Physik*. Though a complete stranger to you, I do not feel any hesitation in making such a request. Because we are all your pupils though profiting only by your teachings through your writings."

The two had corresponded earlier, when Bose had asked Einstein if he could translate his paper on generalized relativity into English for which Einstein had agreed. Bose's first paper stated that, in the thermal equilibrium of massless particles (photons), the number of particles is not conserved due to the absorption and emission of photons. These particles could be described in a new way—with Bose statistics, which used the counting of cells in one-particle phase space instead of the previous method of totalling the number of standing waves in a cavity in order to obtain the number of states. Only one year earlier, Arthur Compton had published his seminal paper on the Compton effect. Bose interpreted  $Z$ , the number of states in the frequency interval between  $f$  and  $f+df$  as the number of cells that contain a given number of photons with frequency  $f$ , and not the number of particles, as was previously done by Boltzmann. On 14<sup>th</sup> June, he sent Einstein his second paper: "I hope my first paper has reached your hands. The

result to which I have arrived seems rather important (to me at any rate). You will see that I have dealt with the problem of thermal equilibrium between radiation and matter in a different way, and have arrived at a different law for the probability of elementary processes, which seems to have simplicity in its favour.” Both papers put forward the idea that the fundamental assumptions of quantum theory are not compatible with the laws of classical electrodynamics. According to Bose, all previous derivations of the relation between energy density and the average energy of a resonator use classical assumptions and resulted in logical flaws. He stated that Einstein’s 1917 derivation used “Wien’s law based on the classical theory and the Bohr correspondence principle, which assumes that the quantum theory agrees with the classical theory in certain limiting cases.” Bose went on to say that “a new form of statistical mechanics is required to be compatible with quantum theory; these logical flaws can be solved by using statistical mechanics without any assumption of mechanism of elementary processes on which the energy exchange depends.” Bose followed Einstein’s light-quantum hypothesis and considered blackbody radiation as light-quanta in a volume. He then continued in several steps, the most significant of which was how to calculate the number of states of a light-quantum in the frequency range of  $f$  and  $f + df$ . Bose extended Planck’s “first quantization” of the material oscillators to the radiation field itself (photons). With the knowledge of the Compton effect, Bose assumed that the photon of frequency  $f$  “has momentum of magnitude  $hf/c$  in direction of its motion.” Bose divided the total phase space volume into cells of volume  $h^3$  and multiplied the resulting formula by a factor of two. His paper explained that the factor of two was required “in order to take into account the fact of polarization.”

While Einstein had both of Bose’s papers published in *Zeitschrift für Physik*, his comments that were appended on each were very different. On Bose’s first paper, Einstein was enthusiastic and viewed the work as a significant contribution. But Einstein’s long appended comments on the second paper were very different: “Your principle is not compatible with the following two conditions: (1) the absorption coefficient is independent of the radiation density. (2) The behaviour of a resonator in a radiation field should follow from the statistical laws as a limiting case.”

Bose was disappointed with Einstein’s comments on his second publication and on 27<sup>th</sup> January, 1925, he wrote his rebuttal to Einstein: “I have written down my ideas in the form of a paper which I send under separate cover ... I have tried to look at the radiation field from a new standpoint and have sought to separate the propagation of quantum of energy from the propagation of electromagnetic influence...” Bose later stated that, in his paper, he gave a quantum mechanical explanation for the factor of two, but that Einstein removed it and replaced it with the polarization argument. While the original Bose paper in English is missing from the archives, it is likely that Bose postulated the light-quanta had an intrinsic spin with only the values of  $\pm h/2\pi$ . He felt that his postulated idea of photon spin was lost when Einstein presumably removed it from his paper and replaced it with the sentence about polarization. Bose then stated: “The total number of cells must be regarded as the number of possible arrangements of a quantum in a given volume.” He then showed that the factor  $8\pi f^2/c^3$  in Planck’s law is the total number of quantum states of the radiation. Next, he calculated the thermodynamic probability of a state. Furthermore, he stated, “... since each cell is to be counted as a single quantum state ... consequently the cells can be partitioned into distinct classes characterized solely by their occupation numbers.” Finally, he followed the standard

techniques to derive Planck's law. Bose never cited the previous works of Natanson nor the works of Ehrenfest and Onnes.

Bose believed that Einstein misunderstood the content of his paper. This appeared to have dampened his desire to pursue research. While in Germany, Bose did not publish any papers and even after he returned to India, he did not produce any original work in theoretical physics for the next 12 years.

### **Bose-Einstein Condensate**

One week after he received Bose's first paper, Einstein extended Bose's statistics and applied them to a monoatomic ideal gas whose numbers are conserved. He submitted three papers on this work to the Prussian Academy of Science in Berlin on 10<sup>th</sup> July 1924, 8<sup>th</sup> January 1925 and 29<sup>th</sup> January 1925. He did this without Bose's consent and without asking him to collaborate! Furthermore, in two of the papers, Einstein incorrectly cited Bose's statistics as having been devised by D. Bose, referring to another physicist, Debendra Mohan Bose. The paper Einstein presented to the Prussian Academy on 8<sup>th</sup> January 1925 showed that, below a critical temperature, there was a collection of identical atoms, some of which would make a transition to the first quantum state—a state without kinetic energy. Einstein wrote: "A separation occurs - one part 'condenses,' the rest remains a 'saturated ideal gas.' " The concept of a BEC changed from an idea to reality in 1938 when Fritz London made the proposal that the 1928 discovery of superfluidity in Helium-4 was due to a BEC. A modern description states that, at high temperatures, the particles in a Boson gas are distributed into energy levels given by Bose-Einstein statistics. Below a critical temperature, a macroscopic number of particles condense in the ground state and form a BEC. Thus, we can observe quantum behavior on a macroscopic scale and investigate many of the fundamental properties of matter. The first BEC of a gas was made in 1995 by Eric Cornell and Carl Wieman; they and Wolfgang Ketterle shared the 2001 Nobel Prize in Physics for their work.

### **Work in Europe and later life**

From 1924 to 1926, Bose lived in Europe. He spent the first year in Paris and then went to Berlin, where he was hoping to work with Einstein, since he knew that Einstein had published a subsequent paper that extended his work and predicted the Bose-Einstein condensation. When they finally met in Berlin, Einstein was working on a new subject: the unification of the electromagnetic and the gravitational fields. This change of research precluded them from working together; however, Einstein gave Bose a letter of introduction, which proved helpful for Bose to meet many German physicists.

With letters of recommendation from Albert Einstein, Paul Langevin and Herman Mark, Bose became a professor and the head of the department of physics when he returned to Dhaka, despite the fact that he did not have a doctoral degree. Bose's mission was to introduce the latest developments in physics and chemistry to his university.

In 1945, Bose moved to Calcutta University, where he remained until 1956 when he became a professor emeritus upon his retirement. He then taught physics at Santiniketan, the school

founded by Rabindranath Tagore, the well-known poet and educationist in 1921. Bose and Tagore were friends, and Tagore dedicated his book 'Our Universe' to Bose. However, Bose faced severe opposition from the other teachers in the arts there, who feared that the teaching of science would move the schools' focus away from their subjects; therefore, after two years at Santiniketan, Bose again returned to Calcutta as a national professor.

Later in his career, Bose received many awards and honours for his contributions to science education and research in India. He was elected president of the Indian Physical Society in 1945 and held the position until 1948. He also served as president of the National Institute of Sciences of India from 1948 to 1950. In 1958, he was made a Fellow of the Royal Society. From 1954 to 1959, he was made a member of the upper house of the national parliament.

Bose died one month after his 80<sup>th</sup> birthday on 4 February 1974. As a tribute to his life's work, the government of India established the Satyendra Nath Bose National Center for Basic Sciences in Calcutta in 1986. Although they didn't always agree, Bose's work with Einstein changed the landscape of new physics in the 20<sup>th</sup> century. Fifty years after his death, his contributions to scientific knowledge continue to benefit the community and will do so for generations to come.

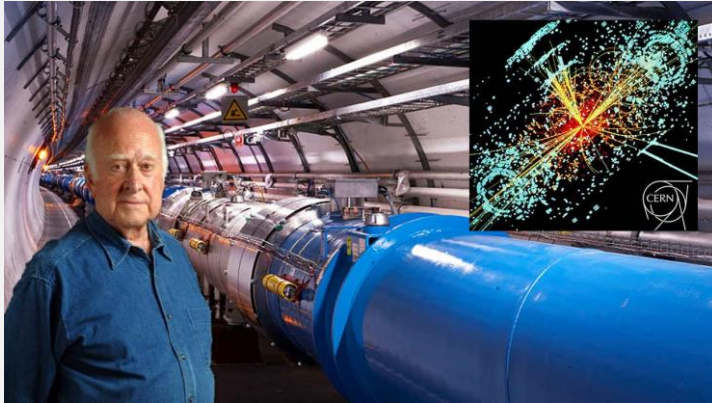
\*\*\*\*\*



## Peter Higgs Obituary: the shy man who changed our understanding of the Universe

(Georgina Rannard, BBC News Climate & Science)

Prof Peter Higgs was best known for that mysterious-sounding thing nicknamed the 'God particle' - or just simply, and probably better-put, the Higgs boson. He came up with the revolutionary idea in the 1960s when he wanted to explain why the basic building blocks of the Universe - atoms - have mass.



His theory about what binds the Universe together, which other scientists also worked on at the same time, sparked a 50-year search for the Holy Grail of physics.

The particle was finally discovered in 2012 by scientists using the Large Hadron Collider at the European Organization for Nuclear Research (CERN) in Switzerland. It completed what is called the standard model of

particle physics. A famously shy man, he told journalists: "It's very nice to be right sometimes." His work earned him the Nobel Prize for physics a year later.

Peter Higgs was born in Newcastle upon Tyne in 1929. At school in Bristol he was a brilliant student who won prizes for his science work - though it was in chemistry, not physics. He completed a PhD at King's College in London but was beaten to a job there by his friend. Instead he went to the University of Edinburgh where he continued to ask the question: why do some particles have mass? His theory struggled to find a place in scientific journals - partly because few understood it - but it was finally published in 1964. Despite rumours about "Eureka" moments, he said his theory was formed over years.

Two other groups of scientists also published work at that time about the same idea. But the particle became known as the Higgs boson - and for 50 years scientists looked for it using some of the most spectacular technology on Earth. Prof Higgs retired from the University of Edinburgh in 2006, but he continued to watch developments at Cern in Geneva, where scientists were using the Large Hadron Collider to look for the Higgs boson.

The particle accelerator, built at a cost of \$10bn, was the most powerful yet. It was considered the machine that could prove - or disprove - Higgs's theory. The boson had been nicknamed the 'God particle' by the media, after a book by Nobel laureate Leon Lederman. Scientists object to the term because they say religion has no role to play in evidence-based physics. In 2012 physicists at Cern finally announced to great fanfare that they had discovered the Higgs boson.

An advance notice had been sent: "Peter should come to the CERN seminar or he will regret it." He changed travel plans to visit Geneva for the stunning announcement. "It's been a long wait but it might have been even longer, I might not have been still around," Higgs said. "At the beginning I had no idea whether a discovery would be made in my lifetime."

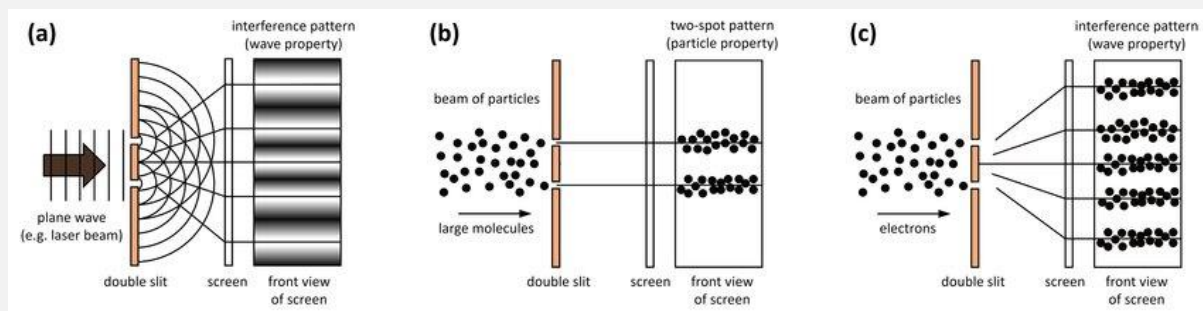


A year later the Royal Swedish Academy of Sciences tried to call him. It's become a trope that winners miss the crucial phone call telling them they have been awarded a Nobel Prize. But Peter Higgs did not even own a mobile phone. The announcement was made in his absence.

A neighbour stopped him in the street to break the news that he'd won - alongside Belgian physicist Francois Englert. He was known first for the boson, but second for his shy and low-key personality - more interested in his work than fame.

Oxford emeritus professor Ken Peach talked about returning from a conference where scientists were referring constantly to Peter Higgs. "I saw Peter in the coffee lounge and said 'Hey Peter! You're famous!'" He responded with a diffident smile. And some friends feel Peter Higgs did not make the kind of impact that might be expected of a physicist of his ability. "I wouldn't say he was shy," said Prof Michael Fisher, who died in 2021. "I might say that he was a little too retiring perhaps for the good of his own career."

### Interference of electrons



## GRAVITATIONAL WAVES – A NEW TOOL TO PROBE THE UNIVERSE

**Dr T. Shivalingaswamy**

Professor of Physics, PG Department of Physics,  
Maharani's College for women, Mysuru

**Abstract:** This article articulates gives a brief account of sources of gravitational waves, different methods available for their detection, the role of LIGO in its detection and lastly highlights the profundity of its impact as a part of multi-messenger astronomy.

*'If you ask me whether there are gravitational waves or not, I must answer that I do not know. But it is a highly interesting problem.'* - **Albert Einstein**

**1. Introduction:** Many Studies of gravity have advanced human knowledge and understanding of the universe to a very great extent. Two greatest scientists of all time, namely, Sir Isaac Newton and Albert Einstein stand in the front row among those who have made significant contributions to this field. Newton published his Universal Law of gravitation in *The Mathematical Principles of Natural Philosophy* (1687), commonly known as the *Principia* in which he stated that 'Every mass attracts every other mass in the universe, and the gravitational force between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them'. Before Newton published this work, it was presumed that there existed two types of gravity:

- 1) terrestrial gravity (causing attraction of objects towards the center of the Earth), and
- 2) astronomical gravity (causing attraction between celestial objects).

Newton's law of gravitation unified the above two and stated that gravity is universal and is valid for any two masses. This law of gravitation implied instantaneous action between any two masses at a distance, a hypothesis which shaped Newtonian mechanics for over two hundred years. It violated the principles of relativity. However, it does not explain the nature of gravity. Two hundred years later Albert Einstein changed scientists' perception of gravity. Through his famous field equations, derived in 1915, Einstein was able to establish that the gravity is nothing but curvature in the space-time fabric due to mass and energy, which pervades the universe. This new perception of gravity, as space-time curvature has been experimentally validated by phenomena such as anomalous precession of the perihelion of Mercury over a period of time due to the curvature of space-time around the massive sun, gravitational redshift and bending of light around intense gravitational field. It also led to the phenomenon which is referred to as *gravitational lensing*.

Analogous to an accelerated charge emitting electromagnetic waves, an accelerated mass generates fluctuations in space-time and these fluctuations (*ripples*) in space-time that propagate in spacetime are called *Gravitational Waves* (GW). GW also propagates at the speed of light away from their source and they hardly interact with matter on their way. Similar to other waves, the intensity of GW gets reduced with distance. When a GW traverses, the space is stretched and squeezed alternately in the direction perpendicular to the propagation direction. The effect is opposite in perpendicular directions. Based on the directionality of the process of stretching and squeezing of space with respect to its own direction of propagation, GW are said to exhibit two types of polarizations, namely, plus (+) and cross (×). (figure?) The detection of GW was a great necessity for physicists for several reasons. Right from prediction

by Einstein of General Theory of Relativity (GTR), GW remained elusive. They would create new window for the understanding of the universe. Like a new sensing tool, they added a new dimension to astronomy and astrophysics. Their detection verified the prediction made by GTR and helped physicists to understand gravity itself. It is one thing to say that gravity explained terrestrial and celestial phenomena. It is another thing to say that gravity itself became explicable. The tool of explanation itself became the subject of explanation. This is a remarkable shift in our study of the universe. Added to this, the detection of GW paved the way for the existence of black holes (BH), massive binary systems etc. It may also throw some light on celestial objects that existed in the early universe, which we either know only a little or do not know at all.

**2. Sources of Gravitational waves:** Several factors lead to the generation of GW. In the first place, massive and compact objects, several times the mass of the sun, rotating very fast, may produce GW. Several Neutron stars, Pulsars, BH, etc., exist in binary form. During Einstein's time, these were yet to be discovered. Interestingly, Einstein doubted the existence of both BH and GW. BH were too incredible to be believed. Understandably, Einstein and his contemporaries doubted the existence of GW. GTR predicts that when there is a merger of massive binary system, huge amount of mass (of the order of  $10^{30}$  kg) is converted into energy and thus carried away by GW. GW are produced also whenever one celestial object inspirals towards the other and between them there exists an extremely high mass ratio. ( formula for gravitationl radiation rate?) Rapidly rotating neutron stars that deviate from their spherical symmetry and also asymmetrical explosion of stars emit also GW. Similar to other conventional waves, GW also carry energy of the order of  $10^{47}$  J. Since they hardly interact with matter, it is almost impossible, to detect them. If neither energy nor momentum is exchanged between any two bodies, then there is no way to detect the same (as in the case of weakly interacting particles such as neutrinos). Thus, a careful mechanism is required to enable their detection.

**3. Methods of detection of GW:** Several methods were proposed to detect GW. Some of them are referred to as indirect methods as they just indicate the existence of Gravitational waves through secondary results. Among indirect methods some are mentioned below:

**i. Resonant Bars:** Joseph Weber in the early 1960s designed the first *Resonant Bar Detector* in which GW impinging on the massive aluminum cylinders (of a few thousand kg) would set the cylinders in vibration. A small change in the length of the cylinders due to impinging of GW causes piezoelectric strain gauges at center of bar which, in turn, produces a small electrical voltage. But GW can deform the bar to the order of  $10^{-16}$  m. The electrical voltage generated by this small strain is not strong enough to be measured by any device. At one stage, Weber claimed that he was successful in the detection of GW. However, the follow up searches failed to confirm his claim. Physicists upgraded this technique by introducing superconducting quantum interference device (SQUID) to amplify signal voltage. Many laboratories came up based on this method. This proved that Weber was successful in convincing physicists of the relevance of this technique. Major laboratories that employed this technique are listed below:

1. ALLEGRO (Baton Rouge, USA), Mass of the bar 2296 kg, length 3 m, bar temperature 4.2K
2. AURIGA (Legrano, Italy), Mass of the bar 2230 kg, length 2.9 m, bar temperature 0.2K

3. EXPLORER (CERN, Switzerland), Mass of the bar 2270 kg, length 3m, bar temperature 2.6K
4. NAUTILUS (Frascati, Italy), Mass 2260 Kg, length 3 m, bar temperature 0.1 K



Figure 1: Weber and one of his room temperature bars (60's) (Credit: LSU Gravity Allegro group)

**ii. Binary Pulsars:** Russell Hulse and Joseph Taylor discovered in 1974 a binary system of a pulsar and a neutron star orbiting about a common centre of mass. A pulsating star (abbreviated as *pulsar*) emits radio waves at a very precise interval of time. A pulsar is thus referred to as a high- precision celestial clock. Hulse and Taylor measured the orbital period of this pulsar and found that there was a systematic reduction in its value over the period of observation. This can happen only if the pulsar is continuously losing its energy. Using the principles of GTR Hulse and Taylor calculated the amount of energy lost per rotation. The observed shift in period of the pulsar precisely matched with the one theoretically calculated assuming that energy is carried away by GWs in such a system. This is an indirect evidence for the existence of GW. For their work, Hulse and Taylor were awarded the Nobel Prize in Physics in 1993. From then onwards several other binary pulsar systems have been studied and similar calculations have led to similar inference about the existence of GW.

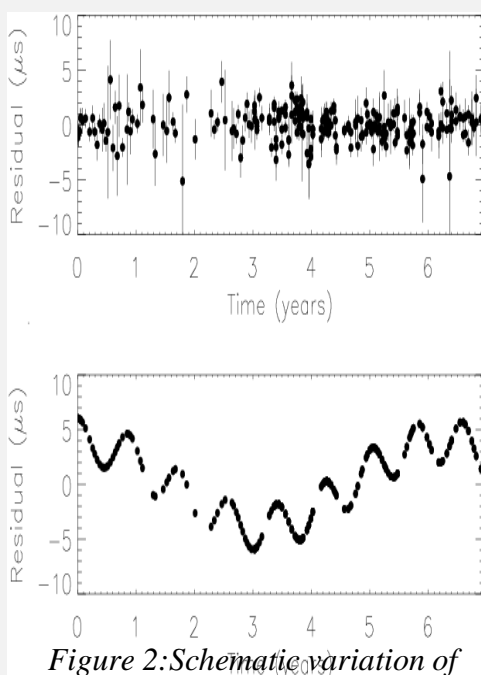


Figure 2: Schematic variation of orbital period variation of a binary pulsar.

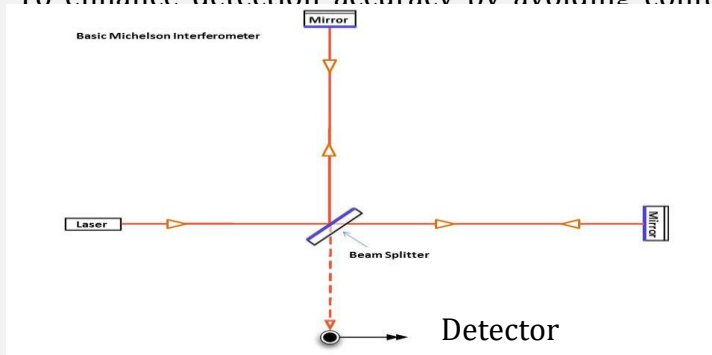
**iii. Laser Interferometers:** The first light interferometer was devised by Albert Michelson. In 1890s he used this interferometry technique for precise measurement of the speed of light. During this time there was a suggestion to use interference of light waves to measure the small displacement that a GW would bring in the detector arms. Light Interferometers exploit quadrupole nature of GW. These interferometers consist of a laser source that gives a powerful laser beam that is transmitted in perpendicular directions using a beam splitter and combine them on return from mirrors to construct interference patterns as shown in figure-1. The essence of this method is that modification in the distribution of intensity of the waves due to superposition of the split waves depends on the

distances travelled by them up to the point of interference.

Alternatively, if the distances of the mirrors from the detector are rigidly fixed, the intensity distribution of the wave at the points of superposition will exclusively depend on the speed of the wave. Thus, if the speed of the light wave is kept constant, then the distribution of intensity at the points of superposition will be a measure of change in distances travelled by light waves before superposition (if it had happen by some means). Since GW alters the space-time when they are impinged on matter, one can use this deformation produced by GW to detect them. This is the vital idea of ground based light interferometers used for detection of GW. The sensitivity of such detectors mainly depends on arm length. Thus, Laser interferometers with large arm length were installed at many places around the globe. Few of them are listed below:

- a) **LIGO** – US project. Two 4km and one 2km detector. At Hanford and Livingston
- b) **GEO 600**– British/German project. One 600m detector.
- c) **VIRGO** – Italian/French project. One 3km detector.
- d) **TAMA 300**– Japanese project. One 300m detector.
- e) **AIGO** – Australian project. One 80m detector.

To enhance detection accuracy by avoiding confusion due to irrelevant signals from



a space-based interferometer, LISA jointly by NASA/ESA. LISA consists of a large baseline (about 5 million km). LISA will detect GW when it comes into operation in the next chapter in astronomy.

*Figure 3: Schematic Image of Laser Interferometer  
(Credit: <https://www.ligo.caltech.edu/page/ligos-ifo>)*

### LIGO (Laser Interferometer Gravitational Observatory)



LIGO is a programme with two observatories located in the cities of Hanford in Washington State and Livingston, in Louisiana State of the United States of America. The distance between these two detectors is about 3000 km. This huge separation is to ensure that the detectors are not responding to the locally generated fake signals. LIGO was funded by National Science Foundation (NSF) and led



by Kip Thorne and Ronald Drever of California Institute of Technology (Caltech) and Rainer Weiss of Massachusetts Institute of Technology (MIT) in 1992. LIGO is a joint project involving scientists at MIT and Caltech. At present, more than 900 members from more than 80 institutions in 17 countries are working and analyzing the data. The LIGO detector situated at Hanford has two arms in perpendicular directions. Each arm is 4 km in length. GWs alternatively stretch and compress space. Therefore, if there is a phase difference between the electromagnetic waves, then it must be due to the fact that one arm has been stretched while the other has been compressed. This can be observed with change in fringe pattern at detector site. On 14<sup>th</sup> Sep 2015, LIGO detectors, in Livingston and Hanford, with a time difference of 7 milliseconds recorded the first ever signal of GW. However, the official announcement of this

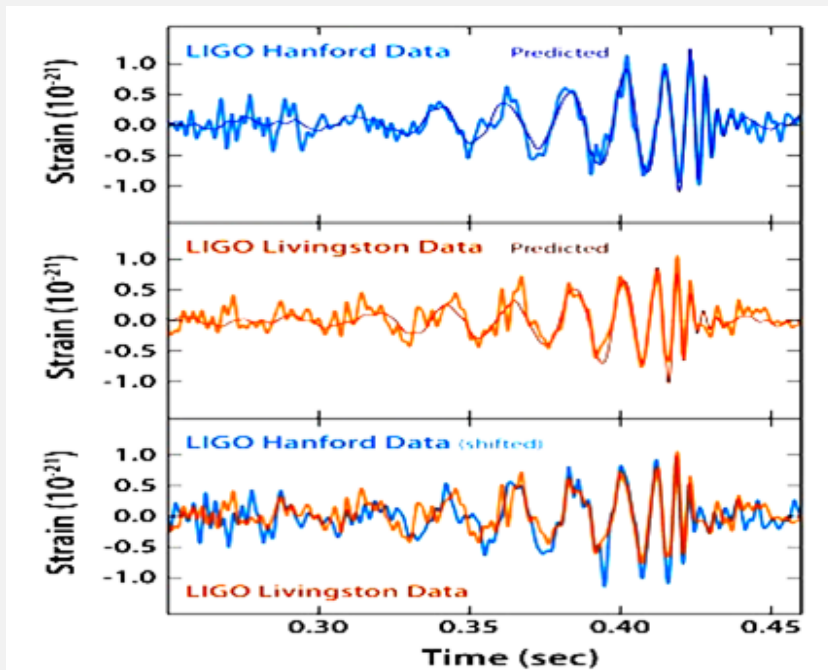


Figure 4: First signal recorded by LIGO detectors  
(Credit: <https://www.ligo.org/detections/GW150914.php>)

path-breaking discovery was made on 11<sup>th</sup> Feb 2016, after a thorough verification of the data. LIGO announced that the signal which was recorded is the result of the merger of two BH with a total mass of about 65 solar masses merged into a single super massive BH of 63 solar mass. The missing mass was entirely converted into energy in accordance with the famous Einstein's equation:  $E = mc^2$ , and is carried away by GW. This merger took

place 1.3 billion light years away from the detector. Thus LIGO detected an event happened 1.3 billion years ago. This great discovery not only proved the existence of GW but also gave a round about evidence for the existence of BH. Recently VIRGO joined LIGO and has recorded more than five signals. For the decisive contributions to the LIGO detector and the observation of GW, Rainer Weiss, Barry Barish and Kip Thorne were awarded Nobel Prize in Physics for 2017.

#### 4. Indian Initiative in Gravitational Wave Observations (IndIGO)

The major objective of IndIGO is to enhance the network of gravitational wave detectors worldwide. The network includes the two LIGO detectors in the US (in Hanford and Livingston), the Virgo and GEO 600 detectors in Europe, and the proposed KAGRA detector in Japan. The three pilot institutions in India namely, Institute of Plasma Research (IPR), Inter-University Centre for Astronomy and Astrophysics (IUCAA) and Raja Ramanna Centre for Advanced Technology (RRCAT) are leading the project. On 17<sup>th</sup> February 2016, less than a week after LIGO's landmark announcement about the detection of GW, the Government of India granted 'in-principle' approval to the IndIGO project. At present, land survey has been



done and a place near Hingoli district in Maharashtra State has been identified for its installation. IndIGO currently has over 70 member scientists; Bala Iyer of International Center of Theoretical Sciences is the Chairperson of IndIGO Consortium.

**5. Discussion:** Gravitational waves bear certain important information such as mechanism by which they were created, mass/energy that is responsible for its creation, the distance from the Earth to its origin etc. This information in sequence may give clue to the nature of celestial objects that generate GW. So far, the Universe has been studied with the aid of electromagnetic waves (right from gamma rays to radio and microwaves). However, the discovery of GW has opened up a new window to study the Universe. Definitely, if LIGOs works with light-based telescopes and observatories, then experiments will have two senses: light-based observatories can *see* and LIGOs can *hear* so that we shall have *Multimessenger Astronomy*. This may even chuck some light on 96% of the unknown universe - dark matter and energy.

**8. Acknowledgements:** My thanks are due to Mangala Gowri M, University College of Science, Tumkur University, Tumakuru, I greatly acknowledge the discussions carried out with Sri Nandan M. R. Associate Professor of Philosophy (Retd.), Smt. N.S. Sindhu, Associate Professor, Maharani's Arts College Mysuru and Prof. B.A. Kagali, President, KPA, Bengaluru.

**Web References:**

1. <http://www.gravity.pd.uwa.edu.au>
2. <http://www.ligo.org>
3. <http://www.ligo-la.caltech.edu>
4. <http://focus.aps.org>
5. <http://www.physicscentral.com>

\*\*\*\*\*

## World Famous Indian Scientists/Physicists

Dr B. Rudraswamy

Professor of Physics (retd.), Bangalore University

The Indian Scientists contributed immensely for all round development of Science not only within India but at the world stage. Both India and the entire world immensely benefited by their extraordinary scientific contributions. Our lives have immensely improved in view of their sacrifice. The World famous Indian Scientists /physicists are : 1.CV Raman 2.Subramanyam Chandrasekhar 3. Vikram Sarabhai 4. Homi J Bhabha 5. APJ Abdul kalam 6 .Jagadish Chandra Bose 7.Satyendra Nath Bose 8.Meghnad Saha 9. Srinivasa Ramanujam 10.Har Gobind Khorana 11.M.Visveswaraya 12 . Salim Ali 13.Birbal sahani

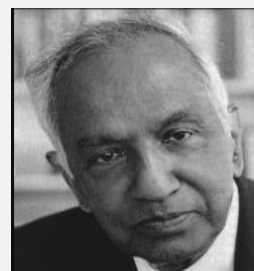
### 1. CV Raman ( 7 November 1888 - 21 November 1970)



The first Indian who won the Nobel prize for Physics (1930) . He was the first Indian Director of Indian Institute of Science (IISc) Bangalore .He was honored with the Fellow of Royal Society of London, ,Franklin medal and Lenin peace prize awards. He was honored with Knighthood by Indian British Govt due to which “ Sir” was prefixed before his name He served as Professor of Physics in Calcutta University. He discovered well known Raman effect in which light changes its color upon scattering by substance. He was the first Physicist to explain Scientifically the appearance blue color of ocean.

### 2. Subramanyam Chandrasekhar (19 October 1910 -21 August 1995)

The first Indian - American who won the Nobel prize in the field of Astrophysics(1983) for studies on structure and evolution of stars. He served as Professor of Physics spending entire life in America. He was honored with gold medal of astronomy and Royal medal Copley medal awards. The X-ray observatory of Columbia space shuttle was named after him, launched by NASA , America .The famous Chandrasekhar limit theory is being used widely in Astronomy.



### 3. Vikram Sarabhai ( 12 August 1919 -30 December 1971)



He was popularly known as the father of the Indian space program. He was honored with Bhatnagar (1962) and posthumously Padmabushan (1972) awards. He played a key role in the launch of Aryabhata, the first Indian satellite. He was responsible in establishing within India, the Institutes like Indian space research organization (ISRO), Indian institute of management (IIM ) and Electronic and uranium corporations of India (EUCI) . To honor his contribution to Indian space research program, the Lander of recently successfully launched Chandrayan –III was named after him.

**4.Homi J Bhabha (30 October 1909 -24 January 1966)**

He was popularly known as the father of Indian nuclear power program which is being widely used to generate electric power and for defense system. He was honored with the Fellow of Royal Society of London, Padmabhusan (1954), Adams prize and Hopkins prize awards by University and Philosophical society of Cambridge, London. He was the first Chairman of atomic energy of India. He was responsible in establishing the Bhabha atomic research centre (BARC) and Tata institute of fundamental research institute (TIFR) within India

**5. APJ Abdul kalam (15 October 1931- 21 July 2015)**

He was popularly known as the father of Indian missile program. He served as the eleventh <sup>President</sup> of India (2002-2007). He played a key role in Pokran II nuclear test program of India. He rendered immense service both in Defence research and development organization (DRDO) and Indian space research organization (ISRO). He served as Defence scientific advisor and Principal scientific advisor to Govt. of India. He was honored with Padmabhusan (1990) and Bharat Ratna (1997) awards.

**6. Jagadish Chandra Bose (30November 1858- 3 November1957)**

He was popularly known as great Physicist and Botanist He was the first Indian Botanist to invent Crescograph, a device used to measure plant growth and breathing. He was the first Physicist to invent wire telegraphy, a device used to transmit radio signals without cable, before the invention by Italian scientist Marconi. However, the Jagadish Chandra Bose missed this credit due to the lack of not registering the patent well in time. He was the first Indian to start writing science frictions. He was honored with the Fellow of Royal Society of London, and Knighthood by Indian British Govt.

**7. Satyendra Nath Bose (1 January 1894 - 4February 1974)**

He was popularly known as the Einstein of India. He developed the popular theories such as Bose –Einstein statistics and Bose condensation in collaboration with World famous Physicist Abert Einstein. He was honored with fellow of Royal society of London ((1953) and Padmabhusan (1954) awards. The Spin  $\frac{1}{2}$  particles like electron, protons, neutrons etc., are together named after his name as “ Bosons “.



**8. Meghnad Saha (6 October 1893 -16 February 1956)**



The famous Indian astrophysicist, whose equation is popularly known as the "Saha equation," is being used worldwide to understand the characteristic features of spectral lines of stars. He was honored with the Fellow of the Royal Society of London. He was responsible for establishing the famous Saha Institute of Nuclear Physics. He also played a key role in establishing the Indian Physics Association in Calcutta. Additionally, he was responsible for preparing the original plan of the Damodar Valley.

**9. Srinivasa Ramanujam (20 December 1887-6 April 1920)**

He was popularly known as the genius of mathematical science. He was the first Indian mathematician elected as a Fellow of Cambridge University in London. He compiled independently around 4000 world-class mathematical results and published several mathematical results on the global stage. His unpublished results are now being verified by many mathematical experts worldwide. He died at the age of 32 due to health complications. Even without proper formal education, he did brilliant mathematical work that was appreciated globally.



**10. Har Gobind Khorana (9 January 1922- 9 November 2011)**



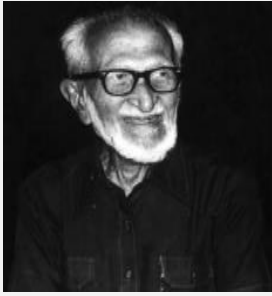
He won the Nobel Prize in 1968 for his work in physiology and medicine. He was an Indian-American who served in various countries like Switzerland, Canada, and America. He interpreted the genetic code and its function in proteins. He synthesized artificial genes in living cells and was honored with the Albert Lasker Medical Medal and National Medical Science Awards.

**11. M. Visveswaraya (15 September 1861-14 April 1962)**

He was popularly known as the father of Modern Mysore State. He was honored with the Bharat Ratna award for his contribution to the field of Architecture. He served as Diwan of Mysore (1912-18). He was honored with Knighthood by Indian British Govt due to which "Sir" was prefixed before his name. He was the chief architect in the construction of Krishna Raja Sagar dam. He was responsible for establishing Mysore sandal oil factory, Chrome tanning factory and Iron and steel factory in Karnataka, India.



**12. Salim Ali (12 Nov 1896-20 June 1987)**



He was the first Indian scientist to conduct a systematic bird survey. He was highly acclaimed naturalist and ornithologist, a specialist in bird science study. He was honored with Padmavibhusan(1976), the British ornithologist union gold medal (1967) and the Indian society academy sunder hora memorial medal awards. He was honored with Doctorate degrees from various universities such as Aligarh Muslim, Delhi and Andhra.

**13. Birbal Sahni (9 January 1922 - 9 November 2011)**

He was the first Indian Paleobotanist, a specialist in ancient life study based on fossilized evidence. He was honored with Padmashree (1973), Padmavibhusan(1976) and Royal Asiatic Society of Bengal Barley medal awards. He was responsible for establishing the famous Paleobotany Research Institute (1948) in Lucknow, India. He served as Professor in Hindu Banaras (BHU), Punjab and Lucknow universities.



\*\*\*\*\*



## **GALILEO GALILEI – A Polymath**

Dr. B. S. Srikanta

Professor of Physics (Rtd.)

Former Principal, RBANM's College

Former Academic Director and Principal, Surana College

Former Professor, Principal and Director, Sindhi College

Galileo's name is quite familiar even amongst primary and secondary school students, who remember him for his contribution to science of motion, astronomy, law of falling bodies, laws of pendulums, invention of refracting telescope and mathematics. His experiment on law of falling bodies conducted from the top of Leaning Tower of Pisa has etched a permanent place in the minds of children (though it is not clear whether this experiment was conducted in reality or it was a thought experiment. Galileo is said to have conducted the experiment around 1589). Hence, I honestly feel that writing a brief article on Galileo and some of his works thereby refreshing the memory of his admirers is a befitting tribute to the memory of a great physicist and an astronomer who lived in the second half of the sixteenth century and the first half of the seventeenth century.

Galileo Galilei born in Pisa, Italy on 15th February 1564 is considered as the father of modern science and he made significant contributions to the fields of physics, astronomy, mathematics and philosophy. His invention of improved telescope enabled him to observe and also describe satellites of Jupiter, Saturn's rings, the phases of Venus, Sunspots and Lunar craters.

Galileo could have easily become the first (perhaps the last) scientific martyr. But he cleverly or may be unwillingly escaped from it by choosing to swear in front of the church authority that his results were wrong (especially in regard to Copernican notion of heliocentrism) though in his heart he strongly believed that his results were right.

Galileo's era lasted between the renaissance period of Leonardo da Vinci and the scientific age of Newton. The renaissance witnessed the rebirth of the Greek idea of believing in the truth revealed by experimental investigations rather than surrendering to the authority. Galileo's adherence to this principle invited the wrath of the Church resulting in his inquisition and house arrest during the last days of his life.

With the use of various measuring instruments, Galileo confirmed the heliocentricity of the solar system and scientific realities. Earlier to Galileo's time, it was believed that laws of physics were applicable only to the Earth and not to planets and stars. After Galileo, doors were opened to all encompassing scientific description of the universe and Newton entered the scene with proper answers. Interestingly, it is to be noted that Galileo died in the year 1642 (January, 8th) and Newton was born in the same year (December, 25th). Perhaps, God did not want to have any vacuum in the field of physics research in particular and scientific research in general. It is really heartening to note that the inventions and discoveries remain as scientific obsession even today benefitting the mankind.

### **Early Life**

Galileo Galilei was born in 1564 in Pisa, Italy. He was the first child to his parents Mr. Vincenzo Galileo and Mrs. Giulia. His father was a musician and an expert in musical theory.



When Galileo was ten, the family moved to Florence where his father was appointed as a court musician. Galileo was educated particularly in logic for three years from 1575 – 1578 in Vallombrosa Abbey, about 30 Kms from Florence. As his father wanted Galileo to become a doctor (earnings of a doctor was much more than that of a scientist), in 1580, he joined University of Pisa to study medicine. But soon he developed interest in mathematics. Galileo was attracted by the lectures given by the court mathematician Ostilio Ricci, who willingly encouraged Galileo to interact with him. Galileo discontinued the study of medicine and took up the study of mathematics quite seriously. Galileo was very much impressed by the works of Euclid and Archimedes. He demonstrated that he too was highly gifted and in 1583, he made an important discovery viz., the laws of simple pendulum.

### **Isochronism of the Pendulum**

On a Sunday morning, while Galileo was attending a mass in Pisa Cathedral, he was fascinated by a swinging chandelier hung by a long wire from the ceiling. He noticed that whatever be the arc of its swing, the lamp took precisely the same time to complete one oscillation. Afterwards, he made a number of observations with different lengths of the string and different masses of the pendulum bob and formulated the laws of pendulums. He found that the period of oscillation of the pendulum is independent of its amplitude and mass of the bob. The period depends only on the length. Galileo also constructed a pendulum device that could be used to measure a patient's pulse.

In 1589, Galileo was appointed as Professor of Mathematics at Pisa on a meagre salary of 60 crowns much to his dismay. It is believed that during this period, Galileo might have conducted his famous experiment from the top of the Leaning Tower of Pisa.

### **Leaning Tower of Pisa Experiment**

The legend says that Galileo performed the famous Leaning Tower of Pisa experiment and proved that acceleration at which objects fall is the same irrespective of their masses. According to a biography of Galileo written by his pupil Vincenzo Viviani, Galileo is said to have conducted this experiment between 1589 and 1592.

He dropped objects of the same material but of different masses from the top of the tower and proved that objects fall at the same speed and reached the ground at the same time irrespective of the difference in their masses. This result was contradictory to Aristotle's argument that heavier objects travel faster. But Galileo did not give an explanation for why two bodies of different masses fall at the same rate. It is to be noted that the explanation was given by Newton with his law of gravity a century later. This fact was again proved to be true several years later when, in the Apollo 15 moonwalk mission, David Scott dropped a hammer and a feather at the same time. As it was essentially a vacuum with no air resistance, both fell at the same rate and reached the moon's surface at the same time, thus providing proof for Galileo's observation. This is sometimes referred to as Galileo's theory of gravity which states that all objects fall at the same rate irrespective of their masses.

It is worth mentioning here that though Galileo relied more on experimental observation rather than theory, in the university, he continued to teach Aristotelean physics especially the geocentric theory of our solar system in conformity with the views of the church.

### **Principle of Inertia and Laws of Motion**

Inertia is the tendency of objects in uniform motion to stay in uniform motion and the objects at rest to stay at rest unless a force acts on them to change their speed or direction. It is needless to say that it is one of the fundamental laws of classical physics described by Issaac Newton in his first law of motion. Inertia is a manifestation of mass. Historically speaking, the theory of motion that prevailed in the pre-renaissance period was that of Aristotle. On the earth's surface, the property of inertia of physical objects is often obscured by gravity, friction, and air resistance which tend to reduce the speed of moving objects. This led Aristotle to conclude that the objects would move only as long as force was applied to them. He said that force produced speed. On the contrary, Galileo said force produced acceleration. Galileo, in his principle of inertia stated that a moving body on a level surface will continue to move in the same direction at a constant speed unless disturbed.

It is also worth mentioning that Galileo, in 1632, concluded that it is impossible to tell the difference between a moving object and a stationary one without some outside reference to it. Further, based on experiments performed using inclined planes, Galileo formulated three laws of motion stated as under: 1. All bodies dropped from the same height reach the ground in equal times 2. In falling, their final velocities are proportional to their times of travel 3. Distances of travel are proportional to the square of their times of travel. He demonstrated these laws with his inclined plane setup. Besides, Galileo was able to show that a projectile followed a parabolic path.

In 1592, Galileo was selected to be the Chair of Mathematics at Padua University founded in 1222. He taught geometry, mechanics, and astronomy until 1610. During this period, Galileo studied the kinematics of motion.

### **Galileo on Heliocentrism**

Galileo doubted the Ptolemaic notion of the geocentric universe and seems to have inclined towards the Copernican view of the heliocentric universe advocated by the Polish astronomer Nicolaus Copernicus. Copernicus maintained that planets go around the Sun in circular orbits moving at constant speeds. Tycho Brahe's hard work spread over twenty years in his underground observatory, collecting huge data and detailed analysis of the data by Johannes Kepler for several years resulted in the enunciation of Kepler's laws of planetary motion.

Galileo started corresponding with Kepler. He seems to have confessed to Kepler that he believed in Copernicus's heliocentric theory but was afraid of admitting it in public. He thought he would be ridiculed by his colleagues who were ardent followers of Aristotle.

### **Invention of Telescope and Astronomical Observations**

The invention of the telescope played a very significant role in advancing our understanding of the universe and also the Earth's place. The first telescopes were created in the Netherlands in 1608 by spectacle makers Hans Lippershey Zacharias Jansen and Jacob Metius independently. Early telescopes were primarily meant for making terrestrial observations. In 1609, Galileo on reaching the city of Venice heard the rumours that Dutch spectacle makers had invented an instrument that could make distant objects appear closer. Having grasped the basic principle behind the construction, Galileo successfully built the instrument which we now

call the telescope, with 3X magnification. Later, he improved it to 30X magnification. Galileo began to explore the heavens with his telescope and studied phases of Venus, Sunspots, and Saturn's rings.

In November 1609, Galileo aimed his telescope at the Moon. He found that the Moon's surface was uneven with mountains and craters. In January 1610, he discovered four moons of Jupiter and concluded that they were orbiting Jupiter. Galileo called them Medicean stars. Now, they are called Io, Europa, Ganymede, and Callisto. Many astronomers and philosophers refused to believe as it did not conform to Aristotelean cosmology.

In September 1610, Galileo observed the full set of Phases of Venus very similar to that of the Moon. The heliocentric Copernicus model predicted that it was possible to see the phases of Venus. Because, as Venus orbits round the Sun, the illuminated hemisphere faces the Earth when it is on the opposite side of the Sun and faces away from the Earth when it is on the same side as the Earth. But, according to Ptolemy's geocentric model, it is impossible to see the phases. This observation of Venus, viz, crescent, gibbous, and full phase supported the heliocentric model of the solar system; Ptolemy's model became unacceptable.

Galileo made telescopic observations of Sunspots and the Milky Way. The Milky Way was found to consist of innumerable numbers of stars, previously believed to be a nebula. He also observed Saturn's rings. He also observed Neptune but did not identify it as a planet. Galileo published all these observations in the "Starry Messenger" published in 1610, which became a sensation in Europe. With all these observations, Galileo rejected Kepler's idea of elliptical planetary orbits. Throughout his life, he believed in the Aristotelean notion that planetary orbits were circular.

Galileo showed that the Earth's laws of physics were universal and applicable in the heavens also. He also published a short book on "Sunspots" which became a best seller.

### **Inquisition**

The publication of "Starry Messenger" and the short book on "Sunspots" and the popularity that followed antagonized advocates of the Aristotelean theory who openly said that the heliocentric universe is not consistent with the views of the universe put forward in the Bible. Galileo was pushed deeper into the quagmire of Vatican politics. In 1616, Copernicus's book about "The Revolution of the Heavenly Bodies" was banned by the Church and termed Copernicus's view of the universe as both "false and erroneous". Galileo was strongly warned that he should not try to defend Copernican views. Galileo went into seclusion. Though he chose to refrain from getting into controversies and arguments with the Church, still he maintained that "the Bible shows the way to go to heavens and not the way the heavens go".

Galileo's work, written in the form of dialogue titled "Dialogue Concerning the Two Chief World Systems, the Ptolemaic and the Copernican", led to further antagonization of the Church authorities. The Pope ordered the immediate prosecution of Galileo. But it could not be carried out as the book had been permitted by the papal authorities. However, the Church authorities found a way out. They dug into the stack of files and found an incriminating document scripted in 1616 in which Galileo had promised that he would stop teaching or eulogizing Copernican

views. Galileo was admonished and made to reject his Copernicanism and swear that he abjured, cursed, and detested his heliocentric views. Galileo was sentenced to house arrest. He spent the last 8 years of his life in seclusion under house arrest. Galileo eventually expired on January 8th, 1642, as an infirm and blind but celebrated European physicist. After three hundred and fifty years in 1992, the Vatican Church admitted that it had committed an error in torturing Galileo.

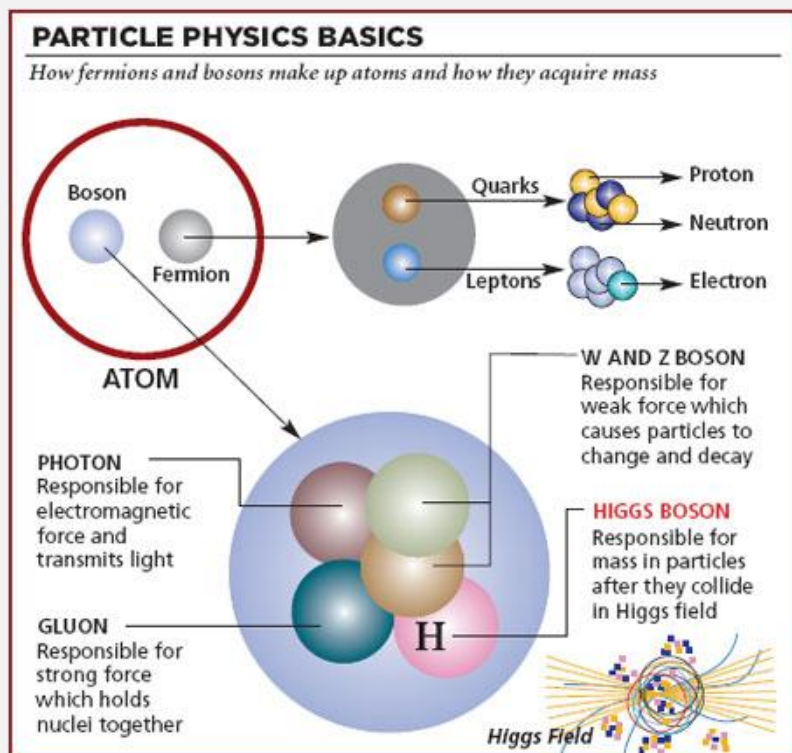
### Conclusion

Galileo was an introvert, inquisitive, intuitive, and intellectual. He was analytical and logical in his approach to any problem. According to his disciple Viviani, Galileo was quick to anger and as quickly mollified. He was a good orator, a teacher, and an enthusiastic researcher. It is said that he had a knack for making complicated topics easy to comprehend. Through his intellectual pursuits, Galileo has left an indelible mark in the history of science. He was one of the gifted geniuses whose seminal inventions and discoveries in the field of science, particularly in physics, have made this world a better place to live. Let me conclude with a quote by Galileo:

The legend says that the Galileo

**“Passion is the genesis of genius”**

\*\*\*\*\*





## ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ - ಒಂದು ವೈಜ್ಞಾನಿಕ ವಿಶ್ಲೇಷಣೆ

ಡಾ. ರಾಮಕೃಷ್ಣ ದಾಮ್ಲೆ  
ನಿವೃತ್ತ ಭೌತಶಾಸ್ತ್ರ ಪ್ರಾಧ್ಯಾಪಕರು  
ಬೆಂಗಳೂರು ವಿಶ್ವವಿದ್ಯಾಲಯ

ಯುದ್ಧ, ಭಯೋತ್ಪಾದನೆ, ಆರ್ಥಿಕತೆಯ ಹೊರತಾಗಿ ಇತ್ತೀಚೆಗೆ ಅತೀ ಹೆಚ್ಚು ಚರ್ಚಿತವಾಗುತ್ತಿರುವ ವಿದ್ಯಮಾನ ಎಂದರೆ ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ ಮತ್ತು ಹವಾಮಾನ ಬದಲಾವಣೆ. ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯಿಂದಾಗಿ ಕಳೆದ ಒಂದೆರಡು ದಶಕಗಳಿಂದ ಹಲವಾರು ಪ್ರಕೃತಿ ವೈಪರೀತ್ಯಗಳು ಸಂಭವಿಸುತ್ತಿರುವುದನ್ನು ನಾವು ಕಾಣುತ್ತಿದ್ದೇವೆ. ಜಗತ್ತಿನ ಕೆಲವು ಭಾಗಗಳಲ್ಲಿ ವಾರ್ಷಿಕವಾಗಿ ಹೆಚ್ಚು ಮಳೆ, ಕೆಲವು ಕಡೆ ಅನಾವೃಷ್ಟಿ, ಸಾಮಾನ್ಯಕ್ಕಿಂತ ಹೆಚ್ಚಿನ ಹಿಮಪಾತ, ಸಮುದ್ರದ ಮಟ್ಟ ಏರಿಕೆ, ಹೆಚ್ಚಿನ ಚಂಡಮಾರುತಗಳ ಅವಾಂತರ ಇವೆಲ್ಲವನ್ನೂ ನಾವು ಗಮನಿಸುತ್ತಿದ್ದೇವೆ. ಇದರಿಂದಾಗಿ ದೇಶಗಳ ವಿಜ್ಞಾನಿಗಳು, ಆಡಳಿತಗಾರರನ್ನು ಒಳಗೊಂಡು ಸಾಮಾನ್ಯ ಜನರೂ ಸಹ ಆತಂಕಕ್ಕೀಡಾಗಿದ್ದಾರೆ. ಈ ಎಲ್ಲ ಹವಾಮಾನ ವೈಪರೀತ್ಯಗಳಿಗೆ ಕಾರಣರಾರು? ಮಾನವನೇ ತನ್ನ ಚಟುವಟಿಕೆಗಳಿಂದ ತಂದುಕೊಂಡ ಅಪಾಯವೇ ಅಥವಾ ಇದು ಸ್ವಾಭಾವಿಕ ಪ್ರಕ್ರಿಯೆಯೇ? ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ ಮತ್ತು ಅದರ ದುಷ್ಪರಿಣಾಮಗಳ ಕುರಿತು ನಿಖರವಾದ, ನಂಬಲರ್ಹವಾದ ವೈಜ್ಞಾನಿಕ ಪುರಾವೆಗಳಿವೆಯೇ? ಮಾನವನ ಚಟುವಟಿಕೆಗಳು ಹೀಗೆಯೇ ಮುಂದುವರಿದರೆ ಭವಿಷ್ಯದಲ್ಲಿ ಈ ಭೂಮಿಯ ಹವಾಮಾನ ಹೇಗಿರಬಹುದು? ಇದಕ್ಕೆ ಪರಿಹಾರವಿದೆಯೇ? ಇದ್ದರೆ ಏನು? ಹೇಗೆ? ಈ ಎಲ್ಲ ಪ್ರಶ್ನೆಗಳು ಹಾಗೂ ಸವಾಲುಗಳು ನಮ್ಮ ಮುಂದಿವೆ.

ವಿಜ್ಞಾನಿಗಳ ವೃಂದದಲ್ಲಿಯೇ ತಾಪಮಾನ ಏರಿಕೆ ಹಾಗೂ ಭವಿಷ್ಯದಲ್ಲಿ ಅದರಿಂದಂಟಾಗುವ ದುಷ್ಪರಿಣಾಮಗಳ ಕುರಿತು ಈ ಹಿಂದೆ ಒಮ್ಮತ ಇರಲಿಲ್ಲ. ಹೆಚ್ಚಿನ ವಿಜ್ಞಾನಿಗಳು ತಾಪಮಾನ ಏರಿಕೆಯ ದುಷ್ಪರಿಣಾಮಗಳ ಬಗ್ಗೆ ರಾಷ್ಟ್ರಗಳ ನೀತಿನಿರೂಪಕರನ್ನು ಸತತವಾಗಿ ಎಚ್ಚರಿಸುತ್ತಲೇ ಬಂದಿದ್ದರೂ, ಕೆಲವು ವಿಜ್ಞಾನಿಗಳು "ಇದು ಒಂದು ಹುಸಿ ಬೆದರಿಕೆ ಅಷ್ಟೇ; ತಾಪಮಾನ ಏರಿಕೆಯಿಂದ ದೊಡ್ಡ ಅನಾಹುತಗಳಾಗುವ ಸಂಭವ ಕಡಿಮೆ" ಎಂದು ವಾದಿಸಿದ್ದಾರೆ. ಈ ಗುಂಪಿನವರಿಂದ ಕೆಲವು ಪುಸ್ತಕಗಳೂ, ಲೇಖನಗಳೂ ಪ್ರಕಟವಾಗಿವೆ. ಇವರ ವಾದದ ಪ್ರಕಾರ "ತಾಪಮಾನ ಏರಿಕೆ ಒಂದು ಸ್ವಾಭಾವಿಕ ಪ್ರಕ್ರಿಯೆ. ನಾಗರಿಕತೆಯೇ ಇಲ್ಲದಿದ್ದ ಸಾವಿರಾರು ವರ್ಷಗಳ ಹಿಂದೆಯೇ ಈ ಜಗತ್ತು ಸಾಮಾನ್ಯಕ್ಕಿಂತ ಹೆಚ್ಚಿನ ಬಿಸಿಯ ಅವಧಿ ಹಾಗೂ ತಂಪಿನ ಅವಧಿಯನ್ನು ಕಂಡಿದೆ. ಇದು ಪ್ರಕೃತಿಯಲ್ಲಿ ನಿರಂತರವಾಗಿ ನಡೆಯುವ ಸಹಜ ಪ್ರಕ್ರಿಯೆ. ಆದ್ದರಿಂದ ಇದರ ಬಗ್ಗೆ ಹೆಚ್ಚಿನ ಕಾಳಜಿ, ಭಯ ಅನಗತ್ಯ." ಉದಾಹರಣೆಗೆ, ಮಧ್ಯಯುಗದ ಕ್ರಿ.ಶ. 5ನೆಯ ಶತಮಾನದಿಂದ 15ನೆಯ ಶತಮಾನದವರೆಗಿನ ಬಿಸಿಯ ಅವಧಿಯೂ ಹಾಗೂ ಕ್ರಿ.ಶ. 1650 ರಿಂದ 1770 ರವರೆಗಿನ ಸಣ್ಣ ಹಿಮಯುಗದ ಇರುವಿಕೆಯೂ ಆಳವಾದ ವೈಜ್ಞಾನಿಕ ಸಂಶೋಧನೆಗಳಿಂದ ದೃಢಪಟ್ಟಿದೆ. ಆದರೆ, ಇತ್ತೀಚಿನ ಸಂಶೋಧನೆಗಳಿಂದ ದೃಢಪಟ್ಟಿರುವ ಹಾಗೂ ವಿಜ್ಞಾನಿಗಳ ಒಮ್ಮತದ ಅಭಿಪ್ರಾಯದಂತೆ 21ನೆಯ ಶತಮಾನದ ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಗೆ ಮಾನವನ ಚಟುವಟಿಕೆಗಳಿಂದ ವಾತಾವರಣದಲ್ಲಿ ಹೆಚ್ಚಾದ ಇಂಗಾಲದ (ಕಾರ್ಬನ್) ಪ್ರಮಾಣವೇ ಕಾರಣವಾಗಿದೆ.

ಈಗ ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ ಅಂದರೆ ಏನು ಎಂದು ತಿಳಿಯೋಣ. ಭೂಮಿಯ ಮೇಲ್ಮೈಯ ಜಾಗತಿಕ ಸರಾಸರಿ ತಾಪಮಾನವು 15°C ಗಿಂತ ಹೆಚ್ಚಾದರೆ ಅದನ್ನು ತಾಪಮಾನ ಏರಿಕೆ (global warming) ಎಂದು ಕರೆಯಲಾಗುತ್ತದೆ. ಕಳೆದ ಒಂದು ಶತಮಾನದಿಂದ ಈ ಸರಾಸರಿ ತಾಪಮಾನವು 0.7°C ನಷ್ಟು ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಕೇವಲ 1°C ಗಿಂತ ಕಡಿಮೆಯಷ್ಟು ಹೆಚ್ಚಾದ ತಾಪಮಾನದಿಂದ ಪ್ರಕೃತಿ ವಿಕೋಪಗಳು ಸಂಭವಿಸುತ್ತವೆಯೇ ಎಂದು ಅಚ್ಚರಿಯಾಗಬಹುದು. ಆದರೆ ಇದು ಸರಾಸರಿ ಲೆಕ್ಕಾಚಾರ. ಜಗತ್ತಿನ ಕೆಲವು ನಿರ್ದಿಷ್ಟ ಪ್ರದೇಶಗಳಲ್ಲಿ ತಾಪಮಾನವು ಸಾಮಾನ್ಯಕ್ಕಿಂತ 5 ರಿಂದ 10°C ವರೆಗೆ ಏರಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಉದಾಹರಣೆಗೆ, ಕೆಲವು ದಶಕಗಳ ಹಿಂದೆ ಬೆಂಗಳೂರಿನ ಬೇಸಿಗೆಯ ಗರಿಷ್ಠ ತಾಪಮಾನ 35°C ಗಿಂತ ಹೆಚ್ಚಿರಲಿಲ್ಲ. ಆದರೆ, ಕಳೆದ ಕೆಲವು ವರ್ಷಗಳಲ್ಲಿ ಈ ಗರಿಷ್ಠ ತಾಪಮಾನ 39°C ತಲುಪಿದ್ದು ಇದೆ. ಈ ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆಯಿಂದಾಗಿ ಧ್ರುವಪ್ರದೇಶದಲ್ಲಿರುವ ಸಾಕಷ್ಟು ಮಂಜುಗಡ್ಡೆ ಕರಗಿ ಸಮುದ್ರಕ್ಕೆ ಸೇರುವುದರಿಂದ ಹಾಗೂ ಸಮುದ್ರದ ನೀರಿನ ಹಿಗ್ಗುವಿಕೆಯಿಂದ ಸಮುದ್ರಮಟ್ಟ ಏರಿಲು ಕಾರಣವಾಗುತ್ತದೆ. ಒಂದು ಅಂದಾಜಿನಂತೆ, ಕೇವಲ 1°C ತಾಪಮಾನ ಏರಿಕೆಯು ಸುಮಾರು 10 ಸೆಂ.ಮೀ.ನಷ್ಟು ಸಮುದ್ರ ಮಟ್ಟದ ಏರಿಕೆಗೆ ಕಾರಣವಾಗುತ್ತದೆ. ಇದರಿಂದ ತೀರದಲ್ಲಿರುವ ಸಾಕಷ್ಟು ಭೂಭಾಗವನ್ನು ಸಮುದ್ರವು ನುಂಗಿಹಾಕುತ್ತದೆ. ನಮ್ಮದೇ ದೇಶದ ಒರಿಸ್ಸಾ ರಾಜ್ಯದ ಕಡಲತೀರದಲ್ಲಿದ್ದ ಹಲವಾರು ಸಣ್ಣ ಹಳ್ಳಿ,

ಜನವಸತಿ ಪ್ರದೇಶಗಳು ಕಳೆದ ಐದಾರು ದಶಕಗಳಲ್ಲಿ ಸಮುದ್ರದೊಳಗೆ ಕಣ್ಮರೆಯಾಗಿದ್ದನ್ನು ನಾವು ನೋಡಿದ್ದೇವೆ.

ಆಧುನಿಕ ನಾಗರಿಕತೆಯು ಶಕ್ತಿಯ (energy) ಮೇಲೆ ಹೆಚ್ಚು ಅವಲಂಬಿತವಾಗಿದೆ. ಅದು ವಿದ್ಯುತ್ ರೂಪದಲ್ಲಿಯೂ, ಇತರ ರೂಪದಲ್ಲಿಯೂ ಇರಬಹುದಾಗಿದೆ. ಬಡವ ಮತ್ತು ಶ್ರೀಮಂತರ ನಡುವೆ ಇರುವ ವ್ಯತ್ಯಾಸ ಅವರು ಬಳಸುವ ಶಕ್ತಿಯ ಮೇಲೆ ಅವಲಂಬಿಸಿದೆ. ಜಾಗತಿಕವಾಗಿ ನಾವು ಪಳೆಯುಳಿಕೆ ಇಂಧನದ (fossil fuels) ಮೇಲೆ ಹೆಚ್ಚು ಅವಲಂಬಿತರಾಗಿದ್ದೇವೆ. ಈ ಪಳೆಯುಳಿಕೆ ಇಂಧನಗಳಾದ ಕಲ್ಲಿದ್ದಲು, ಪೆಟ್ರೋಲಿಯಂ ಹಾಗೂ ನೈಸರ್ಗಿಕ ಅನಿಲಗಳಿಂದ ವಿದ್ಯುತ್ ಉತ್ಪಾದನೆ ಮಾತ್ರವಲ್ಲದೆ ಇವನ್ನು ವಾಹನ ಚಲಾಯಿಸಲು ಹಾಗೂ ಗೃಹೋಪಯೋಗಿ ಇಂಧನವಾಗಿಯೂ ನಾವು ಬಳಸುತ್ತಿದ್ದೇವೆ. ಇವುಗಳ ಉರಿಯುವಿಕೆಯಿಂದ ಇಂಗಾಲದ ಡೈಆಕ್ಸೈಡ್ ವಾತಾವರಣಕ್ಕೆ ಬಿಡುಗಡೆಯಾಗುತ್ತದೆ. ಇದಲ್ಲದೆ ಇತರ ಹಸಿರುಮನೆ ಅನಿಲಗಳಾದ ನೀರಿನ ತೇವಾಂಶ, ಮಿಥೇನ್ ಅನಿಲಗಳ ಪ್ರಮಾಣ ವಾತಾವರಣದಲ್ಲಿ ಹೆಚ್ಚಾಗುವುದರಿಂದ ಭೂಮಿಯ ಶಾಖ ಏರುತ್ತಾ ಹೋಗುತ್ತದೆ. ಈ ಪ್ರಕ್ರಿಯೆಗೆ "**ಹಸಿರುಮನೆ ಪರಿಣಾಮ**" (Green House Effect) ಎನ್ನುತ್ತಾರೆ. ಸೂರ್ಯನ ಬೆಳಕಿನಿಂದ ಬಿಸಿಯಾದ ಭೂಮಿಯು ಅತಿಗೆಂಪು (Infrared) ವಿಕಿರಣವನ್ನು ಹೊರಸೂಸುತ್ತದೆ. ಹಸಿರುಮನೆ ಅನಿಲಗಳು ಈ ಅತಿಗೆಂಪು ವಿಕಿರಣಗಳನ್ನು ವಾತಾವರಣದಲ್ಲಿ ಹಿಡಿದಿಟ್ಟುಕೊಳ್ಳುವುದರಿಂದ ಭೂಮಿ ಬೆಚ್ಚಗಾಗುತ್ತದೆ. ಹಸಿರುಮನೆ ಪರಿಣಾಮವು ಭೂಮಿಯನ್ನು ಬೆಚ್ಚಗಿಡುವುದಕ್ಕೆ ಅತ್ಯವಶ್ಯವಾದರೂ, ಹಸಿರುಮನೆ ಅನಿಲಗಳ ಪ್ರಮಾಣ ವಾತಾವರಣದಲ್ಲಿ ಅಗತ್ಯಕ್ಕಿಂತ ಅಧಿಕಗೊಂಡರೆ ಭೂಮಿಯು ಹೆಚ್ಚು ಹೆಚ್ಚು ಬಿಸಿಯಾಗಿ ತಾಪಮಾನ ಏರುತ್ತಲಿರುತ್ತದೆ.

ಕಳೆದ ಶತಮಾನದ ಆರಂಭದ ಔದ್ಯೋಗಿಕರಣಕ್ಕೂ ಹಿಂದೆ, ವಾತಾವರಣದಲ್ಲಿ ಇಂಗಾಲದ ಪ್ರಮಾಣ ಸುಮಾರು 220 ppm (parts per million) ಅಂದರೆ, ವಾತಾವರಣದಲ್ಲಿರುವ 10 ಲಕ್ಷ ಕಣಗಳಲ್ಲಿ 220 ಕಣಗಳು ಇಂಗಾಲದ್ದಾಗಿದ್ದವು. ಪ್ರಸ್ತುತ ಇದರ ಪ್ರಮಾಣ 420 ppm ಗಿಂತಲೂ ಹೆಚ್ಚಾಗಿದೆ. ಪಳೆಯುಳಿಕೆ ಇಂಧನಗಳ ಅತಿಯಾದ ಬಳಕೆ, ಔದ್ಯೋಗಿಕರಣದಿಂದ ಕಾರ್ಖಾನೆಗಳು ಉಗುಳುವ ಹೊಗೆ, ತ್ಯಾಜ್ಯಗಳ ಸುಡುವಿಕೆ, ಬೆಳೆ ತೆಗೆದ ನಂತರ ಕೊಳೆಯನ್ನು ಸುಡುವುದು ಮುಂತಾದ ಮಾನವನ ಹಲವು ಚಟುವಟಿಕೆಗಳಿಂದ ಇಂಗಾಲವು ಬಿಡುಗಡೆಯಾಗಿ ವಾತಾವರಣವು ಕಲುಷಿತಗೊಳ್ಳುತ್ತಿದೆ. ಇದರ ಜೊತೆಗೆ ಕೃಷಿಭೂಮಿಯಾಗಿ ಪರಿವರ್ತನೆಗೊಂಡು ನಶಿಸುತ್ತಿರುವ ಅರಣ್ಯ ಹಾಗೂ ಹಸಿರು ವಲಯಗಳು ವಾತಾವರಣದಿಂದ ಹೀರಿಕೊಳ್ಳುವ ಇಂಗಾಲದ ಪ್ರಮಾಣವನ್ನು ಕಡಿಮೆಗೊಳಿಸುತ್ತಿವೆ. ಆಳವಾದ ಅನುಕರಣ (simulation) ಅಧ್ಯಯನ ನಡೆಸಿರುವ ವಿಜ್ಞಾನಿಗಳು ನೀಡಿರುವ ಮುನ್ಸೂಚನೆಯಂತೆ ನೈಸರ್ಗಿಕ ಇಂಧನಗಳ ಬಳಕೆ ಹೀಗೆಯೇ ಮುಂದುವರಿದಲ್ಲಿ, ಬರಲಿರುವ ದಶಕಗಳಲ್ಲಿ ತಾಪಮಾನ ಏರಿಕೆಯು 4°C ಗಿಂತಲೂ ಹೆಚ್ಚಾಗಲಿದೆ. ಇದಾದಲ್ಲಿ ಈ ಭೂಮಿಯಲ್ಲಿ ಅತ್ಯಂತ ಘನಘೋರ ಹವಾಮಾನ ವೈಪರೀತ್ಯಗಳು ಸಂಭವಿಸಿ ಅಪಾರವಾದ ಆಸ್ತಿಪಾಸ್ತಿ ನಷ್ಟವಲ್ಲದೆ ಜೀವಹಾನಿಯೂ ಆಗಲಿದೆ. ಜನಜೀವನವೇ ಅಸ್ತವ್ಯಸ್ತಗೊಂಡು ಬದುಕೇ ದುಸ್ತರವೆನಿಸಲಿದೆ.

ಜಗತ್ತಿನಲ್ಲಿ ಉತ್ಪಾದಿಸಲಾಗುತ್ತಿರುವ ಶಕ್ತಿಯಲ್ಲಿ 25% ರಷ್ಟನ್ನು ಕೇವಲ ಅಮೆರಿಕಾ ರಾಷ್ಟ್ರವೊಂದೇ ಬಳಸುತ್ತಿದೆ. ಹಾಗಾಗಿ ಈ ರಾಷ್ಟ್ರವೇ ವಾತಾವರಣವನ್ನು ಅತ್ಯಂತ ಹೆಚ್ಚು ಕಲುಷಿತಗೊಳಿಸುತ್ತಿರುವ ರಾಷ್ಟ್ರವಾಗಿದೆ. ಭಾರತವೂ ಸೇರಿದಂತೆ ಇನ್ನೂ ಅಭಿವೃದ್ಧಿ ಹೊಂದಲು ಶ್ರಮಿಸುತ್ತಿರುವ ದೇಶಗಳು ಪ್ರಗತಿ ಹಾಗೂ ಉದ್ಯೋಗ ಸೃಷ್ಟಿಗೆ ಹೆಚ್ಚು ಹೆಚ್ಚು ಇಂಧನ ಬಳಕೆ ಮಾಡುವುದು ಅನಿವಾರ್ಯವಾಗಿದೆ. ಏರುತ್ತಿರುವ ಜನಸಂಖ್ಯೆಯೂ ಶಕ್ತಿಯ ಬೇಡಿಕೆಯನ್ನು ವರ್ಷದಿಂದ ವರ್ಷಕ್ಕೆ ಅಧಿಕಗೊಳಿಸುತ್ತಲೇ ಇದೆ. ಈ ಹಿಂದೆ ಮಾಡಲಾದ ಅಂತರರಾಷ್ಟ್ರೀಯ ಒಡಂಬಡಿಕೆಯಂತೆ ತಾಪಮಾನ ಏರಿಕೆಯನ್ನು 1.5°C ಗೆ ಸೀಮಿತಗೊಳಿಸಿ ಮುಂದಾಗುವ ಅಪಾಯವನ್ನು ತಪ್ಪಿಸಬಹುದಾಗಿದೆ. ಆದರೆ ತೀರಾ ಇತ್ತೀಚಿನ ವರದಿಯ ಪ್ರಕಾರ, ಕಳೆದ ಒಂದು ವರ್ಷದಲ್ಲಿ ಈ ಮಿತಿಯೂ ಮೀರಿಹೋಗಿದೆ. ತಮ್ಮ ದೇಶದ ಆರ್ಥಿಕತೆಯನ್ನು ಬಲಿಗೊಟ್ಟು ಇಂಧನ ಬಳಕೆ ಕಡಿಮೆಗೊಳಿಸಿ ಈ ಒಪ್ಪಂದಕ್ಕೆ ಬದ್ಧರಾಗಿರುವುದು ಹಲವು ರಾಷ್ಟ್ರಗಳಿಗೆ ಕಷ್ಟಸಾಧ್ಯ. ಇದಕ್ಕೆ ಪರ್ಯಾಯವೆಂದರೆ ಬೇರೆ ಮಾರ್ಗದ ಮೂಲಕ ಶಕ್ತಿಯನ್ನು (ವಿದ್ಯುತ್) ಉತ್ಪಾದಿಸುವುದಾಗಿದೆ. ನಮ್ಮ ದೇಶದಲ್ಲಷ್ಟೇ ಅಲ್ಲದೆ ಹಲವು ದೇಶಗಳಲ್ಲಿ ಕೂಡಾ ಜಲವಿದ್ಯುದಾಗಾರಗಳಿಂದ ಹಾಗೂ ಪರಮಾಣು ಸ್ಥಾವರಗಳಿಂದ ಪಡೆಯಲಾಗುತ್ತಿರುವ ವಿದ್ಯುತ್ ಅಲ್ಪಪ್ರಮಾಣದ್ದಾಗಿದೆ. ಹೊಸ ಜಲವಿದ್ಯುದಾಗಾರಗಳ ಸ್ಥಾಪನೆಗೆ ಅಪಾರವಾದ ಅರಣ್ಯ ಹಾಗೂ ಕೃಷಿಭೂಮಿ ನಾಶ ಅನಿವಾರ್ಯವಾದುದರಿಂದ ಇದು ಪರಿಸರವನ್ನು ಇನ್ನಷ್ಟು ಹಾಳುಗಡೆವಲು ಕಾರಣವಾಗುತ್ತದೆ. ಅದೇ ರೀತಿ ಪರಮಾಣು ಸ್ಥಾವರಗಳ ಸ್ಥಾಪನೆಯು ಕೂಡಾ ಜನರ ಆರೋಗ್ಯ ಮತ್ತು ಸುರಕ್ಷೆಯ ದೃಷ್ಟಿಯಿಂದ ಸಾಧುವಲ್ಲ. ಒಂದು ವೇಳೆ ಅವಘಡ ಸಂಭವಿಸಿದರೆ ಈ ಸ್ಥಾವರಗಳಿಂದ ಹೊರಸೂಸುವ ವಿಕಿರಣ ಅತಿ ಅಪಾಯಕಾರಿಯಾಗಬಲ್ಲದು.



ಇದಕ್ಕೊಂದೇ ಪರಿಹಾರವೆಂದರೆ ನವೀಕರಿಸಬಹುದಾದ ಶಕ್ತಿಯ ಬಳಕೆಗೆ ಒತ್ತುಕೊಡುವುದಾಗಿದೆ. ಸೂರ್ಯನ ಶಾಖದಿಂದ ಹಾಗೂ ಗಾಳಿಯಂತ್ರಗಳ ಮೂಲಕ ವಿದ್ಯುತ್ ಉತ್ಪಾದನೆಗೆ ಮುಂದಾಗಿ ಇಂಗಾಲದ ಹೆಜ್ಜೆ ಗುರುತನ್ನು (carbon footprint) ಕಡಿಮೆಗೊಳಿಸಿ ತಾಪಮಾನ ಏರಿಕೆಯನ್ನು ನಿಯಂತ್ರಿಸಬಹುದಾಗಿದೆ. ಭಾರತವೂ ಸೇರಿದಂತೆ ಜಗತ್ತಿನ ಹಲವು ರಾಷ್ಟ್ರಗಳು ಸೌರಶಕ್ತಿ ಆಧಾರಿತ ವಿದ್ಯುದಾಗಾರಗಳ ಸ್ಥಾಪನೆಗೆ ಮುಂದಾಗಿದ್ದರೂ ಪಾಶ್ಚಿಮಾತ್ಯ ರಾಷ್ಟ್ರಗಳಲ್ಲಿ ನೈಸರ್ಗಿಕ ಇಂಧನ ಬಾವಿಗಳ ಒಡೆತನ ಹೊಂದಿರುವ ಪ್ರಭಾವೀ ಉದ್ಯಮಿಗಳು ಹಾಗೂ ರಾಜಕಾರಣಿಗಳ ಹಿತಾಸಕ್ತಿಯಿಂದ ಈ ಪ್ರಕ್ರಿಯೆ ಇನ್ನೂ ಶೈಶವಾವಸ್ಥೆಯಲ್ಲಿದೆ. ಈ ವಿಧಾನದಿಂದ ವಿದ್ಯುತ್ ಉತ್ಪಾದಿಸಲು ಅಪಾರವಾದ ಹೂಡಿಕೆ ಬೇಕಾಗುವುದರಿಂದ ವಿದ್ಯುತ್ ದುಬಾರಿ ಎನಿಸಲಿದೆ.

ಇನ್ನು ಹಲವಾರು ದೇಶಗಳು ಇಂಗಾಲದ ಹೆಜ್ಜೆಗುರುತನ್ನು ಕಡಿಮೆ ಮಾಡಲು ಆಸಕ್ತಿಯೇ ತೋರದ ಮನಃಸ್ಥಿತಿಯಲ್ಲಿವೆ. ಈ ಬಗ್ಗೆ ಕಳೆದ ಒಂದೆರಡು ದಶಕಗಳಿಂದ ರಾಷ್ಟ್ರಗಳ ಮುಖ್ಯಸ್ಥರು, ರಾಜತಾಂತ್ರಿಕರು ಹಲವಾರು ಸಮ್ಮೇಳನ, ಶೃಂಗಸಭೆಗಳನ್ನು ನಡೆಸಿ ಒಡಂಬಡಿಕೆಗೆ ಪ್ರಯತ್ನಿಸಿದ್ದರೂ ಈ ಎಲ್ಲ ಯೋಜನೆಗಳು ಕೇವಲ ಭಾಷಣಗಳಿಗಷ್ಟೇ ಸೀಮಿತವಾಗಿ ಕಾರ್ಯರೂಪಕ್ಕೆ ಬರಲು ಇನ್ನೂ ಕಾಲ ಪಕ್ಕವಾಗದಿರುವುದು ಕಂಡುಬರುತ್ತದೆ. ಪ್ರತಿ ರಾಷ್ಟ್ರಕ್ಕೆ ತನ್ನದೇ ಆದ ರಾಜಕೀಯ, ಆರ್ಥಿಕ ಸಮಸ್ಯೆಗಳಿರುವುದರಿಂದ ಯಾವ ರಾಷ್ಟ್ರವೂ ನಾಯಕತ್ವ ವಹಿಸಿ ಮನುಕುಲದ ಸಂರಕ್ಷಣೆಗೆ ಮುಂದಾಗದಿರುವುದರಿಂದ ಮುಂಬರುವ ಅಪಾಯದ ಗಂಟೆ ಜೋರಾಗಿಯೇ ಕೇಳಿಸುತ್ತಲಿದೆ. ಜಾಗತಿಕ ತಾಪಮಾನ ಏರಿಕೆ ಮತ್ತು ಹವಾಮಾನ ವೈಪರೀತ್ಯ ಇಂದು ಕೇವಲ ವೈಜ್ಞಾನಿಕ ಸಮಸ್ಯೆಯಾಗಿ ಉಳಿದಿಲ್ಲ. ರಾಷ್ಟ್ರಗಳ ರಾಜಕೀಯ, ಆರ್ಥಿಕತೆ ಇದರಲ್ಲಿ ನಿಕಟವಾಗಿ ಸಮ್ಮಿಳಿತವಾಗಿರುವುದರಿಂದ ಇದೊಂದು ಜಾಗತಿಕ ಸಮಸ್ಯೆಯಾಗಿದ್ದು ಬೆಕ್ಕಿಗೆ ಗಂಟೆ ಕಟ್ಟುವವರು ಯಾರು ಎಂಬ ಪ್ರಶ್ನೆ ನಮ್ಮ ಮುಂದಿದೆ.

ಭೂಮಿ ಸಕಲ ಜೀವಿಗಳಿಗೆ ಆಶ್ರಯ ಕೊಟ್ಟಿದೆ. ಆದರೆ ಭೂಮಿಯ ಇತಿಮಿತಿಗಳನ್ನು ನಾವು ಅರಿಯಬೇಕಾಗಿದೆ. " ಈಗ ಅಥವಾ ಇನ್ನೊಂದಿಗೂ ಇಲ್ಲ" (now or never) ಎಂಬುದನ್ನು ಮನಗಂಡು ನಾವು ಕಾರ್ಯೋನ್ಮುಖರಾಗಬೇಕಾಗಿದೆ. ನಮ್ಮ ಜೀವನಶೈಲಿಯಲ್ಲೇ ನಾವು ಬದಲಾವಣೆ ತರಬೇಕಾಗಿದೆ. ಅರಣ್ಯಗಳನ್ನು ಬೆಳೆಸುವುದು ಮತ್ತು ಉಳಿಸುವುದು, ವಿದ್ಯುತ್ ಪೋಲಾಗುವುದನ್ನು ಸಮರ್ಪಕವಾಗಿ ತಡೆಯುವುದು, ನವೀಕರಿಸಬಹುದಾದ ಶಕ್ತಿಯ ಬಳಕೆ ಹೆಚ್ಚಿಸುವುದು, ಜನಸಂಖ್ಯೆ ನಿಯಂತ್ರಿಸುವುದು, ಮುಂತಾದ ಕ್ರಮಗಳನ್ನು ರಾಷ್ಟ್ರಗಳ ಸರ್ಕಾರಗಳು ನಾಗರಿಕರ ಸಹಕಾರದೊಂದಿಗೆ ಕೈಗೊಳ್ಳಬೇಕಾಗಿದೆ. ನಮ್ಮ ಮುಂದಿನ ಪೀಳಿಗೆಗೆ ಈ ಭೂಮಿಯನ್ನು ವಾಸಯೋಗ್ಯವಾಗಿ ಉಳಿಸುವುದು ನಮ್ಮೆಲ್ಲರ ಕರ್ತವ್ಯ ಹಾಗೂ ಹೊಣೆಯಾಗಿದೆ.

\*\*\*\*\*

## What is Science and who are Scientists?

Dr. S. P. Basavaraju

Professor of Physics (Retd.), BIT, Bengaluru

***“The history of science is the real history of mankind.”***

-Du Bois Reymond, German physician & physiologist (1818 - 1896)

Kids love to hear fairy tales; they are thrilled by the exaggerated wonder involved in the stories. Side by side, they begin wondering about what they see around them such as, the twinkle of the stars, the colors of the rainbow, *etc.*, Questions like - how an electric bulb emits light, how does a fan rotate, what causes a railway engine to move on the rails, how does a rocket zoom into space, ... arise in their minds. Then they begin enjoy learning science because it deals with all they were fascinated in nature. As they grow-up, they come to know about myriads of other phenomena unknown to them such as double refraction, nuclear energy, polaroid, artificial satellites, transmission of signal through space and many other things. A deeper study in science makes them realize about the basic truth responsible for every single phenomenon they were hitherto inquisitive and sometimes felt by them as even mysterious. That quenches their thirst for knowledge.

However, those who develop among themselves a special taste for scientific inquiry, start tackling newer and newer topics in science and get absorbed into the subject. They are the ones who evolve as scientists and no other thing attracts them as powerfully as science does, not even wealth and luxury if he or she is a scientist in the true sense. We have many classic examples of such cases. For instance, Sir C. V. Raman resigned a top civil services job and accepted a professor's job for half of the salary he was drawing earlier. Lord Rayleigh handed over the control over a vast inherited land property to his younger brother so that he could engage himself completely in his scientific investigations. Madam Curie did not patent her historic discovery of radium.

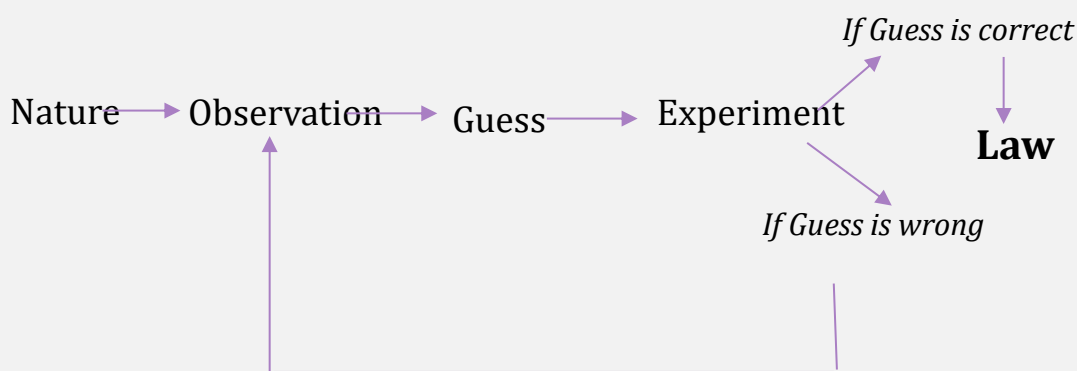
**Origin of ‘Science’:** Now, let us see how the word *science* came into being. This word originated from the Latin word *scientia* which simply means knowledge. It was not meant to be the way it is today. Any knowledge was within its domain. It could have been, mathematics, languages, history, or even the study of religions, *i.e.*, about anything which one can know. Later, when people began to study nature by examining, weighing and other kinds of observations, they called their study – ‘natural philosophy’. Finally, William Whewell, a well-known logician (whom Faraday used to consult for naming the new phenomenon which he used to observe and it's he who proposed the name dielectric to Faraday), introduced the words, *science* and *scientist* to English language in 1833.

As time passed, due to some fancy, instead of calling natural philosophy, people called it natural science, thereby restricting the definition of science. Today, people mean only natural science when they say science. With time, science also grew in the middle of many confused ideas and superstitions, sometimes even dictated by influential heads of society (for instance recall, how people were asked to believe that – the earth is the center of the universe and it was supposed to be science).

After the medieval age, such things became lesser and lesser in number as, giants of science like, Galileo, Newton, Lavoisier, Pasteur, Pavlov, Darwin, ... cleared the mess and established order & system. The world is like this today mainly because of them. An eminent historian has said, '*The scientific works of Newton alone has steered the world in a particular direction in history more than the rise and fall of nations from time to time*'.

**Scientific Analysis:** A proper scientific analysis follows four steps.

1. Observation
2. Guess (hypothesis)
3. Experiment
4. Conclusion



### Process of formulating a law in Science

As an example, let us take the story of Oersted. He was making a demonstration to his students by connecting wire to a battery (Voltaic pile) to show the heating effect. At that time, a magnetic compass happened to lie on the table. It suddenly and unexpectedly showed a deflection when he just completed connecting wire to the battery. In this case, the *observation* is that, when a wire is connected to a battery, a nearby magnetic needle deflects. The *guess* (though obvious) is – since a magnetic needle can be influenced only by a magnetic field, perhaps the current in the wire is capable of producing a magnetic field. (During his times, the belief was, electricity has nothing to do with magnetism as per the views of Coulomb. However, as per some historical accounts, Oersted was having thoughts about the possibility of a relation between the two. Luckily for Oersted, it happened in his demonstration to the students; as Louis Pasteur said, 'Luck favours the prepared mind'.\*)

---

\*For an interesting account on Oersted's earlier ideas, please see the reference given at the end of this article.

Oersted repeated the experiment by reversing the direction of current. Then the deflection occurred in the other way. Further, he must have observed that the deflection grew lesser with increasing distance, *etc.,*. This is the *experimental* part. He *concluded* that, a current must produce a magnetic field. This was a landmark discovery in the history of physics & Oersted became the discoverer of 'Electromagnetism'. Further, this discovery was immediately

followed by the historical achievements of Ampere, Biot & Savart, and Faraday, who became the fathers of electromagnetism elevating Oersted to the position of grandfather of electromagnetism.

Let us now identify the 4 steps here in this case. They are,

**1 Observation – magnetic needle deflects when a wire is connected across a battery.**

**2 Guess – Is the electric current that started flowing in the wire causing the deflection?**

**3 Experiment – Oersted tests by reversing the direction of current and by varying the distance between the wire and the compass box.**

**4 Conclusion – Electric current produces magnetic field.**

So, one can say, when a guess is passed by an experiment, it is certified as a law. Essentially, this is the way a law is formed in science. In certain cases, a guess is made on certain grounds of reasonable possibilities but its experimental verification does not materialise at all because of whatever reason it is. It may be because nobody points out one right way of conducting the experiment for its verification or may be because of the very distrust on the proposition itself. So the guess goes into hibernation. Till the judgement is delivered after conducting the experiment, the guess lies in the state of suspended animation. The possible progress is halted at the stage of guess for an indefinite length of time waiting for someone to undertake a proper experimental verification. Till that time, the guess is verified either as a yes, or as a no. It is sustained as a hypothesis.

For instance, when de Broglie in France proposed his idea of matter waves in 1923, it remained as a hypothesis (in fact, most people ridiculed it) until it was proved – accidentally, but experimentally - by Davisson and Germer in USA in 1927. De Broglie's idea of matter waves then became a watershed in the history of quantum mechanics. All that was known earlier regarding quantum effects was termed '**old quantum mechanics**' and what followed later, as '**new quantum mechanics**' or simply, '**quantum mechanics**'. Here you see, for nearly four years, it remained dormant as hypothesis between the formulation and experimental verification.

In science, any hypothesis, no matter how great the proposer is, it must face the sword of experiment sooner or later. If the hypothesis is found to be correct by experiment, then only it is given the status of *law*. Such laws in science are universally applicable. For instance, the law of buoyancy was discovered by

Archimedes some 2200 years ago. It holds good today and will certainly hold good forever in the future. It was

discovered at Syracuse (now in Italy) but will hold good anywhere not only on the earth but everywhere in the Universe. On the other hand, the hypothesis will be discarded if it fails the test by experiment. Without the experimental proof, there is no way a law could be formulated in science.

Sometimes, even those laws which were thought to be acceptable over centuries, undergo the same fate as that of a wrong hypothesis, when a new and rigorous experiment proves otherwise. For instance, Aristotle had proposed that, anything that is thrown up the sky always return to

earth because earth is the center of the universe. It was accepted over a period of nearly two thousand years. However, later, following the pioneering works of stalwarts such as Kepler, Galileo, Newton, ... his geocentric theory was discarded. (It may be noted that, while his theories regarding biological phenomena were astonishingly closer to the reality, his theories in physics were erroneous. Aristotle deserves to be admired anyway.)

**Aim of Science:** The aim of science is to find the laws of nature. It advances by breaking big problems progressively into smaller ones by learning more and more about the intricacies of every such problem. For instance, the functioning of human body is understood initially, by studying its organs individually. Then we make a collective study of such organs to reason out how a physical action is performed on the basis of the co-ordination of individual organs by the brain.

Science can answer questions – *how*, *when* and *where*. But it is not in the nature of science to answer the *whys* for the simple reason that one *why* leads to another (the way the kids confront the elders and finally sometimes, the elders give up or, escape by mesmerizing the little ones by the dictum ‘it is an act of God’!)

In the history of science, it is said that, when Newton proposed his theory of gravitation, his inveterate enemy Robert Hooke remarked, ‘Let him explain why there is gravitational field?’ Newton did not take the why part and simply replied, ‘It is enough to understand that there is gravitational field’.

In experimental investigations in science, we never know where all it would lead to eventually. For instance, the study of blackbody radiation, which began as a simple curiosity in experimental investigations concerned to emission of light by what is known as a ‘Perfect Blackbody’, gave rise to a fundamentally new subject namely – ‘**Quantum Mechanics**’ the knowledge of which resulted in the invention of **transistors, laser etc.**, that went on to change the world. So, to start with, it is just experimenting for the sake of curiosity without having any idea of what is in store for the future. Every scientist is aware of this and every non-scientist will be sceptical about the consequences of most of the experimental investigations of a new idea, at least to start with. Quoting as it appeared in print in connection with Maxwell the greatest theoretical physicist of the 19<sup>th</sup> century;

*‘I never’, Maxwell told Sir Arthur Schuster, ‘try to dissuade a man from trying an experiment if he does not find out what he is looking for, for he may find something else’.*

Is there anything better than this quote to highlight the spirit of experimental investigations?

**Who are the gifted Scientists:** There are scientists and mathematicians with unmatched capabilities, born in our society at different times and at different places. They possess a great gift of insight to understand and explain what exactly is the truth behind natural phenomena. No matter how hard others may try, only scientists and scientists alone can solve the problem. There are a number of such examples about what those geniuses see, that others just cannot. One classic case is that of Faraday.

We all know that Faraday was the greatest experimental physicist of the 19<sup>th</sup> century. He discontinued his investigations on electromagnetism in 1822 due to some disturbing comments

on his work by his master Humphry Davy and Faraday turned his attention on a different problem. Following this shift, other scientists tried unsuccessfully, albeit relentlessly, over nearly a decade to convert magnetism to electricity, the problem which Faraday was dealing with before he got disconnected from electromagnetism. After the death of Davy in 1829, Faraday took up the investigation again and succeeded in 1831 in developing the principle of generator where magnetism is converted to electricity. He showed how electricity, magnetism and motion are inter-related. It was a landmark result in the history of physics on the foundation on which stand today's multibillion-dollar industries! This discovery shows his unmatched capability in experimental investigations. Now consider the idea of quantization.

In the case of quantum nature of radiation, though Planck had put forward his theory in 1900, the quantization of light energy and thereby the particle nature of light was first brought forward by Einstein while explaining '**Photoelectric effect**' and published in 1905 in the journal '**Annalen der Physik** (German). That Einstein was awarded eventually the coveted Noble prize for this discovery in 1922, is now history. Ironically, Planck never accepted Einstein's theory till 1913. So the real quantum revolution was started by Einstein and not by Planck despite he himself being the originator of quantum concept.

Let us see another case pertaining to electromagnetism.

Heaviside was the one who worked on Maxwell's theory and gave the famous *four Maxwell's equations* in the present form after the unfortunate death of Maxwell at a young age of 49 years. Heaviside was also another genius. Though it was he who formulated those equations, he never understood how they got synthesized in his mind from Maxwell's work and how they worked so fine with every aspect of electromagnetism. In brief, how he got them is a mystery. His own statement was,

*I will continue to eat despite not understanding how digestion works.*

The legendary mathematician Ramanujan had also revealed almost in the same way as how he used to get those amazing mathematical equations in his mind.

In all these four cases, we can only understand this much as obvious,  
*"it just happens and it happens to them alone because they are gifted".*

And ... they are the gifts by nature to the humanity. They are the real heroes of progress of humankind (*and not those emperors and conquerors who led massive invasions stamping out innumerable lives and destroying livelihoods of common men*). Their achievements are the leading lights for generations after generations as long as humanity exists. Their names are gilded in the history of science forever.

### Reference (in French):

Une découverte due au hasard ? (A discovery due to chance?)

By Christine Blondel et Bertrand Wolff

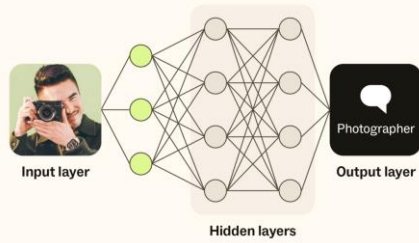
Linc: <http://www.ampere.cnrs.fr/histoire/parcours-historique/oersted/decouverte-hasard>

(The English translation of the same could be obtained with Google Translate.)



## The deep learning process

The algorithm receives data, runs it through the input and hidden layers, and generates an output.



## PHYSICS & CHATGPT

K. C. Guruprakash

Retired as General Manager from Jacobs Engineering MNC Company  
(now renamed as Worley.)

[guruprakash.kc@gmail.com](mailto:guruprakash.kc@gmail.com)

### **A: Why students should prefer a study of Physics over other science subjects?**

Physics offers a unique blend of theoretical concepts and practical applications that make it a compelling subject for students. Here are some reasons why students might prefer studying physics over other science subjects:

**An Understanding of Fundamental Concepts:** Physics delves into the fundamental laws that govern the universe. A study of physics provides a deep understanding of how things work at a fundamental level, which can be applied across various scientific disciplines.

**Problem-Solving Skills:** Physics essentially focuses on problem-solving skills. Students learn to break down complex problems, analyze data, and develop logical solutions. These skills are valuable not only in scientific fields but also in many other disciplines.

**Interdisciplinary Applications:** Physics has strong connections with other scientific disciplines such as chemistry, biology, engineering, and even fields like medicine and environmental science. Students with a background in physics can make an easy transition into these related fields or pursue interdisciplinary research.

**Technological Advancements:** Much technological advancement is rooted in the principles of physics. A study of Physics helps students to gain insights into cutting-edge technologies such as renewable energy, quantum computing, nanotechnology, and space exploration.

**Career Opportunities:** Physics opens up diverse career opportunities. Graduates can work in research and development, academia, healthcare (i.e., medical physics), engineering, finance (quantitative analysis), data science, and more. The analytical and problem-solving skills acquired in physics are highly valued in the job market.

**Intellectual Challenge:** Physics stimulates students to think critically and creatively. It pushes them to question existing theories, explore new ideas, and contribute to the advancement of scientific knowledge.

**Global Challenges:** Many global challenges, such as climate change, energy sustainability, and space exploration, require a strong understanding of the principles of physics. Students studying physics can actively contribute to addressing these pressing issues.

**Personal Growth:** Studying physics can foster curiosity, resilience, and a passion for lifelong learning. It encourages students to think beyond the obvious, explore the unknown, and embrace intellectual curiosity.

Ultimately, whether or not a student should prefer physics over other science subjects depends on their interests, career goals, and aptitude. However, physics undoubtedly offers a rich and rewarding educational experience with broad applications in various fields.

**B: Are there some examples of marvels of Physics in recent times?**

Certainly! Here are some examples of marvels of physics in recent times:

**Gravitational Waves Detection:** Scientists, using the Laser Interferometer Gravitational-Wave Observatory (LIGO), made a groundbreaking discovery in 2015 by detecting gravitational waves - ripples in spacetime - caused by cataclysmic events like merging of black holes. This confirmed a major prediction of Einstein's General Theory of Relativity and opened a new era of gravitational wave astronomy.

**Quantum Computing Advancements:** Quantum computing has seen significant advancements in recent years. Companies like Google, IBM, and others have made progress in developing quantum computers with increasing qubit counts and computational capabilities. Quantum computing promises revolutionary applications in cryptography, optimization, and simulations.

**Development of CRISPR-Cas9 Gene Editing:** While primarily a biological innovation, CRISPR-Cas9 gene editing relies on principles of quantum mechanics and molecular biology. This technology allows precise editing of DNA, potentially leading to breakthroughs in treating genetic disorders, creating disease-resistant crops, and advancing personalized medicine.

**Discovery of Exoplanets:** Advances in astrophysics and observational techniques have led to the discovery of thousands of exoplanets (planets outside our solar system) in recent years. These discoveries provide insights into planetary formation, habitability, and the diversity of planetary systems in the universe.

**Advances in Materials Science:** Materials science has witnessed remarkable advancements, such as the development of graphene (a single layer of carbon atoms with exceptional properties), metamaterials (materials engineered to have unique electromagnetic properties), and superconductors (materials with zero electrical resistance at certain temperatures), all of which have profound implications for technology and industry.

**Higgs Boson Discovery:** With the construction of Large Hadron Collider (LHC) In 2012, physicists at Conseil europeen pour la Recherche Nucleaire or European Council for Nuclear Research (CERN) confirmed the existence of the Higgs boson, a fundamental particle that plays a key role in the mechanism of mass generation. This discovery validated the Standard Model of particle physics and provided insights into the fundamental forces and particles of the universe.

**Advancements in Quantum Teleportation and Communication:** Researchers have made great strides in quantum teleportation and communication protocols, enabling secure quantum

cryptography and potentially revolutionizing information transmission and encryption methods.

These marvels of Physics highlight the continuous progress and innovation in understanding the fundamental laws of nature, pushing the boundaries of scientific knowledge, and unlocking new technologies with profound societal impacts.

Above is not written by me, I just asked “ChatGPT” AI tool (Artificial Intelligence) -and is done with a specific purpose which will shortly become clear -two questions I asked,

A: I asked why students should prefer study of physics over other subjects.

B: Give some marvels of Physics in recent times.

Answer for the first question is summarized in eight paragraphs and answer for the second question is listed in seven paragraphs above; all given by ChatGPT.

The purpose of this article is to encourage using the new tool called ChatGPT, (of course, duly exercising discretion). Questions on physics are considered just as examples. This might have been known to many, however yet an attempt is made for those who may not be aware.

ChatGPT provides access to a vast amount of information across a wide range of topics. This can be incredibly beneficial for users seeking quick and reliable answers to questions or looking to advance their knowledge.

ChatGPT can act as a learning aid by providing explanations, clarifications, and examples related to academic concepts, technical terms, and complex ideas. It can assist students in understanding difficult concepts and reinforce their learning.

Interacting with ChatGPT can help improve language skills, including grammar, vocabulary, and writing style. It can offer suggestions for better communication and help users articulate their thoughts more effectively.

It can introduce users to new ideas, perspectives, and areas of interest. It can engage in discussions, brainstorming sessions, and creative thinking exercises, fostering intellectual curiosity and exploration.

It is available round-the-clock, making it convenient for users to seek assistance or information at any time, regardless of their location or time zone.

Overall, learning to seek help from ChatGPT can enhance one's knowledge, skills, and productivity across various areas, making it a valuable tool for personal and academic growth.

We should not forget that a line of limit to ChatGPT should be drawn. We, humans, excel in creativity, and imagination, and can generate novel ideas. Also, we have ethical and moral reasoning, emotional intelligence, and empathy. These faculties fall outside the applications of ChatGPT.

With the help of AI, humans can adapt to new situations, learn from experiences, and apply knowledge in diverse contexts. We can navigate uncertain or ambiguous environments effectively.

AI systems are programmed using programming languages such as Python, Java, C++, and specialized AI frameworks and libraries. Human programmers write code that instructs AI systems on how to process data, make decisions, learn from experiences (in the case of machine learning), and perform tasks.

Finally, “Human intelligence only created artificial intelligence”. Artificial Intelligence (AI) as we know it today is a product of human intelligence, creativity, and scientific advancements. Hence all necessary discretion and caution must be exercised. To summarize, there is immense help one can derive from AI tools which is simple to use. So those of us who are yet to explore this field should learn and start getting acquainted with this and get the benefit.

To start using ChatGPT, go to the ChatGPT website. Click “Sign up” to create an OpenAI account. Type your instructions for ChatGPT (also known as a “prompt”) in the “Message ChatGPT...” box at the bottom, then hit Enter on your keyboard. ChatGPT will start writing a response! Try it out!

\*\*\*\*\*



## Roddam Narasimha (1933-202: An Engineering Scientist Par Excellence

Sourabh S. Diwan

Associate Professor, Department of Aerospace Engineering,  
Indian Institute of Science, Bengaluru  
sdiwan@iisc.ac.in

Prof. Roddam Narasimha, a world-renowned fluid dynamicist and an engineering scientist, passed away on 14 December 2020 at the age of 87 after a brief illness. He is survived by wife, Neelima Narasimha, and daughter, Maithreyi Narasimha. He was known as “Prof. Narasimha” to his colleagues in India and the world at large, as “Roddam” to his friends and colleagues abroad, and as simply “RN” to his students and close associates; I will refer to him as RN in the rest of this article. RN was a towering personality who established a strong school of fluid dynamics research in India (in particular at the Indian Institute of Science, Bengaluru), headed many important institutions, initiated several scientific programmes of national importance and played a key role in national policy making concerning science and technology. He is most-widely known for his work on flow “turbulence”, although he made far-reaching scientific contributions in several other areas. RN was a true polymath. His interests included not only modern science but also history of science, mathematics and technology in India and the philosophy of ancient Indic thought. He was a great teacher and mentor, and inspired several generations of people who worked with him. He received several prestigious awards and recognitions, such as the Fellow of the Royal Society, London, Foreign Associate of the US National Academy of Sciences, the Padma Vibhushan and the Nature Mentoring Award to name a few, but never lost his simplicity and curiosity which made him a deeply endearing personality. RN was active in research until the very end of his life and corresponded extensively with his collaborators and co-workers except for the last couple of months when he was in and out of hospital. The passing away of RN is an immeasurable loss to the scientific world, and comes in as a great personal loss to me and to all those who knew him well.



(RN receiving Padma Vibhushan in 2013 from the then President of India, Pranab Mukherji)

**Biographical sketch and early work:** RN was born on 20 July 1933 and spent his childhood (and most of his adult life) at Bengaluru (or Bangalore as it was known at that time). His father R. L. Narasimhaiah was a professor of physics at Bangalore's Central College and was well known for his work on wireless technology. In RN's words "... there was a lot of physics at home including some mathematics....The new thing I did was that I studied engineering." Thus, the seeds of scientific enquiry must have been sown in his mind right from his childhood. RN finished his elementary and high school education from Acharya Pathashala in the Gandhi Bazar neighborhood, and his graduation in Mechanical Engineering from the Government Engineering College (now the University Visvesvaraya College of Engineering) affiliated then to the University of Mysore. During his undergraduate education, he attended the Sunday classes at the Gokhale Institute of Public Affairs on English and Sanskrit run by the great Kannada writer D. V. Gundappa. The knowledge of Sanskrit he acquired during this time came in handy for him later in his life when he started reading the original Sanskrit texts on science, mathematics and philosophy in ancient India.

After graduation in 1953 RN joined the Aeronautics Department (now called the Department of Aerospace Engineering) at the Indian Institute of Science (IISc), Bengaluru, for a master's degree (or a "Diploma" as it was called at that time; see Fig. 1). This is where he came in contact with some of the finest fluid dynamicists in the world like Oskar Tietjens, who was the head of the Aeronautics Department and Satish Dhawan, who was a young faculty member at the Department. Dhawan had recently returned from the California Institute of Technology (Caltech), USA and was in the process of putting together an aerodynamics laboratory involving low-speed wind tunnels and a "supersonic" wind tunnel (that generates air speeds greater than the speed of sound). RN helped Dhawan in this endeavour and received first lessons of doing experimental aerodynamics and wind-tunnel testing that served him lifelong.



Fig. 1. RN (extreme right) with his classmates at IISc

After finishing his diploma, RN received an offer from Dhawan to spend another two years doing research with him, which RN accepted. It was during this time that he made pioneering contributions to the field of "transitional boundary layers". A boundary layer is a thin region close to a solid surface formed when a fluid flows past the surface at sufficiently high speeds (or "Reynolds numbers" to be more precise), and is responsible for the frictional resistance that the surface experiences. A boundary layer can either be in a "laminar" state or in a "turbulent" state; the former is an orderly, regular kind of motion whereas the latter is a chaotic, complex and irregular fluid motion. The process of a laminar flow becoming turbulent is called "flow

transition”, during which the flow alternates between laminar and turbulent states (Fig. 2). The fraction of time the flow is turbulent in a velocity signal is defined as “transitional intermittency” and this factor changes gradually from zero to one as the flow turns from laminar to turbulent. RN proposed a theory for determining the intermittency distribution within the transition zone of a boundary layer [1], which was later applied to transition scenarios occurring under a variety of conditions [2]. This distribution has come to be known as the “Narasimha universal intermittency distribution” and has played a central role in our understanding of the boundary layer transition. The early experiments on this work were carried out in a 20-inch (0.5m) cross-section boundary-layer wind tunnel built by Dhawan, which is still operational in the Low-speed Aerodynamics Laboratory in the Department of Aerospace Engineering at IISc (Fig. 2). I feel privileged to be in-charge of this historic wind tunnel at IISc, which is presently being used to further our understanding of boundary layer transition and turbulence.

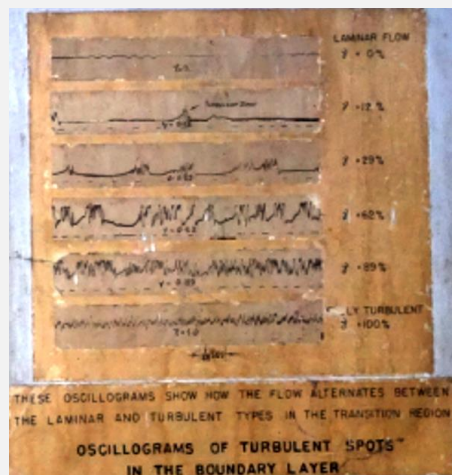
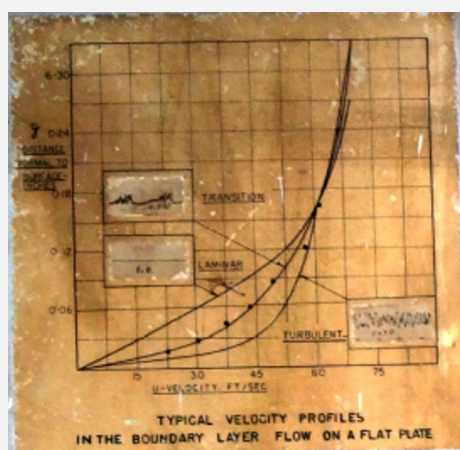
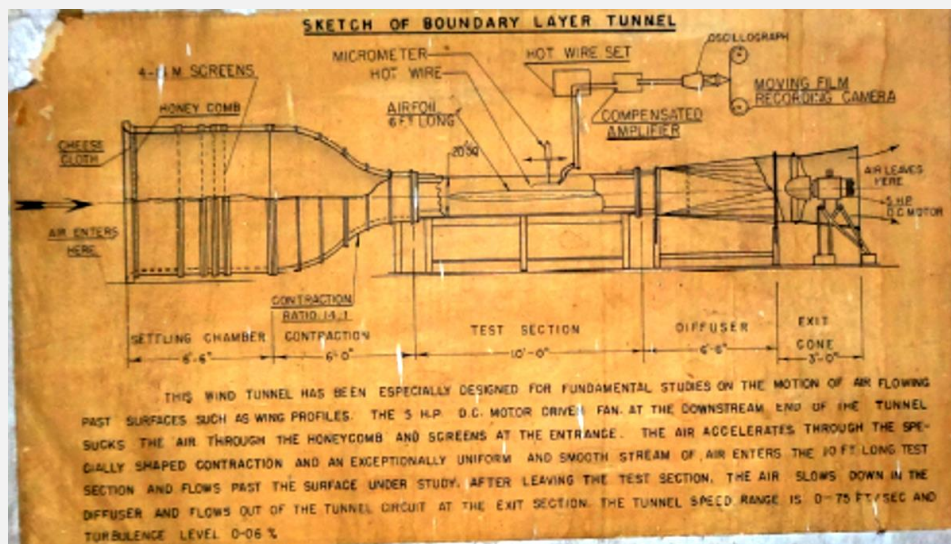


Fig. 2. Extracts from a poster made by RN on his boundary layer research, which adorns one of the walls of the 0.5m boundary layer tunnel at IISc.

RN had a great regard for Satish Dhawan (whom RN considered his *guru*), who was a stalwart in his own right and went on to become the Director of IISc and the Chairman of ISRO (and provided luminary leadership to the science and engineering developments in India for several



decades). RN paid rich tributes to Dhawan through his articles and interviews which are a must read; see, for example, [3], [4].

After two years of research with Dhawan, RN was ready to plunge deeper into fluid dynamics and joined, on the recommendation of Dhawan, the Graduate Aerospace Laboratories at Caltech for doing PhD (Fig. 3) under another great fluid dynamicist, Hans Liepmann. For his PhD dissertation, RN worked on the problem of the structure of “shock waves” using the Boltzmann equation and the principles of rarified gas dynamics (shock waves are typically formed when a flow at supersonic speed encounters an obstacle and turns through an angle less than  $180^\circ$ ). While at Caltech he was exposed to the method of “matched asymptotic expansions”, a mathematical theory that was being developed based on Ludwig Prandtl’s idea of the boundary layer (as mentioned earlier), which essentially applies to problems involving two disparate length scales. For the boundary layer problem, for example, the two disparate length scales are the thickness of the layer and the typical length of the body on which it is formed; the latter being much larger than the former. RN made use of this method extensively in his research and was considered an authoritative figure on the topic.



Fig. 3. RN (right) receiving his PhD degree at Caltech

### Professional career at IISc and JNCASR

RN returned to India in 1962 and joined the Department of Aeronautics at IISc as an assistant professor. His return was a surprise to several of his colleagues in the USA, as the research infrastructure that existed in India in the 1960s was no match to that available in the US. However, it was the natural affection towards his motherland that led RN to return and to dedicate himself to establish a strong research culture in India in fluid dynamics in particular and engineering sciences in general. While at IISc (1962-1999), RN held several important positions such as the Chairman of the

Aerospace Department during 1983-1984 and the Chairman of the Centre for Atmospheric Sciences (which later was renamed the Centre for Atmospheric and Oceanic Sciences) which he founded in 1982, among others. He served as the Director of the National Aerospace Laboratories during 1984-1993 and the President of the Indian Academy of Sciences during 1992-1994. RN was the founder of the Engineering Mechanics Unit at the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) and served as its Chairman during 2000-2014. He was also the second Director of the National Institute of Advanced Studies (NIAS) during 1997 - 2004. While at IISc and JNCASR, RN worked on several research problems such as the structure of turbulent boundary layers, re-laminarization of turbulent flows, relaxation of a turbulent wake to the equilibrium state upon perturbation, mathematical modelling of aircraft airworthiness, stability of a mixing layer, entrainment behaviour of cumulus-cloud flows, design of optimal wing-forms for a turbo-prop aircraft, statistical theory for vortex gas flows and flow transition in gas turbine blades. In the following, I highlight a few of the important contributions he made to the topics of turbulent boundary layers and cloud flows, to

provide a glimpse into his research achievements. (The choice of these topics is purely personal, partly influenced by my own research interests.)

A turbulent boundary layer can be thought of as consisting of two internal layers located adjacent to each other: the inner (closer to the wall) and the outer (away from the wall). Most of the turbulent kinetic energy is concentrated in the inner region, very close to the surface on which the boundary layer is formed, and the physical processes that generates this energy has been an important research question. In the 1960s a pioneering work was done at Stanford University which identified certain structures called “streaks” in the inner region of a turbulent boundary layer and their “bursting” (i.e., their breakdown) was found to be responsible for the generation of turbulence in that region. RN, along with his colleagues at the Institute, tackled this problem experimentally and showed that the average time interval between two bursts scales on the outer time scale (i.e., the time scale imposed by the outer region) [5]. This was a surprising finding at that time as the quantities in the inner layer were believed to scale entirely on the inner length and time scales, and the work created some controversy as the opinions of the researchers were divided. RN continued to work on this problem and also analyzed the data from the atmospheric boundary layer (i.e., the boundary layer formed on the surface of the earth due to its rotation) to establish his point as the Reynolds numbers associated with this flow are very large. It turned out later that the scaling of the bursting intervals is more complex than initially thought, but RN’s work in 1971 clearly established that the turbulent “eddies” in the inner region cannot be entirely independent of the outer region. This was an important foresight as the theme of “inner-outer” interaction in wall turbulence re-emerged nearly four decades later (as high-Reynolds-number laboratory experiments became possible), and it continues to be at the forefront of turbulence research. RN’s interest in the atmospheric boundary layer went beyond understanding the fundamental physics. He was deeply interested in the Indian monsoons and soon realized that understanding and modelling the transport of momentum, heat and moisture by the turbulence in a tropical atmospheric boundary layer were the key to improving the accuracy of monsoon forecasting. (These quantities can get further transported to higher altitudes by convective clouds.) Towards this, he, along with D. R. Sikka from the Indian Institute of Tropical Meteorology Pune, conceived of a field experiment, MONTBLEX (Monsoon Trough Boundary Layer Experiment; Fig. 4) to gather the necessary data on the vertical profiles of velocity, temperature and humidity during the summer monsoon of 1990. Nearly 30-metre-tall towers were erected at places such as the Central Arid Zone Research Institute Jodhpur, IIT Delhi, BHU Varanasi, and IIT Kharagpur, all of them managed by a team from IISc that acquired the data from the towers over a period of 35 days. Despite all the hardships faced by the team, this first-of-its-kind field experiment in India was a great success and inspired several field experiments that have been conducted in India since then.



Fig. 4. A measurement tower erected in Jodhpur as part of the MONTBLEX campaign



Another aspect of monsoon dynamics that captivated RN's mind was the problem of cumulus clouds. Cumulus clouds are fluffy, heap-like clouds with constantly evolving edges and are often called "the queen of the tropical sky". For these clouds atmospheric convection is vigorous, and turbulence plays a major role in their dynamics. RN started working on this problem in the mid-1980s. There had been some earlier attempts to reproduce the macro-scale dynamics and typical shapes of cumulus clouds in the laboratory, but most of them were unsuccessful. RN realized that one of the reasons for the failure of earlier attempts was that they did not account for the effect of latent heat release due to the condensation of water vapour that happens in natural clouds, which was a remarkable insight. With his colleagues at the Centre for Atmospheric Sciences, RN devised and built a laboratory apparatus that was able to generate cumulus cloud shapes similar to what are seen in the atmosphere. The apparatus was based on a simplified flow model of a "plume" (the kind of flow produced by burning an incense stick) with "off-source" ohmic heating to mimic the latent heat release in real clouds. This work was followed by a series of investigations into the "entrainment dynamics" of cumulus cloud flows, which is a process by which the ambient air is drawn into and mixes with the air within the cloud. A much-improved version of the basic apparatus described above (Fig. 5) was built at the Engineering Mechanics Unit at JNCASR in 2009, around the time I joined him as a post-doctoral fellow (a short account of how this conspired will be narrated later). We were able to do some very good experiments at JNCASR and generated a wide variety of cumulus clouds in the apparatus not only in shape but also in their time evolution; two such examples are shown in Fig. 6. We were also successful in relating a measure of entrainment in the laboratory flows with that found in realistic cloud situations. In some sense, we showed that we could bring the real cloud *flows* down to the earth and generate them in the laboratory [6]. The subsequent work showed that the cumulus cloud flows could also be produced, equally realistically, on the computer [7]. These studies helped establish RN's original ideas on a firm footing. He was actively pursuing this work with a PhD student until he passed away in December 2020; he held this problem close to his heart.



Fig. 5. RN with his team members in front of the cloud-flow apparatus at JNCASR (first from left: Subrahmanyam Duvvuri, IISc; third from left: K. R. Sreenivas, JNCASR; fourth from left: G. S. Bhat, IISc; extreme right: the author)

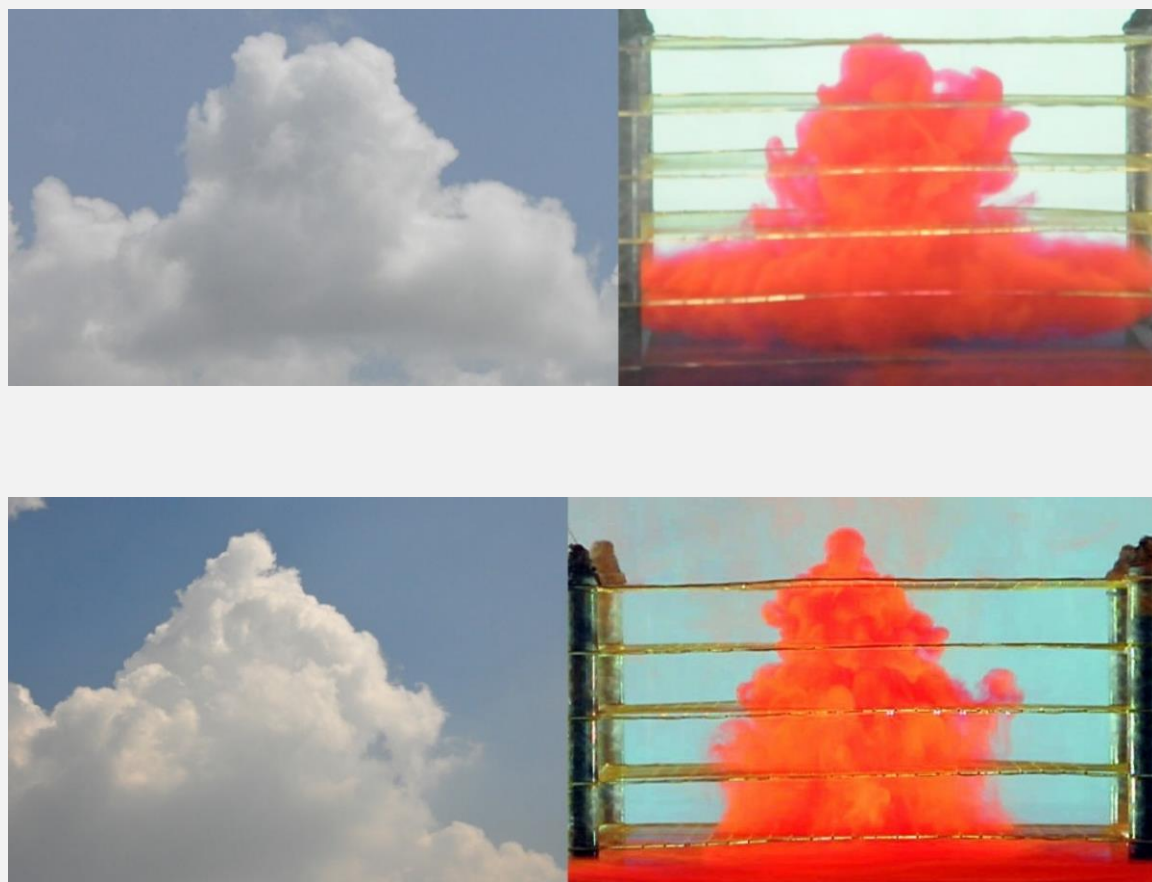


Fig. 6. Two examples of comparison between atmospheric clouds (left) and laboratory clouds (right); for more such pictures see the PNAS and BAMS papers mentioned in the text

Apart from his research contributions, RN played a key role in initiating several projects of national importance such as the indigenous fighter aircraft LCA-Tejas, the civilian aircraft development programmes SARAS and RTA (Regional Transport Aircraft), the first supercomputing facility at NAL, the hypersonic wind tunnel at IISc, and the Indo-French atmospheric research satellite Megha-Tropiques, to name a few. During his time at NIAS he initiated Indo-US dialogues on India's nuclear policy and worked extensively on his interests in the history of science and mathematics in India. RN was a member of the Scientific Advisory Council to former Prime ministers Rajiv Gandhi and Manmohan Singh, and served on several important scientific committees. He was the longest serving member of the Space Commission and also served on the Earth Sciences Commission which he helped establish; he was the only person to have served on both the commissions at a given time.

### **Contribution to Indic studies**

As mentioned earlier, RN had a keen interest in classical Indic studies on science and philosophy. He went through the original Sanskrit texts and wrote several scholarly articles, in his characteristic style, to bring out the authentic information about the original contributions made by Indians to science and mathematics. For more details the reader is referred to the obituary written by the author and Alope Kumar (IISc, Bengaluru) for *Indic Today* (<https://www.indictoday.com/long-reads/professor-roddam-narasimha-world-class-scientist->

deeply-indian-roots/). RN was especially enamored by the text Yoga-Vāsiṣṭha which is a Sanskrit work of epic length with some 27,687 verses that is basically a conversation between the young dejected prince, Rāma and the royal sage of the Ikṣvāku clan, Vasiṣṭha. RN was fascinated by this work (which he described as “a disarming mixture of poetry, fable and reason”) and produced a short booklet named the ‘Verses for the Brave’ (NIAS special publication 2000) consisting of his translations of selected verses from the Yoga-Vāsiṣṭha. An expanded version of the booklet has recently been published by Penguin Viking [8]. RN was able to finish working on the galley proofs of the book before he passed away, although he did not live long enough to see the book published.

### Personal reminiscences and reflections:

My first encounter with RN dates back to 2002. I had joined the Aerospace Department at IISc as a young Master’s student and RN gave a set of lectures on the Fundamentals of Fluid Mechanics at the Centre for Atmospheric and Oceanic Sciences in that semester which I eagerly attended. I had little exposure to research during my undergraduate education and I was struck by his style of teaching which relied heavily on his own research explorations rather than just the textbook stuff. RN was an excellent teacher and communicator, and engaged his audience with his clear and masterful exposition of any subject he taught. I remember at one point, while explaining a somewhat difficult concept which the students were finding hard to follow, he paused and said “You are not asking questions...., so I am not sure if this is making sense....” He then took us by hand through the difficult terrain of the concept, until we had at least a glimpse of what he was leading us to. In 2003, a symposium was organized at JNCASR to celebrate RN’s 70<sup>th</sup> birthday in which I presented a poster on some of the experiments which I had done at IISc. Many leading fluid dynamicists in the world, mostly his friends and associates, attended the symposium, and it was a feast to the young minds like me, who enthusiastically took autographs from some of them, including of course RN, who was a hero to us at that time; see Fig. 7.

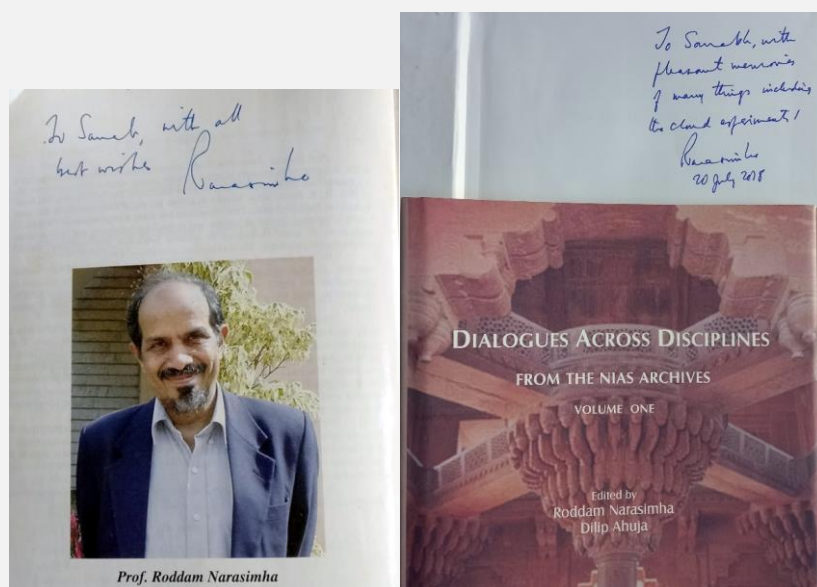


Fig. 7. (Left) RN’s autograph on the symposium proceedings in 2003 organized to celebrate his 70<sup>th</sup> birthday. (Right) RN’s personal message on a book he gifted to the author in 2018 on his 85<sup>th</sup> birthday

I continued to interact with RN on and off during my PhD years at IISc but had not imagined that I would get a chance to work with him. The way things worked out was a pure serendipity. It all started with a talk he gave on cumulus clouds at the IISc centenary conference organized by the Aerospace Department in 2009. I had just finished my PhD and was looking for post-doc positions. After his talk I met him and told him that I was very much interested in working on atmospheric flows and whether he knew of any post-doc opportunities abroad. He paused for a while and somewhat hesitantly said that he himself had a position open and whether I wanted to know more about the problem. When I eagerly said yes, somewhat excited by the prospect of working with him, he gave out a hearty laughter (so characteristic of him) and took me through the ideas on the cloud problem he wanted to pursue. It did not take me long to make up my mind.

I have cherished the remarkable years I spent working with RN at JNCASR. The first thing that struck me was his cheerfulness, which was infectious, and it added greatly to his charm and charisma. It was always wonderful to be with him, discussing technical matters, chalking out plan of action for future work or listening to him talking to another person. Just being in his company was an enlivening experience and it did not always require a verbal communication to connect with him. The research work I did with RN on cumulus cloud flows (as described above) was a learning experience. He had the ability to hold a research question in mind for a prolonged duration, look at it from various angles, mull over it, grasp the entire scope of it and apply “Occam’s razor” (or shall we say “RN’s razor”) to get rid of the peripheral aspects to clearly bring out the essence. While we often jumped to conclusions, he would always be cautious in interpreting results and arriving at conclusion, examining the premise and the reasoning carefully and then re-examining it until it was *precise* or at least *accurate*. I think “reasoning” was a prominent feature of his intellect and even in highly practical experimental matters, like leaking of pipes or failure of heaters, he would advise us to look for the principles to base the solutions on rather than ad-hoc fixes. Another striking feature of RN’s working style was that he was always available, always approachable. It was clear that he was a very busy person handling many tasks and responsibilities at various levels, but he always had enough time to spend with each one of us. It never appeared that he was in a hurry and it was therefore possible to discuss any problem in great depth and breadth. In fact, one of my colleagues made it a point (to an occasional scorn of others in the group) to meet RN every day, and RN would enthusiastically welcome him each time! It was amazing to watch how effortlessly he worked on a variety of problems at the same time. For him what was important was that the problem should be interesting; it did not matter whether it was fundamental or applied. At the time I joined his group he had initiated research on as fundamental a problem as developing a statistical theory of a vortex gas and as applied as optimizing wing form for a turboprop aircraft, both with equal zest. RN was meticulous in writing papers and reports and commented profusely on the drafts which students and post-docs gave him, sometimes repeatedly, to lift them to his standards (Fig. 8). He raised the consciousness of those around him to aspire for higher things but always did it gently, without castigating them for thinking small if they did.



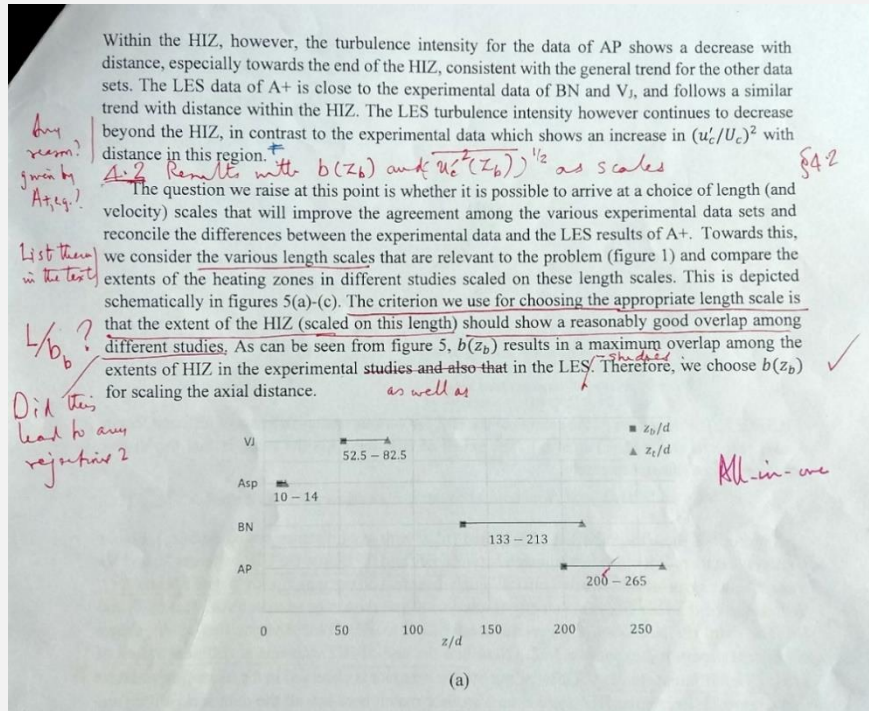


Fig. 8. RN's comments and corrections on a manuscript page, in his typical style



Fig. 9. RN with the author during a dinner in 2014 (Photo Credit: Sachin Y. Shinde, IIT Kanpur)

I left JNCASR in 2009 to join Imperial College, London for my second post-doctoral stint, but continued working with RN on the cloud problem. I would make it a point to visit him whenever I visited Bengaluru during this time (Fig. 9). Our collaboration became deeper after I returned from London and joined the Aerospace Department at IISc Bengaluru as an assistant professor (in 2016). Even at his great age, RN's energy and enthusiasm were boundless. It amazed me how he could still engage in serious research at the highest level or deliver hour-and-a-half lectures at a stretch for the course on turbulence, which he taught at the Department in 2017 along with Prof Garry Brown from Princeton University. I would sometimes wonder if I, at my age, could match the energy that he possessed at his age! During the COVID-19 lockdown, RN and I worked together closely on some analysis we were doing on the cloud problem. I relished the long telephonic discussions with him during this time, although I did



not get an opportunity to see him after February 2020 when I met him last. RN never lost his curiosity and was always ready to explore new areas of research with the fresh mind of an eager young researcher. Around the time the lockdown started in India in 2020, I was toying with the idea of adapting the DNS code his group had developed (for studying cloud flows) towards investigating the cough and sneeze flows with relevance to COVID-19 transmission. I called him in early April of 2020 to sound him out on the idea and he jumped on it instantly. Apparently, he was thinking about doing something similar already and thus began our new collaboration on studying the cough/sneeze/speech flows, with Rama Govindarajan from ICTS, Bengaluru and S Ravichandran from KTH, Sweden (presently at IIT Bombay); see [9]. Unfortunately, RN did not live long enough to see the progress we have made on this problem more recently (Fig. 10) but did provide inspiration and insights during our initial discussions.

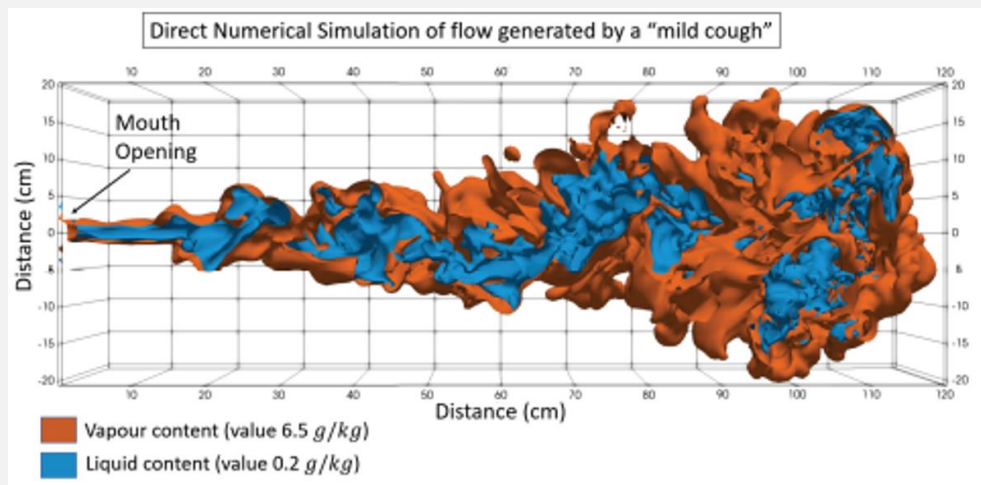


Fig. 10. An example of the kind of flow that is generated during a simulated human cough (Image Courtesy: Rohit Singhal, IISc, Bengaluru)

On the personal side, RN was a warm and affectionate person. Although he had been a highly “decorated” researcher, he carried this weight lightly. As a result, while one was awed by his scholarship and achievements, it never became a barrier in establishing a personal rapport with him. One felt comfortable and friendly in his company, and that made him a perfect gentleman in the definition of Pandit Jawaharlal Nehru. RN was an excellent story-teller and always had in his bag many interesting anecdotes from his versatile career which he narrated with a characteristic charm, much to the delight of the listener. I have personally enjoyed talking to him on various matters, may it be on politics, philosophy, history or the classical Indian thought.

I have said this elsewhere that it was as if RN had carved out a space around him by his intellectual austerity and there was a certain sanctity associated with it. One could not but get touched by it if one’s mind was sensitive enough. Every time I met him, I felt this quality about him and got inspired and refreshed by connecting with it.

We all know that death is an inevitability but one is never prepared for it and when it comes to a person like RN one *does not want* to be prepared for it. This obituary has been a meager attempt on my part to pay my respects to RN, which I offer to him with joined palms. It is more of a personal account and can, in no way, do full justice to his towering personality and astounding achievements; the interested reader is referred to several excellent obituaries

written by many of his distinguished colleagues and former students, available at roddamnarasimha.org.

(Some of the images in this article are taken from web, *Bhavana* – the mathematics magazine and *Connect* – IISc magazine)

#### ACKNOWLEDGEMENT

**The author acknowledges financial support from Science and Engineering Research Board (SERB), India (Grant No.: ECR/2018/002417) toward writing this article.**

#### References:

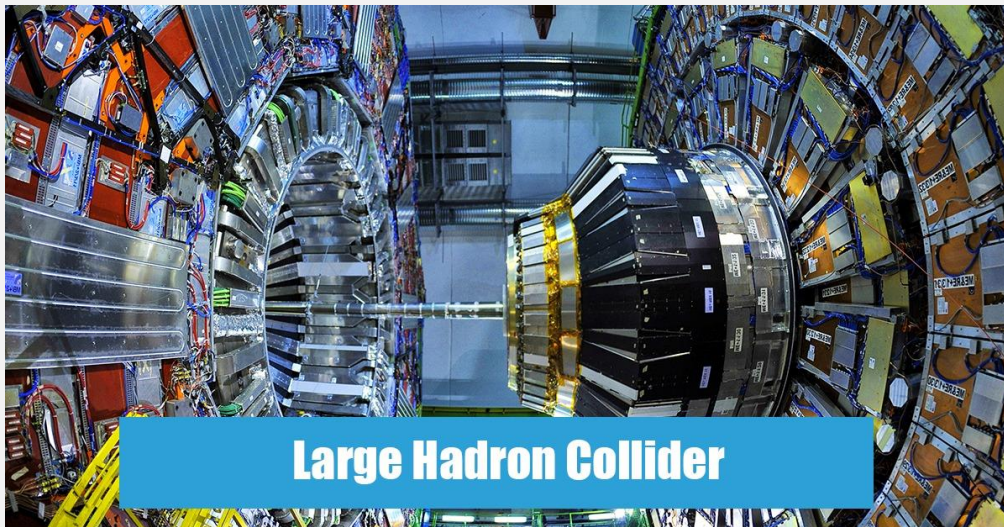
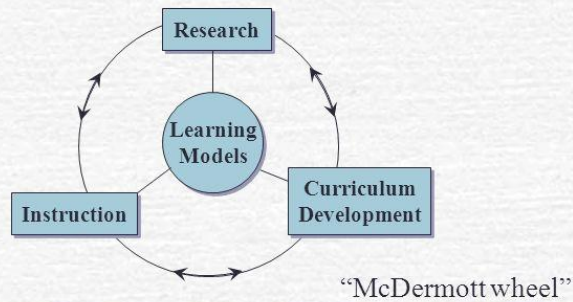
1. R. Narasimha, *Journal of Aeronautical Sciences*, Vol.24, p.711, 1957.
2. S. Dhawan and R. Narasimha, *Journal of Fluid Mechanics*, Vol.3, p.418, 1958.
3. R. Narasimha “Doing Little Science with Dhawan”, *Resonance*, p.40, October 2003.
4. “A Real Patriot: Roddam Narasimha on Satish Dhawan”, *Bhavana – the mathematics magazine*, July 2020.
5. K. A. Rao, R. Narasimha and M. A. Badri Narayanan, *Journal of Fluid Mechanics*, Vol.48, p.339, 1971.
6. R. Narasimha, S. S. Diwan, S. Duvvuri, K. R. Sreenivas and G. S. Bhat, *Proceedings of National Academy of Sciences of USA*, Vol. 108, p.16164, 2011.
7. S. S. Diwan, P. Prasanth, K. R. Sreenivas, S. M. Deshpande and R. Narasimha, *Bulletin of American Meteorological Society*, p.1541, October 2014.
8. R. Narasimha, *Verses for the Brave: Selections from the Yoga-Vasistha*, *Penguin Viking* 2021.
9. S. S. Diwan, S. Ravichandran, R. Govindarajan and R. Narasimha, *Transactions of the Indian National Academy of Engineering*, Vol. 5, p.255, 2021.

#### About the author:

Sourabh S. Diwan (sdiwan@iisc.ac.in) obtained B.E. in Mechanical Engineering from Walchand College of Engineering, Sangli in 2002 and MSc (Eng.) and PhD in Aerospace Engineering from Indian Institute of Science, Bengaluru in 2005 and 2009 respectively. Thereafter, he spent a few years doing post-doctoral research, first at JNCASR Bengaluru (2009-2012), followed by a stint at Imperial College London (2012-2016). He is presently an Associate Professor at the Department of Aerospace Engineering, Indian Institute of Science, Bengaluru. His research interests include experimental aerodynamics, transitional and turbulent boundary layers, and various flow applications. He uses experimental, numerical and theoretical tools as are found fit for tackling a particular problem.

## Physics Education Research

Physics Education Research involves a coordination between *Researching* Student Learning, providing *Curriculum Development*, and enhancing and modifying *Instruction*.



## Glass & Glass-ceramics

### Research Highlights:

#### Glass and Glass-ceramics

- ✓ Developments of high-end glass composites for structural/space applications
- ✓ Developments of bioactive coating for metallic implants

#### Waste Utilizations

- ✓ Production of glassy fertilizers from domestic/industrial wastes
- ✓ Developments of engineering products from agricultural/industrial wastes

### Research Methodology:

