Department of Physics
Cochin University of Science and Technology, India

DECEMBER 2021
VOLUME 1, ISSUE 2

NEWSLETTER

Contents

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Thanu Padmanabhan and the revolution in understanding gravity

Prof. Thanu Padmanabhan, a great theoretical physicist of this century, died on September 17th, 2021, at IUCAA, Pune. He was a well wisher of our Department. In this article, I remember the outstanding contributions made by him in understanding gravity.

Prof. Titus K Mathew
Professor and Head
Physics, CUSAT

Prof. Thanu Padmanabhan, a world-renowned theoretical physicist and a good friend of our Department, passed away on 17th September 2021 at his residence in the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune. It was a shock to the world scientific community and the Indian scientific community in particular. His new theory on gravity, the Emergent Gravity Paradigm, ignites new horizons in understanding gravity. Without giving a full completion of this remarkable theory, his sudden death is, in fact, really un-timely. Padmanabhan advanced substantially to find answers to many questions that emerged, after Einstein's theory of general relativity, in connection with the understanding of gravity and cosmology.

Padmanabhan was born in Thiruvanathapuram as the son of Thanu Iyer and Lakshmi on March 10, 1957. After his school education, mainly at the Govt. School at Karamana, Thiruvananthapuram, he completed his Predegree course (equivalent to today's 11 and 12th classes) from Govt. Arts College, Thiruvananthapuram in 1974.

(**Cont. in page 4**)

Message from Head of the Department of Physics

Dear Colleagues and Students

It is extremely happy that we are releasing the second edition of the newsletter in December 2021. This time it is being released under the editorship of Dr. V V Prasad, our young faculty. We were first faced with the pandemic crisis, and our Department rallied together and found new ways of supporting each other, like never before. Even from a distance, our focus on strengthening relationships has been continued. The variety of activities like teaching, research, etc., were continued with more strength and determination. Although we are still under the threat of the COVID pandemic, we will not dilute any of our academic activities. We are planning for our Diamond Jubilee celebrations in 2022-23. I want to take this opportunity to congratulate and thank all the members of our Department for striving to complete this newsletter.

Prof. Titus K Mathew.

Message from the editorial team

Dear all

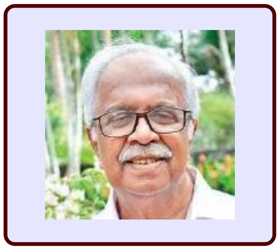
It is with immense happiness that the Department of Physics, CUSAT is releasing the second edition of the Newsletter. The idea of creating a common space to highlight various activities and achievements of the Physics community at the Department was materialised when honourable Vice-Chancellor of CUSAT, Prof. K N Madhusoodanan released the first edition of the Newsletter on 2nd August 2021. The first edition of the newsletter took up the formidable task of creating a comprehensive document on the Departmental activities and to set out the course for future volumes. We thank the dedicated work of the Editor in chief Dr. Anoop K K, the editorial team and the entire members of the Department of Physics who actively participated in the process. With the second volume being released, we feel satisfied that we are able to sustain the rhythm and thereby proceed towards developing it as a platform well-representing the Department activities. The Newsletter contains both academic contributions of the members mirroring their research interests and non-academic articles displaying their artistic capacities. We have also invited articles from alumni members whose immense experience is valuable for the young members.

We greatly appreciate your constructive suggestions to correct the flaws and improve it further. We thank the visionary leadership of the honourable Vice-Chancellor, Prof. K N Madhusoodanan and the guidance of the Head of the Department, Prof. Dr. Titus K Mathew for fulfilling this release. We also thank all the members of the Department at present and past, who have contributed directly or otherwise. Wishing you an enjoyable reading experience.!

The Editorial team.

Honourable Vice-Chancellor of CUSAT, Prof. K N Madhusoodanan releasing the first edition of the Newsletter at the administrative chamber of the Vice-Chancellor. Prof. Titus K Mathew, head of the Department of Physics, Dr. Anoop K K, the Editor-in- Chief and Assistant Professor of the Department of Physics, Dr. Aldrin Antony, Advisory Committee member and Associate Professor of the Department of Physics and two of the student editors, Anamika Ashok and Manosh T M, were present on the occasion.

Trend Transitions in Physics

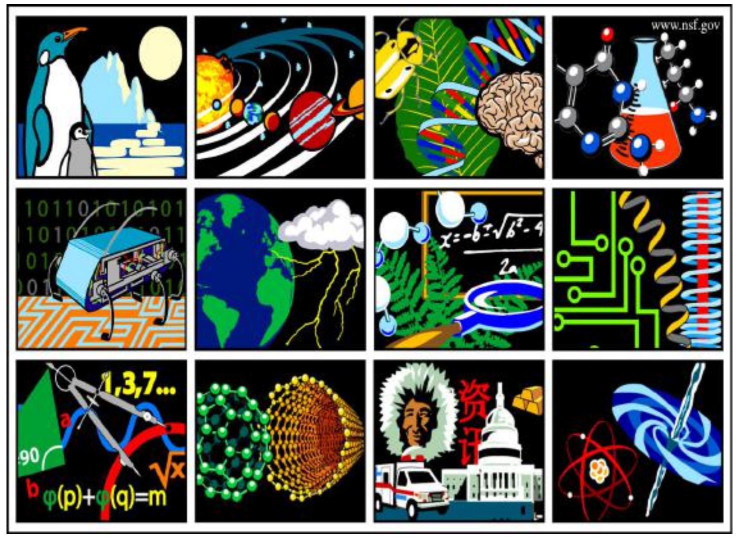


Prof. K Babu Joseph
Former Vice Chancellor
CUSAT

The birth of a new branch of study in any discipline, let alone physics, is like a phase transition familiar in physics. A new phase or state of matter is formed at a critical point marked by some external physical parameters like temperature and pressure. It is always a host of discoveries or inventions that characterise the emergence of a nascent trend in research. The twentieth century witnessed two major revolutions in the subject, namely the discovery of the theory of relativity and the development of quantum mechanics. These have given rise to thousands of new developments in applied science and technology. Still, the foundations laid by relativity and quantum mechanics have remained unchanged.

Following these revolutions, there was a great upsurge of interest in atomic, molecular, nuclear and particle physics. This was consistent with quantum mechanics and the so-called special theory of relativity. Another direction of study, also pioneered by Albert Einstein that captured wide interest was the general theory of relativity or Einstein's theory of gravity which could handle really big questions such as the origin of the universe and its evolution. The birth and death of stars and bizarre objects like black holes was a major problem investigated. The branch called astrophysics gradually spawned a new area of investigations called cosmology, treating the universe as a single system. Developments in atomic, molecular, and condensed matter physics also contributed to a knowledge explosion.

We notice that, from time to time, new trends have appeared in physics studies involving the interaction of different areas of exploration. The earliest instance of this is that of mathematics and physics, typified by the work of Newton and Leibniz, resulting in the development of calculus in mathematics and mechanics in physics. It has been established in the past century that calculus had been discovered by the Kerala mathematician and astronomer Madhava in the 14th century. There are several examples of nontrivial interaction in recent decades such as, between string theory in physics and differential geometry or topology in mathematics. More recently, new branches of interdisciplinary research have sprung up, linking humanities such as economics and sociology with physics, especially through the branch called nonlinear dynamics. Areas such as econophysics and sociophysics are newcomers in cross-disciplinary studies. Chaos theory, an important area of study in nonlinear dynamics, has started setting new trends of research in human biology, including genomics and evolution. An example of cross-disciplinary work in which this author collaborated is described in the paper, Chaos in GDP growth rate of G20 countries, recently published in Econophysics, Sociophysics & Multidisciplinary Sciences Journal (ESMSJ). Our study reveals a chaotic nature of the economic growth rate for most of these countries. This implies, inter alia, the non-existence of a global growth pattern. Another instance of my recent work falls in the intersection between quantum mechanics and logic, bringing out a link between the uncertainty principle and the non-distributive law of propositions in quantum logic, discovered by John von Neumann.



The flowering of novel ideas in interdisciplinary studies is a continuing process, opening new vistas in physics as well as other subjects. Quantum computing, quantum information theory, and quantum biology are upcoming branches evolving from this cooperative learning endeavour. Trend transitions are very much a subject for deep reflection in history and philosophy of science, an area mercilessly ignored in our country. An exposure to this department of inquiry would provide a significant stimulus to creativity. ●

Thanu Padmanabhan - and the revolution in understanding gravity

(Cont. form page 1)

Padmanabhan took B.Sc in Physics from University College, Thiruvananthapuram during 1974-1977. He completed his MSc in Physics from the same college during 1977-79. He passed these two courses under the University of Kerala with first rank and Gold medal.

In 1979 he joined the Tata Institute of Fundamental Research, Mumbai for PhD under the world-renowned cosmologist and Astrophysicist, Prof. Jayant Narlikar. Around this time, he got married to Vasanthi, a fellow research scholar in TIFR. In the continued research life of Padmanabhan, the support rendered by Vasanthi was invaluable. In 1984 he completed his PhD in Quantum Cosmology, after which he spent a short period as a postdoctoral fellow in the Institute of Astronomy of Cambridge University, England. He then returned to India and joined TIFR as a faculty member. In 1992, he moved to the Inter-University Centre for Astronomy and Astrophysics (IUCAA), a world-class institute, which was started under the leadership of his PhD advisor, Prof. Narlikar. His only daughter, Dr Hamsa Padmanabhan, is also a researcher in Gravity and Cosmology.

Prof. Thanu Padmanabhan was educated almost entirely in Kerala. Hence he always had a soft corner for Kerala in his mind. Even though his degree education was in Kerala University, his relationship with the Department of Physics at CUSAT was strong. This association started while he was a student. It could be the research in gravity and cosmology in the Department of Physics, CUSAT, right from that time, the main reason for this strong connection. Moreover, the relation of CUSAT with IUCAA from 2007 onward, as the regional research centre of IUCAA, further strengthened the association of Padmanabhan with the Physics Department, CUSAT. At least one or two visits to this Department every year and giving talks in the scintillating areas of gravity and cosmology was a regular practice of Prof. Padmanabhan. Around 2012, CUSAT Physics started research in Emergent Gravity, a field opened up by Padmanabhan. This tightened the bonding of Padmanabhan with the Department. In February 2019, the Department organized an international workshop on Emergent Gravity Paradigm in which Prof Padmanabhan took a leading role. He was delighted to meet the students and teachers working in Astrophysics, Cosmology, and Gravity and discuss the modern developments in these areas. Many of the research papers published in this area from CUSAT have utilized the expert opinion of Prof. Padmanabhan.

Gravity and cosmology were areas of particular interest to Padmanabhan. His research publications, which come around 300 in numbers, and books more than twelve are good testimonials for his deep involvement in these areas. Many of these books are now adopted as textbooks or references to the courses in renowned institutions worldwide. During the initial period, he mainly worked in quantum cosmology. Later, he switched to the theory of structure formation in the Universe, in the nineties. Around 2000, he came to his all-time best contribution to science, the emergent gravity theory. It was a new and unique step in understanding gravity after Newton and Einstein.

Gravity: Force vs Spacetime curvature

Around 1665, the first theory of gravity was published, and that was due to Isaac Newton. In this theory, gravity was explained as the force of interaction between massive particles. The theory beautifully explained why the planets orbit the Sun and the bodies projected upward from Earth falls. However, the theory was in strong contradiction with the special theory of relativity put forward by Albert Einstein in 1905. According to the special theory of relativity, there is a limit on the speed of anything in the universe, whether it be a massive body, energy, or even interactions like gravity and electromagnetic force. This limiting speed is equal to the speed of light in free space, around 3,00,000 km/s. On the contrary, Newtonian gravity propounds that gravity will propagate with infinite speed.

Einstein solved the discrepancy between Newtonian gravity and the special theory of relativity in 1915 through his general theory of relativity, a modified theory of gravity. According to general relativity, it is not a force; instead, it is manifested as the curvature of spacetime caused by matter and energy. So the planet Earth orbiting the Sun is not due to an attractive force between the two, but due to the curved spacetime around the massive Sun. Therefore the Earth, even though moving in a straight line, due to the curvature in spacetime, its path gets automatically curved, resulting in a circular motion of the Earth around the sun.

The most significant contribution of the 20th century, the general theory of relativity, not only removed the misconception that gravity is a force but could also predict many new phenomena which were alien to the Newtonian theory of gravity. The major one is the prediction about the bending of light near massive objects. Einstein predicts that, like planets, light beams from distant stars will follow a curved path on entering the premises of the Sun. Around 1919, Sir. Arthur Eddington and the team observationally verified this during a solar eclipse. Apart from this, exotic objects like a black hole, the existence of gravitational waves, etc., were confirmed by cosmological observations.

Is Einstein's gravity theory complete?

Despite the marvellous observational verification of many of the effects predicted by Einstein's theory of gravity, it was suspected that even Einstein's theory has some severe drawbacks. The most important among them is related to its unification with quantum theory. From the time of its proposal, attempts were made to unify the general theory with the second significant contribution of the 20th century, the quantum theory. It turns out that, to understand the radiation fully from black holes, the evolution of the early universe, it is essential to combine the theory of gravity with quantum mechanics. Unfortunately, we do not have a successful theory of quantum gravity until today. Padmanabhan came with an alternative solution to this great difficulty.

Padmanabhan on Gravity - Emergent Gravity

Padmanabhan came with a ground breaking concept around 2000. In an article submitted to the Gravity Research Foundation, USA, which won the third prize, he restructured the Einstein equation for gravity as a fundamental thermodynamic law. Through this, it was shown that gravity is the thermodynamics of spacetime. Thermodynamics is the science of hot bodies. So if gravity is the thermodynamics of spacetime straight away implies that like matter and fluids, the spacetime can carry heat; that is, it can be hot.

To understand this idea better, it is needed to go back two centuries back, where the scientists were trying to understand heat. It was thought that heat was some fluid called calorie, having no mass, colour, or weight, which flows from hot to cold substance. Around 1865, Ludwig Boltzmann stated that heat is a form of energy. Moreover, he speculated that the matter should be made up of microscopic structures for carrying heat. This remarkable proposal was made when the scientific world had no idea about atoms or molecules, which rendered the idea of Boltzmann revolutionary.

Following this speculation of Boltzmann, Padmanabhan postulated that, since spacetime can carry heat, it must also have microscopic structures, say atoms of spacetime, technically called microscopic degrees of freedom. In the case of matter, Boltzmann obtained that there contain about 10^{23} atoms in one mole of the substance, which was later confirmed by later observations. Correspondingly, Padmanabhan calculated that in cm^2 of spacetime area, around 10^{66} number of spacetime atoms occur. This implies that the spacetime atoms are so tiny compared to the atoms of matter. This makes the direct observation of the spacetime atoms a Herculean effort, which may not be feasible at least in the coming decades.

Padmanabhan moved further in this direction. Standard thermodynamic parameters like temperature, pressure, volume, density, etc., were the properties of matter as a whole or termed macroscopic properties. For instance, the temperature of a glass of water is 30^o C, say. This temperature is the temperature of water in the glass as a whole and not the temperature of a molecule in that water. Water molecules have only kinetic energy, and the average of the kinetic energies of all the molecules is experienced as the temperature. Hence the macroscopic property, like temperature, has no significance in the microscopic level of molecules or atoms. In short, thermodynamics is a property of the macroscopic world only or can be called an emergent property. This gives an essential turn in the idea of gravity due to Padmanabhan. When you understand that gravity is the thermodynamics of spacetime, like the thermodynamics of matter, gravity too is an emergent property, which does not exist in the microscopic world of spacetime atoms. This gave the name of the proposal of Padmanabhan's concept on gravity as Emergent Gravity. If so, gravity cannot be considered a fundamental property since it does not exist in microscopic spacetime but is only an emergent property.

Emergent Gravity and Quantum Gravity

As mentioned, one of the all-time great dreams is to unify gravity with quantum theory. Right from the inception of Einstein's theory, the scientific world desperately tried to create a quantum gravity but could not succeed so far. Padmanabhan argued that since gravity is an emergent phenomenon, there is no point quantizing the gravity equation. This can be explained as follows.

Just like Thermodynamics, elasticity is also an emergent phenomenon. Due to the property of elasticity, it is possible to change the shapes of the materials, like, say, iron. It is possible to increase the length or flatten a piece of iron. When someone is doing this, definitely is not bending, stretching the very atoms of iron. That is, atoms, say iron atoms, do not have the property, elasticity. On the other hand, the material acquires this property when its atoms form a bulk material. Now, if one quantizes the elasticity equations, corresponds to an emergent property, it is impossible to arrive at the atoms, the microscopic structure of matter. In analogy, since gravity could be an emergent property, quantizing the gravity equations will not help us get an idea about the microscopic structures of spacetime. This gives great insight and an, in fact, a relief to the age-old efforts in quantizing gravity. Hence quantizing gravity becomes a meaningless thing.

Following this, Padmanabhan argued that instead of quantizing gravity, one should start from the microscopic structures of spacetime, and with the help of a suitable statistical method, one can arrive at the emergent property of spacetime, the gravity. This approach proposed solutions to many problems like why the universe is expanding and why the density of dark energy, which accelerates the universe's expansion, is very tiny.

To summarize

In 1665, Isaac Newton speculated that gravity is the force between massive particles. However, in 1905, it came to understand that the Newtonian theory is incompatible with the special theory of relativity. In 1915, Einstein combined Newtonian gravity and the theory of relativity led to the revolutionary idea on gravity that it could be due to the curvature on the spacetime produced by the presence of matter, thus removing the misconception that gravity can be a force. In around 2000, Prof. Padmanabhan argued that gravity could be an emergent phenomenon, and thus properties like spacetime curvature, geometry, etc., have meaning only at the macroscopic level. In other words, gravity is the thermodynamics of spacetime and may not be a fundamental property. So in a way, Einstein's idea that gravity is the spacetime curvature can be a misconception. ●

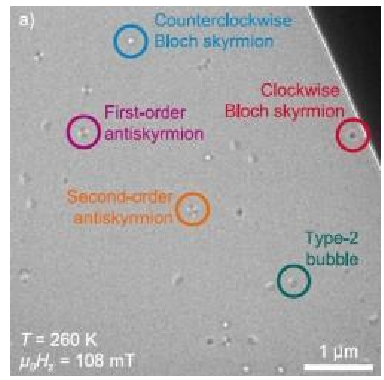
All pictures are adapted from the IUCAA website

A trip to Augsburg, Germany

Dr. Senoy Thomas
Assistant Professor
Physics, CUSAT

In February 2021, I received a scholarship offer from DAAD Germany to pursue a two-month research stay at the University of Augsburg. I was super excited to receive this offer as I have been trying to re-enter Germany since June 2013. Unfortunately, the second wave of Covid came to India in April 2021. Then came a travel ban for the Indian travellers as India was classified as a virus variant region. I had to wait until August 2021 to put in my papers for a short-term visa, and finally, I received the visa by the end of August. Now the wait is over, and I booked the tickets for my Augsburg trip. On 16th September early morning, my flight reached Frankfurt International Airport. I took an Inter-City express heading to Munich to get down at Augsburg from the airport. The journey from Frankfurt to Augsburg was pleasant because the train took me across the main cities in Germany (Manheim, Stuttgart, and Ulm) and across the countryside. At around 12.30 pm on the same day, I reached the Physics Institute of the University of Augsburg.

The physics institute at the University of Augsburg was established in the 1990s. The main research focus of the Institute is on 1) functional quantum and hybrid materials with a particular focus on thin films, hetero, and nanostructures, 2) magnetic and electronically correlated materials, 3) basic and application oriented materials science, and 4) modelling and simulation of complex condensed matter systems. The physics institute offers a bachelor's and master's course in physics and materials science. My research focus for the next two months was basically on the fabrication of soft magnetic nanostructures and imaging spin textures in nanomagnetic objects using Lorentz transmission electron microscopy. The experimental physics IV group I was associated with is well equipped with the advanced characterization of magnetic materials. The main facilities include a Lorentz transmission electron microscope. Lorentz microscopy is a method to observe magnetic spin textures of a ferromagnetic material using a TEM. Electrons passing through a ferromagnetic material undergo a Lorentz force that depends on the magnetization direction; thus, their travelling direction changes (electrons are deflected). Adjoining magnetic domains experience different deflections, thus producing contrast between the magnetic domains. The experimental physics IV group at the Institute of Physics, University of Augsburg, now has well-established techniques to image spin objects in magnetic multilayer such as skyrmions, antiskyrmions, and bubble domains. An exemplary Lorenz image adapted from their recent publication in Nature Communications 12, 2611 (2021) is shown above.



After a fruitful research stay of 2 months at Augsburg, I returned to Cochin on 15th November with new insights and motivation to continue my research at CUSAT. ●

Carrier selective contacts and upconversion phosphors for silicon solar cells

Dr. Kurias K Markose
Recipient of Distinguished Young Researcher Award 2020, CUSAT

Introduction

Global energy consumption is rising almost every day due to the increasing human population, urbanisation, and industrial activity in developed and emerging economies. Energy consumption is predicted to upsurge by roughly 48% in 20 years to meet human needs. The majority of the globe relies on fossil fuel energy sources like coal, oil and natural gas to supply the energy demands. Fossil fuels are not viable due to their finite and diminishing availability and their environmental effects. As a result, moving to renewable energy sources is critical to provide a long-term, ubiquitous, sustainable, low-cost and carbon-neutral alternative to conventional fuels for future generations. Renewable energy sources such as wind, solar, geothermal, and hydropower can eventually replace fossil fuels. Renewables are expected to account for about 30% of total power output in 2021, the greatest percentage since the Industrial Revolution [1]. Photovoltaic (PV) devices are especially of great interest as they convert solar energy to usable electricity. PV technology has evolved fast in the last decade, thanks to various technologies such as wafer-based, thin films, organic, perovskite and advanced concepts. However, the wafer-based crystalline silicon (c-Si) PV technology still dominates the PV industry, accounting for nearly 95%. Several high-efficiency silicon solar cell technologies have been reported in the past two decades.

Most of the Si PV available in the market is based on the Al-back surface field technology (Al-BSF) using p-wafers (figure 1(a)), with conversion efficiencies (η) of around 18% [2]. These solar cells are mainly limited by the rear side recombination due to heavy doping and the direct metal-semiconductor contact resulting in Fermi level pinning. Nevertheless, the p-type wafers encounter light-induced degradation issues. Later, passivating emitter and rear contact cell (PERC) (figure 1(b)) technologies are developed, where SiO_x or Al_2O_3 is used to passivate the front and rear side of the cell. The metal contacts were made through small openings forming local n^+ and p^+ regions. Reducing the reflection losses by using textured wafers and anti-reflection coatings, these technologies achieved efficiencies around 24%. In the interdigitated back contact cell (IBC) concept (figure 1(c)), both electron and hole contacts are formed at the rear side, thus reducing the shading losses and achieving efficiencies above 25%. The industrial viability of IBC and PERC solar cells, on the other hand, is complicated and expensive due to their intricate architecture. Silicon heterojunction with intrinsic thin layer (HIT) technology currently holds the world record efficiency of 26.7% (IBC-HIT) for Si wafer-based technologies. In this technology, few nanometres of amorphous Si (a-Si) layers are used on both sides to passivate the c-Si wafer (figure 1(d)), displacing the metal contacts from direct contact with the Si wafer and also providing the carrier transport. One of the main advantages of this technology is its low thermal budget since a-Si depositions can be done at low temperatures (200^{o}C). One of the shortcomings of this double side HIT structure is the parasitic absorption losses due to a-Si with bandgap 1.7 eV. Furthermore, the use of plasma-enhanced chemical vapour deposition techniques (PECVD) and toxic gases like silane, diborane, and phosphine limits its commercial applications. Thus, alternative materials that can alleviate these limitations and form carrier selective hetero contact (CSC) with Si have attracted much interest in the past few years [3].

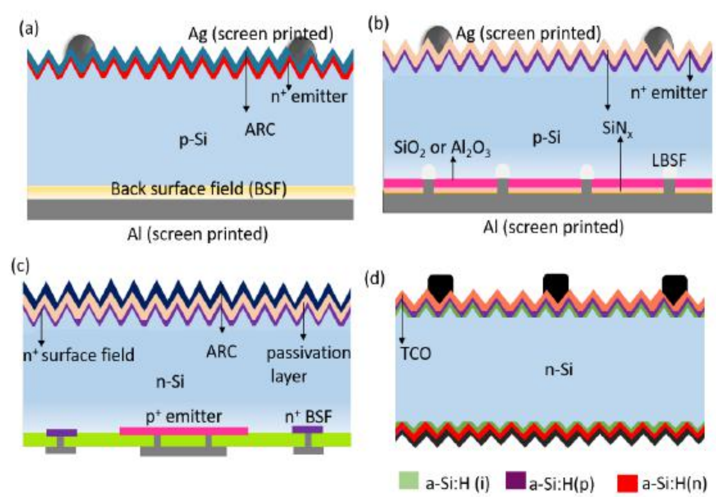


Figure 1: Device sketch of various c-Si solar cell technologies - (a) Al-BSF, (b) PERC, (c) IBC and (d) HIT solar cells

Carrier selective contact solar cells

In the carrier selective hetero contact Si solar cells, the absorber (Si) is sandwiched between two layers called hole selective layer (HSL) and electron selective layer (ESL) (figure 2(a)). The importance of the carrier selective layers is that; they allow only one type of carrier to pass through while the other one is blocked. For example, an HSL allows holes to pass through while electrons are blocked, while an ESL blocks holes and allows electrons. This ensures that the carriers are collected at the opposite contact of the solar cell. Carrier selectivity of a selective contact is attributed to the asymmetry in the hole and electron conductance of the selective layer [4]. In practice, HSL has larger conductivity for holes (σ_h) and offers lower conductivity towards electrons (σ_e), while ESL has $\sigma_e >> \sigma_h$. A good contact has many desirable characteristics, such as low majority carrier resistance, carrier selectivity, and passivation. The effectiveness of the carrier selectivity of the contact is generally determined by the recombination current density (J_0) and contact selectivity (S_{10}) - the ratio between electron to hole conductance. Let us see how CSC works and carrier selectivity is achieved in reality.

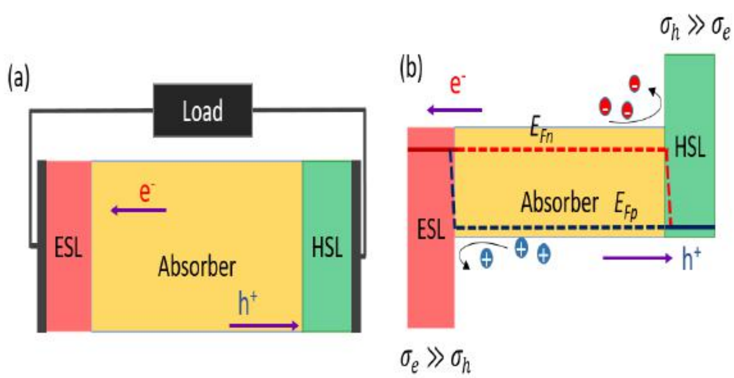


Figure 2: (a) Schematic of a CSC solar cell and (b) the working of a CSC solar cell.

Carrier selective hetero contacts selectively extract electrons and holes by establishing asymmetric band alignment. This is accomplished by choosing materials with extreme work function, which induces an asymmetric band bending in the Si, causing the quasi-Fermi levels (E_{Fn} and E_{Fp}) to move towards conduction band in ESL and valance band in HSL, achieving contact selectivity (figure 2(b)). Figure 3 shows the energy level diagrams of various selective contact materials along with c-Si. Materials such as conducting organic polymers, transition metal oxides (TMOs), and alkyl metal fluorides have been employed as CSC. Generally, high work function (Φ) materials like MoO_x, V_xO_x, Cu_2O and polymers like PEDOT:PSS is utilised as HSL, while low Φ materials like TiO_x, MgF_x and ZnO are explored as ESL [5,6]. Due to their large bandgap (> 3 eV), these materials can significantly reduce the parasitic absorption losses. The ease of deposition (TMOs can be deposited by thermal evaporation, sputtering or solution process) and low-temperature process make them suitable to realise high-efficiency solar cells at a low cost. These CSC are generally referred to as dopant free carrier selective contacts. The term 'dopant free' means that the approach does not involve any high-temperature diffusion process to form a p-n junction.

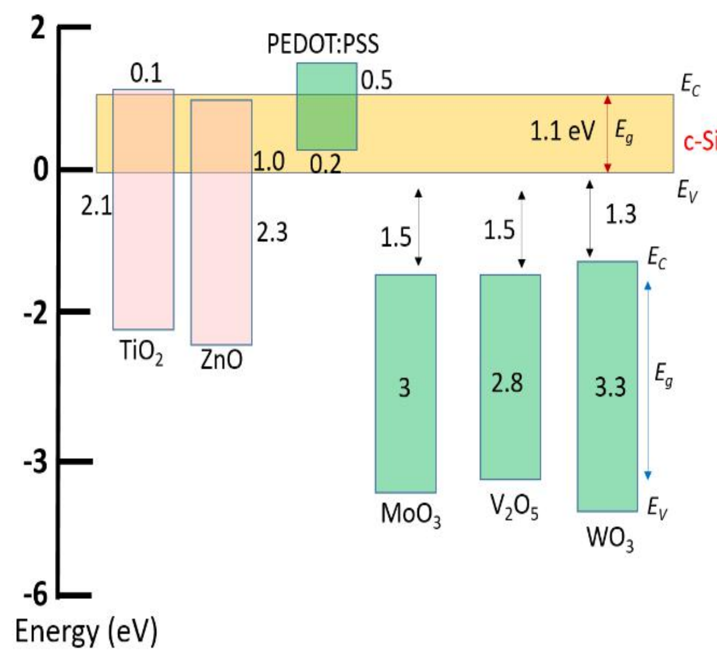


Figure 3: Energy level diagram of some TMOs and PEDOT:PSS with respect to c-Si.

In TMO/n-Si carrier selective heterojunction (figure 4(a) and (b)), the TMO induced band bending at the c-Si interface determines the carrier selectivity (i.e. HSL or ESL). When a high Φ (> 5 eV) TMO and n-Si form a junction, electrons will move from n-Si to TMO to align the Fermi level, which results in an upward band bending at the n-Si surface, inducing an inversion layer (IL) as shown in figure 4(b). The IL results in a high accumulation of holes comparable to a p^+/n-Si junction providing the carrier selectivity.

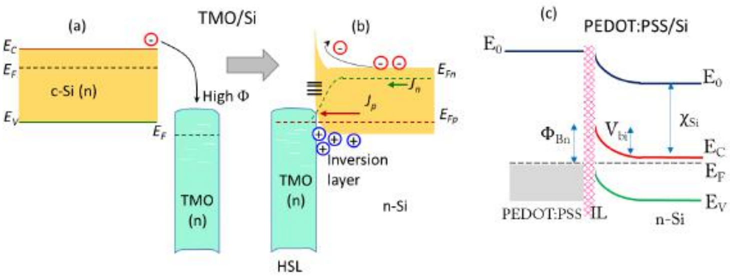


Figure 4: Band diagram of high work function TMO (HSL) and n-Si. (a) Before junction formation, electrons from n-Si transfers to the TMO (high work function). (b) The electron transfers induce an upward band bending in n-Si, inducing an inversion layer similar to p^+ layer. The asymmetry in the band offsets enables holes to pass through while electrons are blocked. (J_p - hole current density; – J_n electron current density). (c) Schematic of the band diagram of PEDOT:PSS/Si hybrid heterojunction.

Another promising carrier selective heterojunction is the organic/Si hybrid heterojunction. These hybrid cells exploit the virtues of inorganic materials like high optical absorption, large minority carrier lifetime and large minority carrier diffusion length and the advantages of simplicity of preparation, conformal coverage and the transparency of the organic polymers. PEDOT:PSS is the most widely used HSL. PEDOT:PSS could be considered as a degenerate p-type material with carrier concentration that can reach up to 10^{20} cm^{-3}. PEDOT:PSS has a high work function > 5 eV and high conductivity ($\sigma > 1000$ S/cm), showing a quasi-metallic behaviour. As a result, an IL is formed similar to the highly doped p^+ region forming a p^+n junction (figure 4(c)), with the minority carrier diffusion as the dominant charge transport mechanism. It has to be noted that band bending occurs in the n-Si of PEDOT:PSS/n-Si junction. Contrastingly, the PEDOT:PSS/Si junction does not suffer from Fermi level pinning, unlike the conventional metal-semiconductor (MS) contact. The inset of figure 5(a) and (b) shows the device architecture of TMO/Si and organic/Si heterojunction solar cells fabricated in our laboratory. The illuminated JV characteristics of dopant free double heterojunction solar cells fabricated using thermally evaporated TMO – MoO_x and alkyl metal fluoride MgF_x as hole and electron selective layers, respectively (figure 5(a)). Thermally evaporated MoO_x formed less stoichiometric films, and these mid-gap state oxygen vacancies dope the material n-type and help in charge transfer by trap assisted tunnelling. The fabricated ITO/MoO_x(10 nm)/n-Si/MgF_x/Al solar cell obtained a moderate η of 9.4% with a V_{OC} of 520 mV, J_{SC} of 30.9 mA/cm^2 and of 58.4%. Figure 5(b) shows the illuminated JV characteristics of organic/Si hybrid solar cells realised using PEDOT:PSS and PEDOT:PSS-CNT composite. PEDOT:PSS/n-Si single heterojunction textured solar cell with SiO_x passivation layer and back surface field (BSF) obtained an η of 9.78% with V_{OC} of 590 mV, J_{SC} of 34.2 mA/cm^2 and FF of 48.5%. The PEDOT:PSS-CNT/Si hybrid planar device (without BSF) obtained an η of 9.05% with V_{OC} of 588.6 mV, J_{SC} of 25.5 mA/cm^2 and FF of 60.8%.

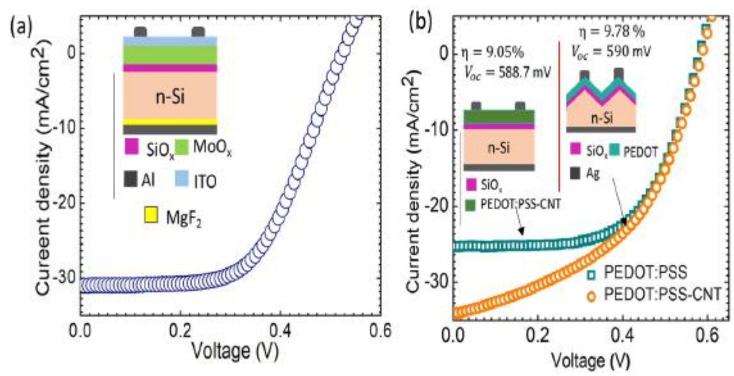


Figure 5: (a) Illuminated JV characteristics of ITO/MoO_x/n-Si/MgF_x/Al CSC solar cell and (b) organic/Si hybrid heterojunctions solar cells.

Tackling the sub-bandgap photons in the solar cell

The photo-conversion efficiency is any solar cell is a function of J_{SC}, V_{OC}, and FF. In order to achieve higher efficiencies, each of these parameters should be maximised. Utilising passivating carrier selective contact approaches V_{OC} and FF can be improved. Mitigating the parasitic absorption loss also improves the J_{SC} of the solar cells. Another serious optical loss in any solar cell is the sub-bandgap photon losses or transmission losses. The transmission losses in a solar cell can be reduced by upconverting the transmitted low-energy photons to higher-energy photons, which can then be utilised by the solar cell [7]. In practice, this can be achieved by incorporating upconversion (UC) phosphors (materials showing upconversion) to the solar cell (figure 6(a) and (b)).

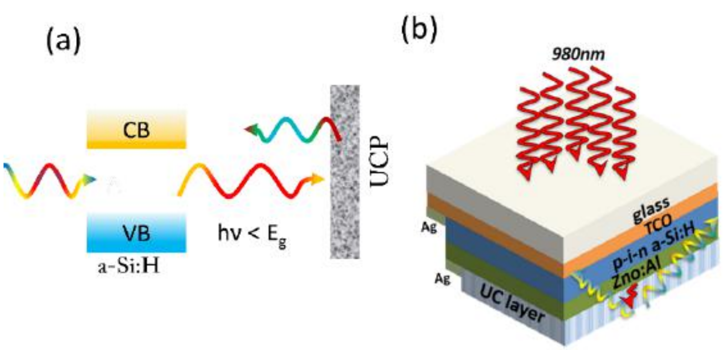


Figure 6: (a) Schematic of tackling the sub-bandgap photons in the solar cell using UCPs and (b) the sketch of device architecture used for the study.

The phenomenon of upconversion comprises obtaining population in an excited state by sequential absorption of photons and the consequent emission of a photon, whose energy is greater than that of the pump excitation photon. In order to demonstrate the proof of the concept, UC phosphors- oxide, oxyfluoride and fluoride of yttrium doped with Yb^{3+}/Er^{3+} were prepared by coprecipitation method was incorporated onto an a-Si:H solar cell fabricated in the p-i-n configuration. Figure 7(a)-(c) shows the JV curves of the different UCPs incorporated a-Si:H with varying excitation IR intensity (980 nm). The J_{SC} value was found to be increasing as the excitation intensity increases in all cases. Form the double log plot of excitation power (P_{ex}) Vs I_{SC} as seen in figure 7(d), a quadratic relation was estimated, which means the enhancement in the J_{SC} was due to upconversion. Among the various UC phosphors, YF_3 :Er^{3+}/Yb^{3+} showed better performance.

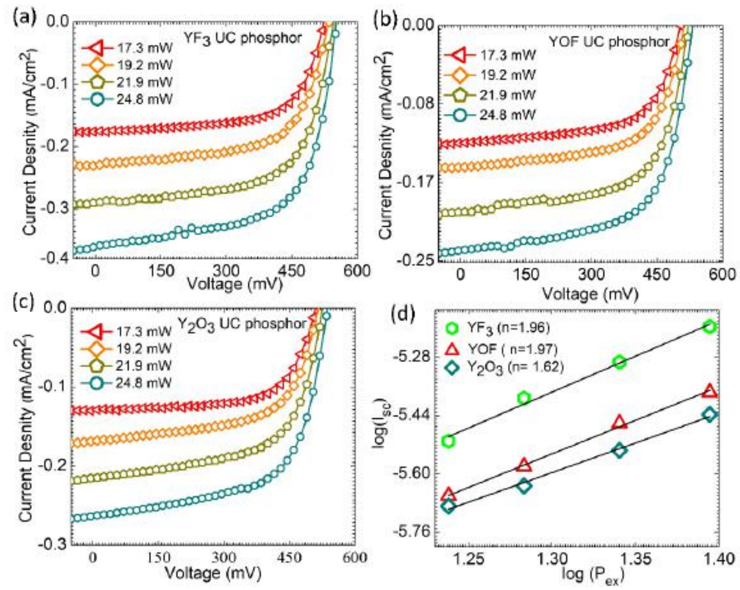


Figure 7: The JV curve of the UCP incorporated a-Si:H with varying excitation intensity (IR laser wavelength – 980 nm) for (a) YF_3 (b) YOF, and (c) Y_2O_3 phosphors. (d) double log plot of P_{ex} versus the I_{SC} for various UCPs.

Conclusion: Two approaches to improve the performance of silicon solar cells-by utilising carrier selective contacts and tackling the sub-bandgap photons by upconversion phosphors were discussed. Silicon heterojunction solar cells with hole and electron selective contacts (without the conventional doped p-n junctions) show promising potential to realise low-cost, high-efficiency solar cells. Carrier selectivity, passivation property, and carrier resistance must be considered while choosing material for selective contacts. Double heterojunction carrier selective contact with MoO_x and MgF_2 and organic/Si hybrid solar cell employing PEDOT:PSS and PEDOT:PSS-CNT were fabricated and obtained moderate efficiencies. In order to tackle the sub-bandgap photons in a solar cell, upconversion phosphors were incorporated into an a-Si:H solar cell and obtained improvement in the J_{SC} when illuminated with NIR radiation. However, this scheme best works with concentrated solar cells. ●

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Dr. Kurias K Markose won the Distinguished Young Researcher Award 2020 bestowed by Cochin University of Science and Technology. His doctoral work entitled "Development of carrier selective contacts and upconversion phosphors for silicon solar cells" was carried out under the supervision of Prof. M K Jayaraj (Vice-Chancellor, University of Calicut) and Dr. Aldrin Antony (Associate Professor, Department of Physics, CUSAT). He has to his credit about sixteen publications in high impact journals, national and international conferences.

Dr. Kurias K Markose receiving the Distinguished Young Researcher Award from Prof. K N Madhusoodanan, Vice Chancellor of Cochin University of Science & Technology

Magnet remembers!

Dr. Vineeth Mohanan P
Assistant Professor
Physics, CUSAT

As we know from childhood, magnets are mysterious objects that exhibit action at a distance! By magnets, we refer to a class of materials known as ferromagnets. They are characterized by two remarkable properties (relevant for this article): spontaneous magnetization and magnetic hysteresis [1]. The key to these is the spin degree of freedom of electrons, responsible for their permanent magnetic dipole moment (that produces magnetic field around them). Spontaneous magnetization is the collective effect of electrons under strong exchange interactions that forces their elementary magnetic dipoles to align parallel [1]. Magnetic hysteresis is a consequence of the complex magnetic energy landscape and non-equilibrium processes [2]. There are numerous applications of magnetic materials, starting from simple toys to electrical motors, electric generators, to name a few. Also, there are elusive ways to use ferromagnetic materials, and I shall briefly present one that takes care of the enormous data storage demands in this information age.

We are familiar with the fact that a magnetic field (generated by a magnet or a current-carrying coil) can magnetize a piece of iron (or any ferromagnet). What happens here is that the external magnetic field aligns the elementary magnetic dipoles within the materials in its direction, resulting in net (non-zero) magnetization. If this is an energetically favourable direction (known as the easy-axis), ferromagnet can retain the magnetization for decades even when the external field is removed. This requires considerable anisotropy energy (K) of the order of 1 MJ/m^3 that provides thermal stability against spontaneous magnetization flips [3]. Thus, ferromagnets have an excellent memory of their magnetic state (ones with large anisotropy)! This retentivity makes ferromagnets extremely useful as a data storage medium, especially in thin-film form (more accurately as nanometer-sized magnets). To reverse the magnetization direction, you need to apply a critical field (coercivity, H_c) in the opposite direction. Thus, one obtains a magnetization vs. field hysteresis as a result (Fig.1(b)). This field-based magnetization reversal technology is used in hard disc drives (HDD) that we use in our day-to-day life. They hold 80% of the global data storage market share (according to GlobeNewswire)

The history of magnetic recording dates back to 1899 with its invention by Poulsen. A relatively modern form of HDD was designed by IBM back in 1956. Its capacity was just 5 MB at an areal-density of 2Kb/in^2 [3]. Over the past 60 years, it has undergone tremendous technological improvements to hit an areal density of 2Tb/in^2.

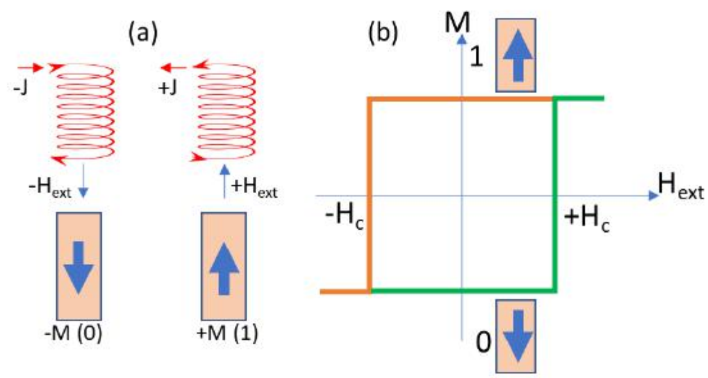

Figure 1. (a) Schematic shows a current-carrying coil that magnetizes a piece of iron (ferromagnet). (b) Schematic of the ideal square hysteresis loop of a ferromagnet. The up-magnetized and down magnetized orientations form the binaries 1 and 0, respectively.

Fig. 1 illustrates how magnetization of a ferromagnet representing binary information (1, 0) can be controlled using an external magnetic field and forms the basis of HDD technology (Fig. 2).

A typical HDD consists of many critical components. These include a magnetic recording media, an electromagnet for magnetizing/recording, and a magnetic sensor for sensing/reading the magnetization. The recording media is a thin magnetic film of ~ 20 nm coated on an Al alloy or glass platter. The microstructure of this thin film is tailored to be in the form of weakly interacting nanoscale grains/crystals that can be permanently magnetized (Fig. 2(b)). A large anisotropy is necessary for the thermal stability of the magnetic bit (collection of a few grains) and allows to shrink its size. Current technology uses CoCrPt alloys (K $\sim 10^6$ J/m^3) whose magnetization is perpendicular to the disc plane (see Fig. 2(c)), and it provides an areal density of 600 Gb/in^2 [4]. The magnetic media has specific seed layers underneath for magnetic field confinement and improving adhesion. Before the 2000s, the magnetic media had its magnetization in the disc plane, and here the storage density achieved was only 35 Gb/in^2 [5]. See Fig. 2 for a schematic of the two types of HDD implementations.

The disc's surface is covered with protective carbon material (~2.5 nm) followed by a polymeric lubricant (~1 nm). The platters rotate at high speeds between 5400-7200 rpm. A recording head, consisting of a tiny electromagnet made of a soft magnetic material (CoFe alloy) wound by a few turns of current-carrying wire, magnetizes the grains (+M/ -M, i.e., the binary 1/0). This process takes place in around one ns. The poles of this electromagnet are designed to apply highly localized magnetic fields down to nanometer length scales and of magnitude $> H_c$ of the magnetic grains. The recording head is positioned only a few nanometers above the disc and hovers along the radius of the rotating circular disc, accessing different sectors [3].

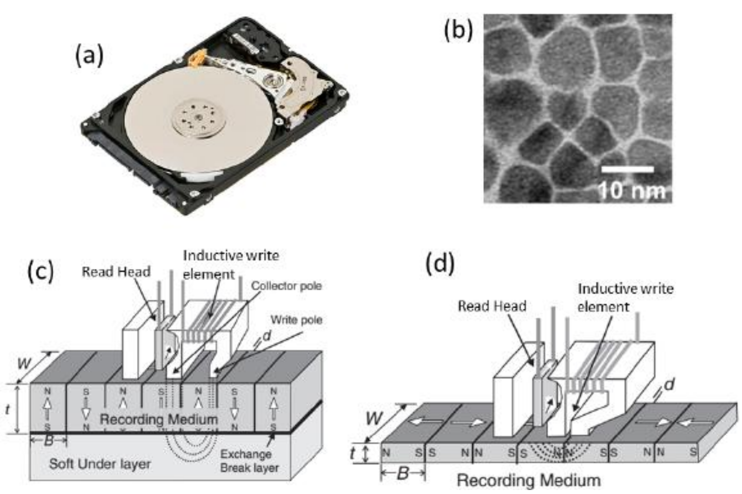

Figure 2. (a) Photograph of the interior of a hard disc drive. (b) Transmission electron micrograph of an out-of-plane magnetized recording media (adapted from [4]). Schematic of a hard disc drive in (c) out-of-plane and (d) in-plane magnetized recording (adapted from [6]).

Once the data is written, the binary information is read back from the fringing field emanating from the magnetic medium. In older days, this was accomplished using inductive heads (using Faraday's Law), which picked up the changing magnetic flux [3]. Later, the fringe field detection is performed using high-sensitivity magneto-resistive sensors (transducer) [7]. They are an important class of spintronics devices whose resistance changes with the applied magnetic field. Thus, the magnetization orientations of the nanoscale magnets within the magnetic medium are converted to resistance or voltage changes. Current technology uses magnetic tunnel junctions as the magneto-resistive sensor (with magnetoresistance ratio exceeding 100 %) [8]. They allowed miniaturization to submicron dimensions without compromising on sensitivity and had a significant impact on increasing the areal density. These magneto-resistive devices are being explored nowadays for building magnetic random access memory that is far superior to semiconductor-based RAM [9](more on this in a future article!). An earlier generation of HDD's magnetic sensors worked on the phenomenon of giant magnetoresistance, the discovery of which led to the Nobel prize in Physics in 2007 [10]. Several factors contributed to the significant improvements in magnetic HDD storage density. These include i) advances in the thin-film materials with high magneto-crystalline anisotropy, ii) the improvements in magnetic sensor head with significant sensitivity, iii) the design of the write head, iv) mechanical design of moving parts of HDD, signal to noise ratio, data acquisition, etc.

The HDD has disadvantages associated with its mechanical design, resulting in slow operations with a significant data access time of several milliseconds [7]. Because of this drawback, HDDs are used as only secondary memory devices in our computers. The magnetic discs struggle to compete with today's semiconductor-based solid-state memory devices (data access time in microseconds) in terms of speed. However, even with this shortcoming, HDD has continued to dominate the data storage business and continually increased the storage density. Adopting advanced technologies like heat-assisted [11] and microwave-assisted recording [3,12] to circumvent 'magnetic recording trilemma', the areal density has recently hit a staggering figure of ~ 2 TB/in2. Without a doubt, a magnetic HDD is a marvel of physics, materials science, and engineering. With the current pace of technology, soon you may purchase a 20+ TB HDD at a reasonable price! HDD is a reminder that there are still hidden possibilities in the microscopic world of magnets. Who would imagine the physics of a simple toy magnet has the potential to such creative solutions to cater to the needs of humanity?

Note: It is hard to do justice to a vast topic so elaborate and involved in a short article like this one. Readers are encouraged to explore scientific papers, reviews, and textbooks cited here to dive deeper. ●

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Technological advances from microstructural control

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Ranging from Elon Musks electric vehicles developed as part of transition to sustainable energy, to the speakers which we plug into daily, permanent magnets appear to be closely integrated to our lives. Quoting John Updikes poem which appeared in Scientific American in 1969 titled "*The dance of the solids*" devoted to materials:

> *...Diffuse material becomes magnetic when another field aligns domains like seaweed in a swell. How nicely microscopic forces yield, in units growing visible, the world we wield!*

Researches associated with the inherent magnetic properties of permanent magnets provide fundamental knowledge and is of technical relevance. Magnetic anisotropies arising due to the crystallinity, shape and induced distortion constitutes as the sources behind the development of permanent magnets ranging from Alnicos, hexaferrites to NdFeB based magnets. The anisotropy components individually or in combination with exchange mechanisms eg: exchange-coupling/ exchange-spring mechanism with hard and soft magnetic components still paves for further studies in development of permanent magnets. Permanent magnets based on ferromagnetic elements like Fe, Co, Ni, etc. eliminating rare-earth elements is similar to the need of Fe-based magnets that evolved after Sm-Co magnets.

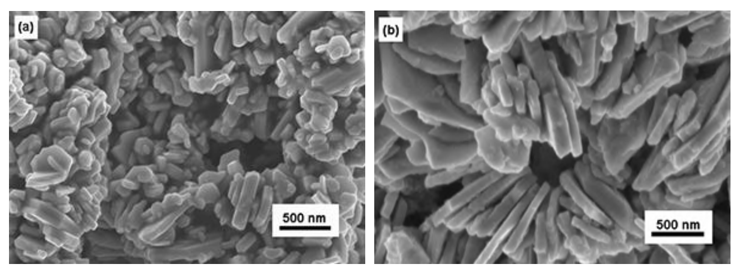


Figure: Hexaferrite platelets synthesized in presence of (a) KBr and (b) K_2CO_3 salt matrix

Primarily this is due to the natural abundance of these elements which possess credible magnetic properties chiefly, high Curie temperature compared to rare-earth-based magnets. Hexaferrites ($Ba/SrFe_{12}O_{19}$) based magnets which are devoid of rare-earth elements have been playing an important role in high volume applications due to their low cost. The anisotropic crystal structure of M-type hexaferrite imparts high uniaxial magneto-crystalline anisotropy ($\sim$3.3 x 10^6 erg/cc), introducing an easy axis of magnetization along the hexagonal c-axis. For platelet-shaped particles, there exists an anisotropy due to shape, which in typical cases is aligned perpendicular to that of magneto-crystalline anisotropy. The competition between the shape and magnetocrystalline anisotropies as a function of their dimensions can provide further insights towards developing high energy density hexaferrite based magnets. In our lab we were able to synthesize hexagonal platelet shaped particles of size ranging from 0.15 – 0.90 μm using a salt-assisted sol-gel technique. It was observed that as the melting point of potassium halide salts increases, the dimensions of platelets increased. We were able to outline the formation of platelet shaped hexaferrite phases based on a template-assisted process from their precursors. We analysed the single-domain to multi-domain range coercive values of platelets as a function of platelet widths.

Controlling the dimensions of phases using a chemical approach is an economically feasible way to gain further insights about their inherent magnetic responses. These hexaferrite platelets can be assembled as monolayers and a soft magnetic phase with high magnetization can be layered on top of the same. The bilayers can serve as a fundamental system to analyse the effects of exchange-coupled, exchange-spring to exchange-uncoupled spectra in enhancing the hard magnetic properties. Plate-shaped hexaferrite particles could be stacked and aligned by applying an external magnetic field and pressure which could result in high-performance bulk hexaferrite magnets. ●

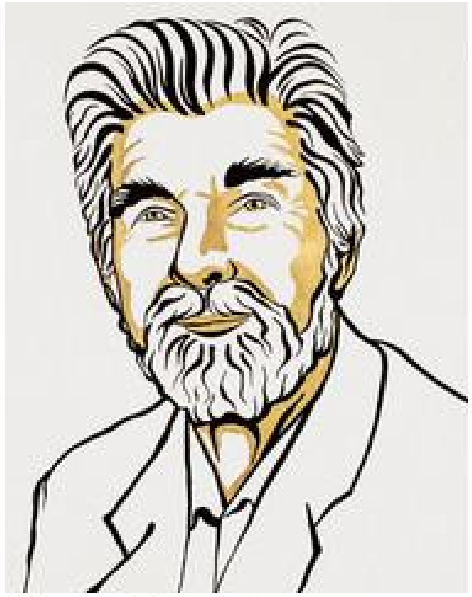
Coffee Beans Tales . . .

Anamika Ashok, Research Student, Physics, CUSAT

I am enveloped by the smell of coffee in its full bloom, it makes me feel like a freshly peeled piece of ginger floating on the surface of warm coffee, in a fancy cup. But as you know, ginger is only one of the ingredients, of course it's special, not exactly a necessity. So if someone doesn't like you, they can simply ignore you or just scoop you out. Ghattu Kakka is one such person. His timing is perfect, always scooping me out of my dream, investing his well-groomed nails, deep into my ears and frowning straight into my eyes. Though my ears did hurt, I cannot but giggle at his idiotic attire, trying to imitate uncle William, who comes by every year, to visit our estate. When I say, our estate, it doesn't mean it's ours, we just work here, and by habit came to consider it as ours. If it really was ours, how different would it have been and that takes me on the longest and fanciest dreams I ever had. Since it might be a little boring for you guys, I am not going into it. Moreover my today's dream allowance has been completed successfully, marked by my red ears. Don't consider me a rude person, that I did not introduce myself in the beginning. I am Jaan, simply Jaan, no middle name, no surname, no nothing. I live with my mother, elder sister and two older brothers, in the most serene and complicated construct, situated amidst green fields, tall mountains, singing rivers and nature enthusiasts, which for ease of your comprehension I would like to refer to as our "hut". Our hut is like all the others in the area, beautifully crafted with large leaves, grass, mud and what not, and vulnerable to fierce wind and rain. Sometimes when I lay, looking at the roof, I feel like it's waiting to come down and embrace us, any time now. That's a bit scary, isn't it? I almost forgot a teeny tiny detail about my family. I also have my grandmother living with us. She is toothless and silver haired. I left her out on purpose. Describing her odd habits might give you guys a terror. Eavesdropping is not a crime, it just happens sometimes, so in one such events I had heard of how she used to swing upside down from the arecanut trees when infested by Neeli, the neighbourhood ghost. We have so many ghosts living around us and as per my calculation, Neeli has the closest proximity to our house and so enhanced probability of entering our bodies. I actually believed in this rubbish, until I was ten. But then I was stricken by a new realisation. If there was something like an afterlife, human beings would be haunted all the time for the countless number of killings of hen, cow, pig etc. etc. If the animals do not reincarnate as ghosts, then why does humans do it? An ant dies, and its story is over. It lived and it died, so shall we. The difference that makes us reborn as ghost is simply our own imagination. What a discovery, right? Anyways I don't have anyone else to share these fabulous ideas, because nobody listens to me. Being youngest in a family of so many members is quite a hardship. Speaking of hardships, reminds me of school, for which I am already pretty late... ●

Nobel Prize in Physics 2021 awarded for research in complex physical systems

Syukuro Manabe
Prize share: 1/4



Klaus Hasselmann
Prize share: 1/4

Giorgio Parisi
Prize share: 1/2

Dr. V Sasidevan
Assistant Professor
Physics, CUSAT

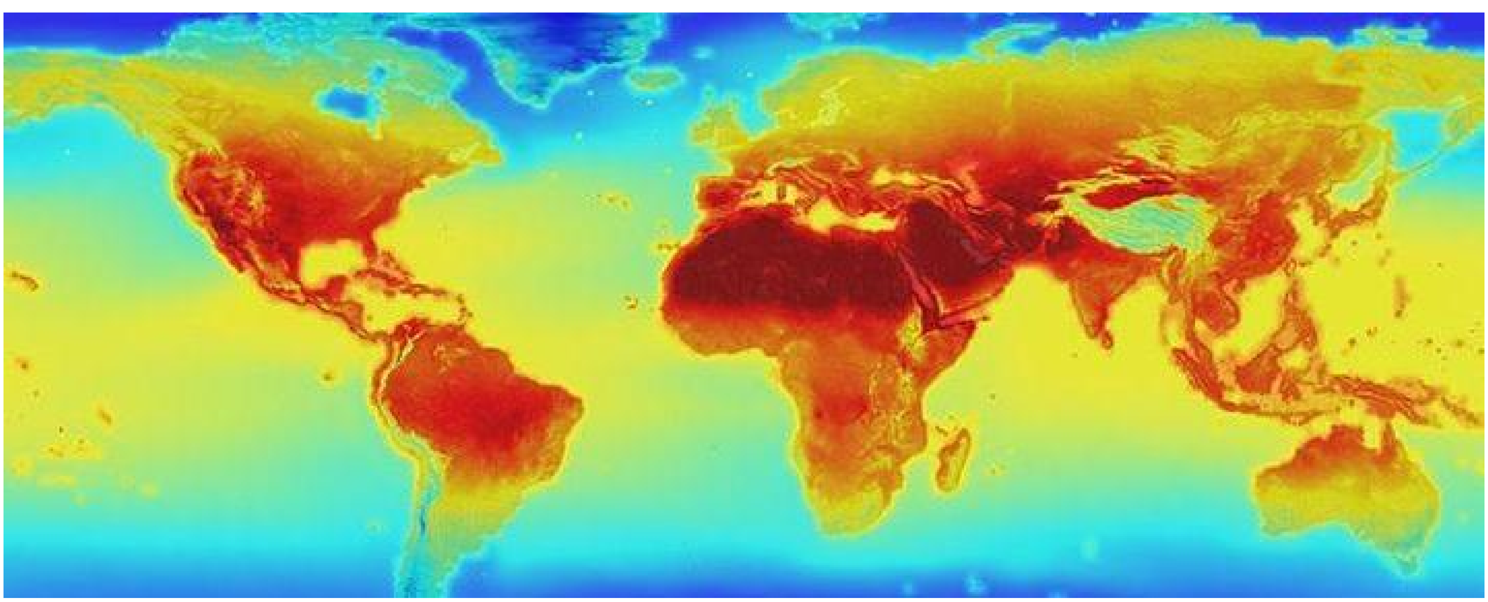
The 2021 Nobel Prize in Physics was awarded to Klaus Hasselmann, Syukuro Manabe, and Giorgio Parisi. The Royal Swedish Academy of Science's statement says the three scientists are awarded the prize "for ground-breaking contributions to our understanding of complex physical systems." Hasselmann and Manabe "for physical modeling of Earth's climate, quantifying variability and reliably predicting global warming" and Parisi "for the discovery of the interplay of disorder and fluctuations in physical systems from atomic to planetary scales." The laureates will receive 10 million Swedish kronor (approximately 9 Crore Rupees), half of which goes to Parisi, and the other half to Manabe and Hasselmann. It is safe to say that the term 'complex physical systems' will be new to many. The term refers to a broad class of systems with many interacting parts. The interacting parts produce global behaviour that cannot easily be explained in terms of interactions between the individual constituent parts. There are plenty of examples of such systems in nature. Disparate systems like glass, bird flocks, financial markets, the human brain, our immune system are all examples of complex systems. The two examples relevant to this year's Nobel prize are the climate systems studied by Hasselmann & Manabe and the spin-glass system considered by Parisi.

Our climate is the result of a large number of interacting parts. Energy reaching the earth from the sun interacts with various factors in our atmosphere and the earth's surface to produce what we see as climate. A significant factor affecting the climate and which sustains life on earth is the Greenhouse effect which maintains our lower atmospheric temperature at habitable levels. A major greenhouse gas is CO_2. There has been a dramatic increase in the levels of CO_2 in our atmosphere since the days of the industrial revolution. From the extended observation carried out at the Mauna Loa Observatory in Hawaii from the 1960s (the result of which is the famous Keeling curve) and the ice-core experiments, we now know that the dramatic increase in the level of CO_2 in the atmosphere is due to our own activities. However, quantifying accurately the effect of a change in the level of CO_2 on climate is no easy task. In 1896, Svante Arrhenius (another Nobel Laureate) developed a crude climate model by considering energy balance between a column of air and the earth's surface to obtain the temperature of the earth's surface. He studied how a change in the level of CO_2 will affect the average surface temperature of the planet. Such energy balance models -as they are known- though useful, were far too simplistic and did not consider many crucial details affecting the climate.

Building on earlier works such as by Arrhenius, starting from the 1960s, Manabe developed numerical models of detailed processes affecting climate. These models included several processes affecting climate at different spatial and temporal scales. Using his model, Manabe studied the effect that a change in CO_2 level would have on the earth's surface temperature. In particular, it was shown that doubling of CO_2 levels in the atmosphere will result in an increase of surface temperature by about 2.3^oC. Halving of CO_2 levels will result in a decrease of surface temperature by approximately the same amount. In the 1970s, Hasselmann introduced stochastic climate models which link weather and climate. He developed a framework to compare climate models and observations systematically and developed a sound statistical framework for identifying a human-caused warming signal. The upshot of these developments was the conclusion that although weather (which refers to the short-term phenomena) is unpredictable, climate (long-term phenomena) is predictable. We are now sure that human influence (mainly the burning of fossil fuels) has been responsible for the observed global warming since the 1950s.

Giorgio Parisi, who received the other half of the Prize, worked on a different complex system: the spin-glass model. Building on some peculiar experimental observations in dilute magnets in the early 1970s, Edwards & Anderson developed a model for these systems. This model was soon adapted to a mean-field setting by Sherrington & Kirkpatrick, resulting in a more analytically tractable one. The Sherrington-Kirkpatrick model turned out to be a paradigmatic one for several complex systems. The low-temperature phase of this model turned out to be very challenging to understand. It was Parisi who solved the model and, in the process, developed several concepts and ideas which turned out to have far-reaching implications for the study of a variety of complex systems ranging from ordinary glasses to neural networks. Parisi has already won some of the highest honours in science, including the Boltzmann medal, Dirac medal, and Enrico Fermi Prize, and is considered as one of the most outstanding living scientists in theoretical physics.

Complex systems are inherently hard to study. Understanding their behaviour constitutes one of the most challenging scientific inquiries we have undertaken. Increased computational power, together with the development of new theoretical tools, turns out to be the key to understanding complex systems more deeply. Understanding the science of complex systems such as the climate, financial markets, and human immune systems is extremely important for our own survival and well-being. Disorder and randomness play an important role in the dynamics of such systems and cannot be ignored as we normally do for many other systems. This year's Nobel prize acknowledges the first solid steps scientists have taken towards a theoretical understanding of complex physical systems. ●



Recent publications from the Department

- **Magneto-optical properties of a magneto-plasmonic nanofluid based on superparamagnetic iron oxide and gold nanoparticles**, Archana V N, Shan Abraham Sam, Aravind Puthirath Balan, M R Anantharaman, Journal of Magnetism and Magnetic Materials, Oct 15 2021. IF: 2.993
- **Nanocomposite Permanent Magnets Based on $SrFe_{12}O_{19}$-Fe_3O_4 Hard-Soft Ferrites**, Shan Abraham Sam, Aravind Puthirath Balan, Aswathy Kaipamangalath, Manoj Raama Varma, Rahul Raveendran Nair & Senoy Thomas, Journal of Superconductivity and Novel Magnetism, Nov 1 2021. IF: 1.506
- **Tailoring surface enhanced Raman scattering platform based on pulsed laser deposited MoS_2 - Ag hybrid nanostructure**, Anju K S, Midhun P S, K Rajeev Kumar, M K Jayaraj, Materials Chemistry and Physics, 15 January 2022. IF: 4.094
- **Charge transfer mechanism of AZO-ZnO photoanode based on impedance study for solar cell application**, Frenson P Jose, Sreekumar Rajappan Achari, Madambi K Jayaraj, Asha Arackal Sukumaran, Journal of Electroanalytical Chemistry, 15 November 2021. IF: 4.464
- **Eggshell Derived Europium Doped Hydroxyapatite Nanoparticles for Cell Imaging Application**, T K Krishnapriya, Ayswaria Deepti, P S Baby Chakrapani, A S Asha , M K Jayaraj, Journal of Fluorescence, 21 September 2021. IF: 2.217
- **Plasticity and learning behavior emulated in a ZnO based transparent artificial synapse**, P S Subin, K J Saji, M K Jayaraj, Thin Solid Films, 1 November 2021. IF: 2.183
- **Decaying vacuum and evolution from early inflation to late acceleration**, N Sarath and Titus K Mathew, Modern Physics Letters A, Vol. 36, No. 23, 2150160 (2021), 29 July 2021. IF: 2.066
- **Mpemba effect in an anisotropically driven granular gas**, Apurba Biswas, V V Prasad and R Rajesh, Accepted in Europhysics Letters 2021. IF: 1.957
- **Superhydrophilic TEOS/PF-127 based antireflection coating for solar and optical applications**, R Swathi, J Shanthi, K K Anoop, Optical Materials, Vol. 118, 111246 (2021). IF: 3.08

Collaborative research projects

• Indo-German joint project titled "magnetic spin vortices on curved geometries" for 2 years, coordinated by Dr. Senoy Thomas and Prof. Manfred Albrecht of University of Augsburg, Germany. Total outlay of the project Rs. 5,15,000/-. Start date of the project 27.09.2021.

• Research project "Development of Porous Silicon-Carbon composites as anode materials for Li-ion batteries" was initiated in collaboration with Carborundum Universal Limited. An MOU was signed for this RUSA Phase II project between CUL and CUSATECH, by Dr. Aldrin Antony of the Department of Physics and Dr. Bala Raghupathy from CUL. Ms. Merin K Wilson has joined as the SRF under this program.

MRA Best Paper Award

Kurias K Markose, M Jasna, P P Subha, Aldrin Antony, M K Jayaraj, **Performance enhancement of organic/Si solar cell using CNT embedded hole selective layer**, Solar Energy, Volume 211, 15 November 2020, Pages 158-166.

Archana V N, Shan Abraham Sam, Aravind Puthirath Balan, Anantharaman M R, **Magneto-optical properties of a magneto-plasmonic nanofluid based on superparamagnetic iron oxide and gold nanoparticles**, Journal of Magnetism and Magnetic Materials, Volume 536, 15 October 2021, 168092.

Alumni Awards

Distinguished alumnus of the year

Dr. Subhash Narayanan
Founder and CEO of Sascan Meditech Pvt. Ltd.
Thiruvananthapuram
For his contributions to the early detection of oral and cervical cancers using spectroscopic and imaging devices.

Best Thesis – Experimental Physics

Dr. Jasna M

Dr. Jasna's thesis work (Development of flexible carbon nanotube-polymer composites for optoelectronic, energy storage and electromagnetic shielding applications) was guided by Prof. M K Jayaraj (Vice-Chancellor of Calicut University and former faculty of department of Physics, CUSAT).

Best Thesis – Theoretical Physics

Dr. Sijith E

Dr. Sijith's thesis work (Long-baseline sterile neutrino searches in the NOvA Experiment) was guided by Dr. Ramesh Babu T (Emeritus scientist and former faculty of department of Physics). He worked at Fermilab USA along with Dr. Alexander I Himmel as the co-supervisor. He is currently a postdoc at DUNE collaboration.

PHYCA

Endowment Awards for MSc Students

Prof. M Sabir Endowment Award for Quantum Mechanics.

Milan K B and Sneha Boby

Prof. Ramesh Babu T Endowment Award for Electrodynamics and Classical Mechanics

Milan K B and Abhijith Sharma

Prof. S Jayalekshmi Endowment Award for Statistical Mechanics

Milan K B, Surya G and Niranjana

Recent PhDs

Dr. Archana V N
Thesis supervisor: Prof. M R Anantharaman
Tailoring Magnetic Nanofluids for Microwave, Magneto-Optical and Sustainable Energy Applications
29 June 2021

Dr. Jasna M
Thesis supervisor: Prof. M K Jayaraj
Development of flexible carbon nanotube-polymer composites for optoelectronic, energy storage and electromagnetic shielding applications
6 July 2021

Dr. Divya N G
Thesis supervisor: Prof. M Junaid Bushiri
Zn^{2+} ion assisted growth of α-Fe_2O_3 and electrochemical sensing of α-Fe_2O_3 and $ZnFe_2O_4/\alpha$-Fe_2O_3-graphene hybrid nanomaterial
12 August 2021

Dr. Kurias K Markose
Thesis supervisor: Prof. M K Jayaraj & Dr. Aldrin Antony
Development of carrier selective contacts and upconversion phosphors for silicon solar cells
23 september 2021

Dr. Krishna Sagar C K
Thesis supervisor: Prof. M Junaid Bushiri
Photoluminescence studies of Europium doped ZnS microspheres and Zn_2SnO_4 nanostructures for bioimaging application
26 October 2021

Dr. Paxy George
Thesis supervisor: Prof. Titus K Mathew
Studies on holographic running vacuum model of the late accelerating Universe
28 October 2021

Dr. Sreeram P R
Thesis supervisor: Prof. M R Anantharaman
Fabricationof Thermoelectric Devices Based on Tellurides and Manganites - A Material to Device Approach
19 November 2021

Students Achievements

PhD Students Placements

- **Dr. Krishna Sagar C K**, Kerala Government Service.
- **Dr. Sajan P**, Assistant Professor, Collegiate education.
- **Dr. Anjana R**, Assistant Professor, Collegiate education.
- **Frenson P Jose**, Kerala General Education Department.

MSc Students Placements

Batch: 2018 – 2020

- **Nikhil Mohan**, GSI Helmholtz Centre for Heavy Ion Research, Germany, **PhD Student**.
- **Syam Sadan**, Norwegian University of Science and Technology, Norway, **PhD Student**.
- **Liya Antony**, University of Salento, Lecce, Italy, **PhD Student**.
- **Abhishek A K**, CSIR - NIIST, India, **Project Associate**.
- **Ayana Ayyappan**, Ruhr University Bochum, Germany, **Master's Student**.
- **Anjana Roy**, Friedrich Schiller University Jena, Germany, **Master's Student**.
- **Anitta Jose**, Friedrich Schiller University Jena, Germany, **Master's Student**.
- **Priyanka Arun**, Tata Institute of Social Sciences, India, **Master's Student**.

Batch: 2019 – 2021

- **Anish A**, Central University Hyderabad, **PhD Student**.

First Rank

Jithu J Athalathil

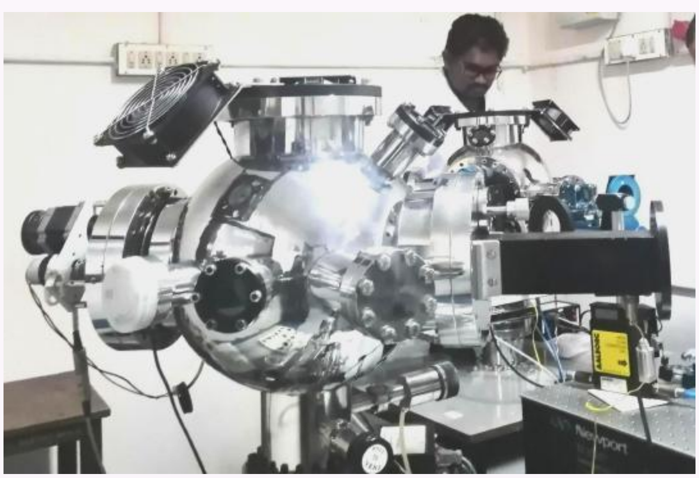
MSc Physics

2019 – 2021

University Chess Team:
Abhijith Sharma (2-nd Year MSc).
Second Prize for Prof. Susan Memorial Intercollegiate Physics Quiz, Baselius College:
R Rajesh (2-nd Year MSc).
Prathibha Scholarship:
Praveena M, Gopika Ajay Kumar (3-rd Year IMSc)
INSPIRE Scholarship:
Gopika P, Shanila M (3-rd Year IMSc), Ganga S, Ram Manohar, Abhirami S. Raghu, Divya Shaju , Mathew James, Sreekant A, Parvathi K, Megha V Karnavar, Sreelekshmi M Pai (I-st year MSc)
Higher Education Scholarship (Kerala Govt):
Vipin Satheesh (I-st year MSc)
Scranton Scholarship by Scranton Women's Leadership Center , South Korea:
Aleena Eldho (I-st year MSc)
ICCR:
Ahmed Saleh Moh'd (I-st year MSc)

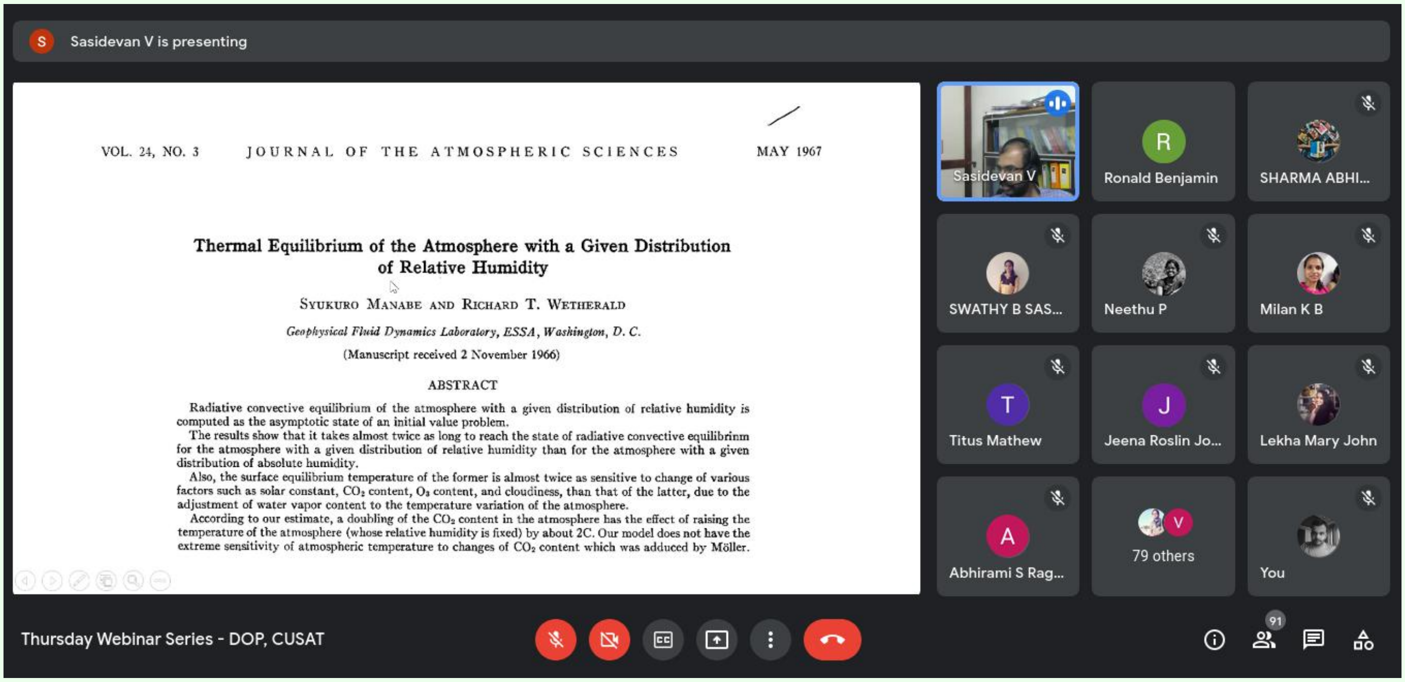
Research facilities in various labs

- 10 inch Telescope / Workstations
- Automated Spray Pyrolysis Deposition System
- Hydrothermal Oven with temperature controller
- Ball Milling Unit
- Optical Microscope
- Thermal Evaporation Unit
- Glove box
- Spectroradiometer
- 8 Channel Battery Analyser
- Impedance Analyser
- Micromagnetic Simulation Facilities
- DC and RF Magnetron Sputtering Unit
- Magneto-optic Measurement System
- Pulsed Laser Deposition System
- Nd:YAG Laser
- HR XRD ; Powder XRD
- Atomic Force Microscope
- Sensor Measurement System
- Micro Raman Spectrometer
- Chemical Vapour Deposition System
- Stylus Profilometer
- Ellipsometer
- UV Visible NIR Spectrophotometer
- Photoluminescence Spectrometer
- Fluorescence Microscope
- Electrochemical Workstation
- Fourier Transform Infrared Spectrophotometer
- Semiconductor Parameter Analyser
- Field Emission Scanning Electron Microscope Facility
- Laser Induced Breakdown Spectroscopy Facility
- Laser Surface Structuring Facility
- Plasma Ion Dynamics and Imaging Facility
- TRIAX Spectrometer



Thursday Webinar Series

Thursday webinar series is a weekly discussion forum of research activities within and outside of department of Physics, coordinated by Dr. Asha A S (Assistant Professor, Department of Physics) in association with SPIE CUSAT student chapter. Research scholars and Faculties of the department handle the webinar sessions, with an active participation from graduate and post graduate students. The discussion continues to be conducted via online platform (meet – google) due to COVID situation. The recent webinars are:



Mr. Mohammed Shareef V: **Bayesian analysis of bulk viscous dominated universe based on IS model**
Ms. Sreeja E M: **Introduction to Li-S batteries and Electrochemical Characterizations (GCD & CV)**
Ms. Angelin Abraham: **Photocatalysis: Basics of Dye Degradation**
Ms. Anupama A: **Metal organic frameworks - Introduction and drug delivery application**
Mr. Hari Narayanan V: **Luminescence and Nanomaterial**
Dr. V Sasidevan: **Complex Systems and Climate Modelling**
Ms. Nandhida Krishnan P: **Barrow Holographic Dark Energy Model**

Outreach and Talks

- Dr. Anoop K K: Oral Presentation on 'Simulation of optical emission spectra of Cu-Sn-Zn Alloy plasmas for Laser-induced breakdown sprectroscopy applications' at the Second International Conference on Physics of Materials and Nanotechnology (ICPN 2021), October 29, 2021.

- Dr. Anoop K K: Resource Person for National level online Faculty development program on Applied Optics and Photonics at Kumaraguru College of Technology, College in Coimbatore, Tamil Nadu. August 12, 2021. Topic: Laser Spectroscopy.

- Dr. Charles Jose: Resource person in Teacher Professional Development Program on "Mathematical modelling using technology-enabled and student-centred Learning" at various institutions including Cochin and Calicut University, organised by HBCSE and KSCSTE, along with CUSAT.

- Dr. V Sasidevan: Resource person in Teacher Professional Development Program on “Mathematical modelling using technology-enabled and student-centred Learning” at various institutions including Cochin and Calicut University, organised by HBCSE and KSCSTE, along with CUSAT.
- Dr. Rhine Kumar A K: Resource Person in “National Faculty Development Programme” (Online) held at Goswami Ganesh Dutta Sanatan Dharma (GGDSD) College, Kheri Gurna (Banur), Punjab on 11th June 2021.
- Dr. V Sasidevan: Talks related to Nobel Prize in Physics 2021 at Webinar organized by LUCA (09 October 2021) and Webinar organized by KSCSTE (01 November 2021).
- Prof. Titus K Mathew: Memorial talks commemorating Prof. Thanu Padmanabhan, at various venues, including: Kannur FM Radio, KSSP Science talk, Breakthrough Science Society etc.
- Dr. Asha A S: Talk on Nuclear reactions in connection with the Hiroshima day observed at Bhavan’s Vidya Mandir, Elamakkara, Ernakulam, on 6th August 2021.

Oral Presentations at 8th Indian Association of Physics Teachers (IAPT) National Student Symposium on Physics, Indian Academy Degree College, Bengaluru, India from November 12 – 14, 2021.

- **Nabeel Salim** and A. K. Rhine Kumar “A Study on Nuclear Pairing using BCS Theory”
- **Dani Rose J Marattukalam** and A. K. Rhine Kumar “Skyrme-Hartree-Fock-Bogoliubov calculation of nuclear structure properties in Pt isotopes”

Consultancy project at the Department

Dr. Aldrin Antony, Associate Professor, Department of Physics has received a consultancy project of Aqoza Technologies Pvt Ltd. to develop ‘Air Corrosion Sensor Probes’. The project is funded for a period of 6 months to develop the prototype.

Programmes organised

- Dr. Aldrin Antony organised webinar on “Futuristic Thin Films & Semiconductor Devices and Fabrication Process” on September 9th and 10th of 2021, in association with Centre of Excellence in Advanced Materials, LabIndia Instruments and Sentech Germany. Eminent Professors from IIT Bombay, CMTI Bangalore, SSPL Delhi, CEERI Pilani and Scientists from industry delivered lectures.
- Prof. Titus K Mathew organised M. Sabir Memorial Talk on October 8, 2021. Talk by Dr. P K Suresh, Professor, University of Hyderabad. Title: “On the possibility of testing quantum gravity”.
- Dr. V Sasidevan organised Teacher Professional Training programme “Mathematical modelling using technology – enabled and student – centred learning systems, on September 23-24, 2021, and October 21-22, 2021 at Department of Physics, CUSAT; on 18 -19 November, 2021 at WMO College Muttil Wayanad; on November 22-23, 2021 at Bishop Moore College, Mavelikkara in association with KSCSTE and HBCSE - TIFR.

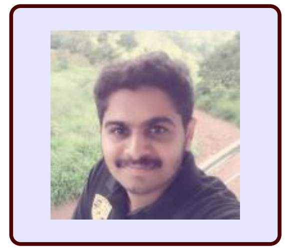
WELCOME

PhD Students


Fazil Najeeb


Parvathi V Nair


Vishnu A Pai


Muhammed Anees P

MSc Students


Abhirami S Raghu


Ahmed Saleh Moh'd


Asna M A

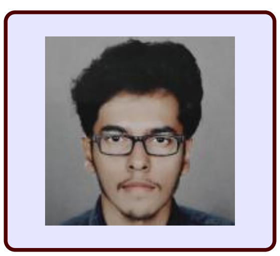

Gayathri S


Abhishek R Nath


Akhil Krishnan S


Chaithanya R


Irin Mary Joseph

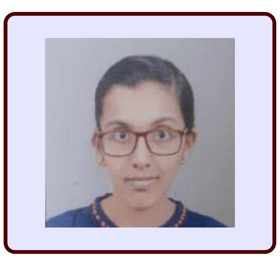

Adarsh R


Aleena Eldho


Divya Shaju


Kiran M R


Adhithyan C S


Anagha Mohan


Ganga S

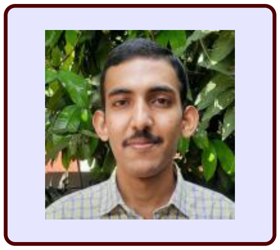

Lakshmi M S

Lakshmy T A

Milin Babu Mathew

Parvathi K

Ram Manohar



Mathew James

Nayana J

Pranav K K

Sreekant A

Megha V Karnavar

Noora Nasreen

Pranav Raj M V

Sreelekshmi M Pai

Theja Raj Etakanambath

Uma Shankari M

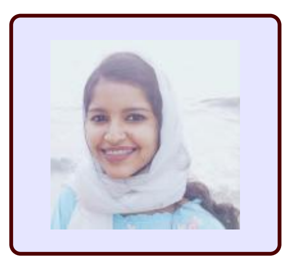
Vipin Satheesh

IMSc Students

Afreen S

Ahalya P Krishnan

Akhil N



Alisha B J


Anagha K B


Gopika P


Merline C U


Shanila M


Avani S R


Juby Biju


Praveena M


Sreehari E


Gopika Ajay Kumar


Malavika L S


Sandra Narayanan


Swaraj V


Vivek Sudhir

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