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IISER undergraduate curricula for Materials Science Research

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The purpose of this article is to portray the role of Indian Institute of Science Education and Research (IISER) system in shaping future science leaders of India, with an emphasis on materials chemistry. Starting from an overview of the expectations from science students, the article provides a glimpse of the IISER system and the 5-year BS-MS dual degree program. The various aspects of materials science and its impact are discussed, particularly based on renewable energy conversion and storage, environmental and healthcare applications. Finally, a detailed overview of the BS-MS course curriculum and its advantages in making future scientists particularly for materials chemistry research is presented.

Keywords: IISER, Science Pursuit, BS-MS Curricula, Materials Science.

Science pursuit by Indian students

High quality scientific research needs a comprehensive understanding of the what's, the how's and the whys, breaking boundaries and moving beyond the comfort zone of available knowledge. A genuine scientific research culture gets inculcated within the student at different stages, starting from high school which takes a mature shape during bachelor's and master's studies and finally acquires a direction during the doctoral studies. Just like scientific research do not obey any pre-defined boundaries between the major disciplines of biology, chemistry, physics, mathematics and/or different engineering branches, a student's mind should follow a similar pattern. The vibrant scholarly mind should never be prejudiced and to do that students need to be nurtured by thought provoking teachers and most importantly a diverse course curriculum. One such curriculum requires the student to be in touch with the basic knowledge from different disciplines during the journey through advanced research activities. This will allow a student of mathematics to do research in biology or a student of physics being awarded a PhD degree in Chemistry and vice versa. Thus, learning is not knowledge when it is only for securing good grades, unless we can translate that learning to its application in dealing with worldly problems. As of today, India has the second largest youth population of 229 million in the age group of 15-24 years. This is a unique advantage that many developed countries lack and we should be able to sensitize the young minds in scientific research, at least try our best by providing a unique comprehensive course structure. Students should have inquisitive minds starting at an early age, and need not take the teacher's words at face value. Indeed, there are sporadic examples in India where a spirit of adventurism is observed among aspiring scientists who have learnt to be inquisitive, thus generating a much-needed irreverence in the pursuit of addressing major scientific challenges. This is a quality highly valued by Nobel Laureate Richard Feynman and a vision endorsed by the multifaceted Indian Chemical Engineer Dr. R. A. Mashelkar[1]. Students are the future scientists and one day will replace the current generation of faculty/scientists to become independent researchers. There is no better alternative than having future scientists with a curious mind and comprehensive knowledge to design novel research problems and solve them individually or through collaborations.

IISER system

India is blessed to have elite institutions such as Indian Institutes of Technology (IITs) and Indian Institute of Management (IIMs) since 1950s and 1960s, respectively. Although the IITs are well known to be the *premier* autonomous public technical and research universities, they are mostly focused towards establishing engineers of global standards. Creative pursuits in basic science received a tremendous boost from the establishment of Indian Institute of Science Education and Research (IISER) system in 2006 with a strong flavour of undergraduate teaching, thus creating a separate identity besides the elite 111 years old Indian Institute of Science (IISc) Bangalore. IISER started with two Institutions at Kolkata and Pune in 2006 and now has blossomed into five other Institutes at Mohali (2007), Bhopal (2008), Thiruvananthapuram (2008), Tirupati (2015) and Berhampur (2016). A primary goal of the IISERs is to strengthen and promote interdisciplinary science education and research, as well as to enable young science aspirants to address societal problems relevant to the nation.

IISERs have found the right path to contribute to the nation's intellectual property through the able guidance of faculty members and the IISER Directors. The seven IISERs being "Institute of National Importance" contribute in shaping bright students, publishing impactful scientific literature, and patenting new science. The credit for these achievements goes to the motivated faculty members, passionate students, and support from the Government of India. All the IISERs are autonomous institutions offering integrated Bachelors and Masters (5-year BS-MS Dual Degree Program), Integrated PhD, MS in specific subjects, and PhD degrees.

BS-MS dual degree program at IISERs

In the BS-MS dual degree program, students can enrol themselves right after their 12th standard. However, they have to undergo a competitive selection process. The IISER Admission Board (IAB) follows a collective procedure of selecting students for this program through three channels, namely Joint Entrance Examination (JEE), Kishore Vaigyanik Protsahan Yojana (KVPY), and State and Central Board (SCB) (see Chart 1). Every year nearly 1400 students are admitted to the seven IISERs spread across the country. Each IISER has its systematically designed course structure, emphasizing interdisciplinary science education that prepares the students for research, academics, and industrial careers. Well-equipped with modern research facilities, IISER Kolkata provides tremendous opportunities to its students to explore a broad spectrum of scientific disciplines before the student decides which one to pursue. Like other IISERs, IISER Kolkata also follows a semester-based system for the BS-MS dual degree program and a total of ten semesters in 5 years. Students take all the basic science courses that include physics, chemistry, biology, mathematics, earth sciences, and computer sciences in the first two semesters. The primary goal is to introduce first-year students to the pure science disciplines and make them comfortable with interdisciplinary science education. As the students are promoted to their third semester, they select three pre-majors from the core basic science subjects. In the fifth semester, the student specializes in one subject as the major, and she/he has the independence to take up any course from the pre-major subjects. The next three semesters comprise advanced classes in the major discipline. The final two semesters are dedicated to a full-time master's dissertation and a few courses that lead to completing the BS-MS dual degree. Moreover, one can also receive a minor-degree in subjects other than the major, based on the number of credits completed. Overall, the BS-MS course curriculum at IISER Kolkata is research integrated, flexible, and interdisciplinary which helps

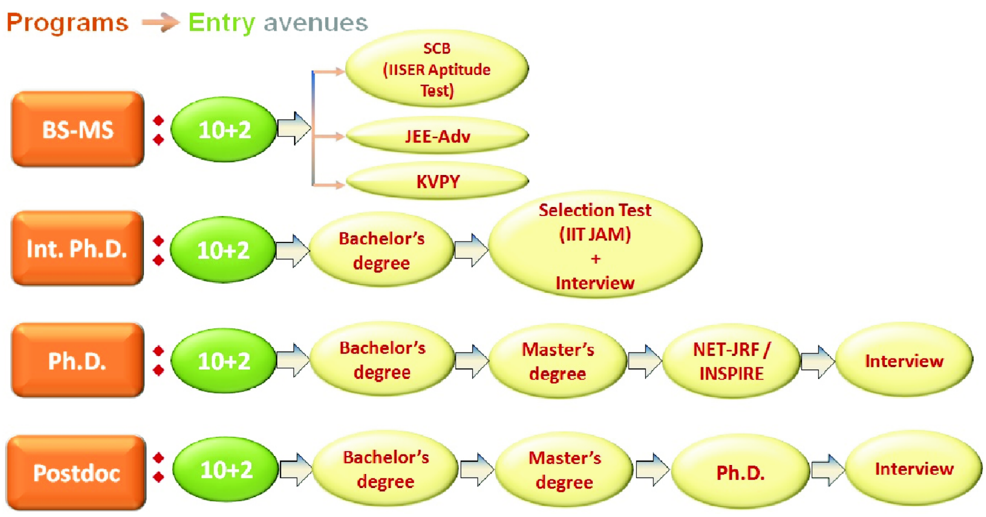

Chart 1. Route of entry to different programs at IISERs.

in the making of future science and technology leaders with inquisitive scientific minds.

Materials science and its impact

Bestowed with an interdisciplinary flavour, the students at all the seven IISERs are involved in high-quality research activities that often fetch them with important publications even before they join any top graduate school for their PhD. One of the topics that gained tremendous momentum among the students is materials science, a diverse field of research encompassing several disciplines. The multi-faceted field of materials science is quite synonymous to the famous saying by Claude Bernard, the 19th century French physiologist: "Art is I; science is we". The existence of materials science can be traced back to the beginning of human civilization and has been impacting humankind's every single step on this planet since time immemorial. The influence of materials on human society is such an important aspect that historians termed the entire period as the Stone Age, the Bronze Age, and the Iron Age based on the predominant material used[2]. Many historians prefer to call the modern period the Silicon Age due to its large-scale utilization in today's age of information. Development and discovery of new materials sometimes happened serendipitously or as an outcome of trial-and-error, and often inspired from existing materials. All these advances lead us to the present-day world and to the future. This area of research has rapidly infused into the most critical challenges of the 21st century i.e. energy, health science, and environmental sectors (see Chart 2). The advancements in chemical sciences, physical sciences, and sophisticated instrumentation have allowed the scientists to extract more information on materials ranging from nanoscale to macroscale. As a result, we envisage the utilization of new materials for better healthcare, more futuristic means of energy storage and conversion, and low/ zero-carbon technologies. The design and development of new materials have relied on Chemistry which gave rise to a new interdisciplinary sub-branch of Materials Science, materials chemistry. Materials chemistry generally involves the design, synthesis, characterization, and molecular-level understanding of potentially useful materials. For example, although magnetism is primarily a topic in the physics discipline, only materials chemists can design new materials for magnetoresistive random-access memory (RAM) or next-generation permanent magnets. The potentially useful materials suggest possible applications in catalysis, optoelectronics, biomedical science, environmental remediation, desalination, etc. Before emphasizing on how the IISER undergraduate curricula

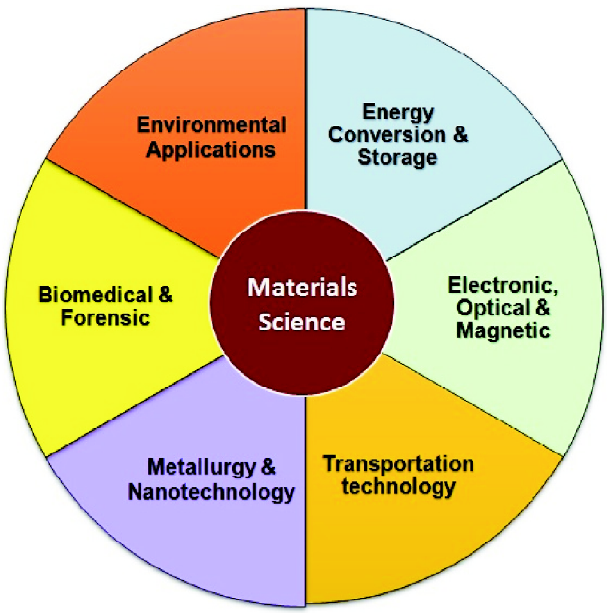

Chart 2. Materials science application areas of the 21st century. Applications of materials science in renewable energy conversion and storage.

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helps in shaping future scientists in a broad discipline of materials science, it is useful to first provide a brief overview of the material chemistry challenges and advancements in energy, healthcare and environmental sectors.

In the era of increasing demand for energy and rapid depletion of non-renewable energy resources such as coal, natural gas and petroleum deposits, solar energy stands as the best alternative energy resource. The world would need 30 TW of energy resources by 2050 to sustain the economic growth[3]. Sunlight is converted into electrical energy by using a solar cell, which works by the principle of photovoltaic (PV) effect. PV devices are utilized in power sources, solar home systems, satellites, space vehicles, communications, reverse osmosis plants, and also for megawatt scale power plants. All that solar cells require is a light absorbing material to absorb the photons and generate free electrons. It involves the generation, trapping, recombination and transport of electron-hole pairs in the semiconductor and the contact electrodes. The chemistry of solar cells is affected by the photoactive layer and its special inhomogeneities, such as defect chemistry, non-stoichiometry etc.[4]. The scopes of PV technologies are grouped into 1G (silicon wafers), 2G (polycrystalline semiconductor thin films) and 3G (organic, dye sensitized, quantum dot sensitized and perovskite solar cells)[5]. Only 1G and 2G technologies are available in mass production for civil applications while 3G cells are yet to be commercialized. The use of metal-halide perovskites (crystal structure of ABX_3) as light absorber in solar cells has shown promising high efficiency, from 3.8% in 2009 to 25.5% in 2019. Another field of interest is the quantum dot sensitized solar cells (QDSSCs), due to their excellent characteristics of tunable band gap through size and composition control, high molar extinction coefficient and better thermal and moisture stability in comparison to the dye molecules and perovskites. Over the past 12 years, the power conversion efficiency (PCE) of QDSSCs has shown a dramatic improvement from less than 1% to nearly 13%[6].

Besides utilizing solar energy, sustainable and eco-friendly electrochemical energy production is always considered a suitable alternative to fossil fuels. Systems such as batteries, fuel cells, and supercapacitors can efficiently store and convert electrochemical energy. In batteries and fuel cells, chemical redox reactions generate electrical energy, while in the case of supercapacitors, the orientation of electrolyte ions at the electrical-double layer delivers electricity[7]. Batteries are closed systems with both energy storage and conversion occurring in the same compartment, for example, lithium-ion battery. On the other hand, fuel cells are open systems with energy stored in the tanks, and conversion happens in the locally separated device. Specifically, charge transfer happens at the cathode and anode while the active masses undergoing redox reactions are transferred from outside, for example a hydrogen fuel-cell. Today batteries have the most application market, supercapacitors have found some applications as memory protection in electronic devices, and fuel cells are still at the development stage[8]. Materials chemistry plays a significant role in designing the anodes and cathodes, separators, and polymer/solid-electrolytes of these devices. For instance, in a Li-ion battery, transition metal oxides like $LiCoO_2$, $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$, $LiMnO_2$ and other polyanions are used as layered cathodic materials, graphitic and hard carbons are used as the anode material and the separator is made up of porous polymer membranes[9]. Similarly, activated carbon, carbon fibre-cloth, carbon aerogel, graphite, and carbon nanotubes (CNTs) are commonly used to construct supercapacitor electrodes. In fuel cells, Pt-based electrocatalysts are employed to achieve hydrogen oxidation reaction (HOR) at the anode and oxygen reduction reaction (ORR) at the cathode[10].

On a similar note, water splitting is a possible technology for a smooth transition to the hydrogen economy. It can generate molecular hydrogen from intermittent renewable energy sources and utilize it for fuel-cells, ammonia production, etc. Water splitting involves the dissociation of H_2O molecules to produce molecular hydrogen and oxygen. Both the hydrogen evolution and oxygen evolution reactions (HER and OER) are sluggish in nature and require efficient catalysts. Water splitting can be achieved photochemically, photo-electrochemically utilizing photons and electrochemically in the dark. Among the three processes, electrochemical water splitting has reached the market while the other two are in the development stage. Generally, Pt group metals (PGMs) are used as electrocatalysts in current water electrolysers[11]. Pt-based materials are well-known catalysts for HER, while RuO_2 and IrO_2 are known for OER. The high-cost and low-abundance of PGMs have demanded the search for non-noble metal-based electrocatalysts. A large number of low-cost and earth-abundant materials are reported for acidic and alkaline water splitting like transition metals phosphides, sulfides, and carbides for HER[12] while various transition metal oxides for OER[11,13,14]. TiO_2 with Pt, RuO_2[15], ZrO_2[16], Al-doped $SrTiO_3$[17] are some of the photocatalysts studied for water-splitting. However, to provide a complete

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solution of hydrogen conversion and storage, a team-up of chemists and chemical engineers is much needed.

The fields of electrochemistry and solid-state materials are also vital in CO_2 capture and utilization as well as for the benign production of ammonia-based fertilizers. The increase in anthropogenic CO_2 emissions is a major environmental concern of the 21st century which has caused global warming and seawater acidification. Researchers are trying to address this issue by exploring various materials and technologies that can capture CO_2 and convert it into chemical feedstocks. Electrochemical CO_2 reduction using efficient electrocatalysts is envisioned as a future green technology. It generates useful value-added carbonaceous (2C) products. The good news is most of the studies show that cost-effective Cu-based electrocatalysts are potential CO_2 reduction catalysts[18]. However, there are challenges with the selectivity and yield of the products as well as controlling the thermodynamic parameters for electrochemical CO_2 reduction. In another context, a great invention of the 20th century, the Haber-Bosch process is mostly utilized to produce ammonia to feed the whole world, but is not an environmentally benign method. The molecular hydrogen required for this process comes from fossil fuels (natural gas), and it is an energetically demanding method that requires high temperature and pressure. A future alternative is the electrochemical reduction of nitrogen into ammonia under ambient conditions. Inspired by the nitrogenase enzyme, several non-precious metal-based electro-catalysts are explored for nitrogen reduction reaction (NRR). Nearly 30% of the electrocatalysts studied are Fe and Mo based systems[19]. Nitride based systems are also interesting for the electrosynthesis of ammonia as the lattice nitride ions can participate in the reaction mechanism[20]. This field is still at an early stage, and there exist several challenges that include selectivity for ammonia production, achieving high yield, and controlling the thermodynamic parameters.

Materials science in environmental applications

We are aware that heavy metal pollution leads to serious health consequences in all living beings, humans, animals as well as plants. Trace amounts of heavy metals are naturally present in certain geographic locations where anthropogenic activities are responsible for creating the contaminant sites. The United States Environmental Protection Agency (USEPA) categorized lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury

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(Hg), and nickel (Ni) as the eight heavy metals found widely in the environment[21]. Among them, Pb, Cr, As, and Cd are disposed by industries and are severely toxic. A microgram concentration of these elements can cause severe health issues. This is one area where researchers are trying to design nanomaterials to remediate these toxic metals by sorption techniques. Herein metal-organic frameworks[22,23], zero-valent iron nanoparticles[24], and g-C_3N_4[25] have a high propensity towards heavy metal sorption.

Another pertinent environmental concern is to supply drinking water at every corner of this earth and the major factors to contribute to this dearth of fresh water supply are rapid industrialization, urbanization, contamination of available freshwater resources and climate change. According to the World Health Organization (WHO), predictably nearly half of the world's population will live in water-stressed regions in the near future. This has led to a search for alternative methods of utilizing desalted seawater or recycling wastewater for efficient water consumption. The two most prominent desalination categories are thermal and membrane-based desalination processes. The thermal process utilizes evaporation and condensation for salt separation, while membrane-based desalination needs semi-permeable membranes to restrict the salt passage by reverse osmosis (RO) and electrodialysis[26]. Today RO is the most widely used desalination techno-logy[27] where a variety of functional materials are required. Photocatalysts like TiO_2 are also used for disinfecting and degradation of pollutants in water through generation of active oxygen species like $^{\bullet}OH$ radicals[28] whereas electrochemically functionalized membranes made of CNTs can degrade organic and inorganic pollutants through electrochemical oxidation processes[29]. In addition, hydrophobic photothermal materials are used for harvesting solar energy for water desalination by evaporation at air-water interfaces[30]. Various adsorbents like zeolites, CNTs, graphene etc. are widely used for removing the salt from aqueous solutions[31].

Materials science in healthcare applications

Biomaterials have a wide range of applications for implants, medical devices, surgery, dentistry and drug delivery. This class of materials should be non-toxic, minimally invasive, noncarcinogenic, chemically inert, stable, and mechanically robust enough to withstand the repeated forces of a lifetime. Several classes of metals, alloys, polymers and ceramics have been tested and commercialized for

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meeting the requirements[32,33]. Starting from the targeted and controlled killing of tumours to alleviating the effects of viral infections, nanomaterials have come a long way in the field of nanomedicine and healthcare. Monodisperse nanoparticles with uniform shape and size have tremendous potential in influencing the field of medicine from nanobiotechnology, nanofluidics, biosensors and microarrays to tissue micro-engineering. One of the most promising applications of nanomaterials is the promise of targeted, site-specific drug delivery[34]. Functionalization of nanoparticles to deliver drugs through the blood-brain barrier for targeting brain tumours can be regarded as a brilliant outcome of this technology[35]. For drug delivery an appropriate nanofluid is required by accurate control over the nanoparticle emulsions in the fluids, which can afford drug loading and release characteristics, prolonged shelf life, and biocompatibility[36]. Although regulatory mechanisms for nanomedicines along with safety/toxicity assessments might be a subject of future development, the field of nanomedicine has already been revolutionized by important discoveries of nanocarriers, minimally invasive systems and nanobots. There are in fact several other areas where creativity, crazy thoughts and innovations are sought after. All these endeavours are not only limited to experimental research but duly supported by computational materials science from molecular to macroscopic systems, which nonetheless form a separate sub-discipline.

The influence of IISER BS-MS courses on materials chemistry research

The authors being associated with the Department of Chemical Sciences at IISER Kolkata, the primary focus in this section would be on IISER Kolkata's BS-MS course curricula and its favourable influence to pursue material chemistry research. Research in material chemistry is highly interdisciplinary and thus, one can easily find undergraduate students, PhD scholars and postdoctoral researchers from different disciplines, working together in a material chemistry group. This section provides a detailed analysis of how the interdisciplinary course structure at IISER Kolkata helps a student in initiating research in this area (see Chart 3).

The introductory theory and laboratory courses at IISER Kolkata aim to spark curiosity and excitement among the freshmen in the first year. The curriculum is designed to help the students to transition smoothly from the high school to college level along with strengthening the base for the upcoming years in academics

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1st year	2nd year	
Elements of Chemistry	Elements of Chemistry II	Introduction to Computation
General Physical Chemistry	Quantum Chemistry I	Analysis I & II
Chemistry Lab I	Fundamentals of Spectroscopy	Linear Algebra I
Physical Chemistry Lab	Reaction Mechanisms in Organic Chemistry	Mathematical Methods II
Introduction to Computer Programming	Inorganic Lab	Probability I
Earth and Planetary Sciences	Synthesis and Characterization Lab	Mechanics II
Earth System Processes	Biogeochemical Cycles	Waves and Optics
Introduction to Biology I & II	Hydrology and Geodynamics	Thermal Physics
Biology Lab I & II	Geophysics	Basic Quantum Mechanics
Mathematics I & II	Introduction to Environmental Science	Physics Lab III & IV
Mathematical Methods I	Biochemistry	
Mechanics I	Biophysics	
Physics II	Evolutionary Biology	
Physics Lab I & II	Biology Lab III & IV	

3rd year (Chemistry)	4th year (Chemistry)		5th year (Chemistry)
Transition Metal I	Organometallic Chemistry and Catalysis	Natural Products and Medicinal Chemistry	Sustainability and Chemistry
Organic Chemistry I & II	Molecular Structure and Symmetry	Physical Methods of Structural Elucidation	Principles of Physical Chemistry
Quantum Chemistry II	Group Theory and Spectroscopy	Statistical Thermodynamics	Principles of Organic Chemistry
Physical Organic Chemistry	Important Perspectives of Organic Chemistry	Research Methodology	MS thesis project
Main Group Elements I	Organic Functional Materials	Chemistry of Materials	
Applications of Chemical Thermodynamics	Fluorescence Spectroscopy: Principles and Applications	Molecular Reaction Dynamics	
Chemical Kinetics	Chemical Perspectives of Biological Pathways	Advanced Quantum Chemistry	
Advanced Physical Chemistry Lab	Transition Metal II	Polymer Chemistry	
Organic Synthesis Lab II	Organic Chemistry III	Introductory DFT	
Inorganic Synthesis and Characterization Lab	Bioinorganic Chemistry		

Chart 3. Five-year course structure in the BS-MS program with chemistry major at IISER Kolkata. The courses shaded in blue have perceptible implications on the research activities in materials science.

and research. Instructors mainly focus on enhancing learning by integrating theory and experiments, organizing group discussions, and teaching essential

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concepts from each discipline. The idea is to introduce students to think, analyse, and improve their problem-solving skills. All the courses are beneficial for students pursuing any field, and many of them are prerequisites for interdisciplinary subjects including materials chemistry. For instance, the fundamentals of redox chemistry and thermodynamics from first-year "Elements of Chemistry" and "General Physical Chemistry" courses are vital for materials chemistry.

These chemistry courses also teach the introductory concepts in organic, inorganic, and physical chemistry that lay the foundation for advanced studies. The first-year physics courses are also necessary as they include essential ideas on electricity, electromagnetism, and quantum mechanics that help to understand the properties and application of materials. The mathematics courses include topics like partial derivatives and matrix algebra which help in understanding basic quantum chemistry. Also, the introductory computer programming course mostly teaches the tools to analyze materials and their properties. The introductory biology courses unravel the basics of cell structure and cellular transport, the knowledge of which is needed for material scientists working on surface engineered cells for various applications, for example bioimaging and sensing, tissue engineering, etc. The chemistry and biology laboratory courses are vital too. They focus on synthesizing organic and inorganic compounds and introducing various analytical techniques like optical absorption, separation and purification methods.

In the 3rd semester, the chemistry course "Inorganic Chemistry" consists of the structural aspects of main group elements as well as transition elements, which form the basis for understanding the fundamental properties of various materials. This course also teaches redox chemistry and symmetry operations required for synthesis and crystal structure determination. The "Quantum Chemistry" course also provides a glimpse of the periodic potential, which is vital to understand the band theory of solids. Furthermore, the students get hands-on experience in nanomaterial synthesis, UV-Visible spectroscopy, and IR spectroscopy through the "Inorganic and Spectroscopy Laboratory" coursework. Subsequently, 4th-semester chemistry courses like "Fundamentals of Spectroscopy" deliver lessons on the required rotational, vibrational, electronic, NMR and Raman spectroscopy theories often used in characterizing chemical fingerprints on the surface of various materials. The organic chemistry courses strengthen the basic understanding of organic reaction mechanisms, aromatic compounds, and functional groups which are essential for students willing to work on organic and polymeric materials.

Apart from chemistry, the second-year earth science courses include topics like carbon cycle and groundwater contamination, which are parts of some major application areas in the field of materials science. Similarly, a mathematics course on Probability and Statistics teaches the students about various probability distributions and error calculations which are crucial for managing data in research. The biology courses such as biochemistry and biophysics give theoretical insights into the synthesis, growth mechanism, and colloidal behaviour of various biomolecules. Likewise, physics courses like Electricity and Electronics, Quantum mechanics, and Thermal Physics are necessary for the theoretical understanding of solid-state materials and their potential application in multiple fields. Moreover, the Optics and Modern Physics laboratory course provides the requisite experience in carrying out experiments required for the research on photonics.

The most relevant chemistry courses start from the 5th semester onwards. The 5th and 6th semester courses like “Main Group Elements” and “Transition Metals” are essential inorganic chemistry courses for igniting curiosity driven research in inorganic materials. One gets in-depth knowledge about the properties of various elements and their compounds crucial for designing new materials. Similarly, the “Quantum Chemistry II” and “Group Theory and Spectroscopy” courses provide profound knowledge in the fundamental understanding of elements, molecules, their symmetries, and how to categorize them. The organic synthesis theory and laboratory courses are equally important to better grasp the reaction mechanisms and knowledge about crucial organic molecules, especially conjugated compounds and their functional groups. Additionally, the inorganic chemistry and advanced physical chemistry laboratory courses provide hands-on experience in inorganic synthesis and advanced characterization techniques like X-ray diffraction (XRD), electron paramagnetic resonance, infrared (IR) spectroscopy, etc. The course “Instrumentation in Chemistry”, not included in Chart 3, is designed for the integrated PhD students and course work for the research scholars as well as BS-MS students to get the fundamental knowledge on XRD, electron microscopy, X-ray photoelectron spectroscopy, Raman spectroscopy and several other techniques useful for their future research on solid state and polymeric materials. Along with chemistry, a minor course like “Mineralogy” from earth sciences introduces students to crystallography, symmetry, and diffraction in crystals which is an essential part of the characterization of materials.

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The advanced fourth-year courses play a significant role in carving a path for the students to choose materials chemistry as their research field. The “Molecular Structure and Symmetry” course gives a fundamental understanding of qualitative Molecular Orbital diagrams using SALC and projection operators. It is also useful in analysing the electronic structure of solid-state materials. The catalysis part of the course “Organometallic Chemistry and Catalysis” touches upon polymer synthesis, a material chemistry sub-branch as well as reaction mechanisms for catalysis of C-H activation, C-C activation, hydroformylation, etc.; reactions for which, the path of materials chemistry is often chosen. Further, there are advanced courses on Chemical Thermodynamics which is essential to understand the thermodynamic properties of materials like colligative properties and fluorescence spectroscopy, which elaborates on the photoluminescence behaviour of various materials, introduces students to quantum dots and their photovoltaic applications. In the 8th-semester, the core course “Physical Methods of Structural Elucidation” provides a detailed structural analysis of crystals using single crystal XRD and organic molecules using nuclear magnetic resonance, mass spectrometry, etc. This course is beneficial for materials characterization and analysis. Another important course is the “Chemistry of Materials,” a combination of solid-state chemistry and nanomaterial chemistry. The first part of the course focuses on crystal structures, crystal symmetry, reciprocal lattice and band theory, while the second part comprises nanomaterial synthesis, characterization, and applications. Two other biochemistry courses on “Bioinorganic Chemistry” and “Natural Products and Medicinal Chemistry” are useful for the students wanting to work in biomaterials for drug-delivery, biomimetics, etc. which are some of the major fields in healthcare science. An elective course on “Polymer Chemistry” provides a detailed analysis on the synthesis, properties and application of all types of polymers, immensely useful for students interested in the field of polymeric materials. The optional course “Advanced Quantum Chemistry” is also important if someone wants to know Density Functional Theory and other first-principle calculations required for computational material chemistry. An additional course from biological science: “Structural Biology”, talks about soft materials construction using peptides and their characterization techniques.

The 9th-semester chemistry course “Principles of Physical Chemistry” contains many concepts related to electrochemistry, semiconductors, and laser spectroscopy. Most of the theories required in electrochemistry and photovoltaics are discussed in this course, helping students correlate research findings to existing ideas. This specific course is an introductory one for students pursuing electrochemistry, semiconductor chemistry, and optoelectronic devices for energy conversion and storage applications. The updated curriculum offers "Sustainability and Chemistry" as the 9th semester course to introduce the students to challenges in sustainability and their potential solutions. To bolster the technical knowledge in energy research, a new 8th semester course on "Chemistry for Alternative Energy Solutions" is at the planning stage. The 9th and 10th semesters are meant to focus on the MS-project by joining a laboratory. Apart from the structured courses, students interested in materials chemistry research join the advanced functional materials laboratory, nanomaterials laboratory, porous materials laboratory, supramolecular chemistry, crystal engineering and polymer research laboratories at IISER Kolkata in the mid of their undergraduate courses. They do so to become familiar with different synthesis and characterization techniques. A few laboratories in the biology and physics disciplines also allow students to carry out interdisciplinary materials research.

Overall, the IISER Kolkata BS-MS course curriculum plays an important role in shaping up a student's interest in materials chemistry research. It provides the basic and advanced scientific education required to pursue their field of interest and inculcates the concept of interdisciplinary science in them, which is crucial in today's scientific environment. Much credit goes to the faculty selection that has diversified a wide spectrum of research fields in the Department of Chemical Sciences that offers the students to choose and nurture themselves in a research area out of a wide spectrum of available expertise. Besides the MS graduates pursuing their PhD career in top schools around the world, several students have contributed significantly to the materials chemistry research endeavours at IISER Kolkata even before embarking on their PhD career. The students have excelled in publishing high quality research articles in leading journals such as Angewandte Chemie, Nature Communications, Chemical Science, Chemistry of Materials, Journal of Material Chemistry A, ACS Applied Materials & Interfaces, Carbon etc. in the fields of solar cells[37–40], electrochemical and photochemical water-splitting[41–45] to name a few.

Summary

In summary, the BS-MS curricula of IISERs is a perfect blend for creating curiosity driven research by students in a broad spectrum of scientific disciplines, especially materials chemistry. Although this article highlights the course curricula of IISER Kolkata chemistry, the basic structure remains similar across all IISERs. The students are given a flavour of interdisciplinary research by a unique course structure whereby they remain up-to-date with different branches of science throughout the 5 years of their study period. Most importantly a student self-evaluates the most appropriate research area in which she/he can excel and joins a research group to nurture their skills accordingly. As cherry on the cake, besides learning the ethics and basics of scientific research from a young age, they are involved in many extracurricular activities which make them the future leaders, the nation looks up to.

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