Integrated MSc Physics
with a minor*in
Scientific Computing/ Data Science

with exit option for

BSc Honours in Physics
with aminor*in
Scientific Computing / Data Science

(From academic years 2022-2023 onwards)

* A minor option is to be chosen in the 3rd semester. Selection for a minor in Data Sciencewill be based on merit and availability.

BScHonours exit option is to be given by students at the end of 6th semester. It has a different set of coursesin the4thyear involving research and project components.

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Program Educational Objectives, Program and Program Specific Outcomes

Program Educational Objectives

The educational objectives of our program are to ensure that the graduates are strong in the fundamentals, practical, dependable, collaborative, and professional. Specifically, three to five years after graduation, the successful graduates will have

- Made use of learning opportunities in formal and informal settings to maintain and enhance technical excellence and professional growth.
- Engaged in successful professional practices in their chosen discipline.
- Demonstrated collaboration and communication skills in the work environment and society at large and will have been leading a life of responsibility to oneself, the society, the nation.

Program Outcomes

PO1.   **ScienceKnowledge:** Gain knowledge of basic science, mathematicsfundamentals.

PO2.   **Problem Analysis:** Develop analytical and abstraction skills to identify, formulate, research literature, and analyze complex phenomena usingfirst principles of mathematics and basic sciences.

PO3.   **Design/development of solutions:**Design solutions for complex problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4.   **Conduct investigations of complex problems**: Acquire experimental and computational skills, use research-basedknowledge and research methods including design of experiments,analysis and interpretation of data, and synthesis of the information toprovide valid conclusions.

PO5.   **Modern Analytical Tool Usage:**Select, and apply appropriate techniques, resources, and modern analytical tools.

PO6.   **The scientist and society:** Apply reasoning through the contextual knowledge to assess societal, health, safety, legal and cultural issues, and the consequent responsibilities relevant to the professional chemical/scientific practice.

PO7.   **Environment and sustainability:** Understand the impact of chemical/scientific processes in societal and environmental contexts, and demonstrate the knowledge, and need for sustainable development.

PO8.   **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of scientific practice.

PO9.   **Individual and teamwork:** Think critically and work independently, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10. **Communication:**Communicate orally and in writing on complex scientific activities with the science community and with society at large, such as, being able to comprehend and write effective reports and design documents, make effective presentations, and give and receive clear instructions.

PO11. **Project management and finance:** Demonstrate knowledge and understanding of the scientific and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12. **Life-long learning:** Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of scientific and technological changes as well as in social relations.

Program Specific Outcomes

PSO1. Students will demonstrate a knowledge of mathematical methods, classical mechanics, electromagnetism, quantum mechanics, thermal and statistical physics, and related subjects and be able to apply this knowledge to analyze a variety of physical phenomena.

PSO2. Students will gain experimental skills to take precise measurements in physics laboratories and analyze the measurements to draw valid conclusions. In addition, students will be able to demonstrate enhanced skills in solving problem using computational-tools in the field of physics and in multi-disciplinary settings.

PSO3. Students will manifestenhanced oral and written scientific communication skills and be able to think critically and work independently as well as in a team and play a beneficial role in the society as a person with better scientific outlook.

Department of Physics, Amrita Vishwa Vidyapeetham, Amritapuri campus

Curriculum and Syllabus– Year 2022-2023 Onwards

Integrated MSc in Physics /BSc Honours in Physics with a minor*in Scientific Computing/Data Science

Course Code	Course Title	L T P	Cr	ES	Course Code	Course Title	L T P	Cr	ES
	SEMESTER 1					**SEMESTER 2**			
22MAT103	Single Variable Calculus	3 1 0	4		22MAT113	Multivariable Calculus	3 1 0	4	
22MAT104	Vectors and Geometry	3 1 0	4		22MAT123	Differential Equations and Linear Algebra	3 1 0	4	
22PHY107	Introduction to Mechanics (Physics)	3 1 0	4		22PHY114	Electricity and Magnetism	3 1 0	4	
22CHY105	Chemistry I	3 0 0	3		22CHY114	Chemistry II	3 0 0	3	
21ENG101	Communicative English	2 0 2	3			Free Elective	1 0 2	2	
22AVP103	Mastery Over Mind (MAOM)	1 0 2	2		21ENV200	Environmental Science and Sustainability	3 0 0	3	
22ADM101	Foundations of Indian Heritage	2 0 0	2		22ADM111	Glimpses of Glorious India	2 0 0	2	
22CHY184	Chemistry Lab	0 0 3	1		22PHY185	Physics Lab I	0 0 3	1	
22CSA105	Hands-on Introduction to Computing I	1 0 3	2		22CSA113	Hands-on Introduction to Computing II	0 0 3	1	
	Semester Total		**25**			**Semester Total**		**24**	
	Total credits at the end of first year = 49								
	SEMESTER 3					**SEMESTER 4**			
22PHY205	Intermediate Mechanics I	3 1 0	4		22PHY216	Intermediate Mechanics II	3 1 0	4	
22PHY206	Thermal Physics	3 1 0	4		22PHY217	Optics	3 1 0	4	
22PHY207	Mathematical Methods for Physics I	3 1 0	4		22PHY218	Mathematical Methods for Physics II	3 1 0	4	
22MAT231	Introduction to Probability and Statistics	3 1 0	4		22PHY219	Electronics	3 1 0	4	
22CSA201	Programming for Scientific Computing	3 0 2	4			Minor Course 1	3 0 2	4	
22PHY285	Physics Lab II	0 0 3	1		22PHY286	Physics Lab III	0 0 3	1	
21SSK201	Life Skills I	1 0 2	2		21SSK211	Life Skills II	1 0 2	2	
	Amrita Value Programme I	1 0 0	1			Amrita Value Programme II	1 0 0	1	
	Semester Total		**24**			**Semester Total**		**24**	
	Total credits at the end of second year = 97								
	SEMESTER 5					**SEMESTER 6**			
22PHY305	Classical Mechanics	3 1 0	4		22PHY315	Statistical Mechanics	3 1 0	4	
22PHY306	Electrodynamics I	3 1 0	4		22PHY316	Electrodynamics II	3 1 0	4	
22PHY307	Introduction to Quantum Physics	3 1 0	4		22PHY317	Quantum Mechanics I	3 1 0	4	
22PHY308	Mathematical Methods for Physics III	3 1 0	4		22PHY318	Condensed Matter Physics I	3 1 0	4	
22PHY383	Physics Lab IV	0 0 3	1		22PHY384	Physics Lab V (Electronics Lab)	1 0 3	2	
21SSK301	Life Skills III	1 0 2	2		22PHY391[@]	Open Elective/Live in Labs[@] (2nd Summer)	3 0 0	3	
	Minor Course 2	3 0 2	4			Minor Course 3	3 0 2	4	
	Semester Total		**23**			**Semester Total**		**25**	
						Total Credits for BSc Physics Exit-option#		**145**	
	SEMESTER 7**					**SEMESTER 8**			
22PHY506	Quantum Mechanics II	3 1 0	4		22PHY514	Atomic and Molecular Physics	3 1 0	4	
22PHY507	Condensed Matter Physics II	3 1 0	4		22PHY515	Nuclear and Particle Physics	3 1 0	4	
22PHY508	Research Methodology and Seminar	1 0 1	2			Elective I	3 0 0	3	
22PHY509	Advanced Electronics	3 1 0	4			Elective II	3 0 0	3	
22PHY584	Physics Lab VI (Adv. Electronics)	0 0 4	2		22PHY586	Physics Lab VIII	0 0 4	2	
22PHY585	Physics Lab VII	0 0 4	2			Minor Course 5		3/4	
	Minor Course 4		3/4						
22PHY592*	(Optional Internship*, 3 Credits)**								
	Semester Total**		**21/22**			**Semester Total**		**19/20**	
	Total credits at the end of fourth year = 185-187								
	SEMESTER 9					**SEMESTER 10**			
	Elective III	3 0 0	3		22PHY599	Project		18	
	Elective IV	3 0 0	3						
22PHY593	Mini Project		9			**Semester Total**		**18**	
	Semester Total		**15**			**Int MSc Physics Major Credits**		**200**	
	Minor Credits	**18-20**				**Toral Credits for Integrated MSc with Minor options**		**218-220**	

* Students can choose any of theminors in the 3rd semester. Selection for Data Science minor is based on merit and availability.

Exit option for **BSc Physics** is to be given in the 5th semester. Exit option for **BSc Honours** is to be given by 6th semester.

** Internship may be optionally carried outduring the summer, after end of6th or 8thsemester, for an additional 3 credits. Credit will be given in the following semester.

A student may optionally register for more courses for additional credits if time permits from physics or other departments, with the written approval of allthe concerned departments and instructors. Total credits mentioned are the minimum requirements.

4th year courses for BSc Honours in Physics with a minor*in Scientific Computing/Data Science

BSc Honours in Physics with a minor in Scientific Computing/Data Science – 4th Year Courses									
SEMESTER 7**						**SEMESTER 8**			
22PHY509	Advanced Electronics	3 1 0	4				Minor Course	3/4	
22PHY584	Physics Lab VI (Adv. Electronics)	0 0 4	2				Physics Course II/ Elective	3/4	
22PHY508	Research Methodology and Seminar	1 0 1	2			22PHY398	UG Project	12	
	Physics Course I / Elective		3/4						
	Minor Course		3/4				**Semester Total**	**18-20**	
22PHY397/ 22PHY393*	UG Mini Project/ Internship*		3				**Minor Credits**	**18-20**	
	Semester Total	**17-19**					**BSc Honours Physics Major Credits**	**162-164**	
							Toral Credits for BSc Honours Minor options	**180-184**	

* Students can choose any one minor in the 3rd semester. Selection for Data Science minor is based on merit and availability.

Exit option for BSc Honours in Physics with a minor in Scientific Computing/Data Science is to be given by 6th semester.

†**Physics Course Options for BSc Honours Students**

Physics Course I & II Options				
22PHY506	Quantum Mechanics II	3 1 0	4	
22PHY507	Condensed Matter Physics II	3 1 0	4	
22PHY515	Nuclear and Particle Physics	3 1 0	4	

†† **Electives:** Any of the offered physics electives listed below in the next page.

††† Internship may be optionally carried out during the summer after the end of6th semester in lieu of the UG mini project.

**A student may optionally register for more courses for additional credits if time permits from physics or other departments, with the written approval of all the concerned departments and instructors. Total credits mentioned are the minimum requirements.

Minor Requirements

Students can choose any of the minors in the 3rd semester. Selection for Data Science minor is based on merit and availability.

Minimum of 18 credits of minor courses of which a few are mandatory, and others are soft-core option courses. List of courses for each minor is give below.

Course Requirements for Minor in Scientific Computing			
Mandatory Courses for Scientific Computing Minor (12 Credits)			
22CSA512	Introduction to Data Structures and Algorithms (Physics)	3 0 2	4
22MAT216	Numerical Methods	3 0 2	4
22PHY516	Computational Methods in Physics	3 0 2	4
Scientific Computing Soft Core Options (any two) (6/8 Credits)			
22CSA311	Introduction to Machine Learning	3 0 2	4
22CSA503	Advanced Machine Learning	3 0 2	4
22MAT317	Optimization Techniques	3 0 2	4
22PHY519	Principles of Remote Sensing	2 0 2	3
22PHY520	Advanced Remote Sensing§ (Prereq: Principles of Remote Sensing)	3 0 2	4
22PHY517	Satellite Meteorology	3 0 2	4
22PHY518	Numerical Weather Prediction	3 0 2	4
	Total Credits for Minor in Scientific Computing		**19/20**
Course Requirements for Minor in Data Science			
Mandatory Courses for Data Science Minor (16 credits)			
22CSA512	Introduction to Data Structures and Algorithms (Physics)	3 0 2	4
22CSA301	Introduction to Data Science	3 0 2	4
22CSA311	Introduction to Machine Learning	3 0 2	4
22CSA503	Advanced Machine Learning	3 0 2	4
Data Science Soft Core Options (one) (3/4 credits)			
22CSC531	Advanced Topics in Deep Learning	3 0 0	3
22CSC532	Advanced Topics in Machine Learning	3 0 0	3
22CSC533	Data Base Management for Big Data	3 0 0	3
22CSC534	Data Visualization	3 0 0	3
22PHY516	Computational Methods in Physics	3 0 2	4
	Total Credits for Minor in Data Science		**19/20**

‡Depends on availability and demand. Certain courses are either only in odd or even semesters.

§ May be offered once in two years depending on availability and demand and subject to other constraints. Certain courses are either only in odd or even semesters.

Physics Electives

ELECTIVES‡							
Code	**Course**	**L T P**	**Cr**	**Code**	**Course**	**L T P**	**Cr**
22PHY553	Epistemological Foundations of Quantum Mechanics	3 0 0	3	22PHY575	Advanced Optics	3 0 0	3
22PHY554	Introduction to Quantum Computing (Physics)	3 0 0	3	22PHY576	Fourier Optics	3 0 0	3
22PHY555	Introduction to Nonlinear Dynamics	3 0 0	3	22PHY577	Nonlinear Optics	3 0 0	3
22PHY556	Introduction to Astrophysics	3 0 0	3	22PHY578	Fibre Optic Sensors and Applications	3 0 0	3
22PHY557	Introduction to Gravitation and Cosmology	3 0 0	3	22PHY579	Fibre Optics and Technology	3 0 0	3
22PHY558	Fluid Dynamics	3 0 0	3				
22PHY559	Plasma Physics	3 0 0	3				
22PHY560	Space Physics	3 0 0	3				
22PHY561	Physics of the Atmosphere	3 0 0	3				
22PHY562	Elementary Meteorological Theory	3 0 0	3				
22PHY563	Introduction to Earth System	2 0 2	3				
22PHY564	FOSS in Physical Sciences	2 0 2	3				
22PHY565	Methods of Experimental Physics	3 0 0	3				
22PHY566	Thin Film Physics	3 0 0	3				
22PHY567	Physics at Nanoscale	3 0 0	3				
22PHY568	Solid State Electronic Devices	3 0 0	3				
22PHY569	Optoelectronics	3 0 0	3				
22PHY570	Nanophotonics	3 0 0	3				
22PHY571	Lasers and Applications	3 0 0	3				
22PHY572	Biophotonics	3 0 0	3				
22PHY573	Mesoscopic Physics and Quantum Conductors	3 0 0	3				
22PHY574	Topics in Computational Condensed Matter Physics	3 0 0	3				
OPEN ELECTIVES‡							
22OEL299	History and Philosophy of Science	3 0 0	3				

Depends on availability and demand and subject to other constraints. Certain courses are either only in odd or even semesters.

Free Electives (Languages)

Free Elective (Languages)							
Code	**Course**	**L T P**	**Cr**	**Code**	**Course**	**L T P**	**Cr**
21ENG111	Professional Communication	1 0 2	2	21TAM111	Tamil II	1 0 2	2
21TAM101	Tamil I	1 0 2	2	21HIN111	Hindi II	1 0 2	2
21HIN101	Hindi I	1 0 2	2	21MAL111	Malayalam II	1 0 2	2
21MAL101	Malayalam I	1 0 2	2	21SAN111	Sanskrit II	1 0 2	2
21SAN101	Sanskrit I	1 0 2	2				

New names for Amrita Value Programmes for UG - Amrita Value Programme I & II			
Course Code	**Title**	**L-T-P**	**Credits**
22ADM201	Strategic Lessons from Mahabharatha	1-0-0	1
22ADM211	Leadership from Ramayana	1-0-0	1
22AVP210	Kerala Mural Art and Painting	1-0-0	1
22AVP218	Yoga Therapy and Lessons	1-0-0	1
22AVP212	Introduction to Traditional Indian Systems of Medicine	1-0-0	1
22AVP201	Amma's Life and Message to the modern world	1-0-0	1
22AVP204	Lessons from the Upanishads	1-0-0	1
22AVP205	Message of the Bhagavad Gita	1-0-0	1
22AVP206	Life and Message of Swami Vivekananda	1-0-0	1
22AVP207	Life and Teachings of Spiritual Masters of India	1-0-0	1
22AVP208	Insights into Indian Arts and Literature	1-0-0	1
22AVP213	Traditional Fine Arts of India	1-0-0	1
22AVP214	Principles of Worship in India	1-0-0	1
22AVP215	Temple Mural Arts in Kerala	1-0-0	1
22AVP218	Insights into Indian Classical Music	1-0-0	1
22AVP219	Insights into Traditional Indian Painting	1-0-0	1
22AVP220	Insights into Indian Classical Dance	1-0-0	1
22AVP221	Indian Martial Arts and Self Defense	1-0-0	1
22AVP209	Yoga and Meditation	1-0-0	1

Open Electives

Course Code	Course Title	L – T – P	Cr.	ES
	Open Electives			
21OEL231	A Journey towards Free India	3 0 0	3	J
21OEL232	Political Leadership	3 0 0	3	J
21OEL233	Social issues in Contemporary India	3 0 0	3	J
21OEL234	The Story of Indian Business	3 0 0	3	J
21OEL235	Industrial Psychology	3 0 0	3	J
21OEL236	Advertising	3 0 0	3	J
21OEL237	Basic Statistics	3 0 0	3	J
21OEL238	Citizen Journalism	3 0 0	3	J
21OEL239	Creative Writing for Beginners	3 0 0	3	J
21OEL240	Desktop Support and Services	3 0 0	3	J
21OEL241	Development Journalism	3 0 0	3	J
21OEL242	Digital Photography	3 0 0	3	J
21OEL243	Emotional Intelligence	3 0 0	3	J
21OEL244	Essence of Spiritual Literature	3 0 0	3	J
21OEL245	Film Theory	3 0 0	3	J
21OEL246	Fundamentals of Network Administration	3 0 0	3	J
21OEL247	Gender Studies	3 0 0	3	J
21OEL248	Glimpses of Indian Economy and Polity	3 0 0	3	J
21OEL249	Graphics and Web-designing Tools	3 0 0	3	J
21OEL250	Green Marketing	3 0 0	3	J
21OEL251	Healthcare and Technology	3 0 0	3	J
21OEL252	History of English Literature	3 0 0	3	J
21OEL253	Indian Writing in English	3 0 0	3	J
21OEL254	Industrial Relations and Labour Welfare	3 0 0	3	J
21OEL255	Introduction to Ancient Indian Yogic and Vedic Wisdom	3 0 0	3	J
21OEL256	Introduction to Computer Hardware	3 0 0	3	J
21OEL257	Introduction to Event Management	3 0 0	3	J
21OEL258	Introduction to Media	3 0 0	3	J
21OEL259	Introduction to Right to Information Act	3 0 0	3	J
21OEL260	Introduction to Translation	3 0 0	3	J
21OEL261	Linguistic Abilities	3 0 0	3	J
21OEL262	Literary Criticism and Theory	3 0 0	3	J
21OEL263	Macro Economics	3 0 0	3	J
21OEL264	Managing Failure	3 0 0	3	J
21OEL265	Media Management	3 0 0	3	J
21OEL266	Micro Economics	3 0 0	3	J
21OEL267	Micro Finance, Small Group Management and Cooperatives	3 0 0	3	J
21OEL268	Negotiation and Counselling	3 0 0	3	J
21OEL269	New Literatures	3 0 0	3	J
21OEL270	Non-Profit Organization	3 0 0	3	J
21OEL271	Personal Effectiveness	3 0 0	3	J
21OEL272	Perspectives in Astrophysics and Cosmology	3 0 0	3	J
21OEL273	Principles of Marketing	3 0 0	3	J
21OEL274	Principles of Public Relations	3 0 0	3	J
21OEL275	Science, Society and Culture	3 0 0	3	J
21OEL276	Statistical Analysis	3 0 0	3	J
21OEL277	Teamwork and Collaboration	3 0 0	3	J
21OEL278	The Message of Bhagwad Gita	3 0 0	3	J
21OEL279	Understanding Travel and Tourism	3 0 0	3	J
21OEL280	Videography	3 0 0	3	J
21OEL281	Vistas of English Literature	3 0 0	3	J
21OEL282	Web-Designing Techniques	3 0 0	3	J
21OEL283	Organic Farming	3 0 0	3	J
21OEL284	Basic Legal Awareness on Protection of Women and Rights	3 0 0	3	J
21OEL285	Ritual Performances of Kerala	3 0 0	3	J
21OEL286	Documenting Social Issues	3 0 0	3	J
21OEL287	Fabrication of Advanced Solar Cell	3 0 0	3	J
21OEL288	Basic Concepts of X-ray Diffraction	3 0 0	3	ES
21OEL289	Introduction to FORTRAN and GNUPLOT	3 0 0	3	J

21OEL290	Introduction to Porous Materials	3 0 0	3	J
21OEL291	Forensic Science	3 0 0	3	J
21OEL292	Introduction to Solar Physics	3 0 0	3	J
21OEL293	Recycling Recovery and Treatment Methods for Wastes	3 0 0	3	J
21OEL294	Acting and Dramatic Presentation	3 0 0	3	J
21OEL295	Computerized Accounting	3 0 0	3	J
21OEL296	Kerala Mural Art and Painting	3 0 0	3	J
21OEL297	Painting	3 0 0	3	J
21OEL298	Reporting Rural Issues	3 0 0	3	J

Evaluation Scheme and *Grading System*

R.14   Assessment Procedure

R.14.1 The academic performance of each student in each course will be assessed on the basis of Internal Assessment (including Continuous Assessment) and an end-semester examination.
Normally, the teachers offering the course will evaluate the performance of the students at regular intervals and in the end-semester examination.

R.14.2   In theory courses (that are taught primarily in the lecture mode), the weight for the Internal Assessment and End-semester examination will be 50:50. The Internal assessment in theory courses shall consist of at least two periodical tests, weekly quizzes, assignments, tutorials, viva-voce etc. The weight for these components, for theory-based courses shall be 20 marks for the Continuous assessment, comprising of Quizzes, assignments, tutorials, viva-voce, etc. and 15 marks each for both the Periodical Tests. At the end of the semester, there will be an end-semester examination of three hours duration, with a weight of 50 marks, in each lecture-based subject.

R.14.3   In the case of laboratory courses and practical, the relative weight for internal assessment and End-semester examination will be 80:20.The weight for the components of internal assessment will be decided by the course committee/class committee at the beginning of the course.

Evaluation pattern for course having both Theory and Lab components:

Courses having only one hour per week for lecture/tutorial, be treated as a Lab. course, for evaluation purposes; and evaluation pattern will be 80 marks for continuous assessment of lab work and 20 marks for end-semester lab examination.

Courses having two hours per week for theory and/or tutorials, be given a weight of 60 marks and 40 marks for the Theory and Lab components, respectively; The Lab. component evaluation will be based on continuous evaluation, without any end-semester practical evaluation. 10 marks will be for continuous assessment of the theory portion, 10 marks for each of the two periodical tests, 30 marks for the theory end-semester examination and 40 marks for continuous assessment of lab work and

Courses having three hours per week for theory and/or tutorials, be given a weight of 70 marks and 30 marks for the Theory and Lab components, respectively; The Lab component evaluation will be based on continuous evaluation, without any end-semester practical evaluation. 15 marks will be for continuous assessment of the theory portion, 10 marks for each of the two periodical tests, 35 marks for the theory end-semester examination and 30 marks for continuous assessment of lab work.

R.14.4   It is mandatory that the students shall appear for the end-semester examinations in all theory and weight courses, for completion of the requirements of the course. Those who do not appear in the end-semester examinations will be awarded 'F' grade, subject to meeting the attendance requirement.

At the end of a semester, examinations shall be held for all the subjects that were taught during that semester and those subjects of the previous semester s for which the student s shall apply for supplementary examination, with a prescribed fee.

R.14.5   PROJECT WORK: The continuous assessment of project work will be carried out as decided by the course committee. At the completion of the project work, the student

will submit a bound volume of the project report in the prescribed format. The project work will be evaluated by a team of duly appointed examiners.

The final evaluation will be based on the content of the report presentation by student and a viva-voce examination on the project. There will be 40% weight for continuous assessment and the remaining 60% for final evaluation.

If the project work is not satisfactory, he/she will be asked to continue the project work and appear for assessment later.

R.15 PUBLICATION / INTERNSHIP

R.15.1 All students, if they are to be considered for award of the Degree at the time of graduation, are required to have published ONE paper in Scopus-indexed Journal/Conference.

R.15.2 Additional 5-10 marks will be awarded for each Publication, subject to a maximum of ONE paper per semester.

The additional marks shall be awarded in the semester in which the paper is published or accepted for publication, if applied for, within10 days of the publication of results of the concerned semester. The additional marks can be awarded to any course(s) where the student has to improve his/her grade.

R.15.3 All publications shall be in Scopus-indexed Journals/Conferences and shall be as per the guidelines prescribed by the University.

R.15.4 Students who have undergone Internship at reputed organizations or National / International Institutions, with the prior approval of the concerned Departmental Chairperson and the Head of the School, may be considered for waiver of the requirement of publication, for the award of Distinction. However, the decision of the Departmental Chairperson and the Head of the School, in this regard, shall be final.

R.17 Grading

R.17.1 Based on the performance in each course, a student is awarded at the end of the semester, a letter grade in each of the courses registered.

Letter grades will be awarded by the Class Committee in its final sitting, without the student representatives.

The letter grades, the corresponding grade points and the ratings are as follows:

Letter Grade	Grade Points	Ratings
O	10.0	Outstanding
A+	9.5	Excellent
A	9.0	Very Good
B+	8.0	Good
B	7.0	Above Average
C	6.0	Average
P	5.0	Pass
F	0.0	Fail
FA	0.0	Failed due to insufficient attendance
I	0.0	Incomplete (awarded only for Lab courses/ Project / Seminar)
W		Withheld

R.17.2 'FA'grade once awarded stays in the record of the student and is replaced with the appropriate grade when he/she completes the course successfully later.
Students who have secured an 'FA' in a course must re-register for the course or register for the course, if offered, under run-time re-do mode.

R.17.3 A student who has been awarded 'I' Grade in a Lab course, due to reasons of not completing the Lab., shall take up additional Lab. whenever offered next and earn a pass grade, which will be reflected in the next semester's grade sheet.
The 'I' grade, awarded in a Project/Seminar course, will be subsequently changed into appropriate grade, when the student completes the requirement during the subsequent semester. If he/she does not complete it in the next semester, it will be converted to 'F' grade.

R.17.4 A student is considered to have successfully completed the course and earned the credit, if he/she scores a letter grade 'P' or better in that course.

R.22　　　Semester Grade Point Average (SGPA)

On completion of a semester, each student is assigned Semester Grade Point Average (SGPA) which is computed as below for all courses registered by the student during that semester:

$$SGPA = \frac{\sum C_i \times Gp_i}{\sum C_i}.$$

where C_i is the credit for ith course in that semester and Gpi is the grade point for that course.

The summation is over all the courses registered by the student during the semester, including the failed courses. The SGPA is rounded off to two decimals.

R.23　Cumulative Grade Point Average (CGPA)

The overall performance of a student at any stage of the Degree programme is evaluated by the Cumulative Grade Point Average (CGPA) up to that point of time.

$$CGPA = \frac{\sum C_i \times Gp_i}{\sum C_i}.$$

where C_i is the credit for ith course in any semester and Gp_i is the grade point for that course.

The summation is over all the courses registered by the student during all the semesters up to that point of time, including the failed courses. The CGPA is also rounded off to two decimals.

R.24　Ranking

The ranking of the students in a batch at any intermediate or final stage is based on CGPA. Only those students who have passed all courses up to that stage in the first attempt are considered for ranking. Students are eligible for final ranking, only if the programme is completed within the normal duration, i.e., within two years from joining the programme.

R.25　Classification of successful candidates:

R.25.1 A student shall be considered to have successfully completed the programme, if he/she has:
  i) registered and successfully completed all the core courses, electives and projects as mentioned in the curriculum;

ii) earned the required minimum number of credits as specified in the curriculum corresponding to the programme, within the stipulated time;

iii) published a paper at a Scopus-indexed Journal/Conference.

R.25.2   Candidates who have successfully completed the programme, within a period of four semesters from entering the programme, shall be classified as follows:

Candidates securing a CGPA of 8.00 and above   – FIRST CLASS WITH DISTINCTION*

Candidates securing a CGPA between 6.50 and 7.99   – FIRST CLASS

and the same bementioned in the Degree certificate.

(*Subject to satisfying the condition mentioned at R.15.1 and having passed all the courses, in the first attempt, in four semesters, from the date of joining the programme).

If the programme is completed after four semesters of study, the candidates securing even a CGPA of 8.00 and above, shall be classified to have completed the programme, only with FIRST CLASS.

Syllabus

Technical Courses from Other Departments

Chemistry Courses

22CHY105	CHEMISTRY I	(3 0 0 3)

Course Outcomes:

CO-1 Gain an understanding and describe basic aspects of various chemical bonding.

CO-2 Gain an understanding of basics of thermochemistry and apply to solve problems in chemical reactions, apply them solve problems.

CO-3 Gain an understanding of concepts of chemical kinetics, reaction rates, to explain the rates of certain reactions and how to control their rates, apply them to solve problems.

CO-4 Gain an understanding of mechanisms in electrochemical reactions, electrolytes, associated fundamentals and theories and apply them solve problems.

CO-5 Gain an understanding of law of photochemistry and apply them to explain photochemical processes, including fluorescence, phosphorescence, chemiluminescence.

Unit 1 Chemical Bonding

Review of orbital concept and electronic configuration, electrovalency and ionic bond formation, ionic compounds and their properties, lattice energy, solvation enthalpy and solubility of ionic compounds, covalent bond, covalency, orbital theory of covalency - sigma and pi bonds - formation of covalent compounds and their properties Hybridization and geometry of covalent molecules - VSEPR theory - polar and non-polar covalent bonds, polarization of covalent bond - polarizing power, polarisability of ions and Fajan's rule, dipole moment, percentage ionic character from dipole moment, dipole moment and structure of molecules -, coordinate covalent compounds and their characteristics, molecular orbital theory for H_2, N_2, O_2 and CO, metallic bond - free electron, valence bond and band theories, weak chemical bonds – inter and intra molecular hydrogen bond - van der Waals forces.

Unit 2 Thermodynamic Parameters

Stoichiometry - mole concept, significance of balanced chemical equation - simple calculations - Conditions for occurrence of chemical reactions - enthapy, entropy and free changes – spontaneity – Thermochemistry - heats of reactions - (formation, combustion, neutralization) - specific heats - variation of enthalpy change with temperature - Kirchhoff' relation (integrated form) - bond enthalpy and bond order - Problems based on the above.

Unit 3 Kinetics

Review of molecularity and order of a reaction, rate law expression and rate constant - first, second, third and zero order reactions, pseudo-first order reactions (pseudo-unimolecular reactions) - complex reactions - equilibrium and steady state approximations -mechanism of these reactions - effect of temperature on reaction rates - Arrhenius equation and its significance, Michaelis Menden kinetics-enzyme catalysis.

Unit 3 Electrochemistry

Electrolytes - strong and weak, dilution law, Debye-Huckel theory, faraday's laws, origin of potential, single electrode potential, electrochemical series, electrochemical cells, Nernst equation and its application, reference electrodes- SHE, Ag/AgCl, Calomel.

Unit 4 Photochemistry

Photochemistry, laws of photochemistry - Stark-Eistein law, Beer-Lamberts law, quantum efficiency-determination, photochemical processes - Jablonsky diagram, internal conversion, inter-system crossing, fluorescence, phosphorescence, chemiluminescence and photo sensitization, photopolymerization**.**

Reference Books
1. Principles of Physical Chemistry, B.R. Puri, L.R. Sharma & M.S. Pathania , Vishal Publications, 46th, 2013.
2. Principles of Inorganic Chemistry, B R. Puri,L. R. Sharma, Vishal Publications, 2008

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22CHY114	**CHEMISTRY II**	**(3 0 0 3)**

Course Outcomes:

CO-1   Gain an understanding and explain ionic equilibrium in electrolytes, electrical conductance in dilute solutions, concepts related to pH, apply them to solve problems.

CO-2   Gain an understanding of concepts in chemical equilibria, law of mass action, temperature dependence, Le-Chatelier's principle and its application.

CO-3   Gain familiarity with concepts in organic chemistry, organic compounds, their dominant physical and chemical characteristics and describe them.

CO-4   Gain an understanding of acids, bases, and non-aqueous solvents, describe their general physical and chemical characteristics with examples.

CO-5   Gain an understanding of concepts in coordination chemistry, Weiner's theory, coordination numbers, ligands, nomenclature, isomerism, use of such compounds in qualitative and quantitative analysis, theory of boding in coordination.

Unit 1 Ionic equilibria
Electrolytes, strong and weak – specific, equivalent and molar conductances, equivalent conductance at infinite dilution and their measurement - Kohlrausch's law and its applications - calculation of equivalent conductance at infinite dilution for weak Electrolytes and solubility of sparingly soluble salts - applications of conductivity measurement - conductometric titrations - acid-base precipitation and complexometric titrations, Common ion effect and its application, concept of pH, indicators, theories of indicators – buffers and their pH - Henderson equation.

Unit 2 Chemical equilibria
Law of mass action - equilibrium constant – Relation between K_p and K_c - Temperature dependence – The van 'tHoffs equation – Pressure dependence of the equilibrium constant K_p and K_c – Factors that change the state of equilibrium - Le-Chatelier's principle and its application to chemical equilibria.

Unit 3 Basic concepts in Organic Chemistry
Composition of organic compounds – detection and estimation of elements- carbon – hydrogen -nitrogen, oxygen, sulphur, phosphorous, halogens – Calculation of empirical and molecular formula - determination of molecular weights – physical and chemical methods – Classification and Nomenclature of organic compounds. Organic reactions and their mechanisms: Electron displacement effects – inductive, electromeric, mesomeric and hyperconjugative. Reactive intermediates – carbocations, carbanions, free radicals and carbenes.

Unit 4 Acids, Bases and Non-aqueous solvents

Concepts of acids and bases – hard and soft acids and bases - Pearson's concept, HSAB principle and its application - basis for hard-hard and soft-soft interactions - non-aqueous solvents - general characteristics of non-aqueous solvent - melting point, boiling point, latent heat of fusion and vaporization, and dielectric constant - reactions such as complex formation, redox, precipitation and acid base type in non-aqueous solvents like liquid ammonia, liquid SO_2 and liquid HF.

Unit 5 Coordination chemistry

Werner's theory – Electronic interpretation of co-ordination compounds - EAN rule – types of ligands – Nomenclature, isomerism – stability of complexes – factors influencing stability – Application of coordination compounds in qualitative and quantitative analysis. Theories of bonding in coordination.

TEXTBOOKS:
1. Puri, Sharma & Pathania, 'Priniciples of Physical Chemistry', 42nd edition, Vishal Publishing Co, Delhi, 2007.
2. Morrison and R. N. Boyd, 'Organic Chemistry', 6th Edition, Prentice Hall, 1992.
3. Puri BR, Sharma LR, KaliaKK., 'Principles of Inorganic Chemistry', 23rd Edition, ShobanLalNagin Chand & Co, New Delhi, 1993.

References:
1. S. F. A. Kettle, 'Physical Inorganic Chemistry', Spectrum, 1996
2. J. Clayden, N. Greeves, S. Warren and P. Wothers, 'Organic Chemistry', 2nd edition, Oxford University Press, 2012.
3. R.Stephen Berry, Stuart A. Rice & John Ross, 'Physical Chemistry', 2nd edition,Oxford University press, 2000.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22CHY184	CHEMISTRY LAB	(0 0 3 1)

Course Outcomes:

CO1: To develop knowledge about safety requirements and to make them able to perform experiments as and analyse the results of experiments.

CO2: Explain the concept of various volumetric analysis including acid base titrations, permanganometric titrations, complexometric and conductometric titrations.

CO3: Determinethe transition temperature of the given salt hydrate

CO4: Understand the measurement of viscosity by Ostwald Viscometer

CO5: Understand the measurement of surface tension by Stalagmometer

CO6: Identify the concentration of an unknown solution by photocolorimetry

Experiments:

1. Estimation of sodium hydroxide using A.R sodium carbonate
2. Estimation of oxalic acid
3. Estimation of Total, Permanent and Temporary Hardness of Water
4. Determination of transition temperature and cryoscopic constant of the given salt hydrate
5. Acid Base titration by conductance measurement

6. Viscosity measurement
7. Determination of surface tension
8. Determination of unknown concentration of copper sulphate solution using photocolorimetric method

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Mathematics Courses

22MAT103	Single Variable Calculus	(3-1-0-4)

Course Outcome:

CO1: Understand the elementary functions and concepts of limit, continuity, derivative and integral

CO2: Study techniques of differentiation and use it in optimisation problems and curve sketching

CO3: Defining Integral as a sum and review integration techniques

CO4: Use of integrals for the computation of areas, volumes and arc length

CO5: Discuss some basic concepts in the theory of infinite series with some insight to Power series.

Unit 1
Functions – domain, range, graphs of elementary functions, limits - left limit, right limit, continuity, definition of derivative, derivative as rate of change, implicit differentiation.

Unit 2
Extreme values of functions, critical points, graphing with y' and y'', asymptotes, optimization problems, linearization and differentials, L'Hospital's Rule. Riemann sums and definite integrals (just some elementary examples, not the proof), Area, Fundamental theorem of Calculus.

Unit 3
Area between curves, Volumes of solids of revolution – washer method and cylindrical shell method, Length of plane curves, Areas of surfaces of revolution, Moments and centres of Mass.

Unit 4
Sequences, Infinite series as a limit of sequence, Integral test, Comparison tests, Ratio and Root tests, Alternating Series, Absolute and Conditional convergence.

Unit 5
Power series, Taylor and Maclaurin Series, Error estimates, Applications of Power Series.

Textbook:
Thomas and Finney, *Calculus and Analytic Geometry*, 11th edition, Pearson.

References:

N. Piskunov, *Differential and Integral Calculus Vol. I and II*, CBS Publishers.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of all physical sciences and being a speciality in itself, the entire contents of this course, tutorials and assignments lays mathematical foundation for many mathematics, physics and engineering courses and builds skills required for a career as an educator in schools, colleges and universities, as a researcher, and as a communicator of mathematics in general.

22MAT104	**Vectors and Geometry**	(3-1-0-4)

Course Outcome:

CO1: Understand the parametric equations of curves and surfaces ,find the vector equations of the lines and planes.

CO2: Understand to describe the velocity and acceleration associated with a vector-valued function Use vector-valued function to analyze projectile motion

CO3 Understand to Set up and evaluate definite integrals in two dimensions using polar coordinates. Change from polar to rectangular coordinates and vice versa

CO4: Understand to find a unit tangent vector at a point on a space curve ,the tangential and normal components of acceleration, arc length of a space curve the curve at a point on the curvature .

CO5: Understand to use cylindrical and spherical coordinates to represent surfaces in space

Unit 1
Review of Conic Sections, Eccentricity, Quadratic Equations and Rotations.
Parametrization of plane curves, Polar coordinates, Graphing in polar coordinates, Areas and Lengths in polar coordinates, Conic Sections in Polar Coordinates.

Unit 2
Review of vectors (Dot product, Cross product, Unit vector), Lines and Planes in Space, Cylinders and Quadric Surfaces, level curves.

Unit 3
Vector Functions, Modelling projectile motion, Arc length, Unit Tangent Vector, Curvature and Unit Normal Vector.

Unit 4
Double integrals, Areas, Moments and Centres of mass, Double integrals in polar form.
Triple integrals in Rectangular Coordinates.

Unit 5

Applications, Triple integrals in cylindrical and spherical coordinates, Change of variables.

Textbook:

Thomas and Finney, *Calculus and Analytic Geometry*, 11th edition, Pearson.

References:

N. Piskunov, *Differential and Integral Calculus Vol. I and II*, CBS Publishers.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of all physical sciences and being a speciality in itself, the entire contents of this course, tutorials and assignments lays mathematical foundation for many mathematics, physics and engineering courses and builds skills required for a career as an educator in schools, colleges and universities, as a researcher, and as a communicator of mathematics in general.

22MAT113	Multivariable Calculus	(3-1-0-4)

Course Outcomes:

CO1: Understand the basic concepts of vector valued functions,limits ,derivatives and it's geometrical interpretations.

CO2: Understand the concept of scalar and vector field

CO3: Understand the concept of Line integrals and it's independence of path

CO4: Understand and apply the concepts of double integrals to various problems including Green's theorem for plane

CO5: Understand the concepts of surface integrals, divergence theorem and Stokes theorem.

Unit 1

Limits and continuity of Functions of Severable Variables, Partial derivatives, Differentiability of Functions, Chain rule.

Unit 2

Directional derivatives, Gradient and tangent planes, Extreme values and saddle points, Lagrange multipliers.

Unit 3

Line integrals, Vector fields, Circulation and Flux, Path independence, Potential Functions and Conservative Fields. Green's theorem in a Plane.

Unit 4

Parameterized Surfaces, Surface Areas and Surface Integrals, Orientation of Surfaces

Unit 5

Stokes' Theorem and Divergence Theorem(no proof just applications).

Textbook:

Thomas and Finney, *Calculus and Analytic Geometry*, 11th edition, Pearson.

References:

N. Piskunov, *Differential and Integral Calculus Vol. I and II*, CBS Publishers.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of all physical sciences and being a speciality in itself, the entire contents of this course, tutorials and assignments lays mathematical foundation for many mathematics, physics and engineering courses and builds skills required for a career as an educator in schools, colleges and universities, as a researcher, and as a communicator of mathematics in general.

22MAT123	**Differential Equations and Linear Algebra**	(3-1-0-4)

Course Outcome:

On successful completion of the course students shall be able to

CO1: identify and solve linear, separable, and exact first-order differential equations, and model physical problems.

CO2: recognize and understand the solution methods of 2nd order differential equations and its use in modelling engineering problems.

CO3: Understand the basic arithmetic operations on vectors and matrices, including inversion and determinants; solve systems of linear equations, using row reduction techniques.

CO4: understand the basic terminology of linear algebra in Euclidean spaces, including linear independence, spanning, basis, orthogonality and norm, linear transformations, rank, nullity, and.

CO5: understand and find eigenvalues and eigenvectors of a matrix or a linear transformation and using them to diagonalize symmetric matrices and quadratic forms.

Unit 1

First order Linear ODEs, Separable ODEs, Exact ODEs and Integrating Factors, a few examples of modelling simple physical systems. (2 weeks)

Unit 2

Second Order Differential Equations: Homogeneous differential equations, characteristic polynomial, Superposition, Euler-Cauchy Equations. Wronskian, linear independence of solutions, Existence and Uniqueness. Non-homogeneous linear differential equations of second order, Solution by method of undetermined coefficients and variation of parameters. (Sections 2.1, 2.2, 2.4 to 2.10) (3 weeks)

Unit 3

Systems of linear equations, Matrices and Vectors, Operations on Matrices – Addition and scalar multiplication, Transpose, Special types of matrices. (1 week)

Solution to systems of linear equations: Gaussian elimination and row operations and echelon form, geometric significance of equations and solutions. (Sections 7.1 to 7.3) (1 week)

Unit 4

Properties of vectors in R^3, generalization to R^n and real linear vector spaces, linear combination, linear independence, basis, dimension, span, uniqueness of linear expansions in a basis; inner product spaces, norm, orthogonality; linear transformation and its matrix representations (2x2 matrix examples). (Sec.7.9). (1.5 weeks)

Rank of a matrix, row and column spaces of a matrix, space of solutions a homogeneous equation, rank and nullity; Existence and uniqueness of the solutions – an illustration of the solution spaces of with examples in 2D or 3D geometry. (Sec.7.4, 7.5) (1 week)

Determinants and its properties, inverse of a matrix and its basic properties, Cramer's rule. (Sections 7.6 to 7.8) (1 week)

Unit 5

Matrix Eigenvalue problems (with 2x2 matrix examples): Symmetric and Orthogonal (rotation) matrices, determination of eigenvalues and eigenvectors, eigenvectors basis, construction of similarity transformations, diagonalization; Quadratic forms, principal axes. (2 weeks)

Textbook and References
1. Erwin Kreyszig, *Advanced Engineering Mathematics*, 10th edition, Wiley. (Textbook)
2. W.E. Boyce and R.C. DiPrima, *Elementary Differential Equations and Boundary Value Problems*, 7th edition, Wiley.
3. David C. Lay, *Linear Algebra and its Applications*, Pearson.
4. Gilbert Strang, *Linear Algebra and its Applications*, Cengage.
5. Derek Robinson, *A Course in Linear Algebra with Applications*, Allied publishers.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of all physical sciences and being a speciality in itself, the entire contents of this course, tutorials and assignments lays mathematical foundation for many mathematics, physics and engineering courses and builds skills required for a career as an educator in schools, colleges and universities, as a researcher, and as a communicator of mathematics in general.

22MAT216	**Numerical Methods**	**(3-0-2-4)**

Course Outcome
CO-1: Understand the basic concepts of root finding methods, system of equations and their solutions.
CO-2: Understand the concepts of interpolation and construction of polynomials.
CO-3: Application of numerical methods to understand the concept of Calculus (Differentiation and Integration).
CO-4: Application of numerical concepts to solve ODEs and PDEs.

CO-5: Usage of software tools to solve various problems numerically.

Unit 1
Solution of Nonlinear Equations: Bisection and False position Methods, Newton Raphson and Secant Methods, Rate of Convergence.

Unit 2
Solution of Linear Systems AX=B and Eigen value problems (12 hours): Direct methods, Gaussian Elimination, Gauss Jordan method, LU Factorisation, Jacobi & Gauss Seidel iterative Methods.

Unit 3
Interpolation, Curve Fitting (12 hours): Taylor's Series calculation of Functions, Lagrange's Polynomial Approximation and Interpolation, Newton Polynomial Approximation using divided differences and Interpolation, Error, Newton-Gregory forward and backward difference interpolation, Hermite interpolation, Piecewise and Spline interpolation, Polynomial approximation and Weierstrass theorem, Principle of Least Squares.

Unit 4
Numerical Differentiation and Integration (10 hours): Numerical Differentiation using Lagrange, Finite difference interpolation and Undetermined coefficient method, Numerical Integration using Newton-Cotes method, Gauss-Legendre Integration method, Trapezoidal and Simpson method, Quadrature, Composite Trapezoidal and Simpson's Rule, Romberg Integration, Orthogonal polynomials and Gaussian integration.

Unit 5
Solution of Ordinary Differential Equations (10 hours): Euler method, Modified-Euler, midpoint method, Taylor series method, Runge-Kutta methods, Error analysis.

Lab Exercises to be done Using Python
1. Bisection and False position Methods.
2. Newton Raphson and Secant Methods.
3. Gaussian Elimination, Gauss Jordan method, LU Factorization
4. Iterative Methods for Solving Linear Equations.
5. Polynomial Approximation and Interpolation Methods 1
6. Polynomial Approximation and Interpolation Methods 2
7. Numerical Differentiation.
8. Numerical Integration 1.
9. Numerical Integration 2.

Textbook:
Jain M.K., Iyengar S.R.K. and Jain R.K., *Numerical Methods for Engineering and Scientific Computation*, 3rd edition, New Age International (P), New Delhi, 1995.

References:

1. Qingkai Kong, Timmy Siauw, Alexandre Bayen,*Python Programming and Numerical Methods: A Guide for Engineers and Scientist*, Academic Press (2020)
2. Jan Kiusalaas, Numerical Methods in Engineering with Python 3, 3rd Ed, CUP (2013)
3. Alex Gezerlis, Numerical Methods in Physics with Python, Cambridge University Press (2020)
4. Mahendra Verma, Practical Numerical Computing Using Python: Scientific & Engineering Applications, Self-Published
5. John H. Mathews, Kurtis D. Fink, *Numerical Methods Using Matlab*, 4E, Prentice-Hall.
6. Rudra Pratap, *Getting Started with MATLAB 7: A Quick Introduction for Scientists and Engineers*, Oxford University Press, 2005.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organisations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22MAT231	Introduction to Probability and Statistics (Physics)	(3-1-0-4)

Course Outcomes

On completion of the course, students shall be able to

CO1: understand the basic knowledge on fundamental probability concepts and apply to simple problems.

CO2: understand the mathematics and physical contexts of several well-known distributions, including Binomial, Poisson, and Normal Distributions.

CO3: understand joint distributions of two and more random variables, marginal distributions, statistical independence, transformation of two or more random variables of normal distributions to Gamma and Chi-squared distributions, central limit theorem.

CO4: understand the statistical nature of measurement process, glimpses of finite sample statistics, use t-distribution to estimate error in the sample mean.

CO5: Understand the concept linear least square fitting a given data, estimate error in the coefficients and the quality of the fit.

Unit 1

Probability Concepts: random experiments, sample space, mutually exclusive events, axiomatic definition of probability, laws of addition, multiplication, methods of enumeration; Conditional probabilities, and Bayes theorem. (Ref.1)

Unit 2

Random variables, probability distributions – discrete and continuous, mean, variance, and standard deviation, moment generating function, and their properties, cumulative distributions. Joint distributions of two variables, marginal distributions, covariance and correlation, conditional probability distributions, statistically independent variables; generalization to

many random variables; Chebyshev inequality, law of large numbers. Discrete distributions: Binomial, multinomial, and Poisson distributions. (Ref.1)

Unit 3

Continuous distributions: uniform, normal, exponential, Gamma distributions. (Ref.1)
Transformation of random variables; transformation of Normal distribution to Gamma and Chi-squared distributions in one and two random variables; generalization to many random variables; Addition of two random variables of normal distributions; Student-t distribution. (Ref.2-Ch.7, Ref.1-Secs.5.7,5.8).

Unit 4

Distributions of sampling statistics: sample mean, sample variance, central limit theorem; sampling distributions of the normal population: distributions of the sample mean and sample variance, Chi-squared and Student-t distributions. (Ref.1-Secs.6.1 to 6.5)
Introduction to statistics: randomness in measurements, sampling, binned frequency table and histogram, optimal bin size, probability models, typical behavior of random data. Confidence intervals on a sample mean and sample variance using Student's t-distribution and χ^2 distribution tables, goodness of fit of normal distribution. (Ref.3.Secs.4.1 to 4.5)

Unit 5

Simple Linear Regression and Correlation: linear least squares curve fitting, confidence intervals in regression coefficients, χ^2-test, measure of quality of fit. (Ref.2-Ch.11)
A demonstration of curve fitting using spreadsheet/Matlab/R/plotting software and computational exercises. (Ref.1)

References:

1. S. M. Ross, Introduction to Probability and Statistics for Engineers and Scientists, 6E, Elsevier, 2020
2. Walpole, Myers, Myers, and Ye - Probability & statistics for engineers & scientists (2017, Pearson)
3. Figliola and Beasly, Mechanical Measurements, (5E, Wiley, 2010).
4. Arfken, Weber, and Harris, Mathematical methods for physicists – a comprehensive guide, 7th ed, 2012.
5. Gerhard Bohm and Günter Zech, Introduction to Statistics and Data Analysis for Physicists (3rd Ed., 2017, DESY)
   https://s3.cern.ch/inspire-prod-files-d/da9d786a06bf64d703e5c6665929ca01
6. Richard Isaac - The Pleasures of Probability (1995, Springer-Verlag)
7. D.C. Montgomery and G.C. Runger, Applied Statistics and Probability for Engineers, John Wiley and Sons.

Skills and Employability: In class practice sessions, tutorials and assignments help build foundations in statistical aspects which occur in almost in all experimental investigations of science and data analytics.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22MAT317	Optimization Techniques	(3-0-2-4)

Course Outcomes

CO-1 Understand different types of Optimization Techniques in engineering problems. Learn Optimization methods such as Bracketing methods, Region elimination methods, Point estimation methods.

CO-2 Learn gradient based Optimizations Techniques in single variables as well as multi-variables (non-linear).

CO-3 Understand the Optimality criteria for functions in several variables and learn to apply OT methods like Unidirectional search and Direct search methods.

CO-4 Learn constrained optimization techniques. Learn to verify Kuhn-Tucker conditions and Lagrangian Method.

CO-5 Familiarize the concept of optimization in practical applications to find the best feasible solutions in practical applications

Unit I

Introduction to Optimization, Historical Development, Applications of Optimization, Statement of an Optimization Problem, Classification of Optimization Problems, Optimization Techniques.

Unit 2

Classical Optimization Techniques-Single-Variable Optimization, Multivariable Optimization with no constraints, Multivariable Optimization with Equality Constraints, Solution by Direct Substitution, Solution by the Method of Constrained Variation, Solution by the Method of Lagrange Multipliers, Multivariable Optimization with Inequality Constraints, Kuhn–Tucker Conditions, Constraint Qualification, Convex Programming Problem.

Unit 3

Single Variable Optimization- Optimality criteria, bracketing methods-exhaustive search method, bounding phase method- region elimination methods- interval halving, Fibonacci search, golden section search, point estimation-successive quadratic search, gradient based methods.

Unit 4

Multivariable Optimization, optimality criteria, unconstrained optimization-solution by direct substitution, unidirectional search-direct search methods, evolutionary search method, simplex search method, Hook-Jeeves pattern search method, gradient based methods-steepest descent, Cauchy's steepest descent method, Newton's method, conjugate gradient method-constrained optimization. Multivariable Optimization with no constraints. Multivariable Optimization with Equality Constraints, Solution by Direct Substitution

Unit 5
Solution by the Method of Lagrange Multipliers- Multivariable Optimization with Inequality Constraints, Kuhn–Tucker Conditions, Constraint Qualification, Convex Programming Problem.

Practical/Lab to be Performed Using MATLAB/Python

1. To determine local/Relative optima of a given unconstrained problem.
2. Test whether the given function is concave/convex.
3. Test whether the given matrix is positive definite/negative definite/semi positive definite/ semi negative definite
4. Solution of optimization problems using Karush-Kuhn-Tucker conditions

5. Find optimal solution of single variable functions using
    (i)   Exhaustive search methods,
    (ii)   Bounding phase method
    (iii) Region elimination method interval halving,
    (iv)   Fibonacci search
    (v)   Golden section search
    (vi)   Point estimation-successive quadratic search
    (vii) Gradient based methods

6. Find optimal solution of two variable problems based on the methods
    (i)   Hook-Jeeves pattern search method
    (ii)   Gradient based methods-steepest descent
    (iii) Cauchy's steepest descent method
    (iv)   Newton's method
    (v)   Conjugate gradient method-constrained optimization

Textbooks
1. Edwin K.P.Chong and Stanislaw H.Zak (2004), An introduction to optimization, 2nd Ed, Wiley Inter-science
2. S.S Rao (2009) Engineering Optimization: Theory and Practice, John Wiley & Sons, Inc.

References
3. Kalyanmoy Deb (2004) Optimization for engineering design algorithms and examples, Prentice hall of India, New Delhi
4. M. Asghar Bhatti(2000), Practical optimization methods, Springer-Verlag

Skills and Employability: In class practice sessions, tutorials and assignments help build foundations and develops computational thinking and programming skills leading to industrial computing and engineering software applications in industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Computer Science Courses

22CSA105   **Hands-on Introduction to Computing I**   **(1 0 3 2)**

This course aims to familiarize students to elementary computing using Python programming language. Introductory session will be followed by hands-on sessions.

Course Outcomes: On successful completion, students will be able to

CO1: familiarize basic computer terminology and start using ide as a versatile scientific calculator, use variables, basic data types, input/output data

CO2: Use standard programming constructs including branching, selection, repetition, functions, composition, modules, aggregated data (arrays, lists, etc.)

CO3: Compose simple working program scripts, test and debug a programs.

CO4: Apply basic programming skills to perform basic scientific calculations, plot functions, learn to define custom functions, save results to files

CO5: learn, identify, and use basic data structures for different purposes.

Course Outline with sample applications/exercises:

1. Introduction to computer terminology: architectures and components, programming languages, editors, and compilers. Installation of IDE. Using python interface as a calculator; Data types, basics of strings, assigning and printing variables, formatted output, scientific notation, built-in functions, importing modules, plotting mathematical functions like sin x, tan x, exp(x). Converting formulas into programming statements; sample applications: examples of conversion of units, calculating distances, areas and volumes, the roots of a quadratic equation.

2. Simple examples of defining custom functions; returning multiple values, passing functions as arguments. Sample applications: plotting custom functions, functions to calculate roots of a quadratic equations, functions to covert units, etc.

3. Conditionals and Branching and Looping: Programs to illustrate logical expressions, conditional evaluation of functions in different domains, multiway branching; Iterations: while and for loops.

4. Arrays and list: Arrays, Lists, tuples, sets, dictionaries, mutable and immutable objects, operations on lists, formatted printing of arrays.
   Repetitive operations using looping tools.
   Scientific computing applications: calculations on sequences and series, recursion relations: calculating summation of power series of functions: sample applications: approximations for infinite series for trigonometric, exponential and logarithmic functions, average or mean value of a data set, variance, and standard deviation; Taylor series approximations; Generating data sets from functions and plotting.

5. Plotting simple functions using matplotlib. Basic file operations; Coding style and commenting the code for readability; testing and debugging the code with print statements.

Sample comprehensive example/project for programming tools, algorithm development, and mathematical computing concepts: generating data sets from functions, plotting the functions, determine local and global minima of narrowly spaced data points.

References

1. Svein Linge, Hans Petter Langtangen, Programming for Computations – Python, 2E (2020, Springer)
2. Tony Gaddis, Starting Out with Python, 3E, Pearson, 2015.Book contains flowcharting and pedagogical program development in an introductory Python book. Ch. 1 to 5, Ch 7.
3. Hans Petter Langtangen, A Primer on Scientific Programming with Python, 5E, Springer, 2016.
4. D.J. Pine, Introduction to Python for Science & Engineering (2019, Taylor & Fransis)
5. Zed A Shaw, Learn Python the Hard Way, 3E, Pearson, 2017
6. Mahendra Verma, Practical Numerical Computing Using Python: Scientific & Engineering Applications, Self-Published
7. https://personal.math.ubc.ca/~pwalls/math-python/ (sequences and series, numerical differentiation, numerical integration, linear algebra)
8. One material and tutorials: www.python.org ; https://www.learnpython.org; www.vpython.org.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

| 22CSA113 | **Hands-on Introduction to Computing II** | **(0 0 3 1)** |

Description: Building upon the first course on computing using python, this course further trains students on the use of python programming skills and python libraries to practice numerical calculation on some of the topics covered in single variable and multivariate calculus, differential equations, and linear algebra. These topics are to be covered a theory class in a course taken earlier or done concurrently.

On successful completion of the course, students shall be
CO1: familiar with basic computer terminology and start using ide as a versatile scientific calculator, use variables, basic data types, input/output data
CO2: Use standard programming constructs including branching, selection, repetition, functions, composition, modules, aggregated data (arrays, lists, etc.)
CO4: Apply basic programming skills to perform basic numerical computing for differentiation, integration, solving elementary matrix operations, basic linear algebra calculations.
CO5: learn, identify and use basic data structures for different purposes.

Lab Exercises:
2. Programming: Review of basic python programming techniques –conditionals, branching and looping, arrays, functions, printing and saving. (Ref. 1) [2 weeks]
3. Differential Equations: Program to solve elementary differential equations using first order forward Euler method: Projectile motion or simple harmonic oscillations. [2 weeks]
4. Linear Algebra and Array Operations:
    (i) One and higher dimensional arrays, indexing; column and row vectors, transposition; vector and matrix operations using for loops and built-in vector operations(a selection from): addition, scalar multiplication; inner product of vectors, orthogo-

nality, angle between vectors, norm, unit vectors, multiplication of matrices, unit matrix. [2 weeks]

(ii) Further array operations: submatrices – slicing, reshaping, rearranging, and resizing, conversion of 1D to 2D arrays and vice versa; selected examples from symmetric matrices, transposition and index switching operations. [1 week]

(iii) Determinants, determinants of matrices of given set column or row vectors using built-in functions, volume of a parallelopiped, other properties. [1 week]

(iv) Solution to simultaneous linear equation using row reductions and built-in functions. [1 week]

(v) Special matrices, Orthogonal matrices in 2D, rotations in 2D and their properties; rotation of a vector in 2D; general transformation of a vector.Instructor demonstrationsof transformation of a square: rotations, general deformation, demonstrations of pure compression and pure elongation in certain directions – the idea of eigenvectors. [1 week]

(vi) Finding eigenvalues and eigenvectors of a matrix using built-in functions, properties of eigenvectors; non-degenerate and degenerate cases for 3×3 matrices. [1 week]

Textbooks/References

1. Svein Linge, Hans Petter Langtangen, Programming for Computations – Python, 2E (2020, Springer)
2. https://personal.math.ubc.ca/~pwalls/math-python/ (sequences and series, numerical differentiation, numerical integration, linear algebra)
3. Hans Petter Langtangen, A Primer on Scientific Programming with Python, 5E, Springer, 2016.
4. D.J. Pine, Introduction to Python for Science & Engineering (2019, Taylor & Fransis) (linear least-squares fit)
5. Tony Gaddis, Starting Out with Python, 3E, Pearson, 2015.Book contains flowcharting and pedagogical program development in an introductory Python book.
6. C. Hill, Learning Scientific Programming with Python, 2E (2020, CUP). (Reference for Array methods, Linear Algebra)
7. Mahendra Verma, Practical Numerical Computing Using Python: Scientific & Engineering Applications, Self-Published
8. https://notebook.community/hasan2014/assignment-bank/01_Predator-Prey-Model
9. https://scientific-py-thon.readthedocs.io/en/latest/notebooks_rst/3_Ordinary_Differential_Equations/02_Examples/Lotka_Volterra_model.html

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure*(R.14)

| **22CSA201** | **Programming for Scientific Computing** | **(3-0-2-4)** |

Course Outcomes: On successful completion, students will be able to

CO1: Understand programming language syntax and its definition by example of Python.

CO2: Adequately use standard programming constructs: branching, selection, repetition, functions, composition, modules, aggregated data (arrays, lists, etc.)

CO3: Identify and debug coding errors in a python program

CO4: Understand the concepts of error handling, basic file operations, sets, dictionaries.

CO5: Use programing as a tool to understand probability concepts; understand and fit a straight line to a linear data set, perform numerical differentiation and integration, integrate simple differential equations, solve for eigenvalues and eigenvectors, sort and search them.

Unit 1

Review of programing in Python: Data types, strings, arrays, lists, conditionals, loops and iterative operations, functions, scope; Plotting using matplotlib. Error handling, basic file operations. Writing programs in multiple scripts, debugging the code with print statements or assertions;Remarks on floating point arithmetic. [2 weeks]

Sample applications (lab exercises) [2 weeks]

1. Basic programming practice. Working with arrays:
2. Linear interpolation of data sets; other built-in interpolation functions.

Unit 2

Array and list operations, tuples, object id and references, passing arrays by reference; sets, dictionaries;Introduction toNumPy andSciPy.Random number generators and demonstrations of simulation of probability distributions.[3 weeks]

Sample Applications (lab exercises): [2 weeks]

3. Finding roots: Newton-Raphson and bisection methods.
4. Statistical experiments like coin toss or dice problems; generating statistical samples from distributions like binomial, normal distributions, binned frequency table and histogram, estimation of statistical parameters for finite samples.

Units 3-4

Classes and OOP: definition, attributes, methods, instances, accessor and mutator methods; function classes for mathematical computations, static methods and attributes.Inheritance: generalization and specialization; Polymorphism, class hierarchies, subclasses. [4 weeks]

Sample applications and demonstrations: [5 weeks]

5. Vector and complex number classes; operator overloading.
6. Numerical Differentiation of simple functions; Numerical Integration using Trapezoid or Simpsons' rule.
7. Solving set of first order ordinary differential equations using a Runge-Kutta method – projectile motion, simple harmonic oscillator, planetary motion; SciPy integrators; Particle class for particle dynamics with methods to modify its position, velocity, solving for trajectory of particle using particle class supplying forces and initial conditions.

Unit 5

Recursion; Sorting and searching, and introduction to algorithmic complexity – time and memory complexity; Linear least squares fitting. [2 weeks]

Sample applications and demonstrations: [2 weeks]

8. Factorials, Fibonacci series, Euclid's algorithm for GCD calculation.
9. Sorting randomly ordered eigenvalue-eigenvector pairs in the increasing order of eigenvalues, searching for eigenvector for a given eigenvalue or equivalent examples.

Further applications (if time permits):

10. Sample application for arrays – images.Sample exercises: I/O operations with images; data structure of images, RGB pixel arrays, extracting R, G, and B arrays, grayscale images, flipping and cropping images (slicing image arrays). [1 week]

Aterm project may be given during the last third of the semester, carried out in groups of two to four students.

Textbooks/References

1. Tony Gaddis, Starting Out with Python, 3E, Pearson, 2015.Book contains flowcharting and pedagogical program development in an introductory Python book. Ch. 1 to 5, Ch 7.
2. Hans Petter Langtangen, A Primer on Scientific Programming with Python, 5E, Springer, 2016. Ch. 1 to 3, Ch. 4 (carefully selected material appropriate for first year students)
3. Christian Hill, Learning Scientific Programming with Python, 2016(carefully selected material appropriate for first year students)
4. David J. Pine, Introduction to Python for Science and Engineering (2019, CRC Press)
5. Peter R. Turner, Thomas Arildsen, Kathleen Kavanagh, Applied Scientific Computing with Python (2018, Springer) (SciPy interpolation functions, integrators)
6. Zed A Shaw, Learn Python the Hard Way, 3E, Pearson, 2017
7. Mahendra Verma, Practical Numerical Computing Using Python: Scientific & Engineering Applications, Self-Published
8. One material and tutorials: www.python.org; https://www.learnpython.org; www.vpython.org; https://www.pythonlikeyoumeanit.com.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure*(R.14)

22CSA512	**Introduction to Data Structures and Algorithms**	(3-0-2-4)

Course Outcomes:

1) develop knowledge of basic data structures for storage and retrieval of ordered or unordered data.
2) develop a knowledge of applications of data structures including the ability to implement algorithms for the creation, insertion, deletion, searching, and sorting of each data structure.
3) Analyse and compare algorithms for efficiency using asymptotic notations.
4) Program examples requiring the implementation of the above data structures.

Unit 1

Basic concepts of data structures and abstract data types; Basic analysis of algorithms: notions of time and space complexities, asymptotic analysis and notations, efficiency of algorithms. Review of recursion techniques. [2 weeks]

Unit 2

Stacks, LIFO; Linked Lists, Queues, and basic operations associated with these structures, algorithms,and applications. [3 weeks]

Unit 3

Sorting and searching algorithms: Bubble sort, insertion sort; Divide and conquer strategy; merge sort, quick sort.Linear search, binary search, breadth first and depth first search algorithms, pattern matching algorithms. Other problem-solving strategies: Greedy Method – Fractional knapsack problem, scheduling problem. [3 weeks]

Unit 4

Tree:definition and properties,basic tree traversals,Binary Tree,data structure for representing trees,Binary Search Tree, array-based implementation. [2 weeks]

Unit 5

Graphs: data structure for graphs,graph traversals,directed acyclic graphs,weighted graphs,shortest paths,minimum spanning trees. [3 weeks]

Aterm project may be given during the last third of the semester on an implementation of some data structure and a simple application carried out in groups of two tofour students.

Textbook:

Goodrich M T, Tamassia R and Michael H. Goldwasser*, "Data Structures and Algorithms in Python",* Wiley publication, 2016.

References:
1. Clifford A. Shaffer, *"Data Structures and Algorithm Analysis",* Third Edition, Dover Publications, 2012.
2. Tremblay J P and Sorenson P G*, "An Introduction to Data Structures with Applications",* Second Edition, Tata McGraw-Hill, 2002.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22CSA311	**Introduction to Machine Learning**	**(3-0-2-4)**

Course Outcomes

On successful completion, students shall be able to teach

CO1: Understand the domain of machine learning with respect to the regression and classification and its huge potential for providing solutions to real-life problems.

CO2: Have a good understanding of the fundamental issues and challenges in basic machine learning algorithms in terms of data, model selection, and complexity.

CO3: Understand the problem of Curse of Dimensionality and different methods to tackle it.

CO4: Understand the mathematical framework for machine learning (both supervised and un-supervised learning) and methods to tackle under fitting & overfitting.

CO5: Learn the motivation and theory behind learning an artificial neural networks for machine learning applications.

CO6: Be able to design and implement right machine learning algorithm for a given real-world problem.

Unit 1
Introduction: Basic definitions, types of learning, hypothesis space and inductive bias, evaluation, cross validation.
Simple Linear regression, Multiple linear regression, Extensions of the linear model, Classification: overview, Logistic regression, Linear discriminant analysis, comparison of classification methods.

Unit 2
Resampling methods: Cross validation and the bootstrap, Linear model selection and Regularization: Subset selection, Shrinkage methods, Dimension reduction methods, Considerations in high dimensions.

Unit 3
Polynomial regression, step functions, basis functions, regression splines, smoothing splines, local regression, generalised additive models for regression and classification problems, Regression trees, Classification trees, comparison of trees and linear models, Bagging, Random Forests, Boosting.

Unit 4
Support Vector Machines: Hyperplane, Maximum Margin Classifier, Support Vector Classifiers, Support Vector Machines, One vs One Classification and One vs All Classification, Relationship to Logistic Regression. Unsupervised Learning: Principal Component Analysis and its applications, K-Means Clustering and Hierarchical Clustering.

Unit 5
Neural Networks: Introduction, Projection Pursuit Regression, Neural Networks, Fitting Neural Networks, Some issues in Training Neural Networks-Starting Values, Overfitting, Scaling of the Inputs, Number of Hidden Units and Layers, Multiple Minima.

Introduction to Machine Learning Lab to be performed
1. Introduction to R: Basic Commands, Graphics, Indexing Data, Loading Data.
2. Linear Regression: Libraries, Simple Linear Regression, Multiple Linear Regression.

3. Logistic Regression, Linear Discriminant Analysis, Quadratic Discriminant Analysis.
4. Cross Validation and Bootstrap, Validation set approach, Leave-One-Out Cross Validation
5. K-Fold Cross Validation, Bootstrap.
6. Subset Selection Methods, Best Subset Selection, Forward and Backward Stepwise Selection.
7. Ridge Regression and the Lasso.
8. Principal Components Regression, Partial Least Squares.
9. Non-Linear Modelling, Polynomial Regression and Step Functions, Splines, GAMS.
10. Decision Trees, Fitting Classification Trees and Regression Trees, Bagging and Random Forests

Textbook:
1. G. James, R. Tibshirani, *An Introduction to Statistical Learning: with applications in R*, Springer.

References:
1. T. Hastie, R. Tibshirani, *Elements of Statistical Learning: Data mining, Inference and Predicton*, Springer.
2. Kevin Murphy, *Machine Learning: A Probabilistic Perspective*, MIT Press.
3. Tom M. Mitchel, *Machine Learning*, McGraw Hill Education, India.
4. Ethem Alpaydin, *Introduction to Machine Learning*, MIT Press, Prentice Hall of India, 3rdEd. (2014).
5. Ethem Alpaydin - Machine Learning, revised and updated edition (The MIT Press Essential Knowledge series), The MIT Press (2021)
6. Duda R., Hart P., Stork D., Pattern Classification, 2nd Ed., Wiley Interscience (2000)
7. https://sebastianraschka.com/pdf/lecture-notes/stat451fs20/01-ml-overview__notes.pdf
8. https://onlinecourses.nptel.ac.in/noc22_cs97/preview

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22CSA503	Advanced Machine Learning	(3-0-2-4)

Course Outcomes:

CO1: To understand the computing capacity of single layer neural networks, and the need for multi-layer neural networks.

CO2: Learn to tackle the under-fitting, overfitting, and getting into local optimal solutions when learning an artificial neural network.

CO3: Learn about the deep neural networks, CNN to understand how it differ from a deep traditional FFN both in terms of the number of parameters to be learned and in terms of the learning by back-propagation.

CO4: Learn to design and use CNN both as a stand-alone classifier and in transfer learning settings.

CO5: Learn the necessary theory behind different recurrent neural networks and its applications to sequential data analysis.

Unit 1

Machine learning Basics and introduction, Capacity, Overfitting and underfitting, Hyperparameters, Estimator, Bias and Variance, Maximum likelihood estimation, Stochastic Gradient descent

Unit 2

Deep feedforward networks, Learning XOR, Hidden units, Architecture design, Backpropagation

Unit 3

Regularization, L1 and L2 regularization, Noise robustness, Semi supervised learning, Parameter typing and sharing, Sparse representation, Dropout

Unit 4

Optimization, Challenges in neural network optimization, Parameter initialization strategy, Adaptive learning rates, Optimization algorithms

Unit 5

Convolution operator, Pooling, Structured outputs, Efficient convolution algorithms, Unsupervised features, Convolution Neural networks, Recurrent Neural Networks, Encoder-decoder, LSTM and memory architectures, Optimization for long term dependency.

Advanced Machine Learning Lab to be performed
1. Support Vector Classifier, Support Vector Machine, ROC Curves, SVM with Multiple Classes.
2. Principal Component Analysis and Clustering.
3. Overfitting and Underfitting Bias and Variance.
4. Gradient Descent Algorithm.
5. Backpropagation.
6. Neural Network Optimization 1.
7. Neural Network Optimization 2.
8. Convolution Neural networks.
9. Recurrent Neural Networks.
10. LSTM and memory architectures.

References
1. Ian Goodfellow, Yoshua Bengio and Aaron Courville, *Deep Learning*, MIT Press. (Chapters 5-10).
2. "Deep Learning with Python" by Francois Chollet
3. "Machine Learning with PyTorch and Sci-kit Learn" by Sebastian Raschka

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22CSA301	Introduction to Data Science	(3-0-2-4)

Course outcomes

CO1: Able to design visualizations that represent the relationships contained in complex data sets and adapt them to highlight the ideas you want to communicate

CO2: Able to support the visualizations with written and verbal explanations on their interpretation.

CO3: Able to use leading open source software packages to create and publish visualizations

CO4: Ability to understand Regression and Classification problems.

CO5: Enable clear interpretations of big, complex and real world data.

Unit 1
Data Science – Introduction, Overview of Python, Expressions, Data types, Arrays. (Chapters 1 to 6)

Unit 2
Data Visualization—Bar charts, Histograms, Line Charts, Scatterplots, Overlaid plots. (Chapter 7)

Unit 3
Functions and Tables, Joins, Iteration, Simulation, Sampling. (Chapters 8 to 10)

Unit 4
Empirical Distributions, Assessing Models, Decisions and Uncertainty, A/B Testing, Causality, Bootstrap, Designing Experiments. (Chapters 11 to 14)

Unit 5
Linear Regression, Least Squares, Classification, Case Studies. (Chapters 15 to 18)

Textbook:

Ani Adhikari, John DeNero and David Wagner, *Computational and Inferential Thinking: The Foundations of Data Science*, 2nd Edition.

Web Resource: http://data8.org/

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

22CSC531   **Advanced topics in Deep Learning**   **(3-0-0-3)**

Course outcomes

CO1: To understand the fundamentals of deep learning

CO2: To know the main techniques in deep learning and the main research in this field.

CO3: Be able to design and implement deep neural network systems,

CO4: Be able to autonomously extend the knowledge acquired during the study course by reading and understanding scientific and technical documentation.

CO5 Identify new application requirements in the field of computer vision.

Unit 1

Introduction to Tensorflow, Installing and learning its basics, Recap of Neural networks, Convolution neural networks(CNN) and Recurrent Neural Networks (RNN)

Unit 2

Autoencoder and Decoders, Introduction to Generative Adversarial networks (GANs)

Unit 3

Introduction to Speech Processing, important neural network architectures used in them

Unit 4

Introduction to Natural Language processing (NLP), Important neural network architectures used in them

Textbooks:

Ian Goodfellow, Yoshua Bengio and Aaron Courville, Deep Learning, MIT Press.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organizations.

22CSC532   **Advanced topics in Machine learning**   **(3-0-0-3)**

Course outcomes

CO1:Understand to apply Logistic regressions.

CO2: Linear discriminant analysis, Nonlinear methods, Isomap, Local linear embedding

CO3: Able to apply Regression trees, Classification trees, comparison of trees and linear models.

Unit 1

Support Vector Machines: Hyperplane, Maximum Margin Classifier, Support Vector Classifiers, Support Vector Machines, One vs One Classification and One vs All Classification, Relationship to Logistic Regression.

Unit 2

Dimensionality reduction, linear methods including PCA, Linear discriminant analysis, Non-linear methods, Isomap, Local linear embedding, nonlinear PCA, t-SNE

Unit 3

Regression trees, Classification trees, comparison of trees and linear models, Bagging, Random Forests, Boosting.

Unit 4

Bayes Theorem, Prior, Likelihood function, Maximum likelihood estimation, Undirected graphical models, Hidden Markov Models.

Textbooks:

1. G. James, R. Tibshirani, An Introduction to Statistical Learning: with applications in R, Springer.
2. T. Hastie, R. Tibshirani, Elements of Statistical Learning: Data mining, Inference and Predicton, Springer.

References:

3. Kevin Murphy, Machine Learning: A Probabilistic Perspective, MIT Press.

| 22CSC533 | **Database Management for Big Data** | (3-0-0-3) |

Course outcomes

CO1: Understand the basic concepts of database and bigdata.

CO 2.: Understand the database models and its implementation techniques.

CO 3: Ability to learn big data implementation platforms

 CO 4: Ability to learn data base technologies associated with big data.

CO5.: Ability to apply Data Intensive tasks using the Map Reduce Paradigm

Unit 1

Introduction: Overview of DBMS, File vs DBMS, elements of DBMS. Database design: E-R model, Notations, constraints, cardinality and participation constraints

Unit 2

Relational Data Model: Introduction to relational model, Structure of relational mode, domain,keys, tuples to relational models, sql queries.Relational Database Design: Functional dependency, Normalization: 1NF,2NF,3NF,BCNF,table joins**.**

Unit 3

Introduction to Big Data: Types of Digital Data - Characteristics of Data – Evolution of Big Data - Definition of Big Data - Challenges with Big Data-3Vs of Big Data - Non Definitional traits of Big Data - Business Intelligence vs. Big Data - Data warehouse and Hadoop environment - Coexistence.

Unit 4

Big Data Analytics: Classification of analytics - Data Science - Terminologies in Big Data - CAP Theorem - BASE Concept. NoSQL: Types of Databases – Advantages – NewSQL - SQL vs. NOSQL vs NewSQL.

Unit 5

Introduction to Hadoop: Features – Advantages – Versions - Overview of Hadoop Eco systems - Hadoop distributions - Hadoop vs. SQL – RDBMS vs. Hadoop - Hadoop Components – Architecture – HDFS - Map Reduce: Mapper – Reducer – Combiner – Partitioner – Searching – Sorting - Compression. Hadoop 2 (YARN): Architecture - Interacting with Hadoop Eco systems.

Textbooks:

Silberschatz A, Korth H F and Sudharshan S*, "Database System Concepts",* Sixth Edition, Tata McGraw-Hill Publishing Company Limited, 2010.

Seema Acharya, Subhashini Chellappan*, "Big Data and Analytics",* Wiley Publication, 2015.

References:

Judith Hurwitz, Alan Nugent, Dr. Fern Halper, Marcia Kaufman*, "Big Data for Dummies",* John Wiley & Sons, Inc., 2013.

Tom White*, "Hadoop: The Definitive Guide",* O'Reilly Publications, 2011.

22CSC534	Data Visualization	(3-0-0-3)

Course outcomes

CO1: Able to design visualizations that represent the relationships contained in complex data sets and adapt them to highlight the ideas you want to communicate

CO2:Able to Support the visualizations with written and verbal explanations on their interpretation.

CO3:Able to Use leading open source software packages to create and publish visualizations

CO4: Able to Identify the statistical analysis needed to validate the trends present in data visualizations.

CO5: Enable clear interpretations of big, complex and real world data

Unit 1
Goals of data visualization, Data plotting softwares like matplotlib (python) and Gnuplot(available in linux enviornment), Syntax of the codes in these softwares

Unit 2
Different kinds of plots, Plots and subplots, Histogram, Probability density plots, Bar graphs, Pie charts

Unit 3
3D data visualization in 2D, Bubble Plot, Color density plot, 2D Histograms, 4D Data visualization in 3D, making animated plots and movies for data

Unit 4

Graph and Networks visualization, Introduction to software Graphviz, Syntax in grahviz, Drawing small and big networks in graphviz, Introduction to software Cytoscape, Different plotting layouts in cytoscape, visualizing large datasets in cytoscape with examples.

Unit 5

Online data visualization, Introduction to D3 JSON, Plotting a dataset online

References:
Data Visualizations

Geoinformation Systems Courses

22PHY563	Introduction to Earth System	2-0-2-3

Course Outcomes:
CO1: Understand the concept of a coupled Land-Atmosphere-Ocean as a whole system.
CO2: Explain basic Geology and identify Geomorphological and Geological phenomena
CO3: Understanding of landscape evolution and environmental planning
CO4: Describe the composition of atmosphere, Atmospheric parameters, dynamics and thermodynamics
CO5: Summarize the fundamentals of Oceanography
CO6: Outline the various aspects of climate change, biosphere and ecosystem components

Unit 1

Basic Geology and Geomorphology: Nature and scope of Geology; fundamental concepts - stratigraphy and structures; recent trends in Geomorphology. Approaches to geomorphology-static, dynamic, environmental and applied; Landforms: Endogenetic and Exogenetic. climatic and tectonic factors and rejuvenation of landforms. Geodynamics: Introduction to Geodynamics and Diastrophic movements – Epeirogenic and orogenic mountain building, Structural geology: Folds, Faults, Joints and Unconformities. Earthquakes and Seismic zonation. Plate Tectonics, Continental Drift, Concept of Isostasy. Types of weathering, soil formation/profiles and mass wasting. Agents of erosion and deposition. Fluvial systems and concepts of gradation, Sea level changes and coastalevolution. Applied Geomorphology landscape development and environmental planning.

Unit 2

Atmosphere and Ocean: Ocean: Ocean currents; coastal oceanography; Sea Surface temperature Atmosphere: atmospheric composition, structure; Pressure, temperature, humidity; vertical structure of the atmosphere; Global wind systems. Land-Atmosphere interaction; Ocean-atmosphere interaction; coastal erosion and deposition; Atmospheric Radiation: electromagnetic radiations; Radiation laws; Earth's heat budget; scattering; albedo; Hydrostatic equation; hypsometric equation and sea level pressure; Convection, lapse rate, concept of air parcel; atmospheric stability; saturation; lifting condensation level; clouds; Introduction to atmospheric dynamics; equations of motion; atmospheric boundary layer. Tropical weather

systems: Indian monsoon system; El Nino; Tropical cyclones-genesis, structure and climatology: monsoon depressions; other systems.

Unit 3

Concept of an ecosystem: understanding ecosystem, ecosystem degradation, resource utilization. structure and functions of an ecosystem; producers, consumers and decomposers; energy and matter flow in the ecosystem: water cycle, carbon cycle, oxygen cycle, nitrogen cycle, energy cycle; food chains, food web and ecological pyramids; forest ecosystems; grassland ecosystems; desert ecosystems; aquatic ecosystems

Unit 4

Climate change: Climate change history geological evidence; Greenhouse effect: Global $CO2$; Stratospheric ozone; evidence for climate change; extreme weather events; climate change mitigation; climate policy; disaster risk reduction; towards a climate resilient community.

Textbooks/References:
1. Chandrashekhar, A. "Basics of Atmospheric Sciences." Basics of Atmospheric Science280 (2010).
2. Huggett, R. (2016). Fundamentals of geomorphology. Routledge.
3. Masselink, G., & Hughes, M. G. (2014). An introduction to coastal processes and geomorphology. Routledge.
4. Summerfield, M. A. (2014). Global geomorphology.
5. Allen, P. A., 1997, Earth surface processes: Oxford, U.K., Blackwell Science, 404 p.
6. Benn,D. I., and Evans, D. J. A., 1998, Glaciers and glaciation: New York, John Wiley and Sons.
7. Malone, T. (Ed.). (2016). Compendium of meteorology. Springer.
8. Wallace, J. M., & Hobbs, P. V. (2006). Atmospheric science: an introductory survey (Vol. 92). Elsevier.
9. Bharucha (2005), Textbook of environmental studies, Universities Press
10. Understanding the Earth 2017 7th Edition [eds. IG Gass et al.] ELBS edition

22PHY519	Principles of Remote Sensing	2-0-2-3

CO1: Define the concepts of remote sensing and applications
CO2: Describe electromagnetic spectrum and the interactions with various media
CO3: Detail the various sensors and image acquisition
CO4: Acquire remote sensing images from common multispectral platforms
CO5: Apply the basics of image processing to remote sensing images

Unit 1

Introduction, definition, history of satellite remote sensing, Electromagnetic spectrum, radiation laws, The Radiative Transfer Equation, interaction with atmosphere, interaction with

surfaces, Surface Reflection, Spectral Response and Spectral Signature, Spectral, Spatial, Temporal and Radiometric resolutions.

Unit 2

Satellite sensors: Orbits and Platforms for earth observation, sensors and scanners, spectral sensitivity,band combinations-optical imagery, stereo photogrammetry. Digital imagery: spectral sensitivity, digital data formats, band combination - multispectral imagery, radiometric corrections. Elementary image processing: histogram operations, filter operations, image fusion, geometric operations, visual image interpretation.

Unit 3

Active and passive microwave remote sensing: basics of RADAR and LIDAR, radiometry, spectrometers, image restorations and atmospheric corrections, Thermal imagery: basic theory, blackbodies and emissivity, processing of thermal data.

Unit 4

Commonly used multi-spectral remote sensing satellite systems: LANDSAT, SPOT, ENVISAT, RADARSAT, IRS, IKONOS, SENTINEL Family, RISAT, RESOURCESAT etc

Skills acquired: Acquire and perform basic processing of remote sensing images, understanding of various satellite sensors and their applications

Textbooks/References:
1. George Joseph and C Jaganathan,Fundamentals of Remote Sensing, Universities Press, India.
2. Barrett, E. C., Introduction to environmental remote sensing, Routledge(2013).
3. Chuvieco,Emilio, Fundamentals of satellite remote sensing: An environmental approach, CRC press(2016).
4. Lillesand, T., Kiefer, R. W., & Chipman, J, Remote sensing and image interpretation. John Wiley & Sons(2015).
5. Campbell, J. B., & Wynne, R. H. (2011). Introduction to remote sensing. Guilford Press.

22PHY520	Advanced Remote Sensing	3-0-2-4

Prerequisite: Principle of Remote Sensing

Course Outcomes:
On completion of this course, the student shall be able to
1.Understand concepts of Radar systems and its application
2.Gain knowledge in the principles of Lidar data and interpretation
3.Understand the various application domains of hyperspectral remote sensing
4.Gain exposure various image processing techniques

Unit 1: Image processing: Image registration – definition principle and procedure - Fundamental of image recertification, interpolation- intensity interpolation- Radiometric & geometric correction of remotely sensed data. Basic statistical concept in DIP and use of probability methods in DIP- Image enhancement techniques - an overview-Contrast enhancement - linear and nonlinear, histogram equalisation and density slicing Spatial filtering and edge enhancement, Multi image manipulation – addition, subtraction and band rationing; Image Classification: supervised and unsupervised learning techniques.

Unit 2: Hyper-spectral Remote Sensing: Hyper-spectral Imaging: Hyper spectral concepts, data collection systems, calibration techniques, data processing techniques; pre-processing, N-dimensional scatterplots, Special angle mapping, Spectral mixture analysis, Spectral Matching, Mixture tuned matched filtering, Classification techniques, airborne and spaceborne hyperspectral sensors, applications. High-resolution hyperspectral satellite systems: Sensors, orbit characteristics, description of satellite systems, data processing aspects, applications.

Unit 3: RADAR Techniques: Fundamentals of RADAR, SAR Interferometry, and SAR imagery; Introduction to SAR sensors and platforms
Applications of RADAR -soil response-vegetation response- water and ice response- urban area response coherence maps, DEM generation, interferogram and displacement maps SAR Interferometry (InSAR, DInSAR) and Polarimetry: [fundamental concept, application]

Unit 4: LiDAR Principles of LiDAR, LiDAR sensors and platforms, LiDAR data view, processing, and analysis, LiDAR applications: topographic mapping, vegetation characterization, and 3-D modelling of urban infrastructure.

Skills acquired: Theoretical and practical knowledge of acquiring and processing RADAR, LIDAR and hyperspectral data.

Textbooks/References:
1. John A Richards and Xiuping Jia, Remote Sensing Digital Image Analysis: An Introduction
2. FloydM. Handerson and AnthonyJ.Lewis, "Principles and applications of Imaging RADAR", Manual of Remote sensing, 3rd edition, vol.2, ASPRS, Jhumurley and sons, Inc, 1998.
3. Ian Faulconbridge, Radar Fundamentals, Argos Press, 2002.
4. Philippe Lacomme,Jean clande Marchais,Jean-Philippe Hardarge and Eric Normant, Air and spaceborne radar systems - An introduction, Elsevier publications 2001.
5. Roger J Sullivan, Knovel, Radar foundations for Imaging and Advanced Concepts, SciTech Pub, 2004.
6. Marcus Borengasser and William C., Hungate and Russel Watkins, "Hyper spectral Remote sensing: principles and application" CRC, 2008
7. Pinliang Dong and QiChen., Lidar remote sensing and applications ISBN 9781138747241 Published December 12, 2017 by CRC Press220 Pages 40 Color & 143 B/W Illustrations

Physics Courses

Semester 1

22PHY107	Introduction to Mechanics	3 1 0 4

Description: This course is the most fundamental and singularly important course that introduces students to fundamental concepts and mechanics and initiates students to college level problem solving in physics. This course sets the learning paradigm and lays foundation for rest of physics.

Course Outcomes: After successful completion of the course, students shall be able to

CO1: understand and articulate the concepts and solve problems in basic kinematics in one and twodimensions, projectile and circular, and relative motions.

CO2: apply Newton's law of motion to solve, with the help of a free-body diagram, for forces of equilibrium or acceleration, under contact forces, uniform gravity, for rectilinear and circular motions.

CO3: apply the concepts of kinetic energy, work – dot product of force and displacement, work-kinetic energy theorem, power, potential energy and relation to conservative forces, conservation energy, identify types of equilibrium.

CO4: apply Newton's law for centre of mass motion, linear momentum and its conservation, impulse

CO5: understand and apply concepts in rotational motion about fixed axis.

CO6: understand simple harmonic motion, free, damped and forced oscillations.

Unit 1

Kinematics: Dimensions,units,conversion factors, and significant figures [1]; Motion in one dimension [5].

Motion in 2D: Vector notational conventions and nomenclature, vectors of displacement, velocity and acceleration, projectile motion, and uniform circular motion; relative motion. [7]

Unit 2

Laws of motion: inertia, mass, and force, Newton's laws, reference frames; gravitational and other forces; free body diagram analysis for simple applications;frictionand contact forces,viscous drag force and terminal speed, uniform circular motion, banking of curved roads. [10]

Unit 3

Work and kinetic energy: scalar product of two vectors, kinetic energy and work-kinetic energy theorem, work done by gravitational and spring forces, power; Work and potential energy, conservative and non-conservative forces, conservation of mechanical energy; force from potential energy, energy diagrams and equilibrium; power. [8]

Unit 4

Centre of mass of point particles and composite objects, Newton's law for centre of mass motion; linear momentum and its conservation, applications; impulsive forces, review of strategies for solving problems in elastic and inelastic collisions; rockets. [8]

Rotational motion about fixed axis: Rotational variables, linear vs angular variables; rotational kinetic energy, rotational inertia; torque, Newton's II law forrotation;rotational work; Applicationto pulley with mass. [4]

Unit 5

Rolling without slipping on horizontal and inclined surfaces; conservation of angular momentum [2]; An overview ofrotations about asymmetric axis,rate of change of angular momentum in three dimensions, torque; precession of spinning tops [1]; Equilibrium of simple systems [1].

Oscillations: simple harmonic motion, linear spring and Hooke's law, spring-mass system, angular frequency, period, phase, connection with uniform circular motion, angular oscillations and torsion pendulums, small oscillations, average kinetic and potential energies, damped and forced oscillations, resonance, superposition. [5]

Textbook/References

1. D. Halliday, R. Resnick and J. Walker, Fundamentals of Physics, 10E, Ch. 2-11, 15.
2. Serway and Jewett, Physics for Scientists and Engineers, 9E, Cengage Learning, 2013. Ch. 1-10, Ch. 15.
3. R.A. Freedman and H.D. Young, University Physics with Modern Physics, 14E, Pearson India.
4. Halliday, Resnick, and Krane, Physics, Vol. 1, 4th Ed., Wiley Indian Reprint.
5. C. Kittel et al, Mechanics – Berkeley Physics Course Vol. 1, 2E, Ch. 1 – 7, McGraw-Hill.
6. Feynman, Leighton and Sands, The Feynman Lectures on Physics, Vol.1, Narosa, 2008.

Evaluation Pattern: As in the rules for *Assessment Procedure*(R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

Semester 2

22PHY114	Electricity and Magnetism	3 1 0 4

Description: This course is the second one in the foundational series. It introduces to the students a part of basic electricity and Magnetism at an elementary level and introduces to students to problem solving in this topic.

Course Outcomes: By the end of the course students shall be able to

CO1: describe and apply electrostatic forces laws in vector form, superposition of forces, calculate electric fields, electric flux, apply Gauss' law for symmetric charge distributions to calculate electric field.

CO2: understand and calculate potentials, potential energies for basic charge distributions, , electric potential from electric field and vice-versa, dipoles, work and potential energy, capacitance, charge and energy stored in a capacitor, effect of dielectrics on electric field, charge and energy stored in a capacitor.

CO3: understand, describe and solve simple problems on electric current, electrical resistance and Ohm's law, capacitor, basics of resistor networks, RC circuit.

CO4: understand and apply concepts in magnetism, magnetic fields, determine forces due to magnetic field on moving charges and current carrying wires, , magnetic dipoles, torque, use Biot-Savart and Ampere's determine magnetic field due to simple current distributions, solenoids.

CO5: apply Faraday's laws for induced emf, induced electric field, describe laws in induction in integral form, mutual and self-induction, inductors and LRC ac-circuits, resonance and tuning; understand basics of displacement current and Maxwell's equation.

Unit 1

Electric forces and Fields: Coulomb law in vector form, superposition of electric forces; electric fields, calculation of electric fields of static discrete and continuous charge distributions; Gauss' law and determination of electric fields of simple symmetric charge distributions: spherical distribution, line charge, infinite flat sheet of charge. [10]

Unit 2

Energy associated with electric field. Electric potential: work, potential energy, and potential function, potentials of simple distributions of charges, dipoles; calculating electric field from potential, gradient of potential; Conductors:electric field and potential inside and on the surface of a charged conductor. [6]
Capacitors and Dielectrics: Capacitors, energy stored in a capacitor and in an electric field.Capacitors with a dielectric,polarization, electric field and displacement field in a dielectric medium, dielectric constant, Gauss' law for dielectrics.[4]

Unit 3

Electric current: electric current, current density, conservation charge;drift motion in an electric field, resistance and resistivity,Ohm's law, temperature dependence of resistivity, power dissipation. DC Circuits, RC Circuit, time constant. [5]
Magnetostatics: magnetic force on moving charged particles and a current carrying wires, torque on a current loop, magnetic moment and magnetic dipoles, principle of DC electric motors; Biot-Savart and Ampere's laws, magnetic field due to simple static current distributions; solenoid and toroid;Basic ideas on magnetism in matter, magnetic permeability, magnetic field due to a point magnetic dipole and a bar magnet (results only). [9]

Unit 4

Changing magnetic fields: Electromagnetic induction, Faraday's law in integral form, induced EMF, AC generator, moving field sources, universal law of induction, induced electric field, Faraday's law, mutual and self-inductance, LR circuit, energy stored in a magnetic field. [9]

Unit 5

AC Circuits: RLC circuits driven by an AC source, phasors, impedance, power and energy in AC circuits; Resonance inseries and parallel RLC circuits, measurement of inductance and capacitance. [6]

Maxwell's equations: displacement current, Maxwell's equations in integral form.Elementary discussions on gradient, curl and divergence of vector fields, divergence and Stokes'theorems and differential forms of Maxwell's equation, motivation on itsconsequences:electromagnetic and optical phenomena in nature. [3]

Textbook

1. Halliday, Resnick, and Walker, Fundamentals of Physics, 10th Ed., Wiley Indian Reprint, 2008, Chapters 21-32.
2. Serway and Jewett, Physics for Scientists and Engineers, 9E, Cengage Learning, 2013.
3. R.A. Freedman and H.D. Young, University Physics with Modern Physics, 14E, Pearson India.
4. Edward Purcell, Electricity and Magnetism, 2e (SI edition), Tata-McGraw Hill, 2011.
   (Ch. 1, 3; elementary discussions of Ch. 3;Ch. 6 – 9; elementary discussions of Ch. 10, 11; Some sections may be taken from Halliday, Resnick and Walker for simpler presentation. This syllabus has been designed for students who take vector calculus math course in the same semester.)
5. Halliday, Resnick, and Krane, Physics, Vol. 2, 4th Ed., Wiley Indian Reprint.

References

1. Halliday, Resnick, and Krane, Physics, Vol. 2, 5th Ed., Wiley Indian Reprint, 2007
2. Feynman, Leighton and Sands, The Feynman Lectures on Physics, Vol.2, Narosa, 2008.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

Semester 3

22PHY205	Intermediate Mechanics I	3 1 0 4

Description: Building upon the first introductory course on mechanics, this course is the first part of the two courses that introduces advanced techniques in mechanics covering topics of

vector kinematics and dynamics, energy methods, momentum and angular momentum, central force and damped and forces oscillatory motion, coupled oscillations and mechanical waves in elastic media from an intermediate level book on mechanics.

Course Outcomes: After successful completion of this course, students shall be able to
1) Understand kinematics in one, two and three dimensions in Cartesian, polar, cylindrical and spherical coordinates, integrate equations for simple cases; Apply Newton's law for a few simple cases including under constant electric and magnetic fields.
2) Understand energy methods in one and higher dimensions to solve of equations of motion
3) understand the concepts of centre of mass motion, momentum and momentum transport and rocket motion.
4) Understand principles of angular momentum and its conservation, Newton's laws in the application to Kepler's laws.
5) Understand the principles of oscillatory motion, coupled oscillations and mechanical waves.

Unit 1

Examples of motion in 1D; Vector kinematics: displacement, velocity and acceleration from trajectories, vector form of uniform circular motion, formal solutions to kinematic equations.Motion in polar coordinates, tangential and normal accelerations, radius of curvature; sample applications: motion of a bead on circular, elliptical, spiral, and other types of trajectories;bead on a rotating spoke. (Ref.1, Ch.1, Ref.2, Ch.2)   [6]
Dynamics: Newton's laws, the notion of inertial mass, inertial systems; applications to spring forces; sample applications to constrained motion – simple pendulum, conical pendulum or a bead on a rotating hoop, whirling block;motion of charged particles in magnetic fields, circular and helical orbits, mass spectrometer, crossed electric and magnetic fields –velocity selection, lateral drift. (Ref.1-Ch.2,3, Ref.2-Ch.3, Ref.3-Ch.4) [6]

Unit 2

Energy: First integral of motion and work-energy theorem in 1D, potential energy function, conservation of energy, integration of motion for simple forces in 1D, timeofflight; First integral of motion in higher dimensions, line integral of force, conservative forces and path independence of work, examples of work in central and non-central forces, conservative and non-conservative forces. Potential energy function, constant energy surfaces, force from potential energy – gradient; energy diagrams, general description of motion, introduction to phase plot and trajectories. [8]
Momentum: Review of motion of system of particles, centre of mass motion, momentum;Mass flow:mass and momentum transport,momentum flux, damping force on a disc moving through a fluid. [2]

Unit 3

Angular momentum: angular momentum of a particle and system of particles, conservation of angular momentum in central forces, application to Kepler's II law, distance of minimum approach in a nuclear scattering; Gravitational force and potential of spherical objects; Central force motion (1-body problem): first integrals and constants of motion, energy diagrams,

bounded and unbounded orbits, radial equation of motion and elliptical orbits, orbital speed and period, geosynchronous orbits. (Refs.1,2)

Two-body problem: Centre of mass and relative motion: Centre of mass and relative coordinates, reduced mass, Correction to orbital periodsin the planetary motion;molecular vibrations. [8] (Ref.2).

Unit 4

Small oscillations in bound systems:Harmonic approximation,linearity, superposition principle;damped, over damped and critically damped oscillations, relaxation time,use of complex variables; steady-state response of a damped spring-mass system under sinusoidal forces, phase lag, resonance, Q-value, absorption bandwidth, amplification, impedance in mechanical and electrical systems. [5] (Ref.1, 5)

Transverse oscillations: slinky and small oscillation approximations; Free oscillations of systems with two degrees of freedom – 2D harmonic oscillator, longitudinal or transverse oscillations two coupled masses or coupled pendulums, normal modes. (Ref.4, 5)   [3.5]

Linear chain of coupled pendulums*: Propagation of undamped free waves, dispersion relation, mechanical band-pass filter. (Ref.4, 5)   [1.5]

Unit 5

Free oscillations in systems with many degrees of freedom: Transverse waves in strings, wave equation, boundary conditions, standing waves, harmonics, wave velocity, wave number, and dispersion relation; general motion and Fourier series. (Ref.4)   [5]

Travelling solutions, superposition of waves, beats, phase and group velocities, bandwidth theorem (without proof). Forced oscillations and characteristic impedance of a travelling wave, boundary conditions for reflection and transmission; reflection and transmission coefficients (results only); energy flux, reflection and transmission of energy – intensity coefficients (results only); impedance matching and its importance in electrical circuits. (Ref.5) [5]

* Optional topic.

References:
1. Kleppner and Kolenkov, Introduction to Mechanics, 2E (Ch. 1 – 7.)
2. C. Kittel et al, Mechanics – Berkeley Physics Course Vol. 1, 2E, McGraw-Hill. Ch. 1 – 7.
3. Cassiday and Fowles, Analytical Mechanics, 7th Edition.
4. Berkeley Physics Vo. 3, Waves. Wiley India.
5. H.J. Pain, Vibrations and Waves, 6th Edition.
6. Patrick Hamill, Intermediate Dynamics, Jones and Bartlett Publishers
7. David Morin, Introduction to Classical Mechanics, CUP, Ch. 1 – 7.
8. R.P. Feynman et al, Feynman Lectures in Physics, Narosa publications.
9. R. Shankar, Basic Training in Mathematics: Fitness Program for Science Students.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleg-

es, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY206	**Thermal Physics**	**3 1 0 4**

Description: Continuing from previous introductory course on thermal and statistical physics, this course aims to introduce concepts in thermodynamics – physics of macroscopic sized systems and an introduction to statistical physics. This is one of the four core foundation courses along with mechanics, electricity and magnetism and quantum physics.

Course Outcomes:
On successful completion of the course students shall be able to
CO1: understand the concepts of macroscopic thermodynamic systems, zeroth law of thermodynamics, thermal equilibrium, and the equation of states, describe change of states.
CO2: Understand concepts of heat, work, and energy in order to apply those to thermodynamic processes, calorimetry, specific heat of materials, different modes of heat conduction mechanisms, using elementary kinetic theory understand mean free time, Maxwell's velocity distribution, kinetic interpretations of temperature, pressure, specific heats, thermal and electrical conductivities, and self-diffusion.
CO3: understand steady flow processes; understand heat engines and pumps, irreversible processes and second law of thermodynamics, the most efficient engine and process, maximum possible efficiency in thermal energy conversion, Clausius inequality.
CO4: understand the existence of property called entropy and calculate some of its consequences, familiarize with thermodynamic potential and minimum principles, chemical potential and.
CO5: understand the properties of homogeneous and composite systems, conditions for equilibrium and connection with maximum entropy principle, stability, and the third law of thermodynamics; understand the basic ideas in phase transitions and phase equilibrium.

Unit 1
Microscopic vs Macroscopic description(Refs. 1,3). Macroscopic properties, intensive and extensive properties, density; pressure and its measurement; Temperature, thermal equilibrium and Zeroth law of thermodynamics; temperature scales and thermometers, ideal-gas temperature scale. (Ref. 2) [4 hrs]
Thermodynamic systems and the equation of state – hydrostatic – ideal gas and van der Walls equations of state, elastic, magnetic systems. Mathematical description of change of state and change in properties, processes in gases, exact differential, use of partial derivatives, response functions associated with changes in temperature, pressure, and volume. (Ref. 1)[4]
Introduction to first law of thermodynamics: forms of energy, energy transfers by heat and work at the boundary, energy balance and the first law, elementary applications. (Ref.2) [2]

Unit 2
Work: Boundary work in a hydrostatic system,path dependence;magnetic work. (Ref. 1) [2]

Equivalence of work and heat,internal energy function, first law for infinitesimal changes.Heat capacity, specific heats, calorimetry, heat capacities of water, latent heat.Heat equations for hydrostatic systems.(Refs. 1, 4, 7)

Heat transfer mechanisms: conduction, convection, and radiation. (Ref. 1) [4]

Ideal gases (experimental aspects): equation of state, internal energy, specific heats, adiabatic process, velocity of longitudinal wave (results only). (Refs. 1, 7)[2]

Elementary kinetic theory:Mean free path and mean free time, Maxwell's velocity distribution, mean energy, kinetic interpretation of temperature,pressure.Generalization to Boltzmann distribution for energy (kinetic and potential), degrees of freedom, principle of equipartition of energy, specific heats, brief remarks on quantum statistics. (Refs. 5, 6, 8)[4]

Unit 3

Elementary kinetic theory of transport processes: self-diffusion, Brownian motion; thermal and electrical conductivities. (Ref. 3). [2].

Steady flow processes*: Steady flow devices, control volume analysis, flow energy, enthalpy, first law of thermodynamics for steady flow processes,application to simple cases: nozzles and diffusers, throttling devices, compressors, and turbines. [4] (Refs. 2, 8)

The second law of thermodynamics: Heat engines, steam, gasoline and Diesel engines, heat pumps, refrigerators, efficiencies, reversible and irreversible processes, the Carnotcycles and engines, Carnot theorems, thermodynamics temperature scale, Clausius inequality. [6](Refs. 1,2,7,8)

Unit 4

Entropy function, entropy and the second law, principle of increase of entropy, increase of entropy in an unrestrained expansion and conduction across finite temperature difference, loss of useful work,T-S diagrams; entropy of an ideal gas. [4] (Refs. 1, 7, 8)

TdS and energy equations, measurable parameters, energy of expansionof real gases, Joule-Thompson effect, liquefication of gases.Thermodynamic Potentials, Maxwell relations,Open systems, chemical potential.(Refs. 7,1,8) [4]

Unit 5

Composite systems, additive entropy postulate, homogeneity and extensivity, Gibbs-Duhem relation, state postulate. (Refs. 7,9,8)

Conditions of equilibrium and maximum entropy and minimum energy principles; thermal, mechanical, and chemical equilibria in interacting systems,stability; Le Chatelier's principle (without proof); third law of thermodynamics. [4] (Refs. 1, 7, 8)

Introduction to PhaseTransitions: PV, VT, PT, and PVT phase diagrams of water and other pure substances;melting, boiling, and sublimation curves;first order and second order phase transitions, Critical and Triple points, mixed phases and lever rule, conditions for coexistence of phases in equilibrium, Clapeyron-Clausius equation. [4] (Refs. 2, 7, 3, 8)

*The topic of steady flow processes is optional. An overview of this topic may be given in brief without including it in the exams. A discussion of throttling process may be needed for liquefication of gases.

Textbooks/References

1. Zemansky & Dittmann, Heat & Thermodynamics, 8E, McGraw-Hill, 2017
2. Cengel and Boles, Engineering Thermodynamics, 9E.
3. F. Reif, Statistical Physics, Berkeley Physics Vol. 5., 2nd Ed.
4. Serway and Jewett, Physics for Scientists and Engineers, 9th Ed.
5. Resnick and Halliday, Fundamental of Physics, 4th Ed., Wiley India
6. Sears and Salinger, Thermodynamics, Kinetic Theory, and Statistical Thermodynamics, 3rd Ed., Indian Reprint.
7. Kerson Huang, Introduction to Statistical Physics, 2E, CRC Press (Indian Reprint), 2010
8. Ganesh Sundaram, Lecture Noteson Thermodynamicsand Statistical Physics.
9. H. Callen, Thermodynamics and Introduction to Thermostatistics, 2nd Ed. (Advanced text)
10. Tobochnik and Gould, Thermal and Statistical Physics.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY207	**Mathematical Methods in Physics I**	3 1 0 4

Description: The course aims to develop student skill set in applying a variety of mathematical tools that are essential for solving a range of problems in   different branches of physics like quantum mechanics, electrodynamics, statistical mechanics and other fields of theoretical physics.

Course Outcomes: After successful completion of the course, students shall be able to
1) Perform important integrals including Gaussian and exponential integrals, gamma functions, etc., apply complex geometric series to physical problems, understand the basics of Dirac delta functions; solve first order and second order ODEs using Laplace transforms.
2) Understand and describe periodic functions in physics using Fourier series and transforms and solve associated problems.
3) Solve problems involving series solutions, Legendre polynomials and Bessel functions with applications in physics.
4) Recapitulate and apply basics of vector calculus of scalar and vector functions encountered electrodynamics.

Unit 1
Mathematical Preliminaries: Summation notation, Geometric series, adding complex phasors in Fabry-Perot interferometer calculations; summary of criteria for convergence of infinite series; Differentiation under integral sign, Special integrals – use of complex variables, exponential and gaussian integrals, recursion; Gamma function, factorials, Sterling formula; Basic properties of Dirac delta function and Kronecker delta.[6].

Ordinary Differential Equations: differential operators, review of methods for 1st order and 2nd order homogeneous and inhomogeneous linear ODEs, important examples in physics; solution using Laplace Transforms,convolution. [8]

Unit 2

Fourier series and Transforms: Periodic signals and functions in physics, Fourier series of square, triangular, saw-tooth and pulse waveforms, orthogonality of sines and cosines, Fourier coefficients, piecewise functions, Dirichlet conditions, even and odd functions, complex Fourier series, transition to Fourier transforms, application to Gaussian, exponential, and other simple functions, Parseval's theorem, Fourier integral form of Dirac delta function. [8]

Unit 3

Special Functions: Power series solutions to second order ODEs; Legendre equation, Legendre polynomials, orthogonality, generating function, Rodrigues formula, Associated Legendre Polynomials, Spherical harmonics. (Ref.2, Ch 12, Ref. 7) [8]

Unit 4

Cylindrical and other types of Bessel functions, integral representations; Results on Hermite polynomials;Introductory remarks on function spaces: Fourier, Legendre, Bessel and other series, orthogonality, connection with Sturm-Liouville type eigenvalue problems in ODEs. (Ref.2, Ch 12, Ref. 7)[8]

Unit 5

Review of vector calculus: Coordinate systems, functions of many variables, partial and total derivatives, differentials; position vector in Cartesian, cylindrical and spherical coordinates, parametric curves, trajectories; infinitesimal displacement vectors, tangent vectors, unit vectors as normalized parametric derivatives of position vector,orthogonal systems, infinitesimal surface and volume elements, solid angle. Scalar and vector fields in physics; line integral, conservative fields; current density and flux, surface integrals, flow rate; volume integrals, continuity equation. Gradient of a scalar function, direction of greatest change, directional derivative, level surfaces, line integral of a gradient field, gradient in other coordinates, Taylor expansion. Curl and Stokes' theorem; divergence and Gauss' theorem; higher derivatives, selected applications to electrodynamics. (Ref.2.Secs. 7.3 to 7.11, Ref.1). [12]

References
1. Arfken & Weber, Mathematical Methods for Physicists, 7E
2. Mary L Boas, Mathematical Methods in Physical Sciences, 3E, Wiley India
3. R. Shankar, Basic Training in Mathematics: A Fitness Program for Science Students
4. Mathews and Walker, Mathematical Methods in Physics, 2E,
5. Hobson, Riley and Bence, Mathematical Methods for Physics and Engineering, 3E, CUP.
6. E. Keyszig, Advanced Engineering Mathematics, 10E, Wiley India.
7. Sokolnikoff and Redheffer, Mathematics of Physics and Modern Engineering, 2nd Ed., McGraw-Hill
8. Krzywicki and Dennery, Mathematical Methods for Physicists (Advanced text)
9. Sean Mauch's Lecture notes on "Advanced Mathematical Methods for Scientists and Engineers, 2001 (Online)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of physical sciences, the entire contents of this course, tutorials and assignments lays mathematical foundation for physics courses and builds skills required for a career as an educator in physics in schools, colleges and universities, and as a researcher in physical sciences, and as a communicator of science in general.

Semester 4

22PHY216	Intermediate Mechanics II	3 1 0 4

Description: In continuation with part I, the following topics are covered: rotational motion and motion in accelerated frames, special theory of relativity, and elements of continuum mechanics.

Course Outcomes: By the end of the course students will be able to develop an understanding, and be able to

CO1: Understand angular momentum, kinetic energy of a rigid body, principal moments of inertia tensor, Euler's equation, application to torque free wobble, precession of spinning top and gyroscopes.

CO2: Describe motion in linearly accelerating and rotating frames and calculate pseudo forces, explain associated phenomena.

CO3: Describe elastic properties of solids, deformations, stress, strain, their tensor nature, elastic constants, equations of elasticity, strain energy, apply to compression, elongation, shear, torsion, and bending.

CO4: Describe fluid properties, fluid statistics, floating bodies, dynamics of fluid flow, laminar and turbulent flows, incompressible, irrotational flows, ideal and viscous flows, Bernoulli's equations, apply to simple cases, Poiseuille flow, laminar and turbulent flows.

CO5: Understand Galilean transformation, Michelson-Morley experiment and its conclusions, understand and describe postulates of relativity, simultaneity of time, Lorentz transformation, velocity addition, and few relativistic kinematic effects.

CO6: understand descriptions of collisions and laboratory and centre of mass frames, relativistic momentum, mass-energy equivalence, conservation laws, application to relativistic phenomena in atomic and nuclear physics – recoil of an atom on photon emission, pair production, Compton effect; four-vectors, describe equivalence principle, apply to collisions and other relativistic effects.

Unit 1

Rigid body dynamics: Review of rotational motion with fixed axis, moment of inertia, parallel and perpendicular axis theorems; combined rotations and translations – collisions involving combined translation and rotation of rigid bodies with fixed axis of rotation. [4]

Rotation of a rigid body about arbitrary axis, angular displacements, angular velocity vector, angular momentum, principal axes and moments of inertia, rotational kinetic energy;rate of

change of a vector quantity in a rotating frame; Euler equation, torque-free motion of a symmetric body, gyroscope, precession of equinoxes. [5] (Refs.1, 2)

Unit 2

Accelerated frames: Linearly accelerated systems, pseudo-forces, tilted pendulumand fluid levels; rotating coordinate systems: velocity and acceleration, pseudo forces: centrifugal, Coriolis and Euler forces, forces on a bug moving on a rotating platform, weather systems and Foucault pendulum. [5] (Ref.1,2)

Elements of solid mechanics: the concept of an elastic body, internal forces – longitudinal (tension, compression) and shear stresses; deformations and strains, Hooke's law,longitudinal and shear moduli, yield and ultimate strengths;sample application: indeterminate force problems in rigid body supports. [1.5] (Ref. 3)
Response of a solid under longitudinal stresses in 3-dimensions, uniform strain-stress relations,longitudinal and bulk moduli, Poisson's ratio,superposition of stresses,relationship among elastic moduli and Poisson's ratio; torsion and twists of a rod and shear modulus; beam bending theory: bending moment. [5.5] (Ref. 4)

Unit 3

Introduction to theory of elasticity*: General stresses, force on an arbitrary surface and stress tensor, hydrostatic compression; Small deformationsand strain tensor; generalized Hooke's law, strain energy, elasticconstants for an isotropic solid (without proof). [3] (Ref. 4)
Elements of fluid mechanics: fluid pressure and statics, pressure variation in oceans and atmosphere, force on a surface due to fluid pressure – floating objects, dam;shape of surface of a rotating fluid(Ref.3). Fluid motion: pressure gradient, continuity equation, equation of motion for incompressible flow, total derivative; incompressible, irrotational, non-viscous, and steady flows; streamlines. (Refs. 3,4) [5]

Unit 4

Bernoulli's equation and applications; Viscosity and viscous flow, flow through a circular tube – Poiseuille equation.Elementary discussions of laminar flow vs turbulence, Reynolds number, Navier-Stokes equation; . (Refs. 3,4) [4]
Special theory of relativity: Galilean transformation and consequences; Michelson-Morley experiment, postulates, relativity of simultaneity, time, and space, Lorentz transformations, time-dilation and length contraction, velocity addition, relativistic Doppler and a few other relativistic effects. [6] (Refs. 5, 1)

Unit 5

Relativistic dynamics: collisions, laboratory and centre of mass frames, momentum, energy, transformation of energy and momentum, conservation of momentum-energy, mass-energy equivalence, Example applications including, recoil of an emission, centre of mass frame calculations, fusion of colliding nuclei, energy threshold for pair production, Compton effect. [6](Refs. 5, 1)
Transformation laws for forces; motion in uniform electric and magnetic fields.
Equivalence principle, gravitational and inertial masses, gravitational red shift and bending of light near stars. [4] (Refs. 5)

*This topic is optional.

References
1. Kleppner and Kolenkov, Introduction to Mechanics, 2E, Ch. 7 – 9, 12 – 13.
2. Cassiday and Fowles, Analytical Mechanics, 7th Edition.
3. Resnick and Halliay, Fundamentals of Physics, 4th Edition. (Chapters on Fluid Mechanics)
4. Feynman Lectures in Physics, Vol 2, Ch. 31, 38 – 41.
5. C. Kittel et al, Mechanics – Berkeley Physics Course Vol. 1, 2E, Ch. 11 – 14, McGraw-Hill.
6. Wheeler and Taylor, Space-time Physics.
7. Patrick & Hamill, Intermediate Mechanics, Jones & Bartlett Learning.
8. J.R. Taylor, Classical Mechanics, University Science Books, (Especially for Ch. 16 on elastic solid and fluid mechanics)
9. David Morin, Introduction to Classical Mechanics, CUP, Ch. 8 – 14.
10. Marion and Thornton, Classical Dynamics of Particles and Systems, 5E.
11. Rana and Joag, Classical Mechanics, McGraw-Hill. Ch. 13, 14.

Evaluation Pattern: As in the rules for *Assessment Procedure* in the Rules & Regulations(R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY217	**Optics**	3 1 0 4

Description: Wave phenomena is the foundation of development of modern communication technology as well as quantum physics; This course introduces theory of wave phenomena in matter, electromagnetic waves and light, interaction of light with matter, and elementary discussions of geometric optics, wave phenomena.

Course Outcomes: After successful completion of the course, students will be able to

1) Understand the concepts in geometrical optics, Fermat's principe, lens systems, aberration, and a few optical systems
2) Understand and describe basic ideas of waves in 2D and 3D, wave vector, cylindrical and spherical waves, electromagnetic waves and its origin from Maxwell's equation, energy and momentum transport, radiation pressure; Understand the concepts in polarization, method of polarizing a light and applications.
3) Understand propagation of electromagnetic waves in dielectric media, dispersion relations, refractive index, reflection and transmission at boundary, application to fibre optics.

4) Describe and apply concepts in interference, multi-beam interference for Fabry-Perot interferometer.

5) Apply concepts of Fraunhofer diffraction to understand diffraction by single and double slits, gratings, Raleigh criterion and resolution of images; apply concepts in Fresnel diffraction integral and Fraunhofer approximation to understand diffraction by circular apertures;understand Huygens-Fraunhofer principle with application to half period zones, and diffraction by circular apertures and circular discs.

Unit 1

Geometrical Optics: Corpuscular and wave models, Fermat's Principle, Laws of reflection and refraction from Fermat's principle; Refraction at a single spherical surface, thin lens systems, aberrations, prisms, optical systems; basics of fibre-optics. [10]

Unit 2

Basic ideas on plane waves in three dimensions, wave vector and wavelength, wave and group velocity, frequency-wavevector relation, cylindrical and spherical waves. Maxwell's equations and electromagnetic waves in vacuum, plane waves, energy and momentum transport, radiation pressure. [8]

Unit 3

Polarization: linear and circular polarizations, polarizers, Malus' law; dichroism, birefringence, mechanisms of polarization of light; retarders and circular polarizers – full wave, quarter wave, and half wave plates. [6]
Dispersion of light in dielectric media: dispersion relation, index of refraction, Cauchy dispersion formula, boundary conditions, reflection and transmission, Fresnel's equations, Brewster angle.Reflectance and transmittance, phase shifts, Total internal reflection, evanescent wave.
[6]

Unit 4

Interference: superposition of waves of same frequency, coherent sources, division of wavefront and amplitude, Young's double slit experiment, intensity, interference from thin films, multi-beam interference – Michelson and Fabry-Perot interferometers; Introduction to concepts in optical coherence, coherence length, linewidth, spatial coherence, fringe visibility in Young's double slit experiment (basic ideas, results, and discussion). [10]

Unit 5

Diffraction: Fraunhofer diffraction, diffraction by single and double slits, diffraction gratings, diffraction by circular aperture – results, intensity distributions, resolution, and Raleigh criterion. Fresnel diffraction: scalar diffraction theory, Fresnel diffraction integral, Fraunhofer approximation and Fourier transform of aperture function, Fraunhofer diffraction by a circular aperture; Basic ideas andresults on Fresnel diffraction:Huygens-Fresnel principle,half-period zones, zone plates, diffraction by circular aperture and opaque disc, Babinet's principle, Fresnel number. [12]

Textbooks/References
1. Ajoy Ghatak, Optics, 6E, TMH, 2016

2. E. Hecht and A.R. Ganesan, Optics, 4E, Pearson
3. Frank S. Crawford, Waves – Berkeley Physics Vol 3 (SIE), Ch. 1 – 7. (RLC circuit oscillations and LC-transmission lines may be skipped).
4. A.P. French, Vibrations and Waves, Introductory MIT Physics Series, CBS

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY219	**Electronics**	3 1 0 4

Course Outcomes
CO1. To understand different current votage theorems and apply it to solve different electrical networks.
CO2. To undertand the basic physics of the conduction process in semiconducting materials and applications of different semiconductor devices and apply this in solving numerical problems related to semiconducting devices and circuits.
CO3. To understand the working and application of transistors and apply this in solving numerical problems related to transistor circuit.
CO4. To classify different amplifiers and understand the operation of Oscillators; To Explain the operation of JFET and other high power devices and classify it based on the mode of operation.
CO5. To understand the working, mode of operation and different gains of differential amplifier and Operational amplifier; To solve simple op-amp circuits to identify its output.

Unit 1
Kirchhoff's laws, Voltage and current sources, Thevenin and Norton's theorems; applications. [8]

Unit 2
Semiconductors: Intrinsic and extrinsic semiconductors, PN junction diode characteristics, forward and reverse bias, Diode circuits – rectifiers, efficiency, ripple factor, filter, clipper and clamper circuits, Zener diode- voltage regulator, metal-semiconductor junction and Schottky diodes. [12]

Unit 3
Bipolar Junction Transistor: the transistor action, transistor current components, Modes of operation, Current-voltage characteristics of CB, CE, CC configuration, current gain,, saturation and cut-off regions; Biasing, DC load line, ac load line, Q-point; Transistor as switch, ac resistance of the emitter diode, ac-equivalent circuits CE amplifier in voltage divider biasing,

input and output impedance, voltage gain, power gain, frequency response of CE amplifier, band width, gain in dB. [12]

Unit 4

Power amplifiers: Class A, Class B, Class C amplifiers, Push pull amplifiers, Negative and positive feedback circuits, Oscillators- RC phase shift, Hartley Oscillator, Colpitt's, Oscillator. [4]

FETS, characteristics, common source and common drain amplifiers, biasing, MOSFET; Silicon controlled rectifiers, UJT, Diac, Triac, characteristics and applications. [8]

Unit 5

DifferentialAmplifier using Transistors: Working, Common mode and Differential mode, tail current.Operational amplifiers: CMRR, Virtual ground, open loop gain and closed loop gain, Uses- Inverting and non-inverting amplifier, integrator, differentiator, summing amplifier, comparator, Waveform generators. [10]

Textbooks/References

1. A. Malvino and D. J. Bates, Electronic Principles, 8E, Mcgraw-Hill, 2015
2. Mitchel E. Schultz, Grob's basic electronics, 11E, Mcgraw-Hill, 2011
3. S. M. Sze, Semiconductor Devices, Physics and Technology (2nd Ed.), Wiley India, 2008.
4. Electronic fundamentals & applications: John D Ryder, PHI, 4thEdn.
5. R.L. Boylestad, Introductory Circuit Analysis, 12E, Pearson
6. R.L. Boylestad and L Nashelsky, Electronic Devices and Circuit Theory, 11E, Pearson
7. Jacob Millman and Christos C Halkias, Integrated Electronics, International Student Edition, Mcgraw-Hill,1972
8. Principles of Electronics: V. K. Mehta, S. Chand Ltd.,2005

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual and theoretical foundation in electronics required for basic physics lab equipment and instrumentation and builds skills required for a career as an educator in physics in schools, colleges and universities, and as a researcher in experimental physics, and as a communicator of science in general.

22PHY218	**Mathematical Methods in Physics II**	**3 1 0 4**

Description: This the second course aims to develop student's in-depth understanding of the advanced topics and a skill set in applying a variety of mathematical tools that are essential for solving a range of problems in different branches of physics like quantum mechanics, electrodynamics, statistical mechanics, and other fields of theoretical physics.

Course Outcomes: After successful completion of the course, students shall be able to

1) Apply techniques of complex analysis like the concept of analytic functions, Cauchy's theorem, Residues, multiple valued functions, branch points etc. to solve problems in contour integration. Solve problems involving Taylor and Laurant series expansions, Fourier and Laplace transforms.

2) Understand important phenomena in physis and their modelling using PDEs; solve some paradigm PDEs using methods of separation of variables, eigenfunction expansions.

3) Use integral transforms techniques and contour integration to solve ODEs, PDEs and construct Green's functions for inhomogeneous problems in physics, such as Poisson's equation, wave equation for a electric dipole radiation.

4) Use basic probability concepts to understand and calculate quantities of interest in the walk problem, relate it to diffusion equation using binomial and normal distributions, problems involving Poisson processes, statistics of distinguishable and identical particles.

Unit 1
Complex Variables: review of complex numbers, examples of functions of complex variables, analytic functions, contour integration, Cauchy's theorem, singularities, multiple valued functions and branch point and branch-cuts; Complex power series, convergence, radius of convergence; Taylor & Laurent series; basics of analytic continuation. [10]

Unit 2
Residue theorem, evaluation of definite integrals, Principal value; Schlafli integral representation of Legendre polynomials; Fourier and inverse Fourier and inverse Laplace transforms using complex integrals, Parseval and convolution theorems.
[10]

Unit 3
PDE in physics: boundary value problems in 1D, PDEs in physics, selected examples from Laplace's, wave, heat conduction and diffusion, and Schrodinger's equation in Cartesian, cylindrical and spherical coordinates; Method of separation of variables, eigenfunction expansions. [14]

Unit 4
Solution to simple ODE and PDEs using Laplace and Fourier transform techniques and contour integration. Green's functions: Green's function for one-dimensional problems; Green's functions for Poisson's and diffusion equations. [8]

Unit 5
Probability: basic laws, random variables, distributions, expectation values; binomial and normal distributions – random walk on a 1D lattice, use of generating functions; Brownian motion, diffusion equation; Poisson process and distribution; joint and marginal distributions, geometric probabilities. [8]

References
1. Arfken & Weber, Mathematical Methods for Physicists, 7E
2. Mary L Boas, Mathematical Methods in Physical Sciences, 3E, Wiley India
3. R. Shankar, Basic Training in Mathematics: A Fitness Program for Science Students.

4. Mathews and Walker, Mathematical Methods in Physics, 2E,
5. Hobson, Riley and Bence, Mathematical Methods for Physics and Engineering, 3E, CUP.
6. E. Keyszig, Advanced Engineering Mathematics, 10E, Wiley India.
7. Dennery and Krzywicki, Mathematical Methods for Physicists (Advanced text)
8. Sean Mauch's Lecture notes on "Advanced Mathematical Methods for Scientists and Engineers, 2001 (Online)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of physical sciences, the entire contents of this course, tutorials and assignments lays mathematical foundation for physics courses and builds skills required for a career as an educator in physics in schools, colleges and universities, and as a researcher in physical sciences, and as a communicator of science in general.

Semester 5

22PHY307	Introduction to Quantum Physics	(3 1 0 4)

Description: This course introduces ideas in quantum physics at an elementary level and forms the foundation for more advanced courses.

Course Outcomes:
On completion of this course, students shall be able to
1) Describe phenomena of nature that differed from classical predictions;understand the phenomena origins of quantum nature of the physical world at the atomic scale
2) Get introduced to Schrodinger theory of atomic phenomena and perform basic calculations and correlate with energy quantization; Understand the method of obtaining time-independent Schrodinger equation and eigenfunctions, and quantized energies, interpretation of wavefunctions, and postulates and describe them, and apply to simple 1D potentials, barriers.
3) Understand quantum mechanics of simple harmonic oscillators and vibrational levels of molecules.
4) Understand angular momentum, commutation relations, eigenvalues and eigenfunctions; understand Spin, eigenvalues and spin states, addition of angular momentum and spin and spin-orbit coupling in the vector model, rotational levels of molecules.
5) Understand the application of Schrodinger's theory to Hydrogen atom and its spectrum at gross and fine levels, and spectroscopic notation.

Unit 1
Brief history ofbirth of quantum theory:
Classical and electrical nature of matter and atoms, electrons; Black-body radiation, Photons, photoelectric effect, dual nature of electromagnetic radiation.

Line spectra, Rutherford and Bohr models of hydrogen atom and atomic spectra,Franck-Hertz experiment, generalized Bohr-Sommerfeld quantization rules, energy levels of particle in a box and simple harmonic oscillator, correspondence principle; X-ray spectrum. [9]

Unit 2

Electron diffraction,de Broglie model,wave-particle duality, Schrodinger equation, probability amplitudes and probabilities, superposition of waves, group velocity, uncertainty relations, estimationzero-point energies of simple potentials. [5]

Schrödinger equation and its properties, wave functions, superposition, normalization, expectation values, momentum and energy operators; time-independent Schrodinger equation, stationary states, energy eigenvalue equation, eigenvalues, eigenstates and quantization of energies, infinite and finite potential wells. [6]

Unit 3

Simple harmonic oscillator, vibrational levels of diatomic molecules. [4](Refs.2)

Free particles, wave packets, potential steps and barriers, reflection, transmission and tunnelling, resonant tunnelling, scanning tunnelling microscope. [5]

Particles intwo- and three-dimensional rigid boxes, and simple harmonic potentials in Cartesian coordinates. [2]

Unit 4

Angular momentum and magnetic moment, Stern-Gerlach Experiment, angular momentum quantization, angular momentum operators, Azimuthal angular momentum eigenvalues and eigenstates;uncertainty relations with position, momentum, and angular momentum.[5] (Ref.2)

Schrodinger equation in central fields, Total angular momentum eigenvalues and eigenfunctions– spherical harmonics, vector model, rotational quantum states of molecules. [4] (Ref.2)

Unit 5

Spin angular momentum – states and eigenvalues, spin magnetic moment, spin-orbit coupling energy, addition of Spin and angular momentum in the vector model, Zeeman effect. [4] (Ref.2)

Hydrogen atom: Schrodinger equation in spherical coordinates; radial solutions, complete set of wave functions, classification of energy eigenstates, spectroscopic notation.[4](Ref.2)

Many electron atoms: Identical particles, permutation symmetry, two electron systems, symmetric and anti-symmetric wave functions and spin states, Pauli principle. [2] (Ref.2)

Qualitative discussions of states of helium and many electron atoms. [2] (Ref.2)

Textbooks/References

1. Eisberg and Resnick, Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles, 2E, Wiley India.
2. A.P. French, Introduction to Quantum Physics.
3. S. Gasiorowicz, The Structure of Matter -- A Survey Of Modern Physics (Addison-Wesley, 1979)
4. Alastair I.M. Rae and J. Napolitano, Quantum Mechanics (6E, CRC Press, 2016)
5. D. Griffiths, Quantum Mechanics, 2E, Person
6. Wichmann, Quantum Physics – Berkeley Physics Course Vol 4, McGraw-Hill.

7. R.P. Feynman, Feynman Lectures in Physics, Vol. 3.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY305	Classical Mechanics	3 1 0 4

Description: Building on the earlier two courses on intermediate mechanics, this course provides a survey of variational formalism of solving mechanics problems. This is a foundational course for post-graduate physics courses.

Course Outcomes: After successful completion of the course, students will be able to develop an understanding, and be able to
CO1: describe the fundamental concept of dynamics of a system of particles; understand the concepts of constraints, generalized coordinates, momenta, forces, Hamilton's variational principle and Euler-Lagrange formalism and equation, and apply them to solve problems in classical mechanics, explain the connection between symmetries and invariance in dynamical systems, Noether's theorem for particles.
CO2: understand motion in central potential, symmetries, scattering by Coulomb potential
CO3: Understand and applying Lagrangian formalism to small oscillations coupled oscillations, kinematics and dynamics of rigid bodies.
CO4: understand the Hamiltonian formalism, charged particles in magnetic field, phase space and stability concepts.
CO5: Describe and apply Poisson-bracket formalism, derive various Poisson brackets and equations of motion; State and derive conditions for Canonical transformations, apply them to symmetry transformations, invariants in phase space; describe Hamilton-Jacobiformalisms.

Unit 1
A summary of principles of Newtonian mechanics of a system of particles; Constraints, degrees of freedom, generalized coordinates, generalized velocities, generalized momenta and generalized forces; Principle of virtual work, d'Alembert's principle and Euler-Lagrange equations, Lagrangian.
Variational method: Hamilton's variational principle, derivation Euler-Lagrange equations; transformations, symmetries, invariance, and conservation laws, Noether's theorem for particles; conjugate momentum, cyclic coordinates, energy function and conservation of energy.

Unit 2
Central force motion: two-body problem – reduction to equivalent one-body problem, first integrals of motion, equivalent 1D problem, classification of orbits, virial theorem, results for

power-law potentials, conditions for closed of orbits, Kepler problem, conserved quantities, Laplace-Runge-Lenz vector,precession of orbits;Scattering in a central force field and Rutherford's formula; Two-body collisions in 2-d: centre of mass frame, scattering angles in laboratory and centre of mass frames.

Unit 3

Oscillations: An example of coupled oscillations and normal modes and coordinates, normal modes of infinite chain of coupled masses.

Rigid body motion: coordinates, finite and infinitesimal rotations, Euler angles; angular momentum and inertia tensor, principal axes; motion in rotating coordinate system, Euler equations for rigid body, heavy symmetric top.

Unit 4

Hamiltonian formalism: Legendre transformations, Hamiltonian, Hamilton's equations, applications, phase space and trajectories, charged particle in electromagnetic field; derivation of Hamilton's equations from variational principle, phase space; Dynamical systems, phase space dynamics, phase trajectories, stability analysis.

Unit 5

Poisson brackets: formalism and properties, fundamental and angular momentum Poisson brackets; Poisson brackets involving position, momentum, angular momentum, and Hamiltonian. Canonical transformations: Point transformations in coordinate space, invariance of Euler-Lagrange equations; general transformations in phase space, conditions for invariance of Hamilton's equations, generating functions; infinitesimal canonical transformations; invariance and conserved quantities. Introduction to Hamilton-Jacobi theory.

References

1. H. Goldstein, C.P. Poole Jr, and J.L. Safko, Classical Mechanics, 3E, Pearson.
2. Rana and Joag, Classical Mechanics, McGraw-Hill Education.
3. M.G. Calkin, Lagrangian and Hamiltonian Mechanics, Word Scientific
4. Thornton and Marion, Classical Mechanics of Particles and Systems, 5E, Brooks/Cole.
5. L.D. Landau & E,M. Lifshitz, Mechanics – Course in Theoretical Physics Vol.1, 3E, Elsevier.
6. R. Shankar, Principles of Quantum Mechanics, 2E (revised), Springer. (A chapter on Summary of Classical Mechanics)
7. M. Tabor, Chaos and Integrability in Nonlinear Dynamics.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY306   **Electrodynamics I**   **3 1 0 4**

Course Outcomes: On successful completion of the course, students will be able to

1. Become proficient in Mathematical techniques (notation, definitions, identities, theorems and transformations) that play an important role in the study of Electromagnetism.

2. Gain understanding of Electrostatics and demonstrate its application – Summation and boundary value problems, and calculation of electric field associated with various charge distributions – mainly summation problems. Student will also learn about Rot and Div of electrostatic electric field, their Integral and Differential forms & role of symmetry in computing fields, besides matching conditions for the field.

3. Gain understanding of analytic methods to solve Laplace and Poisson's problems, Uniqueness of Poisson's equation in spaces (vacuum or linear dielectric) bound by conductors, and Image problems. Student will also learn about Laplace equation, discussion of solutions with varying symmetry, besides the electric multipoles and multipole expansion as a systematic approximation for the potential

4. Conceptual understanding of conducting matter, electrostatic induction and dielectric matter. Learn about Polarization, its physical meaning and the field produced. Understand concepts behind total and auxiliary fields, Dielectric responses and energy

5. Gain understanding of Magnetostatics – Concept of vector current density, Lorentz force and the important point that different types of currents produce magnetic fields – electric and magnetization, besides the comparison of magneto- and electrostatic equations and understanding the fact that their differences helps in building physical intuition and calculation skill. Student will also learn about Rot and Div of magnetostatic magnetic field, their Integral and Differential forms & role of symmetry in computing fields, besides matching conditions for the field

6. Learn the concepts behind magnetic scalar and vector potentials, and magnetic field produced by various current distributions involving symmetry. Understand the concept of magnetic multipoles and the systematic scheme of magnetic multipole expansion

7. Physical meaning behind magnetic matter – response of matter to static magnetic field, magnetization, Field produced by magnetized matter, Total and auxiliary fields, and energy

Unit 1
Electrostatics: Electrostatic fields of charge distributions, electric flux, divergence of electric fields and Gauss law and applications; Curl of electric fields, line integral, potentials and its gradient, work and energy, conductors.

Unit 2
Calculation of potentials: Laplace's and Poisson's equation, boundary-value problems in electrostatics, metal sphere in uniform external field, method of images, multipole expansion, and Green's functions.

Unit 3
Electrostatic fields in matter: Dielectrics, induced dipoles, polarization, field of a polarized object, bound and surface charges, filed inside a dielectric, electric displacement, linear die-

lectrics, boundary value problems, dielectric sphere in uniform external field, spherical cavity in a dielectric solid.

Unit 4

Magnetostatics: Lorentz force and elementary applications; Biot-Savart and Ampere law and application to simple current distributions, the divergence and curl of B, magnetic vector potential.

Unit 5

Magnetostatic fields in matter: summary of magnetic properties of matter, torques and forces on dipoles, dipole-dipole interaction; Magnetization, the field of a magnetized object, bound currents, magnetic field B inside matter and the auxiliary field H, fields in linear media, susceptibility.

Textbooks/References

1. D. Griffiths, Electrodynamics, 2E, Ch. 2 – 6.
2. Purcell, E.M., and Morin, D.J., Electricity and Magnetism (Berkeley Physics Series Vol.2), 3E, McGraw-Hill.
3. A. Zangwill, Modern Electrodynamics, CUP (2013).
4. J.D. Jackson, Classical Electrodynamics, 3E, Wiley India.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY308	**Mathematical Methods in Physics III**	3 1 0 4

Description: This the second course aims to develop student's in-depth understanding of the advanced topics and a skill set in applying a variety of mathematical tools that are essential for solving a range of problems in different branches of physics like quantum mechanics, electrodynamics, statistical mechanics, and other fields of theoretical physics.

Course Outcomes

On successful completion of this course, students shall be able to

1) Perform calculations using matrix representations of vectors, transformations, and index notations, Understand and solve problems in complex vector spaces, inner product, orthogonalization, special matrices and eigenvalue problems with applications in physics.
2) Understand and solve problems in function spaces, orthogonal functions, generalized Fourier series, completeness, continuous basis and Fourier transforms, linear operators and eigenvalue problems in function spaces.
3) Understand basic concepts of tensors in physics and their transformation properties.

4) Apply concepts in group theory like discrete groups and continuous (Lie) groups, rotation group in 2-D and 3-D, SU(2), SO(3).

Unit 1

Linear algebra: Real and complex vectors in 2D and 3D, matrix representation of vectors, Dirac notation; generalization to abstract linear vector spaces, linear combination, linear Independence, Basis and Dimension. Inner product and its properties of real and complex vectors, norm, unit vectors, dual vectors, orthonormal basis expansion; generalization to abstract vectors; orthogonality and Gram-Schmidt orthogonalization; orthonormal basisexpansion, completeness; Subspaces. [5]

Linear transformations, rotations in 2D and 3D, matrix elements of an operator, properties of orthogonal transformation; Projection operator, completeness relation, outer product expansion of operators;products of operators, commutators, transpose and adjoint of operators; symmetric, Hermitian, unitary matrices, Pauli matrices; Active and passive transformations, change of basis – transformations ofvectors,inner products, operators, traces and determinants; introduction to direct product of vectors and matrices. [5]

Unit 2

Eigenvalue problem: Eigenvalues and Eigenvectors, non-degenerate and degenerate cases, characteristic polynomial, Diagonalization, Spectral Theorem for Hermitian Matrices,matrix elements of vectors and operators in the eigen-basis; quadratic forms, simultaneous diagonalization of two commuting matrices, Normal matrices, Cayley-Hamilton theorem, functions of matrices, System of ODEs – coupled spring-mass system of two degrees of freedom. [8]

Unit 3

Function spaces: Linear independence of functions and Wronskian, linear vector space of functions, inner product, norm, Hilbert space; orthogonal functions and expansions: Fourier, Legendre and Bessel series as examples of orthonormal basis expansions; Bessel inequality, the notions of convergence in the mean, completeness; Orthogonalization and construction of Legendre polynomials and other orthogonal polynomials; Expansion of Dirac-delta function; Inverse Fourier transform as orthonormal expansion in continuous wavevector basis; functions as infinite dimensional vectors in a discrete or a continuous basis. [6]

Linear operators in function spaces: examples of differential and integral operators; adjoint of operators, Hermitian operators;eigenvalue problemsin functions space, basics of Sturm-Liouville theory, eigenfunctions – orthogonal functions, eigen-basis expansions, and matrix representations; summary of orthogonal functions in physical problemsfordifferent geometries,method of solution to PDEs by eigenfunction expansions. [6]

Unit 4

Introduction to tensors: index notation, rotation matrices in R3, change of basis, matrix of transformation of coordinates; Cartesian tensors, transformation of scalars, first, second and higher order tensors, outer product of vectors; algebra of tensors; Kronecker delta and Levi-Civita tensors, determinant and vector cross product, and related identities, isotropic tensors, Pseudo-vectors and pseudo-tensors, dual tensors; inertia and other important tensors in physics; oblique and curvilinear coordinates, non-Cartesian tensors, Covariant and Contra-variant tensors, metric tensor. [10] (Refs. 6, 2)

Unit 5

Group theory: Basics, finite groups, abelian and non-abelian groups; isomorphism and homomorphism, subgroups, conjugates and classes, symmetry groups of regular polygons; continuous groups, rotation groups SO(3), SU(2), generators. [10]

References

1. Arfken & Weber, Mathematical Methods for Physicists, 7E
2. Mary L Boas, Mathematical Methods in Physical Sciences, 3E, Wiley India
3. R. Shankar, Principles of Quantum Mechanics, 2E, (Ch 1), Springer India
4. R. Shankar, Basic Training in Mathematics: A Fitness Program for Science Students.
5. Mathews and Walker, Mathematical Methods in Physics, 2E,
6. Hobson, Riley and Bence, Mathematical Methods for Physics and Engineering, 3E, CUP.
7. E. Keyszig, Advanced Engineering Mathematics, 10E, Wiley India.
8. Dennery and Krzywicki, Mathematical Methods for Physicists (Advanced text)
9. Sean Mauch's Lecture notes on "Advanced Mathematical Methods for Scientists and Engineers, 2001 (Online)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Mathematics being a language of physical sciences, the entire contents of this course, tutorials and assignments lays mathematical foundation for physics courses and builds skills required for a career as an educator in physics in schools, colleges and universities, and as a researcher in physical sciences, and as a communicator of science in general.

Semester 6

22PHY316	Electrodynamics II	3 1 0 4

Course Outcomes: On successful completion of the course, students will be able to

1. Explain concepts of electrodynamics, and write down Maxwell's equations in linear, isotropic, homogeneous, and magnetic & dielectric media

2. Derive electromagnetic wave solutions and propagation in vacuum, dielectric and other media. Explain transport of energy, Poynting vector and momentum and Maxwell stress tensor, radiation pressure.

3. Show laws of geometric optics originate with Maxwell's equations at dielectric boundaries. Calculate reflection and transmission coefficients for waves at dielectric boundaries

4. Explain gauge invariance of Maxwell's equations, solve for retarded potentials and electric and magnetic fields for simple problems involving time-dependent charge-current distributions

5. Explain the term radiation zone and derive angular distribution of and power emitted by a dipole.

6. Derive fully covariant forms of Maxwell equations, Lorentz gauge condition and continuity equation. Obtain Lorentz transformations for electric and magnetic fields and apply to simple cases

7. Derive Lienard-Wiechert potentials for a moving point charge and also corresponding electric and magnetic fields. Show that acceleration of the charge gives electromagnetic radiation. Apply to cases of charges – slowly accelerating at low velocities, undergoing acceleration collinear with velocity; and in a circular orbit (synchrotron radiation)

Unit 1
Electrodynamics: electromotive force, motional emf; electromagnetic induction: Faraday's law, induced electric field, inductance and mutual inductance, energy in magnetic fields; changing electric fields, Maxwell's equations in vacuum and matter, boundary conditions.

Unit 2:
Conservation laws: Poynting vector and continuity equation, conservation of electro-mechanical energy, momentum and angular momentum, Maxwell stress tensor.
Recap of concepts in waves; Electromagnetic waves: wave equation for electric and magnetic fields, plane waves, polarization, energy and momentum; Propagation in linear media, reflection and transmission, Fresnel's equation, total internal reflection and evanescent waves and tunnelling; Absorption and Dispersion: electromagnetic waves in conductors: skin depth, reflection at a conducting surface; EM waves in dielectrics: frequency dependence of permittivity, dispersion, complex susceptibility and complex permittivity, absorption, anomalous dispersion, Cauchy's formula.

Unit 3
Guided waves: propagation EM waves in wave guides, TE, TM and TEM waves, TE and TM waves in rectangular waves; Coaxial transmission lines, resonant cavity.
Potentials and Fields: gauge transformations, Coulomb and Lorentz gauges, wave equations for potential form; Fields of a moving charge: retarded and advanced potentials, Jefimenko equations, Lienard-Wiechert potentials, fields of moving point charges.

Unit 4
Radiation: Electric and magnetic dipole radiations, radiation from arbitrary sources, radiation by a point charge accelerating linearly and in circular motions, radiation reaction.
Review of special theory of relativity: Lorentz transformation, 4-vector notation, space-time and energy-momentum 4-vectors, transformation of forces.

Unit 5
Relativistic Electrodynamics: charged particle in constant electric and magnetic fields; Magnetism as relativistic phenomena, transformation of fields, Lorentz invariants; Electrodynamics in tensor notation, relativistic four-potentials, gauge transformations and gauge invariance in electrodynamics, Maxwell's equationsand wave equations of four-potentials, invariance under Lorentz transformation, field tensor.

References
1. D. Griffiths, Electrodynamics, 4E. (Ch. 7 – 12).
2. A. Zangwill, Modern Electrodynamics, CUP (2013).

3. J.D. Jackson, Classical Electrodynamics, 3E, Wiley India.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY315	**Statistical Mechanics**	3 1 0 4

Description: This is a basic course for students of physics. It provides an introduction to the microscopic understanding of thermodynamic systems via the laws of statistical mechanics and applies this to various ideal and non-ideal systems.

Course Outcomes: After successful completion of the course students will be able to develop an understanding, and be able to

1) describe and apply principles of macroscopic thermodynamic properties of systems.

2) summarize and apply laws of probability for random walk, density fluctuations in gas.

3) describe micro and macro states and fundamental postulates, statistical approach to thermodynamics – statistical mechanics, apply to ideal gas and other systems.

4) describe and apply the formalism to systems that can exchange energy and particles, and systems containing identical particles to explain from more advanced perspective electrons in metals, black-body radiation, specific heat of atoms, molecules, electrons in solids.

5) describe interacting statistical mechanics of interacting spins and phase transitions, and phenomenology of liquid-gas transitions and universality, apply to estimate parameters of the theory.

Unit 1
Foundations: macroscopic vs. microscopic descriptions, equations of stateof selected systems, laws of thermodynamics, TdS relations, response functions, thermodynamic potentials, chemical potential, minimum & maximum principles, equilibrium, stability, homogeneous systems.[4]
Review of probability: random variables, probability distributions, random walk on a 1-d lattice, continuum limit, Brownian motion, Poisson distribution and density fluctuations in gases, statement of central limit theorem, relative fluctuation in large systems; Examples. [6]

Unit 2
Statistical description: specification of states, micro and macrostates in quantum and classical systems, phase space, trajectories, counting states, density of states; time and ensemble averages, Liouville theorem, ergodicity and the fundamental postulate; Ensembles, microcanoni-

cal ensemble – postulate of equal a priori probabilities, systems in thermal equilibrium, connection with thermodynamics, Entropy of mixing and Gibbs paradox.[8]

Unit 3

Canonical ensembles of quantum and classical systems:partition function, connection with thermodynamics and calculation of thermodynamic quantities, energy; examples: classical and quantized systems of ideal gases, magnetic or spin systems, harmonic oscillator; density and velocity distributions, equipartition of energy, specific heat; Grand canonical ensemble, chemical potential, density fluctuations in classical ideal gases.[12]

Unit 4

Statistics of indistinguishable particles: Maxwell-Boltzmann, Fermi-Dirac and Bose Einstein statistics, properties of ideal Bose and Fermi gases, degenerate Fermi gases, Planck's distribution law of black-body radiation, Bose-Einstein condensation. [10]

Unit 5

Interacting systems and phase transitions: thermodynamics of magnetic systems, paramagnetism; model of interacting spins – Ising model, exact solution in one-dimension, mean field theory,critical exponents,improved mean field approximation and free energy expansion, Introduction to Landau theory; Phenomenology of liquid-gas system;van der Wall's equation of state, law of corresponding states, first & second order phase transitions, Maxwell's construction, critical exponents. [10]

Textbooks/References:
1. Silvio Salinas, Introduction to Statistical Physics, Springer Indian, 2006.
2. F Reif, Statistical Physics, Berkeley Physics Vol 5, TMH
3. F Reif, Foundations of Statistical and Thermal Physics, TMH, 1E, 2011.
4. Tobochnik and Gould, Thermal and Statistical Physics, Princeton University Press, 2010
5. Kerson Huang, Introduction to Statistical Physics, 2E, CRC Press (Indian Reprint), 2010. (Ch.1-4, 10)
6. R.K. Pathria, Statistical Mechanics, 3E, Elsevier India.
7. Kerson Huang, Statistical Mechanics, 2E, Wiley India, 1987.
8. Landau and Lifshitz, Statistical Physics, Pergamon Press.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY317   **Quantum Mechanics I**   **3 1 0 4**

Description: This course is a foundational pre-requisite for many advanced courses in physics and chemistry, and is indispensable for understanding the behaviour of molecules, atoms and elementary particles.

Course Outcomes: On successful completion of the course, students will be able

CO1: understand and explain interpretations of wave functions, Schrodinger equation, probabilities, probabilityconservation, Ehrenfest result on classical-quantum connection, uncertainty relations and solve problems on related concepts.

CO2: Understand stationary states the concepts to simple one-dimensional potentials to obtain energy spectrum, time evolution of superposed states, probabilities, and expectation values, apply to free particle in a box, scattering and bound states, spread of wave-packets, uncertainties on position and momentum.

CO3: understand the concepts of vector spaces and operators in Hilbert spaces toget deeper insights the properties of wave functions, position, momentum, Hamiltonian operators, theireigenvalues, measurements, uncertainties, simultaneous measurements, representations in different bases.

CO4: understand quantum dynamics and its classical analogy, apply them to two-level systems, apply to solve for simple harmonic oscillator eigenstates and energies using analytic algebraic and approaches.

CO5: understand the application of method of separation of variables, angular equations and angular momentum eigenvalues and spherical harmonics, radial eigenvalue problems for axially symmetric and central potentials,hydrogen atom, and describe complete set of eigenstates and eigenvalues, degeneracies,and its underlying symmetries.

CO6: Understand electron spin operators, commutation relations, states and spin dynamics in magnetic field.

Unit 1

Foundations: double-slit experiment – classical vs quantum view, wave-particle duality, wave function, Schrodinger equation; basic properties of Schrodinger equation: probability amplitudes and probabilities, probability currents, continuity equation; elementary discussions of operators, expectation values anduncertainties;time evolution of expectation values, correspondence with classical mechanics – Ehrenfest theorem. [4 hrs](Refs., 1,2,9)

Stationary States: Time-independent Schrodinger equation, eigenstates and eigenvalues of Hamiltonian;eigenfunction expansions, interpretation of expansion coefficients, time evolution of a superposed state and expectation values, meaning of a stationary state.

General properties of bound states in 1D: non-degeneracy of bound states;real and symmetric potentials;application to particle in a rigid box.

Free particles states, continuous basis, Dirac-normalization, wave packet and its time-evolution, dispersion, group and phase velocities. [6]

Unit 2

Dirac-delta potential: bound and scattering states, reflection and transmission coefficients. [3]
Review of strategies for problem solving with bound states of finite potential wells;scattering states, probability currents, reflection and transmission coefficients of step and barrier potentials, tunnelling probability. [1]
Review of mathematical tools through illustrative examples: two-dimensional complex vector spaces in Dirac notation, inner product, dual vectors, norm, normaliza-

tion;orthonormalbasis expansion vectors and dual vectors; higher dimensions andsubspaces. Linear transformations, operators, matrix elements, inner product of matrices with vectors, outer product and projection operators, completeness, outer product expansion of matrices, adjointof an operator, adjoint matrices; Hermitianand Pauli matrices, unitary matrices; eigenvalue problem of Hermitian matrices: properties of eigenvalues and eigenvectors – orthogonality and completeness, diagonalization,spectral decomposition, matrix elements of vectors and operators in the eigen-basis, functions of matrices.Generalization to infinite dimensions and function spaces,inner product and norm; functions as infinite dimensional vectors with discrete, continuous wavevector and position bases; General linear and Hermitian operators in function spaces. [6] (Refs. 9, 2, 10)

Unit 3

Essential Principles: Quantum states, superposition principle – Hilbert space.

Observables and Hermitian operators– discrete and continuous spectrum; position and momentum eigenfunctions.

Measurement, probabilities, and expectation values. Compatible and incompatible observables, commutators, simultaneous eigenstates, and uncertainty relations; minimum uncertainty wave packet.

Quantum Dynamics: time evolution, Ehrenfest theorem, connection with classical Poisson bracket formalism. Schrodinger equation in position, momentum bases, changing basis. Schrodinger equation and Hamiltonian in the energy basis, matrix representation, time evolution of a state of a two-level system; Propagator. [12]

Unit 4

Simple harmonic oscillator –algebraic approach, the energy basis, matrix elements of position and momentum operators; review of analytic approach. [4]

Schrodinger equation in two and three dimensions; commutation relations for position, momentum, angular momentum, Hamiltonian; separation of variables, angular equations,spherical harmonics;connection with angular momentumoperators, eigenvalues and eigenfunctions. [4](Ref.1-Secs.4.1, 4.3).

Unit 5

Axially symmetric potentials: harmonic oscillator andcharged particle in magnetic field in 2-d.Central force potentials: radial equation, free particles, spherical potential wells,isotropic harmonic oscillator (results only);Hydrogen atom; complete set of commuting operators, eigenstates, eigenvalues; introductionto symmetry, invariance, degeneracy, accidental degeneracy. [7](Ref. 2-Secs. 12.3, 12.6;Ref.1-Secs.4.1.3,4.2)

Spin and spin states, Spin operators,commutation relations, eigenstates, expectation values, quantum dynamics of spin in aconstant magnetic field, Larmor-precession, paramagnetic resonance. [5]

References

1. D. Griffiths, Introduction to Quantum Mechanics, 3rdEd., (2018, CUP)
2. R. Shankar, Principles of Quantum Mechanics, Pearson India (LPE), 2E 2005
3. N. Zettili, Quantum Mechanics Concepts and Applications (2E, 2009, Wiley India)
4. E. Merzbacher, Quantum Mechanics, 3rd Ed., Wiley India.
5. L I Schiff, Quantum Mechanics, TMH, 3E, 2010

6. J.S. Townsend, A Modern Approach to Quantum Mechanics, 1E, Viva Books, 2010
7. R.P. Feynman, Feynman Lectures in Physics, Vol.3.
8. JJ Sakurai, Modern Quantum Mechanics, Pearson, 1E, 1994
9. David McMahon, Quantum Computing Explained, Wiley Student Edition.
10. G. Sundaram, Lecture notes on Quantum Mechanics.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY318	Condensed Matter Physics I	3 1 0 4

Description: This course builds on the elementary treatment of the subject at an undergraduate level. The objective is to understand the properties of solids based on the principles of quantum and statistical physics. A basic background in Mechanics, Quantum Physics, and basic ideas in statistical physics, and basic mathematical methods are essential. This is an important foundational course for physics of materials and solid-state devices.

Prerequisites: Concurrent registration of Quantum Mechanics I and Statistical Mechanics.

Course Outcomes: After successful completion of the course students will be able to develop an understanding, and be able to

1) apply the concepts of Bravais lattices and crystal symmetry and classification, periodic functions in crystals, reciprocal lattices, crystal planes, X-ray diffraction to identify crystals, relate lattice plane and reciprocal lattices, find structure factor, and scattering angles.

2) Understand and apply the concepts in binding in solids and its elastic properties, lattice vibrations, phonon spectrum and its scattering properties, lattice specific heat.

3) Describe and apply the concepts of quantum states of free electrons in metals, and its specific heat.

4) Understand the properties of electrons in the periodic potentials and band structure of electronic energiesfor nearly free electrons and tightly bound electrons; understand the origins of metallic, insulating, semiconducting behaviours.

5) Understand and describe semiclassical equations and apply them to explain insulators, concepts of effective mass, holes, and understand motion and transport of electrons in electric and magnetic fields.

6) Understand basics of semiconductor physics.

Unit 1
Crystal structure: Bravais lattices and primitive vectors;primitive, Wigner-Seitz cellsand conventional cells, basis, and related concepts; symmetries, crystal systems and lattices;

Crystal directions, reciprocal vectors and reciprocal lattices, Brillouin zone, Fourier expansion of periodic functions in crystals,crystal planes and Miller indices; X-ray diffraction: Bragg's law and Laue conditions, geometrical significance, structure factor, application to cubic crystals. [12]

Unit 2

Elementary theory of binding in solids: van der Walls and ionic bonding, Madelung constant,cohesion, and lattice energies. (Ref.2) [4]

Elastic waves in crystals: acoustic and optic modes, dispersion (Ref.2); Elastic properties. (Ref.4) [5]

Phonons and phonon spectrum, inelastic scattering by phonons; Einstein and Debye models, lattice specific heat, thermal expansion. (Ref.2). [3]

Unit 3

Theory of free electronsin metals:quantum states of an electron in a box with periodic boundary conditions, degenerate electron gas and its properties – Fermi energy, Fermi velocity, degeneracy pressure;density of states calculationsfor electron gas in 3D, 2D, and 1D;Fermi-Dirac distribution, specific heat of electrons. [5]

Electrons in periodic potentials: Bloch theorem, Bloch states in Brillouin zone; energy bands in a Kronig-Penny model. [3]

Unit 4

Schrodinger equation in k-space, Bloch theorem, empty lattice bands, extended and reduced zone schemes.

An overview of perturbation theory (non-degenerate and degenerate);Approximate energy levels and solution near the origin and the zone boundaries.

Variationalmethod using Rayleigh-Ritz trial function; Tight-binding approximation in one dimensional and other simple lattices in two and three dimensions; metals (mono and divalent), insulators and semiconductors. [8]

Unit 5

Motion of electrons in external fields: Drude and Sommerfeld pictures; Semiclassical equations of motion in a band, limits of validity. Current density in filled bands, band insulator.Concepts of effective mass and holes; motion of electrons in uniform electric fields, Bloch oscillations. [3]

Elementary transport theory: Drude picture of transport of electrons in metals, DC electrical conductivity, mean free time, collision rates and Matthiessen tule.Hall effect and magnetoresistance in metals and semiconductors.[3]

Introduction to semiconductors: band diagrams, effective masses and band gaps, electronic inter-band transitions, optical absorption, mobility and conductivity, cyclotron resonance and effective mass measurement (introductory); Intrinsic and extrinsic semiconductors, impurity levels and bands; non-degenerate semiconductors, carrier density in equilibrium, p-n junction basics. [6]

References

1. Ashcroft and Mermin, Solid State Physics, 1E, Cengage India
2. Kittel, Solid State Physics, 8E, Wiley India

3. M. Marder, Condensed Matter Physics
4. Ibach and Luth, Solid State Physics, 3E, Springer
5. J.J. Quinn and K. Yi, Solid State Physics, Springer
6. J. Singleton, Band Theory and Electronic Properties of Solids, OUP
7. S. Simon, Solid State Basics, OUP

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

Semester 7

22PHY506	Quantum Mechanics II	3 1 0 4

Description: The course is the 2nd part of the two-part course and will cover but relatively advanced topics that are required for every physicist.

Course Outcomes: On successful completion of the course, students shall be able to
CO1: understand the connection between translations and momentum operator and associated commutation relations, connection between rotations and angular momentum operators, angular momentum algebra, transformation of states, symmetries and the associated conservation laws, connection with degeneracy; Describe and calculate Clebsch-Gordan coefficients for addition of angular momenta in simple cases.
CO2: apply time-independent perturbation theory to obtain approximate energy system of complex problems, Hydrogen atom under various approximations.
CO3: Apply variational methods to estimate ground state and 1st excited states and WKB method to obtain energy spectrum and tunnelling properties.
CO4: apply time-dependent perturbation theory to describe level transitions, calculate transition rates.
CO5: describe scattering process, apply scattering theory and Born approximation to calculate scattering cross-section, phase shifts for simple potentials.
CO6: understandKlein-Gordon and Dirac equation.

Unit 1
Brief review of quantum mechanics: Quantum states, linear superposition, probabilities, operators, expectation values,states of free particle in a boxand hydrogen atom. [1]
Transformations, Symmetries, Invariance and Degeneracy:
Translations and momentum operator in 1-d and 2-d,transformations of states and operators – active and passive transformations, infinitesimal and finite transformations,translational symmetry in free electrons and electrons in periodic potentials.

Rotational transformations and angular momentum, infinitesimal and finite rotations, angular momentumalgebra of scalar and vector operators, eigenstates and eigenvalues of angular momentum operators (recap), generation of eigenstates andspherical harmonics; symmetries and invariancefor spherically symmetric potentials, degeneracies;LRL vector and accidental degeneracy (basic ideas); Rotation of spin states and states of total angular momentum; Addition of angular momenta andspins, Clebsch-Gordon coefficients. [8] (Refs. 2, 1)

Unit 2

Time-independent perturbation theory: non-degenerate and degenerate cases, application to simple systems; a selection of calculations in the corrections to energy levels of Hydrogen atom: fine and hyperfine structures,weak-field Zeeman and Stark effects. [8]
Variational: Variational calculus in quantum mechanics, variational estimate of ground state energies in simple systems, Rayleigh-Ritz method. [4]

Unit 3

WKB (semiclassical) approximation of wave functions, tunnelling amplitudes, bound states and Bohr-Sommerfeld quantization rule. [5]
Time-dependent perturbation theory (TDPT): first order correction, constant, sudden, adiabatic perturbations; sinusoidal perturbations, transition rates, Fermi golden rule. [5]

Unit 4

TDPT (contd.):spontaneous emission;lifetime of an excited state; selection rules.[4]
Elementary scattering theory: scattering amplitude and cross section,Born approximation,scattering by Coulomb and Yukawa potentials. [5]

Unit 5

Scattering theory (contd.): free particle states in spherical coordinates, Partial wave analysis, phase shifts; Low-energy scattering and resonances. [4]
Elements of relativistic quantum mechanics: Klein-Gordon and Dirac equations, Dirac equation in EM fields – nonrelativistic limit and spin; free particle solutions, negative energy states. [5]

Textbooks/References:
1. R Shankar, Principles of Quantum Mechanics, 2E, Springer
2. David Griffiths, Introduction to Quantum Mechanics, 2E, Pearson, 2005
3. E. Merzbacher, Quantum Mechanics, 3E, Wiley India.
4. Zettili, Quantum Mecanics, 2nd Ed.
5. L.I. Schiff, Quantum Mechanics, 3E, 2010

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14).

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY507	Condensed Matter Physics II	3 1 0 4

Description: This is course in a continuation of the part I of the course and introduces students to topics more topics.

Course Outcomes: After successful completion of the course students will be able to develop an understanding, and be able to

CO1: understand the basics of electron-electron interaction, Hartree-Fock equations, density functional and Thomas-Fermi theories, and calculations for two electron systems and free electrons in metals.

CO2: describe and apply concepts in semiconductor physics, impurity levels, equilibrium carrier densities, p-type and n-type semiconductors, p-n and Schottky junctions.

CO3: understand quantum states of electrons in magnetic fields, and dHVA effects, measuring Fermi surface parameters, quantum Hall effect.

CO4: understand basic dielectric properties of insulators, semiconductors and metals, dielectric constant, susceptibility, dielectric functions, Drude's model of ac-conductivity, optical properties of insulators, metals, and semiconductors.

CO5: Understand the quantum origin of magnetism, dia-, para-, ferro-magnetism, Van-Vleck and Pauli paramagnetism, Exchange interaction, Heisenberg model, spin waves.

CO6: describe superconducting properties, Ginzburg-Landau theories, explain thermal properties, Meisner, Josephson, flux quantum effects, bound state of a Cooper pair.

Unit 1

More about electron transport: Drude's picture of electrical and thermal conductivities, Wiedemann-Franz law and thermo-electric effects.Basics of Boltzmann transport theory, electrical and thermal conductivities,and thermopower for free electrons, transport coefficients. [4]

More on electrons in external fields: Zener tunnelling; Motion of free and Bloch electrons in magnetic fields, cyclotron frequency and cyclotron effective masses; Hall effect in energy bands. [4]

Landau levels, de-Hass-van-Alphen effect, measurement of Fermi surface; basic ideas on quantum Hall effect. [3]

Unit 2

Electron-electron interaction: Variational formulation of Schrodinger equation, Hartree and Hartree-Fock methods, self-consistent field, application to free electrons; Introduction to Thomas-Fermi and density functional and theories. [8]

Unit 3

Magnetism: dia-, para-, Van-Vleck and Pauli Paramagnetism, quenching of orbital angular momentum; Heitler-London approximation, Exchange interaction, Heisenberg model, mean field theory of ferromagnetism, spin waves. [8]

Unit 4

Introduction to superconductors: Thermal properties, London's equation, basic ideas on Ginzburg-Landau and BCS theories, Josephson tunnelling and SQUID. [8]

Unit 5

Dielectric and Optical properties of insulators: macroscopic polarization, susceptibility, dielectric constant, atomic polarizability, Clausius-Mossotti relation, dipolar polarization – Langevin model; dielectric function of monatomic crystals, metals, and polar crystals; Maxwell's equations and EM wave propagation in dielectric media and metals, ac-conductivity and dielectric function in metals; dispersion relations; optical properties of metals, plasma oscillations, skin depth; optical reflectance; Kronig-Kramer's relations; Ferroelectric transition. [12]

Crystal defects: Schottky and Frenkel defects, F-center; Frenkel and Mott-Wannier excitons; Raman effect in crystals. [3]

References:

1. Ashcroft and Mermin, Solid State Physics, 1E, Cengage India
2. Kittel, Solid State Physics, 8E, Wiley India
3. M. Marder, Condensed Matter Physics
4. J.J. Quinn and K. Yi, Solid State Physics, Springer
5. Ibach and Luth, Solid State Physics, 3E, Springer
6. J. Singleton, Band Theory and Electronic Properties of Solids, OUP
7. S. Simon, Solid State Basics, OUP

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY509	Advanced Electronics	3-1-0-4

The course focuses on learning principles of measurement, sensors, and capturing a real-world data through an electronic platform and to send data to a computing platform, along with studies of digital logic circuits.

Course Outcomes

On successful completion, students shall be able to

1. A fundamental understanding of the operation of digital circuit logic.
2. Explain the principles involved in measurement system connected with various technologies
3. Analyse the mechanisms involved in the measurement systems used in connection with various sensing technologies

4. Understand the operation of microcontroller based development platforms to interface sensors
5. Apply the knowledge of measurements digital logic and other electronic circuits to develop data acquisition systems.

Unit 1

Digital Electronics: Introduction to Boolean Algebra, Number systems, Logic gates. Simulation of logic gates of digital circuits. Optimized implementation of logic functions: Karnaugh map – Strategy for minimization – Minimization of product of sums forms – Incompletely specified functions – Multiple output circuits – Tabular method for minimization – Number representation and arithmetic circuits, Overview on latches, flipflops, counters. [18]

Unit 2

Brief overview of transducers (a selection of temperature, pressure, magnetic fields, vibration, optical) – principles and sample applications.
Measurement System Characteristics – Static and dynamic characteristics of measurement systems.
Measurement and control, signal conditioning and recovery; Impedance matching, amplification (Op-amp based, instrumentation amp, feedback), filtering and noise reduction, shielding and grounding. [16]

Unit 3

Basics of microprocessors and microcontrollers – ARM processor, ATMega16 microcontroller. [4]
Data acquisition systems: Introduction to Arduino platform, Basic digital I/O. Timers, A/D and D/A converters; USART, Control of DC motors, servo motors, Data acquisition, and interfacing with PC. [14]

References
1. P. Malvino, Electronic principles, 06th edition, Career Education (1998).
2. P. Horowitz & Winfield Hill, The Art of Electronics, 02nd edition, Cambridge University Press (1989).
3. J.P.Bentley, Principles of Measurement systems, 4/E, Pearson education ltd, UK, 2005.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY508	**Research Methodology and Seminar**	1 0 1 2

Description: This course introduces the basic ideas to begin research career, methods and tools of research activity, elements of typesetting and scientific reporting and presentation.

Course Outcomes:
CO-1   Familiarize methods of research, purpose, choice of method, construction of models, describe safety and ethical aspects; Understand hypothesis testing and measurement

and sampling, Apply probability and statistical techniques to analyse measured data and arrive at dependency on parameters of the problem.

CO-2 Explore suitable mathematical models to describe phenomena, fit model curves to the data; understand errors in measurements; calculate propagation of errors.

CO-3 Use spreadsheet program to perform basic scientific computing quickly. Familiarize methods and tools of scientific communications, experience writing short scientific reports and present in a classroom.

Unit 1

Overview of research methods in science; Hypothesis driven experiments: Null and alternative hypotheses, improvement of experiments; safety and ethics.

Statistics: measurements, sampling data, Reducing many numbers to few – histograms, means, averages, standard deviation; probability distributions, Connecting data and probability distributions, large numbers, normal distribution and Central Limit Theorem, Z-test and interpretations, confidence intervals, margin of error; t-test: comparing two measurements, Chi-square test; Data with many values of independent variable, goodness of fit.

Lab exercises.

Units2-3

Mathematical Modelling: ingredients of modelling, setting up problems, sketching and naming, functions, estimation, dimensional analysis.

Linear regression analysis, linear and non-linear curve fitting, matching arbitrary functions to data, Fourier transforms and power spectrum.

Error analysis: types of error, precision, accuracy, error propagation.

Spreadsheet software for basic scientific computing: cell operations, sorting, statistical functions, t-test, χ^2-test, charts, scatter plot, histogram, error-bars, trend lines (curve fitting).

Lab exercises.

Units4-5

Scientific information and Communication: an overview of structure of a technical document/proposal, scientific illustrations.Other tools: word processors, LaTeX typesetting, image manipulation and graphics, open source, and free software.

Project and Presentations.

Textbook/References

1. Michael P Marder, Research Methods for Science, CUP (2011).
2. P. Bevington, D.K. Harikatha, Data Reduction and Error Analysis for the Physical Sciences, Mc-Graw Hill, 2002
3. Online resources on LaTeX, and other tools.

Skill: Tutorials, assignments and a project provide an exposure to research methods and gives an experience in documentation and presentation methods to prepare students as a science communicator, physics resource person in journalism and administrative services, instructor/researcher in schools, colleges and universities, research labs.

Evaluation Pattern: Continuous assessment based on assignments, presentations: 50%; One mid-term exam: 20%; End-semester exam: 30%.

22PHY397/22PHY393*   **UG Mini Project/ Internship***   **(3 credits)**

*code for internship

Course Outcomes: After successful completion of the project, students will be able to

1) Gain deeper insights into the chosen areas of research.
2) Gain experience in research methodologies in the chosen area.
3) Develop theoretical/experimental/computational skills in helping explore the research goals.
4) Communicate one's efforts in the form of a well reference scientific report with illustrations, tables, equations, organization conforming to current publication standards.

The aim of the project work is to give more detailed exposure to the student for research methods. This can include literature survey, review, data collection, and theoretical/experimental work on small parts of research in area chosen by the faculty guiding the project work. Equivalently, a student may carry out an internship during the summer after the 6th semester. Evaluation for such an internship will be similar to that for the mini project.

Evaluation Pattern:

Mini Project/ Internship Supervisor evaluation: 50%; End Semester (departmental) Evaluation: 50%.

Skills: Training during the course of the project work help develop theoretical/ experimental/ computational skills and help communicate one's efforts in the form of a well referenced scientific report.

22PHY592   **Internship**   **(3 credits)**

Course Outcomes: After successful completion of the project, students will be able to

1) Gain deeper insights into the chosen areas of research.
2) Gain experience in research methodologies in the chosen area.
3) Develop theoretical/experimental/computational skills in helping explore the research goals.
4) Communicate one's efforts in the form of a well reference scientific report with illustrations, tables, equations, organization conforming to current publication standards.
5) Gain experience working in larger interdisciplinary research settings in academia or industrial settings.

The aim of the (optional) internship is to give more detailed exposure to the student for research methodsin an institution outside this school. This can include literature survey, review, data collection, and theoretical/experimental/simulation work on small parts of research in area chosen by the faculty guiding the project work or even an industrial work contributing to an ongoing work in some appropriate capacity. The work may be carried out during the summer after the end of 6^{th}or 8^{th}semester. Evaluation for such an internship will be similar to to that for the mini project.

Evaluation Pattern:
Internship Supervisor evaluation: 50% ; End Semester(departmental) evaluation: 50%.

Skills: Training during the course of the project work help develop theoretical/ experimental/ computational skills and help communicate one's efforts in the form of a well referenced scientific report.

Semester 8

22PHY514	**Atomic and Molecular Physics**	(3-1-0-4)

Description: The course introduces students to the basic physics of atoms, molecules, their spectra and the interaction of light with matter. This builds upon what students learn from the 2nd course on quantum mechanics.

Course Outcomes: After successful completion of the course, students will be able to
1) Understand and describe electron states of hydrogenic atoms and semiclassical theory of radiation and Einstein work on radiation, selection rule and spectra of one-electron atoms, linewidths.
2) Understand and describe systematically various corrections to hydrogen spectrum.
3) Describe models for helium and multielectron atoms, and their electronic spectra, and distinguish various coupling schemes and their consequences.
4) Describe and apply the models of diatomic molecules to explain electronic, vibrational and rotational levels, Franck-Condon principle, IR and Raman and spectroscopy.
5) Describe NMR, ESR, principles of lasers and masers, their operation principles.

Unit 1
States of an electron in a Hydrogenic atoms, fine structure.
Semiclassical theory of radiation, transition rates, absorption, stimulated and spontaneous emissions; Einstein's A and B coefficients; dipole approximation, selection rules and spectrum of one-electron atoms; line intensities, lifetimes, line shapes and widths, photoelectric effect. [12]

Unit 2
Fine structure of hydrogenic atoms, Zeeman and Stark effects, Hyperfine structure. [4]
Helium atom: variational method, para and ortho states, ground state, singly and doubly excited states. [4]

Unit 3
Multielectron atoms: central field approximation, Hartree-Fock method and self-consistent field; Russel-Saunder's notation of electronic states; LS and JJ coupling schemes, Zeeman effect, quadratic Stark effect, X-ray spectra. [10]

Unit 4

Molecules: Hydrogen molecular ion, Hydrogen molecule, Born-Oppenheimer approximation, Molecular orbitals, vibrational and rotational levels of diatomic molecules, Raman spectra, electronic spectra, Franck–Condon principle, nuclear spin;IR and Raman spectroscopy. [10]

Unit 5
Nuclear magnetic resonance, Electron spin resonance, chemical shift. Lasers: Optical pumping, population inversion, rate equation; modes of resonators, coherence length. [8]

References

1. B. H. Bransden and C. J. Joachain, Physics of Atoms and Molecules, 2nd Ed. (1983), Pearson Education. (Recommended text)
2. D. Griffiths, Quantum Mechanics, 3rd Ed., Pearson India. (Ref. Electron on states and perturbation theory)
3. P. Atkins and R. Friedman, Molecular Quantum Mechanics, 5th edition, Oxford University Press (2011). (Overall Reference)
4. S. Gasiorowicz, Quantum Physics, 3rd Ed., Wiley India. (Ref. on radiation theory)
5. C. Kittel, Solid State Physics, 8th Ed. (Ref. in NMR, ESR)
6. J. B. Rajam, Atomic Physics, S. Chand & Company Ltd. (2007).
7. W. Demtroder, Atoms, Molecules and Photons, Springer-Verlag Berlin (2006).

Evaluation Pattern: As in the rules for *Assessment Procedure*(R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY515	Nuclear and Particle Physics	3 1 0 4

Description: This course introduces the fundamental constituents of matter and their interactions.

Course Outcomes: After successful completion of the course, students will be able to

1) Describe basic nuclear properties based on size, shape, charge, spin, parity, binding energy, and nuclear models
2) Understand nuclear scattering processes, describe nature of nuclear forces and interactions, shell structure and models, explain rotational spectra
3) Describe ideas in nuclear radiations, apply selection rules, fusion and fissions, nuclear reaction mechanisms, nuclear reactions in astrophysics.
4) Familiarize and describe particle detectors and accelerators used in the study of fundamental particles.
5) Classify elementary particles, fundamental forces, quantum numbers, apply invariance and conservation laws in nuclear reactions, describe quark models. Apply symmetry arguments in particle reactions, parity non-conservation in weak interactions, and outline

arguments leading to model of phenomenology of weak interactions, gauge bosons, outline standard model.

Unit 1

Basic nuclear properties: origins: radioactivity and Rutherford scattering; nuclear size, shape – matter and charge distribution, nuclear mass, nuclear angular momentum, spin and parity, nuclear electric and magnetic moments, binding energy – semi-empirical mass formula.

Unit 2

Nature of the nuclear force, form of nucleon-nucleon potential, charge-independence and charge-symmetry of nuclear forces; Deuteron problem; Nucear models: liquid drop model, shell model: infinite square well, harmonic oscillator, and spin-orbit potentials, rotational spectra.

Unit 3

Radioactivity and Nuclear Reactions: alpha, beta and gamma decays and their selection rules; fission and fusion; nuclear reactions, compound nuclei and direct reactions; Nuclear interactions in early universe, primordial and stellar nucleosyntheses.

Unit 4

Detectors: ionization, scintillation, Cherenkov, semiconductor detectors; calorimeters.
Accelerators: electrostatic accelerators, cyclotron, linear accelerator, colliding beams.
Elementary particles: Classification of fundamental forces and elementary particles and their quantum numbers (charge, spin, parity, isospin, strangeness, flavour).

Unit 5

Gellmann-Nishijima formula, Quark model, baryons and mesons, conservation laws;
C, P, and T invariance; Application of symmetry arguments to particle reactions; Parity non-conservation in weak interaction, CP violation; Phenomenology of Kaon and Neutrino oscillations, gauge bosons, weak interactions and standard model.

References:

1. A. Das and T. Ferbel, Introduction to nuclear and particle physics,
2. Kenneth S. Krane, Introductory Nuclear Physics, Wiley 1988
3. B. R. Martin, Nuclear and Particle Physics – An Introduction, 2E, Wiley India
4. Cottingham and Greenwood, An Introduction to Nuclear Physics, 2E, CUP
5. D. Griffiths, Introduction to Elementary Particles, 2E, Wiley-VCH

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

| 22PHY516 | **Computational Methods in Physics** | **3 0 2 4** |

Course outcomes

On successful completion of the course, students shall be able to

CO-1 Write basic programs using concepts of computer programming using Python/MATLAB.

CO-2 Solve ordinary differential equations using numerical methods. Utilize the concepts of numerical stability and convergence to analyse each of the methods.

CO-3 Solve roots of nonlinear equation and apply them to find eigenvalues in simple quantum mechanical potential well problems, estimate integrals using numerical methods with applications in physics and applied fields.

CO-4 Apply finite difference methods to approximate boundary value problems with applications in physics and applied fields.

CO-5 Understand and apply stochastic simulation methods to problems of interest in physics and applied fields.

(Using MATLAB/Python)

Unit 1

Introduction to scientific computing, number representation in computers and roundoff error. Review of programming basics: Algorithms and flowchart, data types, control statements, functions, arrays, classes, input/output, reading and writing files, graphs, and data visualizations. Optional: Parallelization of code for multi-core computing.

Unit 2

Ordinary differential equations: Initial value problems - Euler and Picard Methods, convergence, stability, Runga-Kutta, Verlet, Predictor-corrector methods;Shooting methods.
Sample applications: Projectile Motion, Nuclear decay, Pendulum with dissipation, Lorentz model, Kepler problem and planetary orbits; Shooting method – eigenvalues and eigenfunctions of bound quantum states of a particle in one-dimensional potentials or equivalent applications or scattering states in a spherical potential.

Unit 3

Roots of an equation: bisection, Newton-Raphson, Secant Methods.
Numerical integration: Mid-point, Trapezoidal, and Simpson's rules, errors.
Sample applications: Energy Eigenvalues of the square well potential, First-order perturbation correction to energy, Magnetic field produced by current.

Unit 4

Partial Differential Equations: discretization, Finite difference method, relaxation methods, stability, Crank-Nicholson method, Spectral methods.
Sample applications: Solving Laplace's equation, Diffusion Equation, Wave Equation, Schrodinger equation, Poisson equation, ground water dynamics, wave-packets in a quantum mechanics – step or barrier potentials.

Unit 5

Stochastic Simulations: Random numbers, Pseudo Random number generators, Distributions, Methods of generating random numbers that simulate non-uniform distributions; transformation method and relaxation method; Monte-Carlo integration.

Sample applications: Random Walk and Diffusion, Cluster Growth Models, Ising Model.

A term project may be given during the last third of the semester, carried out in groups of two to four students.

References:
1. An Introduction to Computational Physics – Tao Pang
2. Paul Devries and Javier Hasbun, A First Course on Computational Physics
3. Nicholas Giordano and Hisao Nakanishi, Computational Physics (2nd Ed.), Prentice-Hall.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organisations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY398	UG Project	(12 credits)

Course Outcomes: After successful completion of the project, students will be able to
1) Gain deeper insights into the chosen areas of research.
2) Gain experience in research methodologies in the chosen area.
3) Develop theoretical/experimental/computational skills in helping explore the research goals.
4) Communicate one's efforts in the form of a well reference scientific report with illustrations, tables, equations, organization conforming to current publication standards leading to master's thesis.
5) Hone and demonstrate research and communication skills by submitting a research article to a conference or journal.

The aim of the project work is to give more detailed exposure to the student for research methodology. This can include literature survey, review, data collection, and theoretical/experimental work on small parts of research in area chosen by the faculty guiding the project work. This project work may be a continuation from the Mini Projectcarried out in the previous semester or a separate work.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills: Training during the course of the project work help develop theoretical/ experimental/ computational skills and help communicate one's efforts in the form of a well referenced scientific report.

Semester 9

22PHY593	Mini Project	(9 credits)

Course Outcomes: After successful completion of the project, students will be able to
1) Gain deeper insights into the chosen areas of research.
2) Gain experience in research methodologies in the chosen area.
3) Develop theoretical/experimental/computational skills in helping explore the research goals.
4) Communicate one's efforts in the form of a well reference scientific report with illustrations, tables, equations, organization conforming to current publication standards.

The aim of the project work is to give more detailed exposure to the student for research methodology. This can include literature survey, review, data collection, and theoretical/experimental work on small parts of research in area chosen by the faculty guiding the project work.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills: Training during the course of the project work help develop theoretical/ experimental/ computational skills and help communicate one's efforts in the form of a well referenced scientific report.

Semester 10

22PHY599	Project II	(18 credits)

Course Outcomes: After successful completion of the project, students will be able to
1) Gain deeper insights into the chosen areas of research.
2) Gain experience in research methodologies in the chosen area.
3) Develop theoretical/experimental/computational skills in helping explore the research goals.
4) Communicate one's efforts in the form of a well reference scientific report with illustrations, tables, equations, organization conforming to current publication standards leading to master's thesis.
5) Hone and demonstrate research and communication skills by submitting a research article to a conference or journal.

The aim of the project work is to give more detailed exposure to the student for research methodology. This can include literature survey, review, data collection, and theoretical/experimental work on small parts of research in area chosen by the faculty guiding the project work.
The entire project work may be carried outat other institutions / research laboratories under suitable circumstances.

If so, the experts from these institutions are to be associated in choosing the research topic and its execution. This project work may be a continuation from Mini Projectcarried out in the previous semesteror a separate work through aninternship in another institution.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills: Training during the course of the project work help develop theoretical/ experimental/ computational skills and help communicate one's efforts in the form of a well referenced scientific report.

Laboratory Courses

22PHY185	Physics Lab I	0 0 3 1

Course Outcomes: After successful complete of the course, students will be able to
1. Experimentally verify laws of mechanics, optics, electricity and magnetism and understand them from practical perspective.
2. Handle apparatus and assemble simple experimental setup
3. Record measurements and Perform data analysis
4. Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis

Suggested list of experiments is given below. Equivalent experiments may be considered. A minimum of eight experiments are to be completed from the suggested list.

Experiments:
1. Timing ball and error analysis
2. Viscosity – Stoke's method
3. Compound pendulum / Kater's Pendulum
4. Centripetal force
5. Flywheel/ Moment of Inertia, Angular momentum, Torque, Rotational acceleration, rotational KE
6. Forced Oscillation and Resonance
7. Rigidity modulus – Torsion pendulum
8. Conversion of Galvanometer to DC Ammeter and Voltmeter or Conversion of Ammeter to Voltmeter and Vice Versa
9. Spectrometer: Basics, i-d curve and refractive index of glass prism (Sodium vapour lamp)
10. Fresnel Biprism
11. Sonometer

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as

lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

22PHY285	Physics Lab II	0 0 3 1

Course Outcomes: After successful complete of the course, students will be able to

1. Experimentally verify theoretical concepts in mechanics, electromagnetism, heat, and optics, stochastic processes such nuclear decay using dice.
2. Handle apparatus and assemble simple experimental setup
3. Record measurements and Perform data analysis
4. Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis
5. Appreciate safety protocols and measures taken

Suggested list of experiments is given. Equivalent experiments may be considered.
A minimum of eight experiments are to be completed from the suggested list.

1. Nuclear decay simulation
2. Coupled pendulum oscillations
3. Melde's experiment
4. Meter bridge or Carey Forster's bridge
5. Ballistic Galvanometer
6. Coulomb and Current balance
7. Helmholtz coil (Field along the axis, Biot-Savart's law)
8. Determination of capacitance and dielectric constant using a parallel plate capacitor
9. Dispersive power of Prism (Mercury vapour lamp)
10. Determination of gratings constant (using Sodium line) and Hydrogen/Mercury spectrum using grating spectrometer.
11. Newton's rings

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

22PHY286	Physics Lab III	0 0 3 1

Course Outcomes: After successful complete of the course, students will be able to
1. Experimentally verify theoretical concepts in mechanics, electromagnetism, heat, and optics.

2. Handle apparatus and assemble simple experimental setup
3. Record measurements and Perform data analysis
4. Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis
5. Appreciate safety protocols and measures taken

Suggested list of experiments is given. Equivalent experiments may be considered. A minimum of eight experiments are to be completed from the suggested list.

Experiments:
1. (a) Young's modulus using static bending by hanging weights; (b) Rigidity modulus by static torsion
2. Poiseuille flow
3. Thermo EMF vs Temperature/ Calibration of Thermistor
4. Coefficient of Linear Expansion of Metals
5. Calorimeter - Heat-Electrical Work Equivalent - Specific heat of water
6. Specific heat of solids - Dulong-Petit's law
7. Lee Disc Apparatus – Thermal Conductivity of a Non-metallic Solid
8. Polarization of light – Malus' law. Demonstration of Brewster Angle Experiment
9. Laser diffraction: reflection grating determination of spacing between CD tracks and mm ruling of meter of scale
10. Resolving Power of a Telescope

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY383	**Physics Lab IV**	0 0 3 1

Course Outcomes: After successful complete of the course, students will be able to
1. Experimentally verify theoretical concepts in mechanics, electromagnetism, heat, and optics, and modern physics.
2. Handle apparatus and assemble simple experimental setup
3. Record measurements and Perform data analysis
4. Calculate physical parameters from experimental results and their deviation from theoretical predictions and Error Analysis
5. Appreciate safety protocols and measures taken

Suggested list of experiments is given. Equivalent experiments may be considered. Experiments must include error analysis. A minimum of eight experiments are to be completed from the suggested list.

Experiments:

1. Young's modulus and Poisson's ratio by Cornu's interference apparatus
2. Diffraction of laser light by double slit, gratings, circular aperture, wire mesh, straight wire.
3. Quarter wave plate
4. Gyroscope
5. Young's modulus by resonance of flexural vibrations of a steel bar; Rigidity modulus of a brass wire by resonance of torsional oscillations
6. Determination of High resistance be Leakage
7. (a) RLC Circuit: Determination of L,C, and Resonant frequency - frequency domain response. (b) Time domain response, phase lag determination using DSO
8. Stefan's Constant
9. Franck-Hertz experiment
10. Photo electric effect
11. Fourier Analysis using resonance circuit.
12. AC Bridges Anderson, Maxwell, DeSauty, Owen
13. Temperature Coefficient of Resistance of Copper

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY384	Physics Lab V	1 0 3 2

Course Outcomes: After successful completion of the course, students will be able to
1) Perform experiments on basic circuit analysis, and p-n-junction based circuits
2) identify the characteristics of transistor and amplifiers.
3) design circuits using transistors for different applications and its analysis
4) develop basic skill in using op-amp, apply, design circuits for different applications
5) gain basic skills in electronics experimentation

Suggested list of experiments is given. Equivalent experiments may be considered. A minimum of eight experiments are to be completed from the suggested list.

1. Varification of Thevenin and Norton's theorems
2. Half wave Rectifier (with and without capacitor filter)
3. Full wave Rectifier- Centre-tap (with and without capacitor filter)
4. Full wave Bridge Rectifier (with and without capacitor filter)
5. Diode Clipper (biased and unbiased)
6. Diode Clampers
7. Transistor Characteristics (CB and CE configurations)

8. Hartley & Colpitt's Oscillator- using Transistor
9. Differential Amplifier using transistor-CMRR, Frequency responses
10. Inverting Amplifier & Non-Inverting Amplifier-using op-amp
11. Integrator and Differentiator-using op-amp
12. Comparators using op-amp
13. Sample regulated power supply

A few experiments for the last 2-4 weeks may be replaced by a hands-on projectwork based on the related ideas depending on the available resources.

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY584	Physics Lab VI	0-0-4-2

Course Outcomes
1) Understand the principles of digital electronics and circuits using basic gates, latches, flip flops, registers and counters
2) Understand the digital I/O operations with Arduino
3) Understand the control of DC motors and Servo motors
4) Understand the data acquisition using Arduino and use it for temperature measurement.

Suggested list of experiments is given. Equivalent experiments may be considered. A minimum of first sever experiments are to be completed from the suggested list. A few experiments for the last 3-4 weeks may be replaced by a hands-on project work in group of 2-3 students depending on the available resources, including one among the topics mentioned in the list below in more depth.

Experiments:
1. Digital circuit experiments with basics gates – AND, OR, NOT
2. Digital circuit experiments with universal gates – NAND and NOR
3. Experiments with latch-based circuits – SR latch
4. Experiments with flipflops – D-flipflops , J-K flipflops, Toggle flipflops
5. Experiments with shift registers, serial/parallel shift registers. (demo)
6. Experiments using counters – decade counter. (demo)
7. Digital I/O operation in Arduino
8. Open loop speed control of DC motor
9. Servo motor control using Arduino
10. USART based Communication of ADC data from Arduino to PC
11. Temperature measurement system using Arduino

A few experiments for the last 2-4 weeks may be replaced by a hands-on project work based on the related ideas depending on the available resources.

References

A. P. Malvino, Electronic principles, 06th edition, Career Education (1998).

P. Horowitz & Winfield Hill, The Art of Electronics, 02nd edition, Cambridge University Press (1989).

J.P.Bentley, Principles of Measurement systems, 4/E, Pearson education ltd, UK, 2005.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY585	Physics Lab VII	0 0 4 2

(Suggested list of experiments are given. Equivalent experiments may be considered.)

Course Outcomes: After successful completion of the course, students will be able to

1. Perform some of the advanced level experiments to strengthen experimentation skills.
2. Develop practical skills, which includes understanding of objectives, related experimental design and operation
3. Verify experiments in optics, atomic physics, solid state physics; use skillfully modern equipment such as Michelson and Fraby-Pero interferometers
4. Record observations in a logical order, apply the measurement techniques and develop skill and analyze data, and draw inferences
5. Finally make a detailed discussion by identifying the sources of error.

Suggested list of experiments is given. Equivalent experiments may be considered. Experimentsmust include error analysis.A minimum of eight experiments are to be completed from the suggested list.

Experiments:

1. Michelson Interferometer
   (a) Wavelength of a laser
   (b) Thickness of a glass plate or Dependence of refractive index air on pressure
2. Fraby-Perot Interferometer
3. Ultrasonic diffraction of Laser light
4. Millikan oil drop experiment
5. Arc spectrum using constant deviation spectrometer
6. (a) Dielectric constant of polymer & ceramic capacitors, verification of Curie-Weiss Law
   (c) Ferroelectric transition of BaTiO3
7. Four Probe Band gap of a semiconductor
8. Magnetic susceptibility - Quincke's/Gouy Method
9. Hall effect in n-type semiconductors and Bismuth.
10. Calibration of thermometers: Thermocouple & Si-Diode
11. Capacitance measurement and Dipole Moment of liquids of organic molecules and polar molecules.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

22PHY586	**Physics Lab VIII**	**0 0 4 2**

Course Outcomes: After successful completion of the course, students will be able to

1. Perform some of the advanced level experiments to strengthen experimentation skills.
2. Develop practical skills, which includes understanding of objectives, related experimental design and operation
3. Verify experiments in optics, atomic physics, spectroscopy, solid state physics; use skillfully modern equipment such as Michelson and Fraby-Pero interferometers
4. Record observations in a logical order, apply the measurement techniques and develop skill and analyze data, and draw inferences
5. Finally make a detailed discussion by identifying the sources of error.

Suggested list of experiments is given. Equivalent experiments may be considered. Experiments must include error analysis. A minimum of five experiments are to be completed from the suggested list. A few experiments for the last 3-4 weeks may be replaced by a hands-on project work in group of 2-3 students depending on the available resources,including one among the topics mentioned in the list below in more depth.

Experiments:
1. Absorption spectrum of KMnO4
2. Zeeman Effect
3. Sodium doublet splitting using Michelson Interferometer
4. Electron Spin Resonance/ Nuclear Magnetic Resonance
5. Temperature dependence of Hall Effect in p-type semiconductors
6. Magnetoresistanceof Bismuth, n-Ge
7. BH-curve
8. (a) Thermal and Electrical Conductivity& Lorentz Number of Copper(b) k/e using transistor
9. Lattice dynamics using LC-Chain Transmission Line
10. Solar Cells
11. Phase sensitive detection and Lock-in amplifier

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Lab sessions and experimentation help develop intuition for lab equipment and builds practical knowledge of using lab instruments, measurement techniques and experimental techniques needed for work involving communication of science such as lab instructor/ demonstrator, technical staff, educator or a scientist in schools, colleges, universities, industries and research labs/organisations.

Other Minor Courses

22PHY518	Numerical Weather Prediction	3-0-2-4

Course Outcomes

CO1   Apply the techniques of solving PDEs for meteorological equations
CO2   Experiment with different modelling systems
CO3   Explain the concepts of parameterization of physical processes in weather models
CO4   Summarize the concepts of data assimilation
CO5   Interpret numerical weather model outputs

Unit 1

Numerical Methods: Basic concepts about different methods for solving model equations: Finite difference method. Implicit & semi-implicit scheme. Numerical stability criterion (CFL). Spectral method.

Unit 2

Operational Numerical Models: Operational NWP modelling system: Global Forecast System, Regional and mesoscale forecast system (WRF, ARPS), Nowcast model, Climate Forecast System, Ensemble prediction system, multi-model ensemble technique, Cyclone model Hurricane WRF, vortex relocation and initialization, Antarctica model Polar WRF, Storm Surge modelling, Ocean State modelling, Crop Weather Model.

Unit 3

Parameterization of physical processes: Basic concepts of Planetary boundary layer, Land surface processes, Convection (Deep cumulus and shallow convection), Large scale condensation, Radiation (short wave & long wave parameterization), Cloud Radiation interaction, Dry and moist convective adjustment processes, Cloud microphysical parameterization.

Unit 4

Data Assimilation: Different objective analysis schemes, Cressman techniques, OI scheme (Optimum interpolation). Global Data Assimilation System: Decoding and quality control of GTS conventional/non-conventional observations (including Radar and satellite data), Regional and global data assimilation system: variational data assimilation, 3D vibrational data assimilation, technique (WRF Var).

Unit 5

Post-processing of NWP Products: Different products: Direct and Derived, Post processing of model output: Model output verification: Forecast skills, Forecast errors, Systematic errors, Bias correction. Down scale of NWP model like location specific forecast, Statistical interpretation, NWP products for aviation services, hydrological services, NWP products for localized severe weather, monsoon rainfall prediction, prediction of Western disturbances. NWP based objective cyclone forecast system, NWP based location specific forecast, GIS application for NWP, NWP products in Web.

Practical

Basics of Linux O.S, Configuration of WRF model, Experiment with nesting and nest down techniques, sensitivity experiments for physical parameterization.

Model diagnosis: Illustration of NWP products, Case study of monsoon depression, cyclonic storm, localized severe weather with the use of derived products like divergent, vorticity, flow pattern, precipitable water content, vertically integrated moisture flux, rainfall etc

References

1. Chandrasekar, A. (2022). Numerical Methods for Atmospheric and Oceanic Sciences. Cambridge University Press.
2. Coiffier, J. (2011). Fundamentals of numerical weather prediction. Cambridge University Press.
3. Warner, T. T. (2010). Numerical weather and climate prediction. Cambridge university press.
4. Stensrud, D. J. (2009). Parameterization schemes: keys to understanding numerical weather prediction models. Cambridge University Press.

22PHY517	Satellite Meteorology	3-0-2-4

Course Outcomes

CO1	Explain the basic principles of remote sensing
CO2	Discuss the various meteorological satellite systems
CO3	Produce various satellite derived products
CO4	Interpret observations from insitu and satellite sensors

Unit 1

Remote Sensing: Principles of remote sensing, Application in meteorology, Introduction to satellite meteorology, Orbital mechanics.

Unit 2

Meteorological Satellites: Polar, geostationary and low-inclination orbits, Current and future meteorological satellites of the world. Payloads on meteorological satellites, INSAT, Kalpana, Meteosat, GOES, Himawari, FY, NOAA, Metop, MeghaTropiques, Scatsat-1, Oceansat, Exposure to fundamental concepts like resolution, calibration, navigation, registration, NEDT (Noise equivalent differential temperature).

Unit 3

Satellite derived products, SST, CTT, CTP AOD, OLR, AMV and wind derived Products, UTH, Rainfall products (IMSRA &HE), Fog, Snow, Rainfall Products, Concepts of Image Enhancement techniques, and RGB Images from Imager & Normalized Difference of Vegetation Index (NDVI) from CCD etc. and their application in forecasting/ nowcasting.

Unit 4

Basic Principles of Sounding: Processing of data from infrared and microwave sounders. Retrieval of products from sounders, Temperature and humidity profiles and total ozone. Interpretation and use of sounder products.

Unit 5

Interpretation of Satellite Images: Characteristics of various channels, Identification of typical clouds and weather systems from cloud imageries, Satellite bulletin and its interpretation. Tropical cyclones, their identification and grading using Dvorak's technique. Interpretation of microwave channel images. Image Enhancement Techniques, Interpretation of Imagery and Products (like RGB) from INSAT/Foreign Satellites, Satellite based tools for nowcasting, Concept of rapid scan images and its use, Assimilation of satellite data in NWP models, Use of satellite in very short-range forecast to now casting.

References

1. Kidder, S. Q., KIDDER, R. M., & Haar, T. H. V. (1995). *Satellite meteorology: an introduction*. Gulf Professional Publishing.
2. Kelkar R R (2017) Satellite meteorology, CRC Press
3. Bowman, K., & Yang, P. (2015). Satellite Meteorology and Atmospheric Remote Sensing: An Introduction, Wiley-VCH
4. Hoffman, R. R., & Markman, A. B. (Eds.). (2019). *Interpreting remote sensing imagery: human factors*. CRC press.

Physics Electives

22PHY553	Epistemological Foundations of Quantum Mechanics	3 0 0 3

Description: The main objective of this course is to impart and inculcate an epistemological vision that quantum physics imply and can afford.

Course Outcomes: After successful completion of the course, students will be able to

1) Identify failure of classical mechanics and origin of QM starting from Planck to Schrodinger and later to Bell with a historic and philosophical perspective.

2) formulate quantum mechanical problems in Dirac's Ket and Bra and Hilbert space representation.

3) Analyse the concepts of reality and trajectory of a particle with the experimental paradigms using Mach-Zehnder type interferometers.

4) Distinguish between Fermions and Bosons and be able to connect it to Pauli Exclusion Principle, indistinguishability and symmetry.

5) Identify the paradoxes of QM like de Broglie, Schrödinger's cat, Wigner's friend, EPR paradox, etc. and describe measurement problem using State-vector reduction and justify the same by the concept of decoherence.

6) Analyse Bell type of inequalities (like CHSH inequality) using the notions of Entanglement, Hidden variables and the like using Mermin's Reality machine and Aspects Experiments

7) Describe a variety of interpretations of quantum mechanics like, Statistical, Copenhagen, Bohm's formulation, Transactional, Wheeler's Participatory Universe, Many World, Transactional Interpretation, Consciousness interpretation.

8) Apply the quantum concepts to some modern technological applications like, Vaidman bomb detector, Quantum teleportation, Quantum Erasing, Quantum cryptography and Quantum Computing, dense coding, Quantum Information.

Contents:

Unit 1   Historical & Epistemological Perspctive: Quick review of the failure of classical mechanics and origin of QM: Planck-Einstein, Bohr atom, de Broglie, Heisenberg's uncertainty principle, Experimental verifications – wave-particle duality and Young's double-slit experiment, polarization experiments, Stern-Gerlach experiments, Schrödinger equation - particle in a box, tunnel effect.

Unit 2   Dirac's ket and dual ket formulations and Hibert space representation, Mach-Zhender type interferometers; Reality and trajectory of a particle, Fermions and Bosons, Pauli Exclusion Principle and indistinguishability, symmetry; State-vector reduction and measurement problem, decoherence.

Unit 3   Paradoxes of QM: de Broglie paradox, Schrödinger's cat, Wigner's friend paradox, Entanglement, Hidden variables, EPR paradox, Bell-type Inequalities, Mermin's Reality machine, Aspects Experiments, CHSH inequality, Kohen-Specker theorem.

Unit 4   Various interpretations of QM: Statistical, Copenhagen, Bohm's formulation, Transactional, Wheeler's Participatory Universe, Many World, Transactional Interpretation, Consciousness interpretation – Philosophical implications.

Unit 5   Modern applications of quantum entanglement: Quantum teleportation, Quantum Erasing, Introduction to Quantum cryptography and Quantum Computing, dense coding, Quantum Information.

Reference Books:
Since the subject is rather unconventional, there are no affordable, tailor-made text book is available. Hence the following reference books are suggested for reading. Separate additional lecture notes will be provided.

Suggested Reading:
1. John von Neumann, Mathematical Foundations of Quantum Mechanics, Reprint, PUP, 1996.
2. M. Bell, K. Gottfried and M.Veltman (Eds.), John S. Bell on the Foundations of Quantum Mechanics, World Scientific, 2001.
3. George Greenstein and Arthur G. Zajonc, The Quantum Challenge: Modern Research on the Foundations of Quantum Mechanics, 2nd Ed., Jones & Bartlett Learning, 2005.
4. Bruce Rosenblum and Fred Kuttner, Quantum Enigma: Physics Encounters Consciousness, 2nd Ed., Oxford University Press, 2011.
5. Bernard D'Espagnat, Conceptual Foundations of Quantum Mechanics:, 2nd Ed., Westview Press, 1999.
6. TarjaKallio-Tamminen, Quantum Metaphysics (dissertation, e-copy), University of Helsinki, 2004 (http://ethesis.helsinki.fi/julkaisut/hum/filos/vk/kallio-tamminen/quantumm.pdf)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

| **22PHY554** | **Introduction to Quantum Computing** | **3 0 0 3** |

Course Outcomes: After successful completion of the course, students will be able to

1) Familiarize with basic mathematical tools and principles of quantum mechanics from a Quantum Information computing perspective.
2) Understand and apply concepts in measurements, Entanglement, quantum nonlocality and Bell's inequality.
3) Understand basics of quantum logic gates and quantum algorithms including Deutsch-Jozsa and Shor's algorithms.
4) Understand and explain quantum teleportation and dense coding schemes, and quantum error correction mechanisms
5) Understand the basics of quantum cryptography and quantum information tools such as no-cloning, Shannon measure of information content and entropy.

Contents:

Unit 1

Introduction to quantum mechanics from a QI/QC perspective: Classical information storage and bits, quantum states and qubits, vector spaces, basis, inner product; operators and matrix representations, outer products and projection operators; Hermitian, unitary and normal operators. Eigenvalues, eigenvectors, spectral decomposition; Functions of operators, unitary transformations. Expectation value of an operator, commutators, simultaneous eigenvectors, uncertainty relations. Polar and singular value decompositions, positive operators. Postulates of quantum mechanics.

Many-particle composite states and tensor products. Pure and mixed states, density operators, expectation values and measurements, partial trace and reduced density operator, Bloch vector.

Unit 2

Quantum Measurements: projective measurements of simple and composite systems, generalized measurements, positive operator-valued measures. Entanglement: EPR ideas – non-locality, Bell's inequality, bipartite systems, Bell states, Schmidt decomposition.

Unit 3

Quantum Gates and Circuits: classical logic gates, single cubit gates, basic quantum circuit diagrams, controlled gates, gate decomposition.
Quantum Algorithms: Hadamard gates, phase gate, series and parallel operations, function evaluation, Deutsch-Jozsa algorithm, quantum Fourier transform, Shor's algorithm, Quantum Searching and Grover's Algorithm.

Unit 4

Introduction to teleportation and superdense coding. Introduction to quantum noise and error correction.

Unit 5

Introduction to quantum cryptography: basics of encoding, RSA encryption basics, basics of quantum cryptography. Tools of quantum information theory: no-cloning theorem, trace distance, fidelity, entanglement of formation and concurrence, information content and entropy.

References:
1. David Mahon, Quantum Computing Explained, Wiley India.
2. Quantum Computation and Quantum Information: M.A. Nielsen and I.L. Chuang (2011), CUP.
3. P. Kaye, R. Laflamme, and M. Mosca, An Introduction to Quantum Computing, OUP, 2007

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY555	**Introduction to Nonlinear Dynamics**	3003

Description: This course introduces some basic ideas on nonlinear dynamics and chaos.

Course Outcomes: On successful completion of the course, students will be able to
1) Understand basic concepts in discrete and continuous dynamical systems, maps, period doubling phenomena and chaos.
2) Understand characteristics of nonlinear dynamical systems and chaotic behaviour characterized by ODEs and their numerical integration.
3) Understand and identify nature of stability and fixed points of some important and simple nonlinear dynamical systems.
4) Understand bifurcation and period doubling and other routes to chaos.
5) Understand origins and some measures of chaos with Lyapunov exponent and fractal dimensions, recognize fractal like structures in nature.

Unit 1
Introduction: Examples of dynamical systems, discrete and continuous dynamical systems; Maps: 1 - and 2 - dimensional maps; Logistic map, bifurcations in the logistic map, period doubling, fixed points and their stability; Henon map. [8]

Unit 2
Dynamical system described by ODEs: Logistic differential equation, Harmonic Oscillator (simple, damped, driven and damped), Van der Pol oscillator, Duffing oscillator, phase space, phase space trajectories, conservative systems. [8]

Unit 3
Dynamical system theory: Stability of fixed points in 2- Dimensional systems. Stability matrix, types of fixed points. Attractors: 0 -, 1 - and 2-dimensional attractors;strange attractors, basins of attractions, self-similarity in maps. [6]

Unit 4

Bifurcations: Bifurcations in 1-d and 2-d flows, 1-d and 2-d maps; Introductory remarks on routes to chaos. [6]

Unit 5

Origin and measures of chaos: Sensitivity to initial conditions, Lyapaunov exponents (LE), LE for one- and two-dimensional maps; calculation of largest Lyapunov exponent; power spectrum. [5]

Self-similarity and Fractals: Cantor set, Koch curve, fractal dimensions, Mandelbrot set, fractals in nature. [3]

Numerical demonstrations and experiments are to be done as part of the course.

References:

1. Sprott, J.C., Chaos and Time-series Analysis, OUP, 2003
2. M. Lakshmaman and S. Rajasekar, Nonlinear Dynamics, Springer, 2003
3. Strogatz, S.H., Nonlinear Dynamics and Chaos, Westview Press, 2001
4. Alligood et al, Chaos - an Introduction to Dynamical Systems, Springer, 2000.
5. Hilbom, R.C., Chaos and Nonlinear Dynamics, OUP, 2000
6. Rubin H. Landau, Manuel José Páez, Computational Problems for Physics with Guided Solutions Using Python (2018, CRC Press)

22PHY556	Introduction to Astrophysics	3 0 0 3

Total Lecture Hours: 40

Course Outcomes:

1. Exposure to concepts, vocabulary, and ideas that are fundamental to astrophysics
2. Appreciate the underlying physics behind astrophysical phenomena, processes, and objects.
3. Understand the synergy between observations and theory that has led to great advancements in our understanding of the physical universe
4. Provide the basic background for more advanced courses in astrophysics

Unit 1

Measurement of Light: Basic terms in astronomy - flux, luminosity, specific flux, specific luminosity, bolometric luminosity, inverse square law of light, the magnitude system for quantifying brightness, trigonometric parallax as a means to measure distances to nearby stars, definition of a light year, definition of a parsec, apparent magnitude – absolute magnitude – distance relation - 3 lectures

Introduction to Stars : Stars as blackbody - Blackbody radiation - Planck's theory of black body radiation - Planck function - Rayleigh-Jeans and Wien approximations - Stefan-Boltzmann equation connecting stellar luminosity, radius, and surface temperature; Spectral classification of stars - absorption and emission spectra - description of how they are produced - understanding stellar spectra through Boltzmann equation - Saha equation of thermal

ionization - Harvard system of classifying stars based on their spectra - spectral classes of stars and luminosity classes of stars. - 7 lectures

Unit 2
Interstellar Medium and Formation of Stars: phases of the interstellar medium - their physical properties - a brief qualitative description of the distribution of interstellar gas within the Galaxy; Interstellar dust composition - its distribution within the Galaxy - extinction and reddening of starlight due to dust; Jeans criterion for gravitational collapse leading to star formation, free-fall time scale as time-scale for star formation - 4 lectures

Stellar Nucleosynthesis: Energy generation mechanism in stars - nuclear fusion - mass defect - p-p chain - CNO cycle - energy generated from pp chain and CNO cycle; Energy transport within stars (conduction, convection, radiation) - time-scale for energy transport within stars - Nuclear time scale - 5 lectures

Unit 3
Stellar Evolution: Hydrostatic equilibrium in stars - pressure equation of state; The Hertzsprung – Russell diagram, and the concept of main sequence; Post main-sequence evolution (qualitative) - He burning, and subsequent stages of nuclear burning in stars; Evolution of low mass stars – electron degeneracy pressure - white dwarfs – planetary nebulae; Evolution of high mass stars – supernova – neutron degeneracy pressure - neutron star – black holes, and Schwarzschild radius - 5 lectures

Milky Way Galaxy: The components of the Milky Way (qualitative based on observational evidence) – the Galactic Disk (young thin disk, old thin disk, thick disk, scale height, the distribution of stars and interstellar gas) - Galactic bulge - stellar halo - underlying stellar populations – size and shape of the Galaxy; Open star clusters and Globular star clusters - Kinematics of the Galaxy – differential rotation - rotation curve of the Galaxy – evidence for Dark Matter Halo; Galactic center – observational evidences for the presence of Super Massive Black Hole in the Galactic center - 6 lectures

Unit 4
Galaxies in our Universe: Distances to the nearest galaxies; Morphological classification of galaxies – the Hubble tuning form - trends in the Hubble sequence of galaxies based on color, stellar populations, gas fractions, dust, and star formation rates from spectra; Galaxy groups and galaxy clusters - Mass and size scales of groups and clusters – the Local Group galaxies (qualitative) - velocity dispersion measures of galaxies in clusters, virialization, comparison of luminous mass of galaxy clusters with dynamical mass, and the evidence for Dark Matter. - 4 lectures

Cosmology and the Evolution of the Universe: Expansion of the Universe based on observations of redshifts of galaxies - redshift expression in terms of wavelength and recession velocity - Hubble's constant - Hubble time as a value for the age of the universe - scale factor – the concept of metric - cosmological redshift as due to expansion of space; Friedman equation based on Newtonian cosmology, critical density and density parameter, open, closed and flat universes; Cosmic Microwave Background (qualitative) - observations and the origin of the CMB, evidence for Dark Energy - 6 lectures

Optional Modules:

Signals from Astronomical Sources - Electromagnetic frequencies and photon energies, the Earth's atmosphere and transparency to electromagnetic radiation; Telescopes (qualitative only) - optical telescopes, radio telescopes, X-ray telescopes, space-based observatories with Hubble Space Telescope as an example, its advantages over ground-based telescopes.

Understanding the Night Sky: Concept of celestial sphere; Celestial coordinate systems - alt-azimuth - right ascension-declination; Celestial timekeeping – ecliptic and path of the Sun in the sky, rising and setting of stars in the sky, equinoxes, and solstices.

Reference Books

1. OpenStax's FREE online HTML based astronomy textbook
 https://openstax.org/details/books/astronomy
2. Review of the Universe - A FREE online HTML based book on select topics in astronomy: https://universe-review.ca/
3. Baidyanath Basu, Tanuka Chattopadhyay, Sudhindra Nath Biswas - An Introduction to Astrophysics - Prentice Hall India Learning Private Limited, 2010/2013
4. Arnab Rai Choudhuri – Astrophysics for Physicists, Cambridge University Press, 2010
5. Mark L. Kutner - Astronomy, A Physical Perspective, Cambridge University Press, 2003
6. Bradley W. Carroll, and Dale A. Ostlie: Introduction to Modern Astrophysics, Addison Wesley (II Edition), 1997 – or – Pearson 2006
7. Hannu Karttunen, Pekka Kröger, Heikki Oja - Fundamental Astronomy - Springer 2007

(Syllabus for 'Introduction to Astrophysics' was written by Dr. Anand Narayanan, Professor, Indian Institute of Space Science and Technology, Thiruvananthapuram).

Evaluation policy: As per rules and regulation for an elective theory course.

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY557	Introduction to Gravitation and Cosmology	3 0 0 3

Prerequisite: An introductory course in astrophysics, basic classical, statistical and quantum mechanics, electrodynamics. General theory of relativity is introduced as much as required.

Description: The objective of this course is to give reasonable advanced introductory understanding of select brand of important topics in astrophysics.

CO1: Describe large scale structure in the universe.

CO2: Describe and apply General Theory of Relativity and gravitational equations with Schwarzschild solution as well as geodesics of Riemannian geometry of curved space-time employing the formalism of tensors.

CO3: Apply Robertson walker equations and analyse the various cosmic models-open, critical or closed etc. through deceleration parameters and critical density.

CO4: Describe Einstein field equations in cosmology, Friedman's solution, Einstein de-sitter model, open model, particle and Event horizon.

CO5: Apply Jean's equation for instability in the expanding universe and explain the formation of structures in the Universe and describe the growth in the Post recombination era.

CO6: Analyse small angle anisotropy of CMBR and horizon problem and relate it to the Thermal History of the Universe and distribution at the time of decoupling of matter and radiation in the early universe.

Units1-2

Introduction: Galaxy types, radio sources and quasars, large-scale structures, catalogues of astronomical objects, radiation backgrounds. [1 week]

Introduction to General Theory of Relativity: Space, time, and gravitation, tensors, covariant differentiation, Riemannian geometry, space-time curvature, geodesics, principle of equivalence, action principle and energy tensor, gravitational equations, Schwarzschild solution. [4 weeks]

Unit 3

Cosmology: Newtonian cosmology, Einstein's model, expanding universe and assumptions, Robertson-Walker equation and its properties and solution.Einstein's field equation, energy tensors of the universe, solution of Friedman's equation, Einstein-de Sitter model, open model, particle horizon, Event horizon. [3 weeks]

Unit 4

The formation of structures in the universe: Jean's equation derivation from fluid dynamics and general relativity; evolution of Jean mass, growth in the post-recombination era; Einstein-de Sitter model; closed and open models; Observation constraints: small angle anisotropy, horizon problem, the scale – invariant spectrum, Hierarchy of structures, Age distribution; a brief overview of other aspects. [2 weeks]

Unit 5

Early universe and the thermal history of the universe, Temperature red shift relation, distribution in the early Universe, relativistic and non-relativistic limits, decoupling of matter and radiation, Cosmic microwave background radiation (CMBR), isotropy and anisotropy of CMBR. [2 weeks]

TEXT AND References
1. Introduction to Cosmology, 2nd Ed.,by J.V. Narliker,
2. Astrophysics for Physicists, by Arnab Rai Choudhury, (2010, CUP)
3. Structure Formation in the Universe by T. Padmanabhan, Cambridge University
4. Quasars and Active Galactic Nuclei by A.K.Kembehavia & G.V. Narliker, Cambridge University Press
5. Modern Astrophysics by B.W.Carroll and D.A.Ostlie, Addison-Wesley Publishing Co.

Evaluation policy: As per rules and regulation for an elective theory course.

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY559	**Plasma Physics**	**3 0 0 3**

(Pre-requisite: Two-part course on Electrodynamics)

Course Outcomes: At end of the course students are expected to
1. Gain knowledge of the basic concepts of plasma physics.
2. Gain an understanding of spatial and time scales in plasmas, Debye shielding, single particle motion in different types of magnetic field variations.
3. Gain an understanding of kinetic theory of plasmas, a describe collisoinless plasmas, energy distribution.
4. Gain an understanding of two-fluid description and equations of motion of charged particles in plasmas.
5. Gain an understanding of single fluid theory of magneto-hydrodynamics in plasmas.
6. Gain basic knowledge of the propagation of electromagnetic waves in plasmas

Unit 1
Introduction – Spatial scale of an unmagnetized plasma – Debye Length, time scale - plasma period, gyroradius and gyrofrequency of magnetized plasma, single particle motion in pre-scribed fields - ExB, grad-B, Curvature and polarization drifts, magnetic moment, adiabatic invariants of particle motion, magnetic mirror.

Unit 2
Kinetic theory of plasmas, Boltzmann equation, Maxwell-Boltzmann distribution, Vlasov description of collisionless plasmas, Moments of the Boltzmann equation, Systems of macroscopic equations: Cold and Warm plasma models.

Unit 3
Plasmas as fluids - Two fluid description, equation of motion, Drifts perpendicular to B, parallel pressure balance.

Unit 4
Single fluid theory of plasmas: Magneto hydrodynamics (Hydromagnetic, MHD).

Unit 5
Introduction to waves in plasmas, waves in cold magnetized and unmagnetized plasma, Fourier representation, Dispersion relation, Waves in hot (magnetized) plasmas, Landau Damping, CMA diagram, Instabilities, MHD Waves, Alfven Waves, MHD discontinuities.

Textbooks/References

1. Umran S. Inan & Marek Golkowski, Principles of Plasma Physics for Engineers and Scientists, Cambridge, 2011
2. Francis F. Chen, Introduction to Plasma Physics and controlled fusion, Springer, 2006
3. D.A. Gumett & A. Bhattacharjee, Introduction to Plasma Physics, CUP, 2006
4. Boyd, T.J.M., and Sanderson, J.J.: The Physics of plasmas, CUP,2003
5. Krall, N.A, Trivelpiece, A.W., Principles of plasma physics, McGraw Hill,1973
6. Stix, T.H., Waves in plasmas, Springer, 1992

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY560	**Space Physics**	**3 0 0 3**

(Pre-requisites: Two-part course on electrodynamics, and Plasma Physics)

Course Outcomes:

2) Define what is meant by a plasma, the criteria that an ionized gas must satisfy in order to be called a plasma, different types of plasma and their classification
3) Describe the plasma environment in space, with focus on near-Earth environment, Classify the main domains where Space Physics applies and enumerate their properties, giving specific details
4) Describe and define the relevant key physical theories (particularly from plasma physics) that control the qualitative properties of different space plasma phenomena – Explain how certain important plasma populations in the solar system, e.g. the Earth's ionosphere and magnetosphere, get their basic properties, and how these properties may differ between the planets
5) Calculate the quantitative behaviour of different space physics phenomena using plasma physics analysis methods. Make order of magnitude estimates of some properties in space plasmas and space phenomena, e.g. the power dissipated in the aurora, or the amount of current floating from Earth's Magnetosphere to Ionosphere
6) Demonstrate an understanding of how Space Physics has a practical impact on everyday life in the field of Space Weather. Identify ways in which experimental studies of Space Physics phenomena have advanced our understanding of basic plasma physics
7) Model certain Space Physics phenomena by applying basic physical laws, using simple Mathematics (e.g. model the form of the ionosphere/magnetosphere or estimate the temperature of a sunspot)
8) Describe current research within space physics and explain it to an interested layman

Unit 1 Brief history of solar-terrestrial physics – The variables Sun and the heliosphere, Earth's space environment and upper atmosphere.

Unit 2 Space plasma physics - single particle motion, plasma state, Fluid description, MHD & kinetic theory, Applications

Unit 3 Solid wind & Interplanetary Magnetic field (IMF), Shocks and Instabilities in space

Unit 4 Solar wind interactions with magnetized planets - Introduction, planetary magnetic fields, spherical harmonic expansions, geomagnetic field and its measurements, variations in Earth's field.

Unit 5 Magnetosphere - Dynamics, SW-magnetosphere interactions; Ionospheres, Currents in space and Ionosphere; Neutral atmosphere -Dynamics.

Textbooks/References:
1. Hannu E.J. Koskinen, Physics of Space Storms, Springer, 2011
2. Molwin, M., An Introduction to Space Weather, CUP, 2008
3. Kallenrode, M.B., Space Physics: An introduction to plasmas and particles in the Heliosphere and Magnetosphers, Springer, 3e, 2004
4. Baumjohann, W. & Treumann, R.A., Basic Space Plasma Physics, Imperial College Press, 1997
5. Kivelson & Russell, Introduction to Space Physics, CUP, 1995

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY558	Fluid Dynamics	3 0 0 3

Description: This course will be useful for students wishing to gain an overview of the vast field of fluid dynamics. The course is aimed at imparting basic knowledge of the subject to facilitate research career in plasma physics, astrophysics, soft matter, biophysics, and computational fluid dynamics.

Course Outcomes:

CO-1 Familiarize with the basic concepts of fluid statistics.

CO-2 Describe fluid motion in Lagrangian and Eulerian perspectives. Derive the equations of fluid motion and learn about waves in fluids.

CO-3 Derive the Navier-Stokes equations pertaining to viscous fluids. Apply the concepts of stress and strain tensors to study deformation of fluids.

CO-4 Solve Navier-Stokes equation for laminar flows.

CO-5 Utilize Prandtl's formulation to understand the boundary layer flow. Learn about Non-Newtonian flows. Analyze the fluid flows using the various dimensionless numbers in fluid mechanics, like Reynold's number.

Unit 1
Basics: fluid statics; Conservation equations, equation of continuity, energy and momentum flux.

Unit 2
The Lagrangian and Eulerian description of fluid mechanics, Euler's equation of motion for Ideal flows, Potential flow and related problems, vorticity, Gravity waves.

Unit 3

Deformation of continuous media, strain rate tensor, viscous stress tensor, the equation of motion for viscous flows (Navier-Stokes equation).

Unit 4

Laminar flow and exact solution of Navier-Stokes such as flow in a pipe and rotating cylinder, the law of similarity and its use in solving unsteady flows.

Unit 5

Reynolds's number and other dimensionless numbers in fluid mechanics, Prandtl's formulation of boundary layers and related problems, Non-Newtonian flows.

References:
1. Fluid Mechanics, P. K. Kundu, I. R. Cohen and D. R. Dowling, Elsevier, 5th edition
2. Michel Rieutord, Fluid Dynamics: An Introduction, Springer, 2015
3. Philip J. Pritchard, Introduction to Fluid Mechanics, John Wiley & Sons, 2011
4. Fluid Mechanics films produced by National committee on fluid Mechanics Films at MIT.
5. Fluid Mechanics: L.D. Landau and E.M. Lifshitz (2007) 2E, Pergamon Press
6. Oden Regev, Okran M. Umruhan, and Philip A. Yecko, Modern Fluid Dynamics for Physics and Astrophysics, Springer, 2016.
7. T.E. Faber, Fluid Dynamics for Physicists, CUP, 2001
8. Falkovich, Fluid Mechanics - A Short Course for Physicists, Springer , 2011

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY561	Physics of the Atmosphere	3 0 03

Description: The introduces to the students the basic concepts in the physics of the Earth's atmosphere. This course should help students do projects in weather systems.

Course Outcomes: After successful completion of the course, students will be able to
1. Gain a basic understanding of the Earth's atmospheric system – its structure and composition as well as the energy transfer and general circulation within it.
2. Apply the basics of thermodynamics to the atmospheric system, explain the basics of cloud formation.
3. describe the principle of radiative transfer in the atmosphere, the basic spectroscopy as applied to the atmospheric molecules, scattering of radiation in the atmosphere through the use of a simple scattering model.
4. describe the fundamentals of fluid dynamics, apply them to the atmospheric system, derive the equations of motion in the rotating frame of reference, describe the basic dynamics of weather systems.
5. describe the basic chemical kinetics and Ozone chemistry, apply the basics of thermodynamics, dynamics and chemical reactions to explain the processes and dynamics of air pollution.
6. describe the basics of atmospheric remote sensing.
7. describe the basics of atmospheric modeling and explain a few of numerical models.

8. Describe the basics of climate change.
9. Apply the basics of dynamics/thermodynamics/numerical modeling/remote sensing and successfully finish a small project by reading and reproducing the results of a published article.

Unit 1

Earth - Atmosphere system – Introduction, Composition and structure, Radiative equilibrium, Energy budget, General circulation, Historical perspectives, Weather & Climate

Atmospheric thermodynamics – Ideal gas law, First law of thermodynamics, Atmospheric composition, Hydrostatic balance, Entropy & potential temperature, Parcel concepts, Available potential energy, Moisture in the atmosphere, Saturated adiabatic lapse rate, Tephigram, Cloud formation

Unit 2

Atmospheric radiation – Basic physical concepts, Radiative transfer equation, basic spectroscopy of molecules, Transmittance, Absorption by atmospheric gases, Heating rates, Greenhouse effect revisited, Simple scattering model

Unit 3

Basic fluid dynamics – Mass conservation, material derivative, alternative form of continuity equation, equation of state for the atmosphere, Navier-Stokes equation, Rotating frames of reference, equations of motion in coordinate form, geostrophic and hydrostatic approximation, Pressure coordinates and geopotential, Thermodynamic energy equation; Atmospheric fluid dynamics – vorticity and potential vorticity, Boussinesq approximation, Quasi-geostrophic motion, Gravity waves, Rossby waves, Boundary layers, Instability

Unit 4

Stratospheric chemistry – Thermodynamics and chemical reactions, Chemical kinetics, Bimolecular reactions, Photo-dissociation, Stratospheric ozone, Transport of chemicals, Antarctic ozone hole.

Atmospheric remote sounding – Observations, remote sounding from space and ground; Atmospheric modeling – Hierarchy of models, Numerical methods, Uses of complex numerical models, Lab models.

Unit 5

Climate change – Introduction, energy balance model, some solutions of the linearised energy balance model, Climatic feedbacks, Radiative forcing due to increase in Carbon dioxide.

Projects based on Modules 4 and 5 (Reading a journal paper & reproducing calculations, Numerical modeling and / or data analyses)

Textbooks/References

2. Andrews DG: An introduction to atmospheric physics, 2E, CUP, 2010
3. Salby ML: Physics of the Atmosphere and Climate, CUP, 2012
4. Holton JR: An introduction to Dynamic Meteorology, 4E, AP, 2004
5. Wallace JM & Hobbs PV: Atmospheric Science-An Introductory Survey, 2E, AP, 2006
6. Chandrasekar A: Basics of Atmospheric Science, PHI, 2010

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY562	**Elementary Meteorological Theory**	3-0-0-3

Course Outcomes

CO1 Define and describe the parameters which determine the weather of a place
CO2 Explain the characteristics of various weather phenomena
CO3 Summarize the climatological features over India
CO4 Collect and analyze meteorological observations

Unit 1

Introduction: Introduction, Importance of Meteorology, Atmosphere and its composition. Meteorological elements : Pressure – definition, units of measurement. : Temperature – scales and conversion of one to the other : Humidity - Relative humidity, dew point and wet bulb temperature – definitions, units. : Wind - Definition of wind unit, Wind vane, Anemometer, Squall, Beaufort scale, Buys Ballot's law, Autographic record. : Clouds - Classification, types, description, amount, height of base and direction of movement. : Visibility - Definition, visibility land marks, night visibility.

Unit 2

Weather - Rain, drizzle, hail, haze, thunderstorm, fog mist, smog, dust storm). Present weather – description, definition of various weather phenomena, symbolic representation and past weather.

Unit 3

Indian climatology: Four seasons in India, (in brief) and outlines of weather associated with each season.

Unit 4

Meteorological Instruments : Thermometer – dry bulb, wet bulb, maximum, minimum – description, methods of working, reading, resetting, stevenson screen, exposure, care of instrument., Barometer – Fortin, Kew Pattern, description, reading, correction, reducing the value to mean sea level, QFF, QFE, QNH, Anemometer – description, working, exposure, recording of observation, Rainguage – working, measurement of rainfall, Psychrometer – Assman & Whirling, Autographic instruments – working of Barograph, thermograph, hygrograph, selfrecording rainguage, sunshine recorder etc.

References

1. Chandrasekar, A. (2010). Basics of atmospheric science. PHI Learning Pvt. Ltd..

2. Ahrens, C. D., & Henson, R. (2016). Essentials of meteorology: An invitation to the atmosphere. Cengage Learning.
3. Wallace, J. M., & Hobbs, P. V. (2006). Atmospheric science: an introductory survey (Vol. 92). Elsevier.
4. Harrison, G. (2015). Meteorological measurements and instrumentation. John Wiley & Sons.

22PHY564	FOSS in Physical Sciences	(2-0-2-3)

Description : This course aims to introduce students to various Free and Open Source (FOSS) software, ultimately for solving Physics problems. Computation and data analyses, facilitated by the popularity of easy-to-use language such as Python, and R for Statistical Computing, have become crucial not just for Physics, but also across various fields. Often, multiple programs need to be combined into workflows. The ability to use GNU/Linux operating system and the various associated GNU packages such as command-line utilities via shell scripts facilitate workflows, besides allowing tasks to be automated and streamlined. LaTeX, the high-quality typesetting system is widely used in technical & scientific documentation in academia & across various disciplines. LaTeX skills thus help students to create professional documents & presentations. All these contribute towards professional careers in academia, as well as in information and communication technology (ICT) related fields.

CourseOutcomes (COs) :

1. Understand the basics of R programming language & manipulate data within R
2. perform basic data analysis procedures & Visualize data in R
3. Evaluate GNU/Linux as an OS by demonstrating basic knowledge of working with GNU/Linux and it's use in Physics
4. Use command line to complete a series of tasks (basic file management & navigation etc), besides demonstrating basic scripting
5. Perform GNU/Linux commands to manipulate Physics Data files and export into other environments (such as R)
6. Use the preamble of LaTeX file to generate (scientific) document, report & presentation (Beamer).
7. Learn how to import graphics into a LaTeX document
8. Define and use new commands within LaTeX
9. Use BibTeX to maintain bibliographic information and to generate a bibliography for a particular document.

Modules 1-2: Basics of Statistical computing with R programming language: What is R?, Introduction; Variables & Data types; Inbuilt functions; Data Handling Basics : Preparing & Loading, Cleaning & Munging data &Visualization

Modules 3-4: Introduction to GNU/Linux basics: What is GNU/Linux?, Flavors; Files & processes, Directory structure; Starting terminal, Basic operations on files & directories, path names, . & ..; Redirecting i/o, pipes; Wildcards, filename conventions, Getting help; File system access rights (security), changing, Processes & Jobs, Background processes & Killing

processes**;** Editors, GNU/Linux software packages: downloading & extracting source code, configuring & creating makefile, building package, Compiling & running software; Variables & Environment variables, Using & setting variables; History; Basic Shell Scripting.

Module 5: Scientific writing using LaTeX: What is LaTeX?, Basic typesetting: Sample document & key concepts, Styles, Environments; Typesetting equations: Examples, Equation environments, Customized commands, Miscellany; Further essential LaTeX: Document Classes & overall structure; Errors: Pinpointing errors, Common Errors, Warning Messages; Packages, Inputting files & pictures; Bibliography (BibTex); Making Index; Sample Article, Report & Presentation (with Beamer).

References:

1. "Python Data Science Handbook – Essential tools for working with Data" (Chapters 1-4) – VanderPlas, J; O'Reilly Media, 2016
2. "Effective Computation in Physics" – Scopatz, A & Huff, K D; 1E, O'Reilly Media, 2015
3. "R for Beginners" – Paradis, E
(https://cran.r-project.org/doc/contrib/Paradis-rdebuts_en.pdf)
4. "R for Data Science : Import, Tidy, Transform, Visualize, and Model Data" – Wickham, H & Grolemund, G; 1E, O'Reilly Media, 2017
5. "The Not So Short Introduction to LaTeX 2e" – Oetiker T, Partl H, Hyna I & Schlegl E;
(https://mirror.unpad.ac.id/ctan/info/lshort/english/lshort.pdf)
6. "A Guide to LaTeX" – Kopka, H & Daly, P; Addison Wesley, 4E, 2003
7. "More Math into LaTeX" – Gratzer G, 5E, Springer, 2016
8. "Linux for Beginners: An Introduction to the Linux Operating System and Command Line" – Cannon J, Createspace Independent Publishers, 2014
9. "Linux Pocket Guide : Essential Commands" – Barrett Daniel J, Schroff Publishers & Distributors, 2016
10: "Introduction to Computational Physics for Undergraduates" – Zubairi O & Weber F, ("The Linux/Unix Operating System", Chapter-1), Morgan & Claypool Publishers, 2018
(https://iopscience.iop.org/chapter/978-1-6817-4896-2/bk978-1-6817-4896-2ch1.pdf)

EvaluationScheme: Internal Assessment: Quizzes (8, Bi-Weekly based on class material, 40%), Paper Writing (30%), Final Presentation (30%)

22PHY565	Methods of Experimental Physics	3 0 0 3

Description: To build up the necessary background required to design and carry out important experiments, exposure to the physics behind recent experimental techniques. A reasonable section of topics may be chosen from below.

Course Outcomes: After successful completion of the course, students will be able to develop an understanding, and be able to
  1) Classify and describe the concepts of errors and noise in measurements
  2) Calculate the errors in measurements.
  3) Explain different kinds of techniques involved in measurements.

4) Explain the working of different transducers.
5) Explain thin film deposition and different characterisation techniques.

Contents:

Unit 1

Measurements, uncertainties, error analysis, curve fitting; the value of "zero" in experimental physics, measurement of noise and analysis of noise, filtering and noise reduction, interference, shielding and grounding, phase sensitive detection and Phase locked loops; electrical measurements and precautions: I-V, C-V, resistivity.

Unit 2

Magnetic measurements and precautions: vibrating sample magnetometer, SQUID.
Vacuum techniques: units, gauges, pumps, materials.
Techniques of temperature measurements: very low, medium and very high-temperature thermometers, thermocouples, thermistors, pyrometer, spectroscopy.

Unit 3

Physical principles of transducers and sensors: temperature, pressure/vacuum, magnetic field, vibration, optical, and particle detectors.

Unit 4

Thin film deposition methods: physical, e-beam, sputter, chemical vapor deposition, molecular beam epitaxy, spin coatings, dip coating, electroplating, electroless plating.
Techniques of optical spectroscopy: UV-Vis absorption, photoluminescence, electroluminescence.

Unit 5

Advanced experimental techniques: AFM, atomic and molecular traps, NMR, nano-materials and devices, time-resolved measurements.

References:
1. Practical Physics: G.L. Squires (2001) 4 edition, Cambridge University Press
2. Experimental Physics: R.A. Dunlap (1988) 1 edition, Oxford University Press
3. Characterization of Materials: J.B. Wachtman and Z.H. Kalman (1992) Butterworth-Heinemann

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY566	**Thin Film Physics**	**3 0 0 3**

Description: This course introduces students to physics of thin films, their fabrication, characterization and applications.

Course Outcomes: After successful completion of the course, students will be able to

1. Recognize the importance of thin films in varied applications in science and technology.
2. Classify and describe methods of thin film fabrication - thermal evaporation, cathodic sputtering, Molecular beam epitaxy and laser ablation, electrolytic deposition, and physical and chemical vapour deposition.
3. Explain thickness measurements using electrical, mechanical, optical interference, micro balance, quartz crystal methods.
4. Describe the analytical techniques such as X-ray diffraction, electron microscopy, high and low energy electron diffraction, Auger emission spectroscopy and infer characteristics from the data.
5. Describe and explain using theories the growth of thin films, the post nucleation growth, epitaxial growth, structural defects in thin films, the elastic and plastic nature of thin films.
6. Describe and explain with illustrations the optical properties of thin films such as reflectance, transmittance and absorbance, Categorize the Anisotropic and isotropic thin film.
7. Describe and identify unique features in the electronic properties and applications of semiconductor, insulating-dielectric and superconducting films, apply the molecular-field and spin-wave theories in magnetic thin films to explain magnetic phenomena.
8. Describe applications of thin films for thin film device fabrication.

Unit 1
Preparation methods: Physical methods: thermal evaporation, cathodic sputtering, Molecular beam epitaxy and laser ablation methods. Chemical methods: electrolytic deposition, chemical vapour deposition.

Unit 2
Thickness measurement and Characterisation: electrical, mechanical, optical interference, microbalance, quartz crystal methods. Analytical techniques of characterization: X-ray diffraction, electron microscopy, high and low energy electron diffraction, Auger emission spectroscopy.

Unit 3
Growth and structure of films: General features - Nucleation theories - Effect of electron bombardment on film structure - Post nucleation growth - Epitaxial film growth - Structural defects.

Unit 4
Properties of films: elastic and plastic behaviour. Optical properties - Reflectance and transmittance spectra - Absorbing films - Optical constants of film material - Multilayer films - Anisotropic and isotropic films. Electric properties to films: Conductivity in metal, semiconductor and insulating films - Discontinuous films - Superconducting films.

Unit 5

Magnetism of films: Molecular field theory - Spin wave theory - Anisotropy in magnetic films - Domains in films - Applications of magnetic films.

Thin film devices: fabrication and applications.

Textbooks:
1. K.L. Chopra, Thin Film Phenomena, McGraw Hill (1983),
2. George Hass. Physics of Thin Films: Volumes 1':12. Academic Press (1963).

References
1. K.L. Chopra and I.J. Kaur, Thin Film Solar Cells, Plenum Press (1983).
2. L.I. Maissel and Giang (Eds.), Handbook of Thin film Technology, McGraw Hill (1970).
3. J.C. Anderson, The Use of Thin Films in Physical Investigation, Academic Press (1966).
4. J.J. Coutts, Active and Passive Thin Film Devices, Academic Press (1978).
5. R.W. Berry, P.M. Hall and M.T. Harris, Thin Film Technology, Van Nostrand (1968). 47

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY567	**Physics at Nanoscale**	3 0 0 3

Description: An introduction to nanoscience and its applications, provides a flavour of the current excitement in the field of nanoscience. This course should be of interest to physics, chemistry and biology students.

Course Outcomes: After successful completion of the course, students will be able to
1) Define and describe the nanoscience and nanotechnology by historical perspective; explain size effect and apply classical and quantum models analyse and characterize quantum wells, wires and dots, effective mass, excitons, plasmons, explain scaling laws; Classify the clusters of noble metal, semiconductors and magnetic materials.
2) Distinguish the Hydrophobic-hydrophilic surfaces, self-assembly of materials and other nano structure and their synthesis methods.
3) Describe the synthesis of nanomaterials through physical, chemical and biological methods; nanofabrication methods such as top-down and bottom-up approaches and their applications.
4) Describe, explain and be familiar with the principles of the analysis techniques such as microscopy techniques, electron microscopes, scanning probe micro- scopes, diffraction techniques, X-ray and electron, optical and electron spectroscopy techniques.
5) Describe and identify unique features in mechanical, thermal, structural, optical, electrical and magnetic properties and their applications to electronic devices and other fields.

Unit 1

Introduction: Why nanoscience and nanotechnology? historical perspective; size effect (colour, melting, magnetism etc. and Lotus effect, Gecko effect). Clusters: noble metal, semiconductors, magnetic; Magic numbers. Quantum confinement: quantum wells, wires and dots; Effective mass, excitons, plasmons, scaling laws.

Unit 2
Hydrophobic-hydrophilic surfaces, self-assembly; Some special materials: fullerenes, CNTs, graphene, porous materials.

Unit 3
Synthesis of nanomaterials: physical, chemical, biological methods; Other nanofabrication methods: top-down and bottom-up approaches.

Unit 4
Analysis techniques: microscopy techniques, electron microscopes, scanning probe microscopes, diffraction techniques, X-ray and electron, spectroscopy techniques, optical and electron.

Unit 5
Properties of nanomaterials and applications: mechanical, thermal, structural, optical, electrical, magnetic properties and applications to electronic devices and other fields.

Textbook/References
1. Optical Properties of Semiconductor Nanocrystals: S.V. Gaponenko (1997) Cambridge University Press
2. Nanotechnology: Principles and Practices: S.K. Kulkarni (2009) Capital Pub. Co.
3. Introduction to Nanotechnology: C.P. Poole, Jr. and F.J. Owens (2008) Wiley-India edition
4. The Physics of Micro/Nanofabrication: I. Brodie and J.J. Murray (1992) Springer, Plenum Press
5. Handbook of Nanofabrication: Ed. G. Wiederrecht, (2010) Elsevier
6. T. Pradeep, NANO: The Essentials: Understanding Nanoscience and Nanotechnology, McGraw Hill India (2007)
7. Kelsall et al, Nanoscale Science and Technology, Wiley, 2005

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY568	Solid State Electronic Devices	3 0 0 3

Course outcomes: On successful completion of this course, student should be able:

CO-1. To explain the concept of density of states and apply the Fermi–Dirac probability function to determine the carrier concentrations

CO-2. To outline the basic concepts of quantum mechanics and describe the behavior of electrons under various potential functions.

CO-3. To demonstrate a familiarity with the concept of allowed and forbidden energy bands in the context of quantum mechanics and Schrodinger's wave equation.

CO-4. To present schematically the design, working principles and energy band diagrams of PN junction, bipolar transistors, metal-semiconductor contacts and metal-oxide-semiconductor junctions.

CO-5. To summarize the underlying operating principles of important microelectronic and photonic devices, such as MOSFETs, bipolar junction transistors and semiconductor lasers.

CO-6. To describe the limits of ideal "black-box" models of devices and predict the effect of these non-idealities on real circuits and systems.

CO-7. To demonstrate an understanding of the principles of microfabrication in the context of manufacturing of integrated circuits and state the factors affecting device performance.

Unit 1

Crystal Growth of Semiconductors: semiconductor materials, bulk and epitaxial growth, wave propagation in discrete structures. Summary of atomic structure and band energy structure in semiconductors, carrier concentration, drift of carriers in electric and magnetic fields. [10]

Units 2-3

Excess carriers: optical absorption, luminescence, carrier lifetime and photoconductivity, carrier diffusion. Junctions: Fabrication of PN-junctions, steady state conditions, reverse bias breakdown, transient and ac-conditions; Metal-semiconductor junctions, heterojunctions. [14]

Unit 4

Field-Effect Transistors: operation, junction FET, metal-semiconductor FET, MOSFET and related structures. [8]

Unit 5

Bipolar Junction Transistors: review of BJT operation, amplification with BJT, fabrication, minority carrier distribution and terminal currents, generalized biasing, switching, other important effects, frequency limitations. [8]

Textbook/References

1. Ben G Streetman and Sanjay Banerjee, Solid State Electronic Devices, 7E, Pearson, 2016
2. Simon M. Sze, Kwok K. Ng; Physics of Semiconductor Devices, Wiley, 2012

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY569	Optoelectronics	3 00 3

Prerequisite: Solid State Electronic Devices

Course outcomes: On successful completion of this course, studentsshall be able:

CO-1. To explain the processes of excess electron and hole generation and recombination.

CO-2. To describe the basics of p-n junction diode and apply ambipolar transport equation in deriving the device electrical properties.

CO-3. To construct energy band diagrams of basic p-n junction as well as complex hetero-junctions to describe the carrier transport phenomenon in the semiconductor junctions

CO-4. To demonstrate a knowledge of fundamental properties of optical processes in semi-conductor optical sources and the operation principles of basic optical components.

CO-5. To draw schematically and describe the operation and design architecture of 1st generation solar cells and to outline the basics concepts of 2nd and 3rd generation solar cells

CO-6. To describe the structures and the operation of LEDs and lasers

CO-7. To demonstrate familiarity with the operation and designs of photodetectors

CO-8. To compare operation principles, basic designs and challenges of optical detectors and modulators of light.

Unit 1

Review of semiconductor physics for photonics: density of states in a quantum well structure; carrier concentration & Fermi level, quasi Fermi levels. Semiconductor optoelectronic materials: hetero-structures, strained-layers, band-gap engineering; p-n junctions; Schottky junctions & Ohmic contact. [8]

Unit 2

Interaction of Photons with Electrons and Holes in a Semiconductor.
Rates of Emission and Absorption; Photodetectors: general characteristics of photodetectors, impulse response, photoconductors, PIN, APD, array detectors, CCD, solar cell, [12]

Unit 3

Light Emitting Diode: device structure and output characteristics, modulation bandwidth, materials for LED, and applications. white light LEDs. [6]

Units 4-5

Amplification by Stimulated Emission; Semiconductor Optical Amplifier.
Laser Diodes: device structure and output characteristics, single frequency lasers; DFB, DBR Lasers, VCSEL, Quantum Well and Quantum Cascade Laser, Micro-cavity lasers; Modulation of Laser Diodes, Practical Laser Diodes & Handling. [14]

Textbooks/References

1. Optoelectronics: An Introduction to Materials and Devices, Jasprit Singh, McGraw HILL International (1996) (Text)
2. Semiconductor Devices for High-Speed Optoelectronics, Giovanni Ghione, Cambridge University Press (2009) (Text)
3. Semiconductor Optoelectronic Devices Introduction to Physics and Simulation, JOACHIM PIPREK, Academic Press (2003)
4. Optoelectronics An Introduction, John Wilson and John Hawkes, Prentice Hall (1998)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY570   **Nanophotonics**   **3 0 0 3**

Description: This course introduces the basic principles, applications, and latest advances in the area of Nanophotonics. Student gets a clear view about this excited new area and ready to contribute to the advances of photonic technology in the broad area of applications such as light-matter interactions, lithography, nanophotonic devices, nanophotonics in medicine, nanophotonics in optoelectronics devices like photovoltaics, communication electronics, etc.

Prerequisites: Knowledge of basic principle of optics, electrodynamics and quantum mechanics is helpful.

Course Outcomes: After completing this course student shall be able to
CO1: To understand the basics of photonics, building blocks of photonic circuits and its effects
CO2: To understand devices and general concepts used in nano-optics, nano-photonics and nano-optoelectronics
CO3: To be aware of the major processes and techniques available in nanophotonics.
CO4: To apply the photonics concepts to construct theoretical model of a basic photonic structure and study the behaviour using numerical simulation.

Unit 1
Basic electromagnetism: Maxwell Equation; Wave equation; Optical properties of materials; Optical dispersion models of metals, dielectrics and transparent conducting oxides

Unit 2
Surface plasmon polaritons at metal/insulator interfaces: a single interface; a multilayer system; Excitation of surface plasmon polaritonsat planar interfaces:Prism coupling and grating coupling

Unit 3
Introduction to nanoscale interaction of photons and electrons; Localized surface plasmons; Effective medium theory; Imaging surface plasmon polariton propagation: near-field interaction and microscopy, near-field optics and microscopy

Unit 4
Concept of photonic bandgap – photonic crystals; Metamaterials; Super-lens; non-linear optical phenomenon "Up-conversion"

Unit 5
Plasmonics – metallic nanoparticles and nanorods;Growth and characterization of nanomaterials; Basic ideas of nanopatterning and nanoscale lithography; Biomaterials; Nanophotonics for biotechnology and nanomedicine

Books:
1. David J. Griffiths, "Introduction to Electrodynamics", Cambridge University Press, 3rd or 4th Edition, 2017
2. Stefan A. Maier, "Plasmonics: Fundamentals and Applications", Springer Science, USA, 2007
3. Sergey V. Gaponenko, "Introduction to Nanophotonics", Cambridge University Press, 2010
4. Paras N. Prasad, Nanophotonics, Wiley Interscience, 2004

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY571	**Lasers and Applications**	3 0 0 3

Description: This course introduces to the students the theory of Laser operation, different types of lasers and their applications.

Course Outcomes: After successful completion of the course, students will be able to
1) Describe and apply laws of radiative transitions, calculate transition rates and explain certain transitions, black-body radiation, absorption, spontaneous and stimulated emissions
2) Arrive at conditions for producing laser, apply threshold requirements to obtain population inversion and lasing, power optimization, describe two-level and four-level systems.
3) Describe and explain laser cavity modes.
4) Explain mode locking and pulse shortening techniques.
5) Classify lasers and laser systems, describe many examples.
6) Describe laser applications in various fields of science, engineering, industry, medicine.

Unit 1
Radiative transitions: Radiative decay of excited states, spontaneous emission, decay rate, transition probability, spectral line-widths and line shapes, broadening mechanisms.
Radiation and thermal equilibrium: Radiation in a cavity, oscillation modes, Rayleigh-Jeans formula, Planck's law, relationship between cavity and blackbody radiations, absorption and stimulated emission, Einstein's A and B coefficients.

Unit 2
Conditions for producing a Laser: Absorption and gain of homogeneously broadened radiative transition, gain coefficient and stimulated emission cross section for homogeneous and inhomogeneous broadening; Necessary and sufficient conditions for laser action: Population inversion, saturation intensity, development and growth of a laser beam, shape or geometry of amplifying medium, exponential growth factor (gain), threshold requirements with and without cavity. Laser oscillation above threshold: Laser gain saturation, Laser beam growth beyond the saturation intensity, optimization of laser output power, laser output fluctuations - laser spiking, relaxation oscillations; Laser amplifiers; Requirements for obtaining population inversions: Inversions and two-level systems, rate equations for three and four level systems, pumping mechanisms.

Unit 3
Laser cavity modes: Longitudinal laser cavity modes, FP resonator, transverse laser cavity modes, Properties of laser modes - spectral and spatial hole burning. Stable laser resonators: Stable curved mirror cavities, ABCD Matrices, cavity stability criteria, unstable and ring resonators. Q-switching: Theory, giant pulses, methods of producing Q-switching within a laser cavity, gain switching. Mode locking: Theory, picosecond optical pulses, techniques for producing mode-locking. Pulse shortening techniques: Generation of ultra-short optical pulses, Self-phase modulation, pulse compression (shortening) with gratings or prisms, femtosecond

optical pulses and techniques to characterize femtosecond pulses; Properties of laser beams and techniques to characterize laser beam.

Unit 4

Classification of lasers and laser systems: Two level, three level and four level laser systems, Laser systems involving low density media – He-Ne, Ar -ion, Kr- ion, He-Cd, and Copper vapour lasers; Molecular gas systems: CO_2, N_2, and Excimer lasers; X-ray laser, FEL laser; Laser systems involving high gain media: Dye, Solid state - Ruby, and NdYAG, Nd-glass lasers; Pico and Femtosecond lasers – Alexandrite laser, Ti-Sapphire laser, fiber laser; Laser diode – threshold current and power output, Semiconductor lasers - hetero-junction lasers, Quantum well lasers, DFB laser, surface emitting lasers, Rare-earth doped lasers.

Unit 5

Laser cooling and trapping of atoms: magnetic and optical traps, optical molasses Lasers in computing- optical logic gates.
Lasers in medicine: Photodynamic therapy, laser angioplasty, lasers in surgery.
Industrial applications of lasers: laser absorption in metals, semi-conductors, and insulators; welding, surface treatments, material removal, cutting, scribing, marking etc., generation of plasma, optical fibre splicing, and laser deposition of thin films; Laser Displays.
Lasers in chemistry: isotope separation, laser induced chemical reactions – IR photochemistry. Ultrafast processes in Bio-molecules-monitoring fast chemical reactions, study of photochemical processes and stimulation photochemical reactions.
Fluorescence spectroscopy, energy transfer, sensitization and quenching phenomena, Fluorescence of dyes and rare earth ions.

References:
1. Laser fundamentals, 2nd Ed: W. T. Silfvast, Cambridge University Press 2004. (Text).
2. Fundamentals of Photonics, 2nd Ed: B. E. Salch, M. Teich, John Wiley Sons (2007)
3. Lasers: Theory and application: Ghatak and Thyagarajan, McMillan, 2002.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY572	**Biophotonics**	**3 0 0 3**

Description:
The course introduces to the students the basic concepts of optical physics required to explain life on earth. This course should help students to do research in biophotonics and also to develop advanced equipment for medical industry.

Course Outcomes: After successful completion of the course, students will be able to

1) Explain optics of eye, photosynthesis, fluorescence and optical imaging systems.
2) Understand the physics of Photo-excitation, Optical coherence tomography, special and time-resolved imaging, fluorescence resonance energy transfer, nonlinear optical imaging, Bio-imaging and multi-photon microscopy.
3) Develop articulated arm delivery, hollow tube wave-guides, and fiber optic delivery systems.
4) Design and develop optical biosensors, microscopes and Bio-imaging probes, devices for tissue engineering using light.
5) Understand and explain Phot-dynamic therapy, photo–sensitizers for photodynamic therapy, Contouring and restructuring of tissues using laser, laser tissue regeneration, and femto-second laser surgery.
6) Understand and describe various tools for Flow cytometry, DNA analysis, biomaterials and medicine.

Unit 1

Photobiology: Interaction of light with cells and tissues, Photo–processes in Biopolymers, human eye and vision, photosynthesis. Photo-excitation: free space propagation, optical fiber delivery system, articulated arm delivery, hollow tube wave-guides. Optical coherence tomography, special and time-resolved imaging, fluorescence resonance energy transfer(FRET) imaging, nonlinear optical imaging, Bio-imaging:

Unit 2

Transmission microscopy, Kohler illumination, microscopy based on phase contrast, dark-field and differential interference contract microscopy, fluorescence, confocal and multi-photon microscopy. Applications of bio-imaging: Bio-imaging probes and fluorophores, imaging of microbes, cellular imaging and tissue imaging.

Unit 3

Optical biosensors: Fluorescence and energy transfer sensing, molecular beacons and optical geometries of bio-sensing, biosensors based on fibre optics planar waveguides, evanescent waves, interferometry and surface Plasmon resonance. Flow cytometry: Basics, fluoro-chromes for flow cytometry, DNA analysis.

Unit 4

Laser activated therapy: Photdynamic therapy, photo–sensitizers for photodynamic therapy, applications of photodynamic therapy, two photon phoyodynamic therapy. Tissue engineering using light: Contouring and restructuring of tissues using laser, laser tissue regeneration, femto-second laser surgery.

Unit 5

Laser tweezers and laser scissors, design of laser tweezers and laser scissors, optical trapping using non-Gaussian optical beam, manipulation of single DNA molecules, molecular motors, lasers for genonmocs and proteomics, semiconductor quantum dots for bio imaging, metallic nano-particles and nano-rods for bio-sensing. Photonics and biomaterials: Bacteria as bio-synthesizers for photonic polymers.

TEXTS:
1. Introduction to Bio-photonics - V N Prasad (Wiley-Interscience April 2003)
2. Biomedical photonics: A Handbook - Tu Vo Dinh (CRC Press, Boca Raton, FL 2003)

References
1. A Handbook of Optical Biomedical diagnostics, SPIE press monograph vol pm 107
2. Biomedical Optics - Principles and Imaging - Lihong V and Hsin-IWU, Wiley Interscience 1sted, 2007
3. Optical coherence Tomography - Principles and Applications – Mark E.Brezinski, (Academic press 1sted, 2006)
4. Biophysics - An Introduction - Rodney Cotterill, (John Wiley Student edition)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY573	**Mesoscopic Physics and Quantum Conductors**	3 0 0 3

Course Outcomes: After successful completion of the course, students will be able to
1) Describe preliminary concepts of 1D, 2D, 3D electron gas, effective mass, density of states, characteristic length and time, Fermi liquid theory, apply them to solve problems.
2) Describe and apply foundations of physics to some quantum mesoscopic effects: Aharonov-Bohm effect, weak localization, Quantum point contact, Quantum Hall effect.
3) Describe and apply scattering approach to quantum conduction
4) Analyze noise in quantum systems and its consequences
5) Describe and apply basic principles to quantum electronic systems in interaction: Tomonaga-Luttinger liquid, fractional quantum Hall effect.

Unit 1
Preliminary concept: 1D and 2D electron gas, Effective mass, density of states, characteristic length and time (mean free path, coherence length, elastic time, scattering time), Reminders on Fermi liquid theory, Drift velocity versus Fermi velocity

Unit 2
Introduction to quantum mesoscopic effect: Aharonov-Bohm effect, Weak localization, Quantum point contact, Quantum Hall effect.

Unit 3
The scattering approach to quantum conduction: Toolbox, Two terminals Landauer formula, Conductance in ballistic conductors, Conductance in diffusive conductors, Multiterminal conductor: the quantum Kirchhoff law, Application of Landauer formula: quantum point contact and quantum Hall effect.

Unit 4
Noise in mesoscopic systems: Introduction: "The noise is the signal", Fermi-Dirac versus Bose-Einstein distribution: the importance of the statistics, Thermal noise, Quantum shot noise, Vacuum fluctuation noise, Noise correlations (bunching anti bunching and Hanbury-Brown and Twiss experiment), Quasi-particles entanglement in ballistic conductors.

Unit 5

Introduction to quantum electronic systems with interaction: 1D: Tomonaga-Luttinger liquid theory, 2D: Fractional quantum Hall effect.

Reference books and courses:
1. Electronic transport in mesoscopic systems, Supriyo Datta
2. "Introduction to quantum conductors", D.C Glattli
3. "Shot Noise in Mesoscopic Conductors", Y M Blanter and M. Buttiker
4. "Electronic Quantum Transport in Mesoscopic Semiconductor Structures", T. Ihn

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY574	Topics in Computational Condensed Matter Physics	3 0 0 3

This course is a more advanced version of computational methods in physics. However, could be registered concurrently.

Prerequisites: Quantum mechanics I & II, Condensed Matter Physics I & II, at least a concurrent registration of computational methods in physics, good academic standing and Instructor's permission.

Course Outcomes: On successful completion of this course, students shall be able to
1) Set up computing environment for Python/C++/Fortran, familiarize with parallel computing methods, calculate quantities of interest.
2) Understand the method of coding for calculations using HF method. Examine a simple HF/SE/EHT program for small molecules or linear systems.
3) Choose appropriate DFT functionals for appropriate molecular/solid state properties like Energies, Spectra.
4) Code/Program a simple HF/DFT/EHT code for very small molecular/solid state systems. [This is to gain experience in developing algorithms, coding, testing, debugging].
5) Understand the basics of molecular dynamics simulations, calculate thermal averages of properties for a simple system.

Unit 1
Review of basics of quantum mechanics; states of harmonic oscillator and hydrogen like atoms, free particles in spherical coordinates, variational methods in quantum mechanics.
Lab: Setting up Computing Environment; Parallelization. Sample calculations: parallelization of iterative calculations, spherical Bessel functions, use of Numerov method for spherical problems. [2.5 weeks]

Unit 2

Two and many electron atoms and molecules:Hartree and Hartree-Fock methods, self-consistent field, free electron solutions, Thomas-Fermi theory. Sample HF applications: Helium atom and hydrogen molecule, heavy atoms, molecular structure, and molecular properties in brief. [3.5 weeks]

Unit 3

Density Functional Theory: Formalism, Kohn-Sham equations, Local Density Approximation; Exchange and Correlations; Modern hybrid functionals: General Gradient Approximations (GGA), PBE. Plane wave basis, an introduction to pseudo potentials and application of DFT for crystals. Sample calculations for an atoms, molecules, simple crystals using a program or software. [3.5 weeks]

Unit 4

An introduction to molecular dynamics. [2.5 weeks]

A brief project on a chosen topic. Possible topics: Coding a simple HF program, running and adapting existing codes on DFT, energy bands, molecular dynamics simulations, and the interpretation of the results.

References:
1. Computational Physics, 2nd Ed (2007, Cambridge University Press): J. M. Thijssen
2. The ABC of DFT: Kieron Burke. https://dft.uci.edu/doc/g1.pdf
3. A bird's-eye view of density-functional theory: Klaus Capelle
   (available online at: https://arxiv.org/abs/cond-mat/0211443)
4. A Tutorial on Density Functional Theory: Nogueira, et al. https://www.physics.udel.edu/~bnikolic/QTTG/NOTES/DFT/PRIMER_IN_DFT_SPRINGER_2003/NOGUEIRA=tutorial_on_density_functional_theory.pdf
5. NSF/DOE Quantum Science Summer School: Introduction to density functional theory. https://qs3.mit.edu/images/pdf/tutorial_Giustino_full.pdf
6. Handbook of Computational Quantum Chemistry: David B. Cook
7. Physics of Atoms and Molecules: Bransden and Jochain
8. Tao Pang, An Introduction to Computational Physics, 2nd Ed., 2010, CUP
9. Rubin H. Landau, Manuel José Páez, Computational Problems for Physics with Guided Solutions Using Python (2018, CRC Press)

Suggested evaluation pattern: Assignments and lab exercises and project: 50%; Mid-term exam: 20%; End-semester exam: 30%.

Skills and Employability: Entire course contents with tutorials and assignments help build foundations and develops computational thinking, programming skills – design and implementation of software for scientific, engineering and industrial computing applications in universities, industries and research labs/organisations.

22PHY575   **Advanced Optics**   **3 0 0 3**

Description: This course describes optical phenomena in nature at the graduate level, dealing mainly with wave optics.

Course Outcomes: After successful completion of the course, students shall be able to

1) Summarize and apply results on interaction of electromagnetic radiation with matter, and calculate parameters in reflection, transmission, dispersion in metals and dielectrics.
2) Describe and apply concepts of polarization, relate to angular momentum, polarization using scattering and reflection, quantify using Stokes' and related parameters.
3) Describe and apply complex representations and phasors to deduce conditions for interference, apply to interferometers, thin films, coatings.
4) Describe and apply Huygens-Fresnel principle and Kirchhoff's scalar diffraction theory, Fraunhofer diffraction analysis to single and double slits and other problems.
5) Describe and apply Fourier methods in diffraction, basics of coherence theory, basic ideas in lasers and nonlinear optics.

Unit 1

Basics: Review of Maxwell's equations and electromagnetic waves, summary of results on interaction of electromagnetic waves with matter, Fresnel's equation, reflection & transmission, total internal reflection and evanescent waves, dispersion of waves in metals and dielectrics.

Unit 2

Polarization: Review of linear, circular and elliptical polarizations, angular momentum of photon picture, Malus's law, polarization by scattering and reflection, Brewster angle, selected related phenomena; Stokes parameters, Jones vector and Mueller matrices, Poincare sphere.

Unit 3

Review of Interference: Complex representation of waves, phasors, superposition principle; conditions for interference, spatial & temporal coherence, wave front & amplitude splitting; Michelson, Mach-Zehnder and Sagnac interferometers. Multiple beam interference, Fabry-Perot interferometer, anti-reflection coatings.

Unit 4

Diffraction: Huygens-Fresnel principle, Kirchhoff's scalar diffraction theory; Fraunhofer diffraction single slit, double & multiple slits, rectangular & circular apertures, resolution of imaging systems, diffraction grating. Fresnel's diffraction, half-period zones, circular & rectangular apertures, Cornu spiral, diffraction by slit, Babinet's principle.

Unit 5

Advanced Methods:Fourier methods in diffraction theory: Fourier viewpoint in optics, Fraunhofer diffraction – single and doubleslits; Basics of Coherence theory: visibility, mutual coherence function and degree of coherence. Basic ideas on nonlinear optics.

References

1. E. Hecht and A.R., Ganesan, Optics, 4E, Pearson
2. Ajoy Ghatak, Optics, Tata McGraw-Hill, 2009.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: The entire contents of this course, tutorials and assignments lays conceptual/theoretical foundation for application of laws of physics to problems of scientific interest and builds skills required for a career as an educator/academician in schools, colleges, universities and coaching centres, as a professional researcher in government/industrial research organizations, and as a communicator of science in general.

22PHY576	**Fourier Optics**	3 0 0 3

(Pre-requisite: The course on Wave Optics, good academic standing and Instructor approval)

Course Outcomes:
1. Introduction to the discipline of Optics and its role in the modern society
2. Introduction to the realm of Computational Fourier Optics and review analytic Fourier Theory
3. Physical understanding of Sampling and Shannon-Nyquist Sampling theorem. Student will learn about sampling of functions and their Discrete Fourier Transform
4. Programming of functions, vectors, arrays and Fourier Transforms
5. Understand Scalar Diffraction theory, Monochromatic fields and irradiance & analytic diffraction solution with Fraunhofer diffraction as example. Student will learn about propagation simulation – Fresnel propagation and sampling & Fraunhofer propagation
6. Understand transmittance functions – Tilt, Lens, Grating and other periodic functions
7. Learn fundamentals of imaging & simulation of diffraction limited imaging; Basics of Wavefront aberrations – Optical Path Difference, Primary aberrations, Pupil and Transfer functions, Image quality and Wavefront sampling

Unit 1: Analytic Fourier Theory Review
Analysis of two-dimensional signals and systems – Fourier analysis in 2D, Local Spatial Frequency and Spatial Frequency localization, Linear systems, Two dimensional sampling.

Unit 2: Scalar diffraction & propagation solutions, Simulations
Scalar diffraction theory – Introduction, vector to scalar theory, mathematical preliminaries, Kirchhoff formulation of diffraction by a planar screen, Rayleigh-Sommerfeld formulation, Huygens-Fresnel principle, Angular spectrum of plane waves.

Unit 3: Diffraction
Fresnel and Fraunhofer diffraction – Background, Fresnel and Fraunhofer approximations, Examples of Fraunhofer diffraction patterns and Fresnel diffraction calculations.

Unit 4: Transmittance functions, Lenses & Gratings

Wave optics analysis of coherent optical systems – thin lens as a phase transformation, Fourier transforming properties of lenses, image formation: monochromatic illumination.

Unit 5: Imaging and diffraction limited imaging, wave front aberrations and modulation, simulations

Frequency analysis of optical imaging systems – generalized treatment, frequency response for diffraction limited coherent and incoherent imaging; Aberrations and their effects on frequency response, comparisons of coherent and incoherent imaging, resolution beyond classical diffraction limit; Wave front modulation – incoherent image and coherent optical information processing systems, applications.

* The course has a practical (computational) component.

Textbook/References

1. J.W. Goodman, Introduction to Fourier Optics, 3E, Roberts & Company Publishers, 2005 (Prescribed)
2. E.G. Steward, Fourier Optics – An Introduction, Dover, 2004
3. J.D. Gaskill, Linear systems, Fourier Transforms, and Optics, Wiley, 1978

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Skills and Employability: Entire course centents with tutorials, assignments and computational projects help build foundations develops skills in optical physics and will students will find useful in optics industry and optical software development.

22PHY577	**Nonlinear Optics**	3 0 0 3

Course Outcomes:

CO-1 Understand sources of and propagation of optical electromagnetic waves and predict the possible optical process when nonlinearity in the optical response of a material comes into picture

CO-2 Demonstrate a detailed physical and mathematical understanding of a variety of nonlinear processes as an application of electromagnetic theory, semiclassical theory and quantum mechanics

CO-3 Apply the knowledge to identify the broad variety of ways in which materials exhibit nonlinear behavior.

Unit 1

Introduction to Nonlinear Optics: Brief review of electromagnetic waves - Wave propagation in an anisotropic crystal - Nonlinear optical effects - Polarization response of materials to light, Harmonic generation.

Unit 2

Second order effects: Second harmonic generation - Sum and difference frequency generation - Phase matching - Parametric amplification, parametric fluorescence and oscillation;

Concept of quasi-phase matching; Periodically poled materials and their applications in non-linear optical devices.

Unit 3

Third order effects: Third harmonic generation – bistability - self focusing, self-phase modulation, Temporal and spatial solitons, Cross Phase modulation, four wave mixing, Phase conjugation.

Unit 4

Multiphoton Processes: Two photon process - Theory and experiment - Three photon process, Parametric generation of light - Oscillator - Amplifier - Stimulated Raman scattering - Intensity dependent refractive index optical Kerr effect - photorefractive, electron optic effects.

Unit 5

Nonlinear Optical Materials: Basic requirements - Inorganics - Borates - Organics - Urea, Nitro aniline - Semi organics - Thiourea complex - X-ray diffraction FTIR, FINMR - Second harmonic generation - Laser induced surface damage threshold.

Textbooks:
1. Robert W. Boyd, Nonlinear Optics, 2nd Ed., Academic Press, 2003.
2. D.L. Mills, Nonlinear Optics – Basic Concepts, Springer, 1998.
3. B.B. Laud, Lasers and Nonlinear Optics, 2nd Ed. New Age International (P) Ltd., 1991.
References
1. A Yariv, Quantum Electronics, John Wiley, NY, 1989.
2. A Ghatak and K Thyagarajan, Optical Electronics, Cambridge Univ Press, 1989.
3. Scully and M S Zubairy, Quantum optics, Cambridge Univ. Press, 1997.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY579	**Fiber Optics and Technology**	3 0 0 3

Unit 1   Classification of fiber: based on refractive index profiles, modes guided applications and materials. Fibers for specific applications: polarization maintaining fibers (PMF), dispersion shifted and dispersion flattened fibers, doped fibers. Photonic crystal fibers, holly fibers.Fiber specifications: Numerical aperture of SI and GI fibers, Fractional refractive index difference, V – parameter, Cut off wavelength, dispersion parameter, bandwidth , rise time and Non linearity coefficient.

Unit 2   Impairment in fibers: group velocity dispersion (GVD), wave guide and modal dispersions. Polarization mode dispersion (PMD), Birefringence – liner and circular.
Fiber drawing and fabrication methods: modified chemical vapor deposition (MCVD) and VAD techniques.

Unit 3   Mode theory of fibers – different modes in fibers. Dominant mode, Derivations for modal equations for SI and GI fibers. Approximate number of guided modes in a fiber (SI and GI fibers).Comparison of single mode and multimode fibers for optical communications. LED and LD modulators. Coupling of light sources to fibers – (LED and LD) – Derivations required. Theory and applications of passive optical components: connectors, couplers, splices, Directional couplers, gratings: FBGs and AWGs, reflecting stars: Optical add drop multiplexers and SLMs.

Unit 4   Active components: Optical Amplifiers (OAS) - Comparative study of OAS - SLAs, FRAs, FBAs EDFAs and PDFAs based on signal gain, pump efficiency, Noise Figure, Insertion loss and bandwidth. Design and Characterization of forward pumped EDFAs.

Unit 5   Fiber measurements: Attenuation measurement – cut back method. Measurement of dispersion – differential group delay, Refractive index profile measurement.
Numerical aperture (NA) measurement, diameter measurement, mode field diameter (MFD) measurement, V-Parameter, Cut off wavelength Measurement, splicing and insertion losses, OTDR – working principle and applications. OSA - Basic block schematic and applications in measurements. (John M senior)

Textbooks:
2. Gerd Keiser, Optical Fiber communications, MC Graw Hill,200
3. Maynbav, Optical Fiber Technology, Pearson Education, 2001
4. John M senior, Optical fiber communications, PHI, 1992

References
1. Joseph C Palais, Optical Fiber communications, Pearson Education.1998.
2. Dennis Derickson, Fiber optic test and measurement, Prentice hall,1998.
3. 3 David Bailey and Edwin wright, practical Fiber optics, Elsevier 2003.
4. Franz and Jain, optical Fiber communication systems and Components, Narosa Publishers, 2004.
5. Ajoy Ghatak and K. Thyagarajan, Introduction to Fiber optics: Cambridge university press,1999.

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

22PHY578	**Fiber Optic Sensors & Applications**	3 0 0 3

Description:
The course introduces to the students the concepts of various optical fibers and their applications to sensor technology. This course should help students to do research in sensors in presence of harsh electromagnetic fields and to develop advanced equipment for industry.

Course Outcomes: After successful completion of the course, students will be able to
  1) Understand Explain principle and technology of fiber optics, electro optic and integrated optic modulators.

2) Understand the basic concepts and specifications of optical fiber sensors, micro-bend, evanescent fiber sensors, and polarization modulated sensors.

3) Explain the principle of temperature and strain sensing, multiplexing. FBG, Long period fiber grating sensors and refractive index sensing.

4) Design and develop Interferometric, Mach-Zehnder and Michelson types optical fiber sensors.

5) Understand and explain physics and technology of temperature, pressure and strain measurements, encoded sensors, and fiber optic biosensors.

6) Understand and describe of fiber optic gyroscopes, Faraday effect sensors, Magneto-striction and Lorentz force sensors, applications in industrial and environmental monitoring.

Unit 1

MM and SM fibers for sensing, Lasers & LEDs suitable for sensing, PIN & APDs for fiber optic sensing. Principles of electro optic modulators bulk & integrated optic modulators. Optical sensor types, advantages and disadvantages of fiber optic sensors, Sensor system performance: basic specifications, Intensity modulated sensors, reflective concept, micro-bend concept, evanescent fiber sensors, polarization modulated sensors.

Unit 2

In-fiber Bragg grating based sensors – sensing principles – temperature and strain sensing, integration techniques, cross sensitivity, FBG multiplexing techniques. Long period fiber grating sensors - temperature and stain sensing, refractive index sensing, optical load sensors and optical bend sensors.

Unit 3

Interferometric sensors, Mach-Zehnder& Michelson interferometric sensors, Theory-expression for fringe visibility, Fabry-Perot fiber optic sensors – theory and configurations, optical integration methods and multiplication techniques, application – temperature, pressure and strain measurements, encoded sensors.

Unit 4

Sagnac interferometers for rotation sensing fiber gyroscope sensors – Sagnac effect – open loop biasing scheme – closed loop signal processing scheme – fundamental limit – performance accuracy and parasitic effects – phase-type bias error – shupe effect – anti-shupe winding methods – applications of fiber optic gyroscopes. Faraday effect sensors. Magneto-striction sensors - Lorentz force sensors.

Unit 5

Biomedical sensors, sensors for physical parameters, pressure, temperature, blood flow, humidity and radiation loss, sensors for chemical parameters. pH, oxygen, carbon, dioxide, spectral sensors. Distributed fiber optic sensors – intrinsic distributed fiber optic sensor – optical time domain reflectometry-based Rayleigh scattering – optical time domain reflectometry based Raman scattering – optical time domain reflectometry – quasi – distributed fiber optic sensors. An overview on the optical fiber sensors in nuclear power industry, fly-by light aircraft, oil field services, civil and electrical engineering, industrial and environmental monitoring.

Textbooks

1. Francis T. S Yu, Shizhuo Yin (Eds), Fiber Optic Sensors, Marcel Dekker Inc., New York, 2002

2. Dakin J and Culshow B., (Ed), Optical fiber sensors, Vol I, II, III, Artech House, 1998

3. Pal B. P, Fundamentals of fiber optics in telecommunication and sensor systems, Wiley Eastern, 1994

REFERENCES

1. Jose Miguel Lopez-Higuera (Ed), Handbook of optical fiber sensing technology, John Wiley and Sons Ltd., 2001

2. Eric Udd (Ed), Fiber optic sensors: An introduction for engineers and scientists, John Wiley and Sons Ltd., 1991

3. B. D Gupta, Fiber optic Sensors: Principles and applications, New India Publishing Agency, New Delhi., 2006

4. Bio-medical sensors using optical fibers, Report on progress in physics Vol 59.1,1996

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)

Open Electives (Physics)

22OEL299	History and Philosophy of Science	(3 0 0 3)

Description: Normally the students of science lack a broad historical perspective about the discoveries of science which essential for greater appreciation and even understanding of some the concepts. This course is aimed at bridging this gap.

Course Outcomes: After successful completion of the course, students will be able to

1) Describe the Indian and world history of science starting from Copernican revolution and the rise of modern science in a nutshell.
2) Identify the ancient Indian contribution to science, technology, architecture, Mathematics and Medicine, Astronomy etc.
3) Describe the ancient revolutionary work and writings of Euclid, Aryabhata, Brahmagupta, Jyestadeva, Newton etc.
4) Analyze the aims or goals and philosophy of science to utilize their knowledge and talent to serve society at large.

Contents:

Unit 1   Why History of Science? Astronomy in the ancient world - people, theory and instruments (4 hours) - Astronomy across civilizations of the old world, main discoveries, their contribution and instruments during those times.

Unit 2   The Dark ages in Europe - the Arabian influence - The Islamic science, translations and original contributions of Arabians, dark ages Europe, logic, literature and scientific method, early universities of Europe.

Unit 3   Indian tradition in Science and Technology - an overview - Indian contributions in science and technology - mathematics, astronomy and other sciences.

Unit 4   Texts that changed the course of history science - Elements of Euclid, Aryabhatiya of Aryabhata, Brahmasputa Sidhanta of Brahmagupta, Yuktibhasa of Jyestadeva, Philosophiae Natturalis Principia Mathematica.

Unit 5   The Copernican revolution and the rise of modern science - The background of Copernican revolution, interaction between civilizations, the rise of modern sciences - when and why?

Text and Background Literature:
History and philosophy of science is yet to be established as full-fledged discipline. A suggested anthology of reading materials:
1. Essential reading on history of sciences (in-house publication)
2. http://www.Open2.net/whattheancients/ (Documentaries)

Evaluation Pattern: As in the rules for *Assessment Procedure* (R.14)