COURSE CONTENTS

2013-14

Indian Institute of
Science Education and Research Bhopal

CONTENTS

LIST OF Ph.D. COURSES

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INTRODUCTION

BS-MS (Dual Degree) programme consists of mandatory, common courses (core courses) for all disciplines during the first two years and discipline-dependent professional courses during the remaining three years. Core courses include topics from all the four science disciplines in addition to interdisciplinary courses in earth and environmental sciences, computer science, and humanities and social sciences. During the final year, BS-MS students are required to undertake project work with a faculty supervisor, relevant to their major discipline.

In addition to majoring in one of the four science disciplines, BS-MS students can also minor in another discipline by obtaining a minimum of 14 credits and fulfilling criteria specified by individual departments. The curriculum and other criteria for successfully completing the BS-MS programme in various disciplines are documented in the Undergraduate (UG) Manual.

Ph.D. programme consists of course work, qualifying/comprehensive examination, seminars, and a thesis. Ph.D. students from all disciplines will have to register for a minimum of 24 course credits (16 course credits for lateral entry Ph.D. students) and a minimum of 32 research credits. In order to graduate, they should have a total minimum of 80 credits.

Besides the mandatory requirements, students are encouraged to participate in several professional activities such as workshops, review meetings and conferences. All doctoral students are also expected to participate in the undergraduate teaching programme of the Institute as a part of their training. The curriculum and other criteria for successfully completing the Ph.D. programme in various disciplines are documented in the Postgraduate (PG) Manual.

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ALPHA-NUMERIC NOTATION FOR COURSES

Subject Code:

BIO	Biological Sciences
CHM	Chemistry
CS	Computer Science
EES	Earth and Environmental Sciences
HSS	Humanities and Social Sciences
MTH	Mathematics
PHY	Physics

Three Digit Numbers:

All course codes will consist of a three-digit number in addition to the subject code. The first digit from left denotes the year for which the course is offered (1 to 6). The last digit indicates the semester (odd digits for odd semesters and even digits for even semester). The last digit convention is applicable for undergraduate courses only.

Illustrative Examples:

- CHM 411 means that it is a chemistry course offered in the first semester of the fourth year.
- MTH 302 means that it is a mathematics course offered in the second semester of the third year.

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BS-MS CURRICULUM

Core Courses

1st Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 101	Biomolecules and the Origin of Life	3	0	1	6	3
BIO 103	General Biology Laboratory I	0	3	0	0	1
CHM 101	General Chemistry	3	0	1	6	3
CHM 103	General Chemistry Laboratory	0	3	0	0	1
CS 101	Introduction to Computers	2	1	0	6	3
HSS 103	Basics of Communication Skills	1	0	0	2	1
MTH 101	Calculus of One Variable	3	0	1	6	3
PHY 101	Mechanics	3	0	1	6	3
PHY 103	General Physics Laboratory I	0	3	0	0	1
Total		15	10	4	32	19

2nd Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 102	Diversity in the Living World	3	0	1	6	3
BIO 104	General Biology Laboratory II	0	3	0	0	1
CHM 102	Basic Inorganic Chemistry	3	0	1	6	3
CHM 104	Inorganic Chemistry Laboratory I	0	3	0	0	1
HSS 104	Oral and Written Communication	1	0	0	2	1
EES 102	Introduction to Earth Science	3	0	0	6	3
MTH 102	Linear Algebra	3	0	1	6	3
PHY 102	Electromagnetism	3	0	1	6	3
PHY 104	General Physics Laboratory II	0	3	0	0	1
Total		16	9	4	32	19

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3rd Semester (applicable during 2013-14, 1st Semester ONLY)

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 201	Flow of Genetic Information	3	0	1	6	3
BIO 203	General Biology Laboratory III	0	3	0	0	1
CHM 211	Basic Organic Chemistry	3	3	1	6	3
CHM 213	Organic Chemistry Laboratory I	0	3	0	0	1
CS 201	Introduction to Computers	2	1	0	6	3
HSS 205	Microeconomics	2	0	0	4	2
HSS 207	Macroeconomics	1	0	0	2	1
MTH 201	Multivariable Calculus and Differential Equations	3	0	1	6	3
PHY 201	Quantum Physics	3	0	1	6	3
PHY 203	General Physics Laboratory III	0	3	0	0	1
Total		17	10	4	36	21

3rd Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 201	Flow of Genetic Information	3	0	1	6	3
BIO 203	General Biology Laboratory III	0	3	0	0	1
CHM 211	Basic Organic Chemistry	3	3	1	6	3
CHM 213	Organic Chemistry Laboratory I	0	3	0	0	1
HSS ***	Microeconomics	2	0	0	4	2
HSS ***	Indian Philosophy/Cognitive Sciences/Psychology	2	0	0	4	2
MTH 201	Multivariable Calculus and Differential Equations	3	0	1	6	3
PHY 201	Quantum Physics	3	0	1	6	3
PHY 203	General Physics Laboratory III	0	3	0	0	1
Total		17	10	4	36	19

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4th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 202	Basic Genetics	3	0	0	6	3
BIO 204	General Biology Laboratory IV	0	3	0	0	1
CHM 222	Classical Thermodynamics	3	0	1	6	3
CHM 224	Physical Chemistry Laboratory I	0	3	0	0	1
EES 202	Atmospheric Sciences	3	0	0	6	3
HSS 2**	Research Methods in Social Sciences/ Macroeconomics/ Sociology	1	0	0	2	1
MTH 202	Probability and Statistics	3	0	1	6	3
PHY 202	Basic Electronics	3	0	1	6	3
PHY 204	Electronics Laboratory	0	3	0	0	1
Total		16	12	3	32	19

NOTE: Lec Hr: Lecture Hours per week; Lab Hr: Laboratory Hours per week; Tut Hr: Tutorial Hours per week; SS Hr: Self Study Hours per week

- Every Lecture Hour is associated with a certain number of Self Study Hours
- Tutorials will have no credits
- Typically, every regular course will have 3 lecture hours per week
- Number of Credits = [(Lec Hr + Lab Hr + SS Hr)/3]
- All laboratory work (including notebook writing) should be completed inside the laboratory

For example, CHM 222 has 3 Lec Hr and 6 SS Hr.
So, Number of Credits = [(3+0+6)/3] = 3

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Professional Courses

NOTE:

- Professional courses, as required by various Disciplines, have to be credited to **major** in that Discipline.
- For all laboratory courses, practical work, including notebook writing should be completed during the laboratory hours.
- To **minor** in any discipline, the student has to take a **minimum of 14 credits** (at least 4 open electives) from that particular discipline.
- After the mid-semester examination of the 8^{th} semester, students will be assigned a supervisor for their Project Work.
- Provisions for departmental electives exist in the 9^{th} and 10^{th} semesters for those students who choose theoretical chemistry as their research area.
- Minimum number of credits for earning a BS-MS Dual degree is 188 and a student must clear all the courses opted for.

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Biological Sciences

5th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 301	Cell Biology	3	0	0	6	3
BIO 303	Biochemistry I	3	0	0	6	3
BIO 305	Plant Physiology	3	0	0	6	3
BIO 307	Biology Laboratory I	0	6	0	3	3
*** ***	Open Elective I	3				3/4
*** ***	Open Elective II	3				3/4
Total		15				18/20

6th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 302	Biochemistry II	3	0	0	6	3
BIO 304	Molecular Biology	3	0	0	6	3
BIO 306	Animal Physiology	3	0	0	6	3
BIO 308	Biology Laboratory II	0	6	0	3	3
*** ***	Open Elective III	3				3/4
*** ***	Open Elective IV	3				3/4
Total		15				18/20

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7th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 401/ 601	Immunology	3	0	0	9	4
BIO 403/ 603	Structural Biology	3	0	0	9	4
BIO 405	Biology Laboratory III	0	6	0	3	3
BIO ***	Departmental Elective I	3	0	0	9	4
*** ***	Open Elective V	3				3/4
*** ***	Open Elective VI	3				3/4
Total		15				21/23

8th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 402/ 602	Bioinformatics	3	0	0	9	4
BIO 404/ 604	Neurobiology	3	0	0	9	4
BIO 406/ 606	Cancer Biology	3	0	0	9	4
BIO ***	Departmental Elective II	3	0	0	9	4
BIO ***	Departmental Elective III	3	0	0	9	4
*** ***	Open Elective VII	3				3/4
Total		18				23/24

9th Semester

Course No.	Course Name	Credit
BIO 501	Project Work	10
BIO 5**S	Advanced Topics in Biological Sciences (4 courses)	2 each
Total		18

10th Semester

Course No.	Course Name	Credit
BIO 501	Project Work	18
Total		18

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Chemistry

5th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 301/641	Symmetry and Group Theory	3	0	0	9	4
CHM 311	Organic Chemistry I	3	0	0	6	4
CHM 313	Organic Chemistry Laboratory II	0	6	0	3	3
CHM 321	Physical Chemistry of Solutions	3	0	0	9	4
CHM ***	Departmental Elective I	3				3/4
*** ***	Open Elective I	3				3/4
Total		15				21/23

6th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 302	Chemistry of Transition Metals	3	0	0	9	4
CHM 304	Inorganic Chemistry Laboratory II	0	6	0	3	3
CHM 312	Organic Chemistry II	3	0	0	9	4
CHM 322/642	Principles of Quantum Chemistry	3	0	0	9	4
CHM ***	Departmental Elective II	3				3/4
*** ***	Open Elective II	3				3/4
Total		15				21/23

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7th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 401	Non-transition Metal Chemistry	3	0	0	6	4
CHM 411/611	Physical Organic Chemistry	3	0	0	9	4
CHM 421/621	Statistical Mechanics	3	0	0	9	4
CHM 423	Physical Chemistry Laboratory II	0	6	0	3	3
CHM ***	Departmental Elective III	3				3/4
*** ***	Open Elective III	3				3/4
Total		15				21/23

8th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 402/602	Applications of Modern Physical Methods	3	0	0	9	4
CHM 422/622	Molecular Spectroscopy	3	0	0	9	4
CHM ***	Departmental Elective IV	3				3/4
CHM ***	Departmental Elective V	3				3/4
CHM ***	Departmental Elective VI	3				3/4
*** ***	Open Elective IV	3				3/4
Total		18				20/24

9th Semester

Course No.	Course Name	Credit
CHM 501	Project Work	10
CHM ***	Departmental Elective VII	4
CHM ***	Departmental Elective VIII	4
Total		18

10th Semester

Course No.	Course Name	Credit
CHM 501	Project Work	18
Total		18

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Earth and Environmental Sciences

5th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
EES 313/ 613/614	Science of Sustainability: Managing Earth Resources	3	0	0	9	4
EES 305/ 605/606	Mineralogy	3	0	0	9	4

6th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
EES 308/ 609/610	Microstructure and Thermodynamics of Rock Forming Minerals	3	0	0	9	4

7th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
EES 419/ 619/620	Environmental Biogeochemistry	3	0	0	9	4
EES 421/ 621/622	Remote Sensing of Natural Environment	3	0	0	9	4

8th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
EES 410/ 611/612	Aqueous Geochemistry	3	0	0	9	4

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Mathematics

5th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
MTH 301	Groups and Rings	3	0	0	9	4
MTH 303	Real Analysis I	3	0	0	9	4
MTH 305	Foundations of Mathematics and Elementary Number Theory	3	0	0	9	4
MTH ***	Departmental Elective I	3	0	0	9	4
*** ***	Open Elective I	3				3/4
Total		15				19/20

6th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
MTH 302	Modules	3	0	0	9	4
MTH 304	Metric Spaces and Topology	3	0	0	9	4
MTH 306	Ordinary Differential Equations	3	0	0	9	4
MTH ***	Departmental Elective II	3	0	0	9	4
*** ***	Open Elective II	3				3/4
Total		15				19/20

7th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
MTH 401	Fields and Galois Theory	3	0	0	9	4
MTH 403	Real Analysis II	3	0	0	9	4
MTH 405	Partial Differential Equations	3	0	0	9	4
MTH 407	Complex Analysis I	3	0	0	9	4
*** ***	Open Elective III	3				3/4
Total		15				19/20

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8th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
MTH 404	Measure and Integration	3	0	0	9	4
MTH 406	Differential Geometry of Curves and Surfaces	3	0	0	9	4
MTH ***	Departmental Elective III	3	0	0	9	4
*** ***	Open Elective IV	3				3/4
*** ***	Open Elective V	3				3/4
Total		15				18/20

9th Semester

Course No.	Course Name	Credit
MTH 501	Project Work	12
MTH ***	Departmental Elective IV	4
MTH ***	Departmental Elective V	4
Total		20

10th Semester

Course No.	Course Name	Credit
MTH 501	Project Work	12
MTH***	Departmental Elective VI	4
MTH***	Departmental Elective VII	4
Total		20

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Physics

5th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 301	Mathematical Methods I	3	0	0	9	4
PHY 303	Quantum Mechanics I	3	0	0	9	4
PHY 305	Classical Mechanics	3	0	0	9	4
PHY 307	Physics Laboratory I	0	6	0	3	3
*** ***	Open Elective I	3				3/4
Total		12				18/19

6th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 302	Mathematical Methods II	3	0	0	9	4
PHY 304	Quantum Mechanics II	3	0	0	9	4
PHY 306	Statistical Mechanics	3	0	0	9	4
PHY 308	Physics Laboratory II	0	6	0	3	3
*** ***	Open Elective II	3				3/4
Total		12				18/19

7th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 401/605	Electrodynamics	3	0	0	9	4
PHY 403/607	Condensed Matter Physics	3	0	0	9	4
PHY 405	Condensed Matter Physics Lab	0	6	0	3	3
*** ***	Open Elective III	3				3/4
*** ***	Open Elective IV	3				3/4
Total		12				17/19

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8th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 402/606	Atomic and Molecular Physics	3	0	0	9	4
PHY 404/608	Nuclear and Particle Physics	3	0	0	9	4
PHY 406	Nuclear Laboratory	0	6	0	3	3
*** ***	Open Elective V	3				3/4
*** ***	Open Elective VI	3				3/4
Total		12				17/19

9th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 501	Project Work					14
PHY 5**/6**	Departmental Elective I	3	0	0	9	4
PHY 5**/6**	Departmental Elective II	3	0	0	9	4
Total		6	0	0	18	22

10th Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 501	Project Work					14
PHY 5**/6**	Departmental Elective III	3	0	0	9	4
PHY 5**/6**	Departmental Elective IV	3	0	0	9	4
Total		6	0	0	18	22

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LIST OF Ph.D. COURSES

Biological Sciences

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
BIO 601	Immunology	3	0	0	9	4
BIO 602	Bioinformatics	3	0	0	9	4
BIO 603	Structural Biology	3	0	0	9	4
BIO 604	Neurobiology	3	0	0	9	4
BIO 606	Cancer Biology	3	0	0	9	4
BIO 607	Virology	3	0	0	9	4
BIO 608	Bioinstrumentation	3	0	0	9	4
BIO 609	Biophysics	3	0	0	9	4
BIO 610	Advances in Genetics	3	0	0	9	4
BIO 611	Advances in Microbiology	3	0	0	9	4
BIO 612	Developmental Biology	3	0	0	9	4
BIO 613	Stem Cell Biology	3	0	0	9	4
BIO 614	Ecology	3	0	0	9	4
BIO 601S	Epigenetics	3	0	0	3	2
BIO 603S	Advances in Microscopy	3	0	0	3	2
BIO 605S	Metagenomics and Genome Sequencing	3	0	0	3	2
BIO 607S	Structural Basis of Diseases	3	0	0	3	2
BIO 609S	Signal Transduction	3	0	0	3	2
BIO 611S	Cell Science and Technology	3	0	0	3	2
BIO 613S	Immunotechnology	3	0	0	3	2
BIO 615S	Stress Biology	3	0	0	3	2
BIO 617S	Membrane Biology	3	0	0	3	2
BIO 619S	Biomolecular NMR Spectroscopy	3	0	0	3	2

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Chemistry

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 602	Applications of Modern Physical Methods	3	0	0	9	4
CHM 603	Advanced Inorganic Chemistry	3	0	0	9	4
CHM 605	Bioinorganic Chemistry	3	0	0	9	4
CHM 607	X-ray diffraction: Principles and applications	3	0	0	9	4
CHM 609	Transition Metal Organometallic Chemistry	3	0	0	9	4
CHM 611	Physical Organic Chemistry	3	0	0	9	4
CHM 612	Advanced Organic Chemistry II (Advanced Organic Synthesis)	3	0	0	9	4
CHM 613	Advanced Organic Chemistry I (Asymmetric Synthesis)	3	0	0	9	4
CHM 614	Advanced Organic Chemistry III (Organometallics)	3	0	0	9	4
CHM 615	Frontiers in Organic Chemistry	3	0	0	9	4
CHM 616	Spectroscopy and its Application to Organic Molecules	3	0	0	9	4
CHM 617	Chemical Biology	3	0	0	9	4
CHM 621	Statistical Mechanics	3	0	0	9	4
CHM 622	Molecular Spectroscopy	3	0	0	9	4
CHM 624	Molecular Simulations	3	0	0	9	4
CHM 625	Biophysical Chemistry	3	0	0	9	4
CHM 626	Physical Photochemistry	3	0	0	9	4
CHM 628	Electrochemistry Fundamentals and Applications	3	0	0	9	4
CHM 629	Advanced Molecular Spectroscopy	3	0	0	9	4
CHM 630	Advanced Statistical Mechanics	3	0	0	9	4
CHM 631	Electronic Structure	3	0	0	9	4
CHM 632	Physical Chemistry of Polymers	3	0	0	9	4
CHM 633	Quantum Chemistry	3	0	0	9	4
CHM 635	Mathematical Methods for Chemists	3	0	0	9	4

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Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
CHM 637	Chemistry and Physics of Materials	3	0	0	9	4
CHM 641	Symmetry and Group Theory	3	0	0	9	4
CHM 642	Principles of Quantum Chemistry	3	0	0	9	4
CHM 651	Chemical Dynamics and Non-adiabatic Interactions	3	0	0	9	4

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Earth and Environmental Sciences

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
EES 601/602	Aerosol Science	3	0	0	9	4
EES 603/ 604	Solid Earth Geochemistry	3	0	0	9	4
EES 605/ 606	Mineralogy	3	0	0	9	4
EES 607/ 608	Air Quality Management	3	0	0	9	4
EES 609/ 610	Microstructure and Thermodynamics of Rock Forming Minerals	3	0	0	9	4
EES 611/ 612	Aqueous Geochemistry	3	0	0	9	4
EES 613/ 614	Science of Sustainability Managing Earth Resources	3	0	0	9	4
EES 615/ 616	Global Atmospheric Chemistry	3	0	0	9	4
EES 617/ 618	Geochemistry Principles and Applications	3	0	0	9	4
EES 619/ 620	Environmental Biogeochemistry	3	0	0	9	4
EES 621/ 622	Remote Sensing of Natural Environment	3	0	0	9	4
EES 623/ 624	Structural Geology and Rock Deformation	3	0	0	9	4

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Mathematics

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
MTH 601	Algebra I	3	0	0	9	4
MTH 603	Real Analysis	3	0	0	9	4
MTH 604	Complex Analysis II	3	0	0	9	4
MTH 605	Topology I	3	0	0	9	4
MTH 608	Introduction to Differential Manifolds and Lie Groups	3	0	0	9	4
MTH 609	Sturm-Liouville Theory	3	0	0	9	4
MTH 610	Fourier Analysis on the Real Line	3	0	0	9	4

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Physics

1st Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 601	Advanced Mathematical Methods for Physics	3	0	0	9	4
PHY 603	Advanced Quantum Mechanics	3	0	0	9	4
PHY 6**	Departmental Elective	3	0	0	9	4
PHY 6**/800	Departmental Elective/Ph.D. Thesis					4

2nd Semester

Course No.	Course Name	Lec Hr	Lab Hr	Tut Hr	SS Hr	Credit
PHY 602	Advanced Classical Mechanics	3	0	0	9	4
PHY 604	Statistical Mechanics	3	0	0	9	4
PHY 6**	Departmental Elective	3	0	0	9	4
PHY 6**/800	Departmental Elective/Ph.D. Thesis					4

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COURSE CONTENTS (BS-MS and Ph.D.)

Biological Sciences

BIO 101: Biomolecules and the Origin of Life (3)

Elemental Composition of Biomolecules; Properties of Water, hydrogen bonding and its biochemical properties; Concept of pH, pKa and buffers; Basic structure and function of Biological Macromolecules: Amino acids, Nucleotides and Monosaccharides, fatty acids (building blocks) Proteins, Nucleic Acids, Carbohydrates and Lipids (polymers); Origin of Life- Spontaneous generation; Pasteur and Miller experiments; An Introduction to plant and animal cell - Compare and contrasts, Cell organelles.

Suggested Reading:

- Principles of Biochemistry: Lehninger, Nelson and Cox; W.H. Freeman; 5th edition; 2008.
- Molecular Biology of the Cell: Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walter; New York: Garland Science; 5th edition; 2008
- NCERT basic Biology books

BIO 102: Diversity in the Living World (3)

Living vs. non living; Variations and diversity of life (Five kingdom classification); An introduction to viruses- Structure and function; History of Microbiology; Scope and branches of Microbiology; Microbial culture - media, isolation of pure culture; Physical and chemicals means to control bacteria. Bacterial cell and Eukaryotic cell - Structure and function (Overview, Cell Wall, Cell membrane, Cytoplasm and components therein, Cytoskeleton and cell motility); pathogenic and non pathogenic protists; Basic introduction to plant cell and processes unique to plants. Introduction to various phylums in plant and animal kingdom.

Suggested Reading:

- Molecular Biology of the Cell: Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walter; New York: Garland Science; 5th edition ; 2008
- Essential Microbiology: Stuart Hogg; John Wiley & Sons; 2005
- NCERT basic biology books

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BIO 103: General Biology Laboratory I **(1)**

- Introduction to lab instruments and general lab practices
- Buffer preparation - amino acid titration (Glycine)
- Carbohydrate estimation
- Protein estimation – Bradford and Lowry
- Saponification and use of detergents
- Visualization of cells
- Histology slides
- Moldy jell-O experiment
- Osmosis
- Model preparation

BIO 104: General Biology Laboratory II **(1)**

- Media preparation
- Sterilization
- Antibiotic sensitivity
- Biochemical reactions of bacteria
- Bacterial growth curve
- Pure culture isolation
- Nutrient selection
- Gram's Staining
- Bacterial motility experiment
- Histological animal and plant slides

BIO 201: Flow of Genetic Information **(3)**

Concept of central dogma of life ad variations; Macromolecules and their organizations- DNA, RNA, Protein- Structure, conformation and organization; Chromatin structure and nucleosomes; Genes and genome organization; Plasmids and extra chromosomal DNA, Transposons; Gene regulation; DNA replication in prokaryotes and eukaryotes; Mechanism of transcription in prokaryotes and eukaryotes; Translation: Genetic code, and its degeneracy, regulation of translation process; Concept of RNA world; RNA replication and processing: capping, polyadenylation; Introduction to gene silencing, epigenetics.

Suggested Reading:

- Genes – Benjamin Lewin; Jones & Bartlett Learning; 10^{th} edition; 2009.

- Molecular biology of the gene: James D. Watson, Tania A. Baker, Stephen P. Bell, Alexander Gann, Michael Levine, Richard Losick; Benjamin Cummings; 6th edition; 2007.
- Molecular Biology of the Cell: Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walter; New York: Garland Science; 5th edition; 2008.

BIO 202: Basic Genetics (3)

Principles of inheritance; Concept of gene- allele, multiple alleles, pseudoallele; Mendelian principles - Dominance; Segregation; Independent assortment; Codominance, Incomplete dominance; Non Mendelian inheritance- cytoplasmic inheritance, Maternal effect, Epistasis, Plieotropy. Overview of different mutations: Lethal, conditional, biochemical, loss of function, gain of function, germinal and somatic mutants, insertional mutagenesis; Structural and numerical alterations of chromosomes: Deletion, duplication, inversion, translocation and ploidy; Chromosomal theory of inheritence, Sex linked inheritance, pedigree analysis, Microbial genetics: Methods of genetic transfers-transformation, conjugation and transduction; Cell division-Mitosis and meiosis, Cell cycle and its regulation. Behavioral and population genetics, and environmental effects. Human genetics (blood group, genetic diseases), probability.

BIO 203: General Biology Laboratory III (1)

- Plasmid isolation
- Competent cell preparation
- Transformation and calculation of the efficiency
- Nucleic acid estimation
- Polymerase Chain reaction
- Agarose Gel electrophoresis
- Poly Acrylamide Gel Eelctrophoresis (PAGE)
- Plasmid restriction mapping
- Genomic DNA isolation

Suggested Reading:

- Genetic Analysis and Principles: Robert Brooker; McGraw-Hill Science/Engineering/Math; 4th edition; 2011.
- Genetics- From genes to genomes: Leland Hartwell, Leroy Hood, Michael Goldberg, and Ann Reynolds; McGraw-Hill Science/Engineering/Math; 4th edition; 2010.

BIO 204: General Biology Laboratory IV **(1)**

- Onion root tip – mitosis
- Meiosis slides observation
- Beta-galactosidase based mutation analysis assay
- Complementation test
- Conjugation
- Transduction
- Chromosome preparation
- Model preparation
- Verification of Mendelian laws in model organisms.

BIO 301: Cell Biology **(3)**

Prokaryotic and Eukaryotic cell; Animal and Plant cell; Integrating cells into tissues (animals and plants); Details of cell cycle, cell division and consequences; Cell membrane and its structure; Membrane and vesicular transport; Membrane based ion channels, lipid rafts; Study of cell nucleus and chromosomal DNA; nucleocytoplasmic transport, Study of cell organelles: Mitochondria, Chloroplasts, Golgi, ER and lysosomes; Cell surface signaling: Signaling pathways involving ligands and receptors; Cellular cytoskeleton: Microtubules, Intermediate filaments, actin filaments and microtubule associated proteins (MAPs); Molecular motors and cytoskeletal proteins; Movement of proteins into membranes and organelles; Vesicular trafficking; Secretion, endocytosis and exocytosis; Protein aggregation and protein degradation and chaperones, ubiquitinations and other modifications; Cell-Cell junctions; Cell-ECM junctions, Plasmodesmata; Cell death and cellular apoptosis; Introduction to stem cells, plant meristem; Concept of microscopy (fluorescence and electron microscopy).

Suggested Reading:

- Molecular Biology of the Cell: Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walte; 5th edition New York: Garland Science; 2008.
- Essential Cell biology: Bruce Alberts; Garland Science; 3rd edition; 2009.
- Cell and Molecular Biology-Concepts and Experiments; Gerald Karp. John Wiley; 6th edition; 2008.

BIO 302: Biochemistry-II **(3)**

Ribozymes, Mechanism of energy production: mitochondrial electron transport chain and Chemo-osmotis theory; coenezymes and cofactors, NAD, FAD. Vitamins. Fatty acid biosynthesis and degradation: Digestion, Mobilization, and Transport of Fats, Oxidation of

Fatty Acids, Ketone Bodies; Amino acid biosynthesis and degradation; nitrogen excretion and the Urea Cycle; Nucleotide metabolism: Pathways and their regulations.

Suggested Reading:

- Principles of Biochemistry: Lehninger, Nelson and Cox; 5th edition, W.H. Freeman; 2008.
- Biochemistry: Lubert Stryer; W. H. Freeman; 7th Edition; 2010.
- Biochemistry by Donald Voet, Judith G. Voet; Wiley; 4th edition; 2010.
- The Biophysical Chemistry of Nucleic Acids and Proteins: Thomas E. Creighton; Helvetian Press; 2010.

BIO 303: Biochemistry I (3)

Bioenergetics, Biological oxidation reduction reactions, ATP and its role in various metabolic processes; Functions of various proteins: Immunoglobulin, Oxygen carrier proteins, An introduction to enzymes: Mechanism of enzyme action, introduction to enzyme kinetics, Km, Vmax and Kcat calculation, Enzyme inhibition (Competitive and non competitive), IC50, Allostery, cooperativity, Hill's coefficient; Biological Membranes and Transport: The composition and architecture of membranes, membrane dynamics, Transporter proteins solute transport across membranes; Cell signaling- Receptors and second messenger; Metabolic pathways; Glycolysis, gluconeogenesis, pentose phosphate pathway and their regulations; TCA/Kreb's cycle and its regulation: Production of Acetyl-CoA, reactions of the Citric Acid Cycle Glyoxylate pathway.

Suggested Reading:

- Principles of Biochemistry: Lehninger, Nelson and Cox; W.H. Freeman; 5th edition; 2008.
- Biochemistry: Lubert Stryer; W. H. Freeman; 7th Edition; 2010.
- Biochemistry by Donald Voet, Judith G. Voet; Wiley; 4th edition; 2010.
- The Biophysical Chemistry of Nucleic Acids and Proteins: Thomas E. Creighton; Helvetian Press; 2010.

BIO 304: Molecular Biology (3)

DNA replication: Unit of replication, Enzymes involved, origin of replication and replication fork, Fidelity of replication, extrachromosomal replicons; DNA damage and repair- mechanisms, homologous and site-specific recombination; RNA Synthesis: transcription factors and machinery; initiation complex formation, activators and repressors of transcription, RNA polymerases, capping, elongation, and termination, RNA processing, RNA editing, splicing, and polyadenylation, different types RNA: structure

and functions, RNA transport; Protein synthesis: Ribosome, formation of initiation complex and regulation of initiation factors, elongation and elongation factors, termination, concept of genetic code, translation: aminoacylation of tRNA, tRNA-identity, aminoacyl tRNA synthetase, and proof-reading, inhibitors of translation, post-translational modification of proteins; Protein structure-function correlation: DNA recognition, enzyme catalysis, membrane proteins, proteins of the immune system, viruses; Protein degradation; Protein engineering and design; Techniques for study of protein structures; Regulation of gene expression: Gene expression control at transcription and translational level; Chromatin and gene expression; Gene silencing. siRNA and microRNA; Restriction endonucleases, Recombinant DNA technology and applications: Cloning, plasmid vectors (shuttle and expression vector, RFLP, electrophoresis, heterologous protein expression and promoters). Hybridization processes (Northern, southern and Western)

Suggested Reading:

- Genes – Benjamin Lewin; Jones & Bartlett Learning, 10th edition; 2009.
- Molecular biology of the gene: James D. Watson, Tania A. Baker, Stephen P. Bell, Alexander Gann, Michael Levine, Richard Losick; Benjamin Cummings; 6th edition; 2007
- Molecular Biology of the Cell: Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, Peter Walter; New York: Garland Science; 5th edition; 2008.
- The Biophysical Chemistry of Nucleic Acids and Proteins: Thomas E. Creighton; Helvetian Press; 2010.
- Introduction to Protein Structure: Carl Branden and John Tooze; Garland Science; 2nd edition; 1999.
- Latest/classic research articles and reviews relevant to various topics.

BIO 305: Plant Physiology (3)

Plant Water Relations: Osmosis, diffusion, Mechanisms of water uptake in plants, Bulk-flow hypothesis, transpirational pull, caviation; Solute transport: Transport proteins in plants and their importance; Mineral Nutrition, Classification of mineral elements required by plants, their importance, deficiency symptoms, Hydroponics, different media for plant growth, mineral toxicity, phytoremediation; Mineral assimilation: N2, Sulfur and phosphorous metabolism, Biological Nitrogen fixation, Nodulation, Nod and Nif genes, Nitrogenase enzyme; Photosynthesis: Discovery, Evidence of existence of two photosystems, Macromolecular; organization of PSII and PSI, Photosynthetic Electron transport chain, Photoinhibition, KOK Cycle, Dark Reaction, C3, C2, C4 and CAM, KRANZ anatomy, Starch metabolism; Phloem Transport: Structure and function of Phloem, sieve tubes; Plant Secondary Metabolites, Plant Defense mechanisms: PR

proteins; Hypersensitive response, involvement of phytohormone in plant defense, Systemic acquired resistance; Plant Signaling: Basic mechanism of two-component signaling, involvement of protein shuttling, modification and degradation in gene regulation; Phytochrome, Light controlled Plant Development; Blue Light response and signaling; Phytohormones-Auxin, GA, Cytokinin, ABA, Ethylene, Brassinosteroids, mutants and commercial uses of hormones; Flowering: Regulation of flowering in plants, Vernalization, mutants; Physiology and Abiotic stress response and tolerance: Plant Biotechnology: Micropropagation, Progammed Cell Death and Senescence.

Suggested Reading:

- Plant Physiology: Salisbury and Ross; Brooks/Cole; 4th Revised edition; 1991.
- Plant Physiology by Lincoln Taiz and Eduardo Zeiger; Sinauer Associates Inc. 5th edition. 2010.

BIO 306: Animal Physiology (3)

Tissue system and their functions: Epithelial tissue, Connective tissue, muscular tissue and nervous tissue; Principles of physiology: relationship between structure and function, Adaptation, Homeostasis, Feed-back control systems and regulation; Methods for exploring physiological mechanisms: Use of Molecular, Cellular and biochemical techniques; Endocrine system: Hormones and their Physiological effects; Respiratory system: respiratory pigments, transport of gases in blood, regulation of body pH; Excretory system: Osmoregulation, osmoregulators, obligatory exchanges of ions and water. Osmoregulation in water and terrestrial environment; Nervous system; Digestive system: Acquisition of Energy: Metabolism, and absorption; Reproductive System and unifying themes of animal development.

Suggested Reading:

- Animal Physiology: Hill, Wyse and Anderson; Sinauer Associates, Inc; 3rd edition; 2012.
- Animal Physiology by Randall Burggren & French; W. H. Freeman; 5th edition; 2001.
- Text book of Medical physiology: Guyton and Hall; Saunders; 12th edition; 2011.

BIO 307: Biology Laboratory-I (3)

- Isolation of total RNA from Plant Tissues.
- Isolation of Plant Chloroplast or mitochondria (any one)
- Protoplast preparation/ visualization of stomata
- Coleoptile bending experiment

- Fractionation of cellular organelles using centrifugation and validation by immunoblotting.
- Enzyme kinetics (with or without inhibition) for alkaline phosphatase.
- Purification of proteins using affinity chromatography
- Detection of proteins by CBBR and silver staining
- Size exclusion chromatography for analysis of proteins and nucleic acids
- Introduction to animal cell culture
- Immunofluorescence

BIO 308: Biology Laboratory-II (3)

- Estimation of Hemoglobin using hemometer.
- Estimation of Sugar in blood/urine by glucometer.
- Analyzing the components of blood.
- In vitro transcription.
- In vitro translation.
- Gene amplification from bacterial genome and cloning into commercial vectors; verification of positive clones.
- Protein expression screening in BL21 strains and one-step purification from whole cell lysates.
- Analysis of chromatin structure by Micococcal nuclease.
- Analysis of histones by 2-Dimensional gel electrophoresis.
- Analysis of protein expression upon DNA damage.
- Yeast transformation.

BIO 309: Microbiology (3)

The Scope of microbiology, History of microbiology, Different types of microbes- Algae, Protozoa, Fungi, Viruses, Bacteria, Characterization, classification and identification, Pathogenic and non pathogenic microbes, Morphology and fine structure of bacteria, Gram +ve and Gram –ve bacteria, Cultivation of bacteria and the unculturable ones, Microbes with unusual properties, reproduction and growth, energy production and utilization, microbial motility, pathogenesis and defense mechanisms, control of microbes, antibiotics, environmental microbiology- soil, ocean, skin, gut, food etc., Industrial microbiology, Introduction to microbial genomics and sequencing

Suggested Reading:

- Microbiology 5E by Michael PelCzar, et al.
- General Microbiology by Roger Yate Stanier, et al.

BIO 401/601: Immunology (4)

Introduction to Immune System: organs, cells and molecules; Mechanisms of barrier to entry of microbes into human body. Natural and adaptive immune responses; Differentiation of stem cells to different cellular elements in blood, role of cytokines; Introduction to inflammatory reaction, Chemokines, migration of neutrophils to the site of infection, phagocytosis and microbicidal mechanisms. Interferons and viral infections, Parasitic infections and role of Eosinophils Asthma. Basophils, IgE receptor, immediate hypersensitivity; Innate receptors (TLR, RLRs and NLRs) and sensing of PAMPs. Signal transduction. Opsonization, Fc Receptors, classification. Prostaglandins and leukotrienes. Complements structure and function. Classical and alternative pathways; Antibody structure and function. Classification of immunoglobulins, immunoglobulin domains, concept of variability, crosses reactivity. Isotypes, allotypes and Idiotypic markers; Idiotypic network Immunoglobulin genes, VJ/VDJ rearrangements and genetic mechanisms responsible for antibody diversity, affinity maturation, allelic exclusion; Class switching, receptor and soluble forms of immunoglobulin; Concept of Histocompatibility. Genetic organization of H2 and HLA complexes. Class I and class II MHC molecules, structure and function; T cell receptors, APC-T cell interaction T cell activation, Th1 Th2 cells and cytokines. Intercellular antigen presentation pathways, antigen presentation and MHC restriction; T cell differentiation in thymus, aβ and gd T cells. Thymic selection and tolerance to self. Cytotoxic T cells. Super antigens; Natural Killer Cells, ADCC, Hybrid resistance, NK cell receptors and NK gene complex, inverse correlation with target MHC expression, missing self hypothesis; Immunological techniques, Hybridoma and monoclonal antibodies.

Suggested Reading:

- Essential Immunology: Peter J. Delves, Seamus J. Martin, Dennis R. Burton, Ivan M. Roitt; Wiley-Blackwell; 12th edition; 2011.
- Immunobiology: The immune system in health and disease by Charles Janeway, Paul Travers, Mark Walport, Mark Shlomchik; Garland Science; 5th edition; 2001.
- Kuby Immunology; W. H. Freeman & Company; 6th edition; 2006.

BIO 402/602: Bioinformatics (4)

Introduction to bioinformatics, overview, concepts, utility, scope, applications, skills needed, sequences, biological data; Databases, web resources: NCBI- Entrez, PubMed, GenBank, data organization and retrieval using FTP from NCBI, DDBJ, UCSC, PDB, SwissProt, KEGG, and web resources; Sequence formats: FASTA, GenBank, EMBL, PDB, XML, Medline, GCG, etc. Conversion from one format to another, tools available for format interconversion; Sequence alignment algorithm and tools: Introduction to sequence alignment, homology, similarity, identity. Local and global alignments, multiple sequence alignments, insertions, deletions, gaps, Needleman-Wunsch algorithm, Dot

matrix method, dynamic programming algorithm, scoring matrices- PAM and BLOSUM, Blast, Blat, Clustalw, MAFFT, BLOCKS, etc.; Prediction of genes and annotation methods: Concept of genes, challenges in gene prediction, ORFs, reading frames, codons and codon bias, genetic code, commonly used gene prediction methods- ORF finder, Glimmer, GeneMark, Metagene, etc. Annotation using homology-based alignment using Blast or Blat, COGs and Gene ontology based functional annotation; Phylogenetic analysis: concepts and terminologies, commonly used phylogenetic methods such as PHYLIP, MEGA. Introduction to rRNA, taxonomy and taxonomic classification. Maximum parsimony method, Distance methods, Neighbor-joining methods; Protein classification and structure prediction: Introduction to domains, motifs, fold, family, Helices, beta-sheets, loops, coils. Primary, secondary and tertiary structure. Structure visualization tools such as RasMol; Genome analysis: Introduction to genomes and packages for genomic analysis such as EMBOSS; Introduction to Linux and Perl.

Suggested Reading:

- Bioinformatics- Sequence and Genome Analysis by David W. Mount; Cold Spring Harbor Laboratory Press,U.S.; 2nd Revised edition edition; 2004.
- Introduction to Computational Genomics by Nello Cristianini and Matthew W. Hahn; Cambridge University Press; 2007.

BIO 403/603: Structural Biology (4)

Proteins from primary to quaternary structures: Amino acids, primary sequence, peptide bond, dihedral angle, Geometry and chemistry of di-peptide, Ramachandran map, Secondary structural elements and their geometric description. Collagen triple helix, Super secondary structure, Structural domains, Quaternary association of globular proteins; Basics of nucleic acid structure: The building blocks, DNA secondary structure: the Double Helix, Deviation from the ideal geometry, higher-order structure and nucleosomes, tertiary structure of RNA; Protein structure, function and mechanism: Examples of protein three dimensional structures, molecular mechanism of enzymatic function, protein-protein interaction, chaperons, membrane proteins; Virus structure and assembly; Structural biology and evolution; Current topics in structural biology: membrane protein structure, Signal transduction, cell motility, cell-cell interaction, immune system, protein folding and degradation.

Suggested Reading:

- Biochemistry: Lubert Stryer; W. H. Freeman; 7th Edition; 2010.
- Introduction to Protein Structure: Carl Branden and John Tooze; Garland Science; 2nd edition; 1999
- Research Articles as per requirements.

BIO 404/604: Neurobiology (4)

Organization of the nervous system; Cytology of neurons- structural and functional blue print of neurons, sensory and motor neurons; Ion-channels- importance of ion channel in nerve physiology, characteristics of ion channels, structure of ion channels, techniques used to study ion channels; Bioelectricity, measurement of bioelectricity; Electrical properties of neurons; Membrane potentials- resting membrane potential, Ionic basis of membrane potential; Generation and propagation of action potential; Synaptic transmission- membrane trafficking at nerve terminals, local machinery at nerve terminals for vesicle recycling, genetics and cell biology of synaptic vesicle trafficking; modulation of synaptic transmission; Neurotransmitters- properties, types and classification of neurotransmitters and their synthesis neuromodulators; Synaptic plasticity and its implication in learning and memory; Introduction to perception (with emphasis on Pain, Visual and Odor perception).

Suggested Reading:

- Principle of neural science: Eric R. Kandel, James Schwartz, Thomas Jessell, Steven Siegelbaum, A.J. Hudspeth; McGraw-Hill, 5th edition; 2012
- From Neuron to Brain: Nicholls, Martin, Wallace and Fuchs; Sinauer Associates; 4th edition; 2001.

BIO 405: Biology Laboratory-III (3)

- Immunization of mouse/Rabbit by defined antigen such as OVA
- Estimation of antibody by ELISA
- Preparation peritoneal exudates cells (PECs) from mouse by thioglycollate injection
- Isolation of PECs
- Cell counting
- Culturing and stimulation of PECs with LPS
- Estimation of cytokine by ELISA
- Western blotting experiment
- Modeling protein and DNA secondary structures and tertiary folds (group experiment)
- Protein/DNA secondary structure estimation
- Thermodynamic estimation of protein/DNA stability
- Protein degradation under various conditions.

BIO 406/606: Cancer Biology (4)

Cell division, aneuploidy, polyploidy and chromosomal translocations, consequential uncontrolled growth and cancer; Nature of cancer; carcinogens, DNA damage and mutagenesis; Inherited susceptibility to cancer; Genomic integrity and development of

cancer; Cancer cell cycle and tumor suppressor proteins, cell signaling; Cellular Oncogenes, mitogens and dysregulation of pathways in cancer; Growth factors and associated signaling pathways in cancer; Epigenetics in cancer; Tumor viruses and mechanisms of oncogenesis; Tumor metastasis; Angiogenesis; Cellular immortalization and activation of telomerase in cancer; Apoptosis; Stem cells; Tumor immunology; Role of cytokines and hormones in cancer; Immunotherapy and cancer gene therapy, chemo and radiation therapy.

Suggested Reading:

- The biology of Cancer: Weinberg RA; Garland Science; 2007.
- The Molecular Basis of Cancer: Mendelsohn J, Howley PM, Israel MA, Gray JW, Thompson CB (eds); Saunders Elsevier, Philadelphia; 3rd edition; 2008.

BIO 407/607: Virology (4)

Overview and history; Classification of viruses; Virion components and structure; Viral entry: Viral proteins and host cell surface receptors involved; Mechanisms of viral entry; Viral replication; Viral maturation and release; Pathogenic viruses : Respiratory viruses; Gastroenteritis causing viruses; Hepatitis viruses; Herpesviruses; Haemorrhagic fever causing viruses; Enteroviruses; Congenital viral infections; Retroviruses; Arboviruses and Viral zoonoses; Oncogenic viruses; Viruses implicated in exanthematous diseases.; Agents of viral encephalitis; Emerging and re emerging viral infections (In each of the above groups, to discuss briefly on the following: (i) viruses included (ii) epidemiology (iii) viral pathogenicity); Immunology of viral infections; Strategies for control of viral infections: Antiviral agents; Active and passive immunoprophylaxis; General laboratory methods for diagnosis of viral infections; Case studies from literature, evolving and emerging areas of interest.

Suggested Reading:

- Field's Virology: David M. Knipe, Peter M. Howley, Diane E. Griffin, Robert A. Lamb, Malcolm A. Martin, Bernard Roizman, Stephen E. Straus; Lippincott Williams & Wilkins; 5th edition; 2007.
- Jawetz, Melnick, & Adelberg's Medical Microbiology: Geo. F. Brooks, Karen C. Carroll, Janet S. Butel, Stephen A. Morse, Timothy A. Mietzner; McGraw-Hill Medical; 25th edition; 2010.

BIO 408/608: Bioinstrumentation (4)

Spectroscopy (UV/Vis spectroscopy, Fluorescence spectroscopy, CD spectroscopy); Principle of centrifugation (Density gradient centrifugation; Ultracentrifugation; Analytical centrifugation); Microscopy; (Bright field and dark field microscopy;

Fluorescence microscopy; Confocal microscopy; Electron microscopy); Sequencing of protein and nucleic acid; Next generation sequencing; Realtime QPCR; Chromatography (Ion exchange, Gel filtration, Affinity, Thin-layer); Radioisotope technology.

Suggested Reading:

- Analytical ultracentrifugation for the study of protein association and assembly, Geoffrey J Howlett, Allen P Minton, Germán RivasCurrent Opinion in Chemical Biology Volume 10, Issue 5, October 2006, Pages 430–436
- Analytical Ultracentrifugation: Sedimentation Velocity and Sedimentation Equilibrium. James L. Cole, Jeffrey W. Lary, Thomas Moody, and Thomas M. Laue
- Methods Cell Biol. 2008; 84: 143–179
- Molecular Cloning by Sambrook and Russel Chapter 12
- How to study proteins by circular dichroism Biochim. Biophys. Acta (2005) 1751: 119
- Principles of Fluorescence Spectroscopy by Lakowicz
- Confocal Microscopy for Biologists by Alan R. Hibbs
- Handbook of Biological Confocal Microscopy by James Pawley

BIO 409/609: Biophysics (4)

Basic principle of modern biophysical methods to study macromolecules from the atomic to cellular levels; Basic introduction to molecular spectroscopy: CD, fluorescence, Mass spectrometric technique, NMR spectroscopy; Introduction to X-ray crystallography, cryo electron microscopy; High resolution light microscopy, Atomic Force Microscopy, Single molecule manipulation; Introduction to Quantum Chemistry & Molecular Spectroscopy, Introduction to Statistical Mechanics; Statistical thermodynamics, lattice statistics, molecular distribution and correlation functions, molecular dynamics simulation; The problem of protein folding. Theoretical and experimental approaches to study protein folding; Introduction to Membrane Biophysics. Structure and function of membranes, experimental and theoretical tools for studying biological membrane.

Suggested Reading:

- Spectroscopy for the Biological Sciences: Gordon G; Wiley-Interscience; 1st edition; 2005.
- Biophysical Chemistry: Part II: Techniques For The Study Of Biological Structure And Function by Charles R. Cantor and Paul Reinhart Schimmel; pp 503. W H Freeman and Co, Oxford. 1980.

BIO 410/610: Advances in Genetics (4)

History of genetics; Mendelian Genetics; Extension of Mendelian genetics; Chromosomal theory of inheritance; Patterns of Inheritance; relationship between genotype and phenotype; Mutations and Repair; Linkage and recombination; Gene mapping; Genetic Fate mapping, Tetrad analysis; Functional genomics; Phage genetics; Genetic Analysis of populations and their evolution; Evolution at the molecular level. Making transgenic animals, Use of FLIP-FRT and Cre-lox system

Suggested Reading:

- Genetic Analysis and Principles: Robert Brooker; McGraw-Hill Science/Engineering/Math; 4th edition; 2011.
- Genetics- From genes to genomes: Leland Hartwell, Leroy Hood, Michael Goldberg, Ann Reynolds and Lee Silver, 4th edition; 2010

BIO 411/611: Advances in Microbiology (4)

Microbial taxonomy; Microbial metabolism; Energy production in eubacteria; Energy production in archaea; Microbial genetics; Modes of DNA transfer in bacteria; Bacteriophage biology; Phage display and lambda DNA library. Virus classification; Lytic and temperate phage; Bacteriophage genetics and gene regulation; Microbial Ecology; Nitrogen cycle; Sulphur cycle; Microbial Physiology; Mechanism of drug resistance; Signal Transduction in bacteria; Quorum sensing and Two component system; Stringent response in bacteria; Applied Microbiology (Food microbiology, Microbes and agriculture, Industrial microbiology).

Suggested Reading:

- Microbiology by Prescott, Harley and Klein; McGraw-Hill Science/Engineering/Math; 7th edition; 2007.
- Modern Microbial Genetics by Streips and Yasbin; Wiley-Liss; 2nd edition; 2002.
- Bacterial and Bacteriophage Genetics: Edward Birge; Springer; 5th edition (December 8, 2005.
- E. coli and Salmonella Typhimurium- Vol 1-2: Cellular and Molecular Biology by Neidhardt and Curtiss; American Society for Microbiology; 2 Volume Set edition. 1987.

BIO 412/612: Developmental Biology (4)

Mitosis and Meiosis, gametogenesis (plants and animals), fertilization and embryogenesis, morphogen gradients, differentiation, asymmetric cell division, cell fate and lineage determination; Developmental embryonic stages, zygotic division, incomplete division and consequences, Ecto, meso and endodermal development, neural plate and tube

formation; Early asymmetric division and generation of symmetry in developing embryo in animals and plants; Introduction to plant fertilization, ovule and egg and support cells; organogenesis and morphogenesis, metamorphosis, animal life cycle, sex determination and role of apoptosis in organ development; Role of morphogens and their gradient in axis patterning and determination. Concept of anterio-posterior, dorso-ventral and medio-lateral axis formation; Root and shoot development, seed formation (monocot/dicot) and germination; flowering and nonflowering plants; Model organisms like Drosophila, C. elegans, G. gallus, Xenopus. Cellular differentiation and senescence; Meristamatic tissue, development of root and leaf and floral tissues; Stem cells and pluripotency. iPS cells

Suggested Reading:

- Plant Development: The Cellular Basis: R. F. Lyndon; Topics in Plant Physiology 3. Series editors M. Black and J. Chapman; Unwin Hyman Ltd, 1990.
- Plant growth and Development: a molecular approach: DE. Fosket; Academic Press 1994.
- Developmental Biology: Scott F. Gilbert; Sinauer Associates Inc; 2010.
- Essential Developmental Biology: J. Slack; Wiley Blackwell Scientific. 2nd edition; 2005.

BIO 413/613: Stem Cell Biology (4)

Introduction to concepts in stem cell biology- stemness, potency, lineage, renewal, clonality, etc; Stages of early development (zygote to gastrula) in mouse and human; Classification of stem cells- based on potency, tissue of origin, stage of origin; Embryonic stem cell (ESC)- molecular mechanism of cell renewal and maintenance of pluripotency, epigenetic modifications, spontaneous and directed differentiation, comparison with embryonic carcinoma cells (ECC) and embryonic germ cells (EGC); Fetal stem cell in extra-embryonic tissues; Adult stem cell- stem cell niche, localization and identification of stem cells from various tissues and organs (skin, intestine, blood, brain, retina, muscle); Induced pluripotent stem cell (iPSC)- methods of reprogramming differentiated cells, comparison with ESC; Personalized pluripotent stem cells; Stem cells and cancer; Potential therapies using stem cells- modeling diseases using stem cells, stem cell and tissue engineering for skin graft, stem cell in corneal and retinal regeneration; stem cell therapy for sickle cell anemia, neural stem cells for central nervous system repair, stem cells to repair damaged heart, insulin producing cells for treatment of diabetes, stem cell gene therapy; Ethical issues and guidelines for stem cell research

Suggested Reading:

- Essentials of Stem Cell Biology: Robert Lanza et al, 2nd Edition, Academic Press, 2009.
- Stem Cells: A very short introduction, Jonathan Slack, Oxford University Press, 2012.

- Developmental Biology, Scott F. Gilbert, Eighth Edn, Sinauer Associates, Inc., 2006.
- Classical/recent research papers and reviews relevant to the topics.

BIO 414/614: Ecology (4)

Ecology of Individual Organisms (Physiological ecology- tolerance range, optima, acclimation, limiting factors, ecological indicators, energy balance, photosynthesis, respiration, storage, growth, reproduction, Abiotic factors: temperature, moisture, light, soil, fire, nutrients, pollution); Population Ecology (Population growth and regulation: birth rate, death rate, life tables, survivorship curves, population growth functions, carrying capacity, population pyramids, human populations Evolution: genotype, phenotype, evolution, natural selection, r and K selection, group selection, extinction; Trophic interactions: herbivory, predation, optimal foraging, functional and numerical response, biological control, parasitism, saprobism, competition, mutualism); Community Ecology (Community structure: dominance, diversity, spatial structure, ecological niche, assembly rules, guilds, ecotones; Community change: disturbance, succession, climax, phenology, seasonal pattern Ecosystem Ecology (Productivity and energy flow: food chain, food web, primary producers, primary production, secondary production, consumers, decomposers, decomposition, energy flow, biomass vs. production, ecological efficiency, detritus vs. grazing food chains, transport of production; Biogeochemistry: nutrient cycling, hydrologic cycle, watershed studies, biological control of atmosphere and ocean).

Suggested Reading:

- Life: the science of biology: Sadava, D, Purves, W.K., Orians, G.H., Heller; H.C. Freeman; 9th edition; 2011.
- Biology: Neil A. Campbell, Jane B. Reece, Robert B. Jackson, Michael L. Cain, Lisa A. Urry, Steven A. Wasserman, Peter V. Minorsky; Benjamin-Cummings Pub Co; 8th edition; 2007.

Advanced Topics in Biological Sciences *: (2)

BIO 501S/601S Epigenetics
BIO 503S/603S Advances in Microscopy
BIO 505S/605S Metagenomics and Genome Sequencing
BIO 507S/607S Structural Basis of Diseases
BIO 509S/609S Signal Transduction
BIO 511S/611S Cell Science and Technology
BIO 513S/613S Immunotechnology
BIO 515S/615S Stress Biology
BIO 517S/617S Membrane Biology
BIO 519S/619S Biomolecular NMR Spectroscopy

*S in the course code denotes short-module courses. Each topic will consist of 18-21 lectures of TWO credits each. It will consist of 3 lecture hours and 3 self study hours per week. Students will have to select 4 topics in the 9th semester. Ph.D. students can also credit these courses.

BIO 503S/603S: Advances in Microscopy (2)

Light, Lenses and Images; Light Microscopy- fluorescence microscopy: considerations and controls; Basics concepts in fluorescence, fluorophores and fluorescent markers; Genetically-encoded fluorescent markers and their application; Sample preparation and Image acquisition: parameters, controls and ways to make mistakes!; Live imaging, maintaining live cells and tissues during imaging; Video Microscopy and Video cameras; Applications of scientific grade EM-CCD cameras to Biological Imaging; Confocal Microscopy: Principles, Practice and limitation; Multiphoton deep-tissue imaging; High-resolution Imaging: STED, PALM and STORM; Understanding, processing, analyzing and quantify Images and data-set from a light microscope;Discussion of research paper that led to the advancement for fluorescence imaging.

Suggested Reading:

- Confocal microscopy for biologists by Allan R Hibbs
- Handbook of Biological Confocal Microscopy by James Pawley

BIO 511S/611S: Cell Science and Technology (2)

Basics of Cell Culture - Cell culture- primary culture and secondary culture, confluence, different morphologies of cell culture. Types and use of monolayer, suspension culture, different uses based on cell-types. How in vitro experiments are different from in vivo, special requirements for cells for culture and its importance in immunological studies.

Cryogenic Preservation, Storage and Recovery Different Biosafety Levels Labs/facility, Need for biosafety Labs/facility. Contamination in animal cell culture

Handling and Manipulating Cell Cultures - Passaging techniques by trypsin, scraping, EDTA, passaging of suspension cultures. Introduction of foreign material into cells through different transfection and electroporation techniques.

Cloning of gene and its Identification - Characteristics of vector and foreign DNA and uses based up on the size of DNA fragment being cloned. Mammalian expression vectors and its application. Different strategies for identification of clone-insertional inactivation, blue-white colony screening Site-directed mutagenesis

Techniques associated with Study of Gene- Studying location of a gene, Fluorescent In-Situ Hybridization, Genome In-Situ Hybridization, Studying Location and Dynamics of Gene Expression- Bioluminescence [luciferase assay and in vivo imaging], Microarray Technology

Cell Therapy as Regenerative Medicine- Organ Culture, Stem cell therapy, Cases of cardiovascular diseases and diabetes, Generating blood cells for transfusion

Suggested Reading:

- Culture of Animal Cells: A Manual of Basic Technique and Specialized Applications by R. Ian Freshney
- Essential immunology by *Ivan* M. *Roitt*
- Immunobiology by Janeway
- Latest research papers.

BIO 513S/613S: Immunotechnology (2)

Basic Antigen-Antibody Interaction based techniques- Agglutination, Precipitation, Flocculation, ELISA, ELIPSOT, RIA, Immunoblotting, Immunofluorescence, Polyclonal and Monoclonal antibody, FACS and MACS, Ferritin-Antibody Conjugate System

Classical Serological Techniques- Cellular Antigen, Agglutination-Haemagglutination Assay, Haemagglutinin Inhibition and Blood grouping, Lysis-Bacteriolysis and Haemolysis, Soluble Antigen-Precipitation, Immunodiffusion and Immunoelectrophoresis (1D, 2D and Radial)

Classical Serological cell based Techniques- Complement Fixation, Coomb's test, HLA typing, Tetramer Assay, Mixed Lymphocyte Reaction

Basic nucleic acid based Techniques- PCR Based Methods- Real-Time and Reverse Transcriptase PCR, Chromatin Immunoprecipitation.

Suggested Reading:

- Essential immunology by *Ivan* M. *Roitt*
- Culture of Animal Cells: A Manual of Basic Technique and Specialized Applications by R. Ian Freshney.
- Immunobiology by Janeway
- Latest research papers.

BIO 517S/617S: Membrane Biology (2)

Diversity in biological membranes; ion channels and transporters, the structure and function of ion channels including coverage of the classical work of Hodgkin and Huxley as well a description of our current understanding of the molecular structure of ion channels as deduced from sequence analysis of the channel proteins and high resolution x-ray crystallography, and current hypotheses about the structural basis of channel selectivity and gating; freeze fracture and negative stain analysis of membrane structure, localization of antibodies and other probes by fluorescence and electron microscopy, quantitative stereology of membranes, autoradiography, and electron probe analysis. Role of membrane lipids and proteins in signaling and human diseases.

Suggested Reading:

- Molecular Cell Biology by Lodish et al
- Membrane Microdomain Signaling: Lipid Rafts in Biology and Medicine by Mark Mattson

BIO 601: Immunology (4)

See contents of **BIO 401**

BIO 602: Bioinformatics (4)

See contents of **BIO 402**

BIO 603: Structural Biology (4)

See contents of **BIO 403**

BIO 604: Neurobiology (4)

See contents of **BIO 404**

BIO 606: Cancer Biology (4)

See contents of **BIO 406**

BIO 607: Virology **(4)**

See contents of **BIO 407**

BIO 608: Bioinstrumentation **(4)**

See contents of **BIO 408**

BIO 609: Biophysics **(4)**

See contents of **BIO 409**

BIO 610: Advances in Genetics **(4)**

See contents of **BIO 410**

BIO 611: Advances in Microbiology **(4)**

See contents of **BIO 411**

BIO 612: Developmental Biology **(4)**

See contents of **BIO 412**

BIO 613: Stem Cell Biology **(4)**

See contents of **BIO 413**

BIO 614: Ecology **(4)**

See contents of **BIO 414**

BIO 603S: Advances in Microscopy **(2)**

See contents of **BIO 503S**

BIO 611S: Cell Science and Technology **(2)**

See contents of **BIO 511S**

BIO 613S: Immunotechnology **(2)**

See contents of **BIO 513S**

BIO 617S: Membrane Biology **(2)**

See contents of **BIO 517S**

Chemistry

CHM 101: General Chemistry (3)

Atomic Structure, Periodic Table and the Concept of Periodicity: Atomic structure; Vector model of atom and electronic configuration of polyelectronic atoms; Atomic structure as the basis for periodicity; Applications of the periodic law. Effective nuclear charge; Slater's rules, screening effect. Size of atoms and ions, ionization energies; electronegativity, electron affinity; periodic properties of elements and periodic trends, diagonal relationships; Fajan's rules.

Chemical Bonding: Lewis theory; Formal charges, resonance and rationalization of structures; VSEPR theory and shapes of molecules. Applications of VSEPR theory in predicting trends in bond lengths and bond angles. Molecular orbital theory of homo and heterodiatomic molecules, concept of HOMO, LUMO and SOMO. The solid state structures, lattice energy and Born-Haber cycle.

Electronic effects: Dipole moment, inductive and field effects, polarizability, resonance effect, hyper-conjugation; fundamental aspects of aromaticity.

Acids and Bases: Various theories of Acids and bases; Brønsted acids and bases. Protonic acids, gas-phase *vs* solution behavior of acids. Lewis acidity, 'Hard' and 'Soft' Acids and Bases. Solid acids. Concepts of pH, pK_a, pK_b as applied in different chemical structures.

*Properties of the Gaseous State***:** Gas Laws, equation of states, critical constants, law of corresponding states, Distribution of molecular speeds and its applications, mean-free path, compressibility factor, barometric distribution law.

Heat capacity of gases, real gases and virial expansions.

Suggested Reading:

- *Concise Inorganic Chemistry*, J. D. Lee, Fifth Edition, Blackwell Publishing, 2006.
- *Basic Inorganic Chemistry*, F. A. Cotton, G. Wilkinson, P. L. Gaus, Third Edition, John Wiley and Sons Press, 1995.
- Shriver and Atkins, *Inorgranic Chemistry*, Ed. 4th, Oxford University Press 2006.
- Atkins, P.W., de Paula, J., *Physical Chemistry*, Ed. 9th, Oxford University Press 2009.
- *Chemistry and Chemical Reactivity*, J. C. Kotz, P. M. Treichel, J. R. Townsend, *7th Edition, Brooks/Cole, Cengage Learning, Canada*, 2010.
- *Chemistry*, R. Chang, 9th edition, McGraw-Hill, 2006.

CHM 102: Basic Inorganic Chemistry (3)

Concepts and principles of non transition metal chemistry: An overview of bonding models in inorganic chemistry, Chemical forces, Bent's rule, Application of molecular orbital theory to polyatomic molecules (localized and delocalized orbitals), Walsh diagrams, Fluxional molecules, Atomic inversion, Berry pseudorotation.

Main group Chemistry: General characteristics of s- and p-block elements [hydrides, oxides, halides], comparative study of second short period elements (B to F) with heavy congeners (Al to Cl). Electron deficient molecules, hyper-valency, concept of multi-centered bonding. General characteristics of Transition elements: Color, magnetism, and variable oxidation states.

Oxidation and Reduction: The central role of transfer of electrons in chemical processes. The importance of splitting of water. Redox chemistry of extraction (Ellingham diagrams). Conversion of chemical energy into electricity. Batteries and modern state of solid state batteries, Fuel cells.

Transition metal complexes: types of ligands and stereochemistry of complexes. Preliminary idea about crystal field theory [CFT] (splitting of d-orbital energy levels for O_h, T_d and square planar complexes), application of CFT to explain color and magnetism of transition metal complexes. Concept of 18 electron rule among transition metal complexes. Preliminary ideas about relationship of transition metal complexes and metalloenzymes.

Radioactivity and Nuclear Chemistry: The nature of radioactive radiations, detection and measurements. Theory of disintegration, disintegration series. Half-life and average life period, artificial radioactivity, applications. Nuclear fission, nuclear fusion, critical mass.

Analytical Chemistry: Errors in Chemical Analysis, Precision and Accuracy, Mean, Median, Range, deviations, and errors. Principal of Gravimetric and volumetric Principals, classification of chromatographic techniques, paper chromatography, TLC, Column chromatography.

Suggested Reading:

- *Inorganic Chemistry*, Shriver and Atkins, Fourth Edition, Oxford University Press, 2006.
- *Concise Inorganic Chemistry*, J. D. Lee, Fifth Edition, Blackwell Publishing, 2006.
- *Basic Inorganic Chemistry*, F. A. Cotton, G. Wilkinson, P. L. Gaus, Third Edition, John Wiley and Sons Press, 1995.
- *Concepts and Models of Inorganic Chemistry*, B. Douglas, D. McDaniel, J. Alexander, Wiley India (P.) Ltd., India, 2010.

CHM 103: General Chemistry Laboratory (1)

Suggested Experiments:

- Synthesis of cyclohexanone oxime.
- Acetylation of salicylic acid.
- Synthesis of polymer, Nylon 6-10.
- Determination of strength of acid and base.
- Estimation of acetic acid in vinegar solution.
- Preparation of hexamine nickel chloride $[Ni(NH_3)_6]Cl_2$.
- Detection of common cations and anions.
- The clock reaction
- Thin Layer Chromatography
- Photochemical reduction of ferric oxalate.

CHM 104: Inorganic Chemistry Laboratory I (1)

Suggested Experiments:

- Estimation of Calcium in Milk Powder through EDTA complexometry.
- Estimation of Iodine in Iodized common salt.
- Determination of Acid neutralizing power of Commercial Antacids.
- Estimation of Phosphoric acid in a Cola by Mo-Blue method.
- Recycling of Aluminum: Preparation of Potash Alum from waste Aluminum
- Blueprinting: Study of Photochemical Reduction of a Ferric salt.
- Preparation of $[Ni(NH_3)_6]^{2+}$&Ni estimation (Complexometry & Gravimetrically)
- Caffeine Isolation from Tea Leaves.
- An Experiment of Chromatography: Both TLC and Column separations.
- Separation of β-Carotene & Chlorophyll from Spinach extract by Paper Chromatography
- Preparation of Ni or Co-Acetylacetonate.
- Preparation of a Metal Complex with a Multidentate Ligand: Preparation of Poly-nuclear Thiourea Complex of Copper (I)
- Preparation of a Polystyrene Film.

CHM 211: Basic Organic Chemistry (3)

Stereochemistry:

- Fischer, Newman, saw-horse, etc., projection formulae
- Conformational analysis of ethane, propane, butane, cyclohexane and monosaccharides

- Stereoisomerism, configuration (*R*, *S*), optical isomerism in compounds with one and two chiral centers, and without an asymmetric atom, nomenclatures such as erythro, threo, *α*, *β*, endo, exo epimers, anomers, *E*, *Z*, etc., resolution of racemic compounds
- Biodiscrimination of stereoisomers (amino acids, thalidomide, DOPA, nicotine, morphine)
- *Reactive Intermediates and molecular rearrangements:*
- Introduction to structure, formation, stability and reactions of carbocations, carbanions, free radicals, radical anions, radical cations, arynes, carbenes and nitrenes (in brief)
- Molecular rearrangements (basic principles and migratory aptitude): Wolff, Curtius, Beckmann, Baeyer-Villiger, pinacol-pinacolone, etc.
- *Organic Reactions:*
- Electrophilic and radical additions to alkenes, electrophilic and nucleophilic aromatic substitutions, nucleophilic aliphatic substitutions: S_N1, S_N2, S_Ni reactions, neighbouring group participation, elimination reactions: E1, E2, and E1cB reactions
- Functional group transformations and their reaction mechanisms

Suggested Reading:

- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.
- Hornback, J. M. *Organic Chemistry*, Cengage Learning, **2006**.
- Solomons, T. W. G., Fryhle, C. B. *Organic Chemistry*, John Wiley and Sons, **2007**.
- Morrison, R. M., Boyd, R. N. *Organic Chemistry*, Pearson Education, **2008**.
- Sykes, P. A. *A guide book to mechanism in organic chemistry*, Longman, **2008**.

CHM 213: Organic Chemistry Laboratory I (1)

Suggested Experiments:

- Calibration of melting point apparatus thermometer
- Hydrolysis of ester: Preparation of salicylic acid from methyl salicylate
- Etherification of alcohol: Preparation of 2-ethoxynaphthalene
- Preparation of amide: Synthesis of acetanilide from aniline
- Oxidation of olefin with $KMnO_4$: Preparation of adipic acid from cyclohexene
- Reduction of ketone: Preparation of benzhydrol by $NaBH_4$ reduction of benzophenone
- Aldol reaction: Preparation of dibenzylideneacetone
- Electrophilic aromatic substitution: Nitration of acetanilide
- Nucleophilic substitution reactions: The effect of substrate structure on the reactivity under S_N1 and S_N2 conditions
- Preparation of pyridinium chlorochromate (PCC)

- Beckmann rearrangement: Preparation of benzanilide from benzophenone oxime
- Esterification of an aromatic acid.
- Synthesis of an azo-dye.
- Dakin oxidation of an aromatic aldehyde.

CHM 222: Classical Thermodynamics (3)

Zeroth law of thermodynamics and concept of temperature. First Law of thermodynamics, second law of thermodynamics and concept of entropy, free energy, criteria for equilibrium and stability, third law of thermodynamics.
Phase rule, Claussius-Clayperon equation, phase transitions in one-component systems, chemical equilibrium, interrelations between K_p, K_c and K_x, effect of temperature and pressure on equilibrium constant.
Ideal and non-ideal solutions. Raoult's law and Henry's law. Colligative properties.

Suggested Reading:

- Atkins, P. W., de Paula, J., Physical Chemistry, Ed. 9th, Oxford Press, **2009.**
- Levine, I., Physical Chemistry, Ed. 6th, McGraw Hill, **2009**.
- Berry, R. S., Rice, S. A., Ross, J., Physical Chemistry, Ed. 2nd, Oxford Press, **2000**.
- Castellan, G. W., Physical Chemistry, Ed. 3rd, Narosa Publishing House, **2004**.

CHM 224: Physical Chemistry Laboratory I (1)

Suggested Experiments:

- Determination of acid dissociation constant (pKa) of (A) polybasic acid (H_3PO_4) (B) Monobasic Acid (CH_3COOH)
- Acidic and basic dissociation constants of glycine and its isoelectronic point
- Determination of dissociation constant and equivalent conductance at infinite dilution of weak electrolyte (acetic acid) using conductometry
- Kinetics of saponification of ethyl acetate using conductometry
- Kinetics of the iodide-hydrogen peroxide clock reaction
- Potentiometric Titration of a standard solution of KCl against AgNO3 – Determination of solubility product of AgCl
- Potentiometric Titration of a standard solution of AgNO3 against mixture of halides – Determination of concentration of two salts in a given mixture
- First order kinetics – Acid hydrolysis of methyl acetate (at 30°C) taking different concentrations of [H+] ions.
- First order kinetics – Acid hydrolysis of methyl acetate (at 40°C) taking different concentrations of [H+] ions.

CHM 301/641: Symmetry and Group Theory (4)

Molecular Symmetry: Symmetry elements and symmetry operations, definition of group and its characteristics, subgroups, classes, similarity transformation. Products of symmetry operations, relations between symmetry elements and operations, symmetry elements and optical activity, classes of symmetry operations, Conventions regarding coordinate system and axes, point group and classification, degenerate point groups, examples, Some properties of matrices, representation of groups, reducible and irreducible representations, the great orthogonality theorem, character tables, position vector and base vector as basis for representation, Wave functions as basis for irreducible representations (p- and d-orbitals) direct product, vanishing integral.
Symmetry adopted linear combinations: Projection operators and some examples, e.g. π-orbitals for the cyclopropenyl group etc.

Applications:

Symmetry Aspects of Molecular Orbital Theory: General Principles, symmetry factoring of secular equations, carbocyclic systems, more general cases of LCAO-MO bonding, examples, Huckel Molecular orbital theory systems, e.g., π-systems and conjugated π-systems, benzene and naphthalene, delocalization energies, resonance energies and aromaticity, the bond order (p) and free valence number (F), three centre bonding.
Hybrid orbitals and Molecular orbitals: transformation properties of atomic orbitals, hybridization schemes for bonding and for π -bonding, hybrid orbitals as LCAO, examples, MO theory for AB_n, molecular orbital theory for regular octahedral and tetrahedral molecules.
Molecular Vibrations: Normal Mode analyses *via* IR and Raman spectroscopy. Selection rules, spectral transition probability, vibronic coupling, electronic spectra of inorganic complexes and ions. Splitting of one electron level in an octahedral and tetrahedral environment.

Suggested Reading:

- *Chemical Applications of Group Theory*, F. A. Cotton, 3rd edition, Wiley InterScience, New York, **1990**.
- *Molecular Symmetry and Group Theory*, R. L. Carter, John Wiley & Sons, India, **2004**, **2005**.
- *Molecular Symmetry and Group Theory*, A. Vincent, 2nd Edition, John Wiley & Sons Ltd, England, **2001**.
- *Symmetry and Spectroscopy of Molecules*, K. Veera Reddy, New Age International (P) Ltd, India, **2010**.
- *Group Theory and Chemistry*, D. M. Bishop, Dover Publications, New York, **1993**.

CHM 302: Chemistry of Transition Metals (4)

Coordination Chemistry: Coordination number and stereochemistry of coordination complexes (coordination number 2-9). Electronic configurations and states, the group state and energy levels, free-ion term, Symmetry orbitals and bonding in transition-metals complexes: L-S coupling for d^n states, splitting of one electron levels in an octahedral and tetrahedral environment, Orgel and Tanabe-Sugano diagrams, Charge-Transfer bands, Jahn-Teller distortion. Applications of CFSE, Stereochemistry of non-rigid and fluxional molecules. Thermodynamic aspects of coordination complexes, Nephelauxetic effect, Irving William series, Factors affecting ligand field stabilization energies, First row transition elements, heavy transition elements, M-M bonded complexes, C-H activation, agostic interactions, ortho-metallation. Kinetic aspects: reaction and aquation rates, electron transfer reactions. Reaction mechanism in inorganic reactions. Redox reactions, Trans effect.
Chemistry of Lanthanides and Actinides: Electronic configuration, colour and magnetism, properties of lanthanides and actinides. Synthesis of trans-Uranic elements, chemistry of uranium compounds.
Organometallic chemistry: 18e rule and its exceptions, isolobal and isoelectronic analogies. σ and π bonding, types of ligands, soft *vs* hard ligands. Structure, bonding and reactivity studies of metal carbonyls, nitrosyls, dinitrogen complexes. Homogeneous and heterogeneous catalysis, oxidative addition, reductive elimination reactions, organometallic complexes with metal-metal bonds.
Molecular Magnetism: Paramagnetism, Diamagnetism and Ferromagnetism, Neel and Curie Temperature, Magnetic Susceptibility.
Inorganic Chemistry of Biological Systems: Essential and trace elements in biological systems, energy sources for life, metalloporphyrins, dioxygen binding, transport, and utilization.

Suggested Reading:

- Inorganic Chemistry-Principles of Structure and Reactivity. J. E. Huheey, E. A. Keiter, R. L. Keiter, 4th Edn. Harper-Collins, NY, **1993**.
- Chemistry of the Elements. N. N. Greenwood, and Earnshaw, A. 1st Edn. Pergamon, Oxford, **1989**.
- Concepts and Models of Inorganic Chemistry. B. Douglas, D. McDaniel, J. Alexander, 3rd Edn. John Wiley, New York, **1993**.
- Advanced Inorganic Chemistry. F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, 3rd Edn. John Wiley and Sons Press, **1995**.
- Modern Inorganic Chemistry. W. L. Jolly, 2nd Edn. McGraw-Hill, NY, **1991**.
- Inorganic Chemistry. D. F. Shriver, and P. W. Atkins. 3rd Edn. Oxford University, Oxford, **1999**.

- Theoretical Inorganic Chemistry, M. C. Day, 2nd Edition, East-West Press, India, **2007**.
- Essential Trends in Inorganic Chemistry, D. M. P. Mingos, OUP, New York **2010**.
- Inorganic Chemistry, G.Wulfsberg, Viva Books P. Ltd, India, **2010**.
- *Advanced Structural Inorganic Chemistry*, W.-K. Li, G.-D. Zhou,T. C. W. Mak, IUCr Monograph, OUP, New York, **2008**.

CHM 304: Inorganic Chemistry Laboratory (3)

Suggested Experiments:

- Determination of spectrochemical order of ligands by using electronic spectroscopy of Nickel(II) coordination complexes.
- Demonstration of *cis-trans* isomerisation in coordination chemistry: Case of Cobalt(III) complexes
- Chemistry of a five-coordinate d^1 complex: Case of $V(O)(acac)_2$.
- The effect of symmetry on the infrared spectrum of the sulphate group
- Synthesis and catalytic application of a solid acid, 12-Tungstosilicic acid.
- Synthesis, purification, and metallation of a bio-inorganically important porphyrin ligand
- Organometallic synthesis: Synthesis of ferrocene
- NMR spectroscopic investigation of molecular fluxionality: Case of an allyl-palladium complex
- Synthesis and electrochemistry of $[Ru(bpy)_3]^{2+}$.
- Preparation, recording and indexing of PXRD patterns of simple cubic solids.
- Synthesis of 123-superconductor.

CHM 311: Organic Chemistry I (4)

Stereochemistry:

- Conformational analysis, conformation of acyclic, cyclic, fused and bridged systems
- Strain in cyclic and acyclic molecules including allylic strain ($A^{1,2}$ and $A^{1,3}$)
- Dynamic stereochemistry: Conformation and reactivity, Curtin-Hammett principle

Rearrangement Reactions:

- Electrophilic (Beckmann, Hofmann, Lossen, Curtius, Wolff, Schmidt, Baeyer-Villiger, Pinacol-pinacolone, Wagner-Meerwein etc.), nucleophilic (benzilic acid, Favorskii), and radical rearrangements (Wittig, aza-Wittig)
- Sigmatropic rearrangements (Cope, aza-Cope, Oxy-Cope, Claisen, aza-Claisen, Eschenmoser-Claisen, vinyl cyclopropane-cyclopentene)
- Miscellaneous (Brook, Pummerer)

Oxidations:

- Oxidation of alcohols, ketones and aldehydes (transition metal oxidants, hypervalent iodine based, sulphur based, peroxide and peracid, etc.)
- Oxidation of C-C double bonds (Ozone, $KMnO_4$, $Pb(OAc)_4$, Dimethyldioxirane, OsO_4, 2-sulfonyl oxaziridine etc.)
- Oxidation at unfunctionalized carbon

Reductions:

- Reduction of carbonyl compounds (hydrogenation, reductions using group III, IV hydride donors, reductive deoxygenation), carbon-carbon multiple bonds (catalytic hydrogenation, diimide reduction) and other selected functional groups
- Dissolving metal reductions

Heterocyclic Chemistry:

- General overview and nomenclature of heterocyclic compounds (structure of 3 to 7 membered saturated and 5,6 membered aromatic heterocycles)
- Synthesis and reactions of heterocyclic compounds (in brief)

Suggested Reading:

- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.
- Eliel, E. L., Wilen, S. H., Doyle, M. P. *Basic Organic Stereochemistry*, John Wiley and Sons, **2001**.
- Smith, M. B. and March, J. *Advanced Organic Chemistry*, Wiley Interscience, **2007**.
- Carey, F. A, Sundberg, R. J. *Advanced Organic Chemistry*, *Part A and B*, Springer, **2007**.
- Anslyn, E. V., Dougherty, D. A. *Modern Physical Organic Chemistry*, University Science Books, **2005**.
- Hornback, J. M. *Organic Chemistry*, Cengage Learning, **2006**.

CHM 312: Organic Chemistry II **(4)**

Carbon-Carbon Bond Forming Reactions:

- *via* enolate, enamine and imine chemistry
- Grignard, cuprate and other conjugate reactions
- Olefination (Wittig, HWE, Julia and Peterson) and cyclopropanation reaction
- Radical reactions
- Other classes (via organo silane, borane and tin based reagents, Baylis-Hillman reaction)
- Introduction to Pericyclic reactions

Enantioselective Reactions:

- Principles of enantioselective reactions
- Enantioselective reduction of carbonyl compounds (Corey's oxazaborolidine catalyzed reductions and Noyori's BINAP reduction)
- Enantioselective epoxidation of olefins (Sharpless, Jacobsen, Shi, etc.)

Introduction to Retrosynthesis:

- Basic concepts of retrosynthesis
- Demonstration of its utility with few examples

Suggested Reading:

- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.
- Carruthers, W., Coldham, I. *Some Modern Methods of Organic Synthesis*, Cambridge University Press, **2004**.
- Smith, M. B. and March, J. *Advanced Organic Chemistry*, Wiley Interscience, **2007**.
- Carey, F. A., Sundberg, R. J. *Advanced Organic Chemistry, Part A and B*, Springer, **2007**.
- Smith, M. B. *Organic Synthesis*, McGraw-Hill, **2001**.
- Warren, S. *Organic Synthesis: The Disconnection Approach*, Wiley, **1983**.

CHM 313: Organic Chemistry Laboratory II (3)

Suggested Experiments:

- Preparation of Corey-Bakshi-Shibata (CBS) reagent and enantioselective reduction of a carbonyl compound.
- Preparation of pentacyclic dione via Diels-Alder and photochemical cyclizations.
- Preparation of a Wittig salt and olefination of a carbonyl compound
- Preparation of Evans chiral auxiliary and its use in asymmetric aldol reaction
- Preparation of a Grignard reagent and its addition to a carbonyl compound
- Generation and trapping of benzyne
- Generation of a carbene: The Reimer-Tiemann reaction
- The Fischer indole synthesis
- Sonogashira/Suzuki/Heck coupling reaction
- Olefin metathesis (using Grubbs 1st generation catalyst)
- Baylis-Hillman reaction
- Synthesis of L-Prolinamide ligands
- Synthesis of BINOL
- Synthesis -nitro styrene (Henry reaction)□bf
- Ugi multicomponent coupling.

CHM 321: Physical Chemistry of Solutions (4)

Phase transitions in multi-component systems.

Ionic solutions: Mechanism of electrolysis and Faraday's laws. Conductance, electrolytic conductance, solvation of ions, Debye-Huckel-Onsager conductance equation, degree of dissociation, transport number, free energy and activity, Debye-Huckel limiting law, solubility equilibria, overview of electrode processes, electrical double layer, Faradaic reactions, mass transfer controlled reactions, coupled chemical reactions.

Electrochemistry: Electrochemical cells and reactions, basics of electrochemical thermodynamics, Nernst equation, Butler-Volmer model.

Chemical kinetics: Order and molecularity, kinetics of zero, first and second order reactions. Parallel, reversible and consecutive reactions. Concept of steady state and its application. Arrhenius equation, Lindemann hypothesis, collision rate theory, transition state theory. Enzyme kinetics and catalysis.

Suggested Reading:

- Atkins, P. W., de Paula, J., *Physical Chemistry*, Ed. 9th, Oxford Press, **2009.**
- *Physical Chemistry,* Gilbert W Castellan.
- *Physical Chemistry,* Ira N. Levine.
- *Chemical Kinetics,* Keith J. Laidler.
- *An Introduction to Electrochemistry,* Samuel Glasstone.
- *Electrochemical Methods: Fundamentals and Applications,* Allen J Bard and Larry R. Faulkner, 2nd Edition, John Wiley and Sons.
- *Modern Electrochemistry Ionics: Volume 2,* John O'M. Bockris and Amulya K. N. Reddy, 2nd Edition, Plenum Press.

CHM 322/642: Principles of Quantum Chemistry (4)

Review of basic concepts of quantum theory: wave-particle duality and de Broglie wavelengths, uncertainty principle, superposition and state of a quantum system.

Mathematical background: Operators in quantum mechanics and their properties, eigenvalues and eigenfunctions, commutation relations, unitary transformations and change of basis. Matrix representation of operators.

*Postulates of quantum mechanics***:** States and wavefunctions, observables and the measurement hypothesis, Born interpretation of wavefunction, time evolution of states and the Schrodinger equation, stationary states, compatible observables and the generalized uncertainty principle.

*One-dimensional problems***:** Particle in a well and transmission through a barrier. Probability currents and the equation of continuity. Two and three-dimensional potential wells and degeneracy. Applications to conjugated molecules and other one-dimensional

systems. Linear harmonic oscillator – ladder operator method, parity of harmonic oscillator eigenfunctions. Rigid rotor problem, angular momentum, angular momentum eigenvalues and eigenfunctions.

The hydrogen atom: Atomic orbitals – radial and angular wavefunctions and distributions, electron-spin and spin operators. Virial theorem and application to hydrogen atom and other problems. Hydrogen-like atoms.

Atoms in external fields: Zeeman and Stark effect.

Approximation methods: Time-independent perturbation theory – Anharmonic oscillator, He atom, H^{2+} molecular ion. Variational theorem - He atom, H^{2+} molecule and the LCAO approach.

Suggested Reading:

- Levine, I., *Quantum Chemistry*, Ed. 6th, Pearson Press, **2009**.
- McQuarrie, D. A., *Quantum Chemistry*, Ed. 2nd, University Science Books, **2008**.
- Zettili, N., *Quantum* Mechanics, Ed. 2nd, John Wiley, **2009**.
- Atkins, P. W., Friedman, R. S., *Molecular Quantum Mechanics*, Oxford University Press, **2008**.

CHM 323: Solid State Chemistry (4)

General Concepts, Definitions: Structures of Ionic Solids (crystal chemistry), Metals and Alloys, Band Theory in Solids (Metals, Semiconductors, Inorganic Solids), crystal defects, non-stoichiometric compounds, solid solutions, dislocations and stacking faults.

Structure and Bonding in Solids (Crystalline and Amorphous): Factors governing formation of crystal structures, Lattice Energy, Effective nuclear charge, Kapustinskii's equation, Sanderson's Model, Bond Energy and Bond Order calculations, Mooser-Pearson plots, Ionicities, bond valence, bond length, non-bonding electron effects.

Phase Transitions: Buergers's (reconstructive and displacive), Ubbelohde's Classification (continuous and discontinuous), Applications of G-T diagrams, kinetics, critical size and nucleation rate, Avrami Equation, Martensitic, order-disorder transitions.

Ionic Conductivity and Solid Electrolytes: Conduction Mechanisms, Alkali Halides, Lithium, Silver, Oxide and Halide Ion conductors, Conductivity measurements (D.C. and A.C methods), Applications to electrochemical cells, batteries, sensors, and fuel cells.

*Structure Property Correlation in Inorganic materials***:** Electronic, Electrical, Magnetic, Optical (Luminescence), Dielectric, Ferroelectric and superconductivity.

*Preparative methods***:** Oxides, nitrides, fluorides and characterization of inorganic solids by different physical (diffraction, microscopic and spectroscopic) techniques.

Suggested Reading:

- Solid State Chemistry and its Applications: West, A. R. John Wiley & Sons, UK, 1987.
- Structure and Bonding in Crystalline Materials: Rohrer, G. S. 1st edition, Cambridge University Press, UK, 2001.
- New Directions in Solid State Chemistry: Rao, C. N. R. Gopalakrishnan, J. 2nd edition, Cambridge University Press, UK, 1997.

CHM 324: Physical Properties of Matter (4)

Intermolecular forces - excluded volume, Dispersion forces, van der Waals forces, dipolar interactions, hydrogen-bonding, covalent interactions, Lennard-Jones potential and Morse potential, electrostatic interactions, multipole expansions, polarizability.
Transport properties, Surface phenomena, adsorption kinetics, Langmuir, Freundlich and BET isotherms, surface tension, capillary rise and basic applications.
Micelles and reverse micelles, colloids, thermodynamics of polymer solutions.
Collision theory and potential energy surfaces.

Suggested Reading:

- Atkins, P. W. and de Paula, J., *Physical Chemistry*, Ed. 9th, W. H. Freeman, **2009**.
- Silbey, R. J., Alberty, R. A., and Bawendi, M. G., *Physical Chemistry*, Ed. 4th, Wiley, **2004**.
- Berry, R. S., Rice, S. A., and Ross, J., *Physical Chemistry*, Ed. 2nd, Oxford, **2000**.

CHM 331: Fundamentals of Supramolecular Chemistry (4)

Hydrogen Bonding and Nature of Supramolecular Interactions: Ion-Ion, Ion-Dipole, Dipole-Dipole, Cation-π, Anion-π, π-π, van der Waals, Close packing in Solid State and Hydrophobic Effects.

Concepts: Host-Guest Chemistry; Receptors, Coordination and the "Lock and Key" Analogy; Chelate, Conformational and Macrocyclic Effects; Pre-organisation and Complementarity; Thermodynamic and Kinetic Selectivity.

Ionic Recognition (Cation and Anion Binding Host): Selectivity and Solution Behaviour of Crown Ethers, Crytands, Spherands; Complexation of Organic Cations, siderophores, biological anion receptors, Anticrowns and Coordination Interactions.

Neutral Host Molecules: Inorganic Solid-State Clathrate compounds, clathrates of organic hosts, intracavity complexes of neutral molecules (Fullerenes and Cyclodextrins): Solution and Solid State Binding.

Crystal Engineering: Concepts of Crystal Design and Growth, Applications to Polymorphism and Cocrystal formation.

Self Assembly: Applications to Catenanes, Rotaxanes and Helicates, Role of Positive Cooperativity.

Applications: Structure and function of DNA, Supramolecular Reactivity, Liquid Crystals, Dendrimers, MOF's, Electronic devices (switches, wires and rectifiers) and non-linear optical materials.

Suggested Reading:

- Supramolecular Chemistry. J. W. Steed, J. L. Atwood, John Wiley and Sons, 2000.
- Supramolecular Chemistry. Concepts and Perspectives. J. -M. Lehn. VCH, 1995.
- Principles and Methods in Supramolecular Chemistry. H.-J. Schneider, A.Yatsimirsky, John Wiley and Sons.

CHM 342: Macromolecular and Analytical Chemistry (4)

Part A:

- Monomers, dimers, and oligomers
- Polymerization by carbonyl substitution reactions, electrophilic substitutions, S_N2 reactions, Nucleophilic attack on isocyantes
- Polymerization of olefins: radical polymerization, anionic (living polymerization) and cationic polymerization, Isotactic, Syndiotactic, and Atactic polymerization, Ziegler-Natta polymerization
- Co-polymerization: Synthetic Rubber, Cross-linking polymer
- Biodegradable polymers
- Reactions of polymers: Merrifield resins, peptide synthesis using polymer-bound reagents, polyacryl amide gels

Part B:

- Calculations used in analytical chemistry
- Errors in chemical analysis
- Classical methods of analysis: Gravimetric, Volumetric and Titrimetric, Potentiometric methods
- Separation techniques: Introduction to analytical separation, gas chromatography, and HPLC and related methods
- Preparing samples for analysis: primary, secondary standard etc.

Suggested Reading:

- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.
- Skoog, West, Holler, Crouch., *Fundamentals of Analytical Chemistry*, Cengage Learning.

CHM 343: Chemistry of Biological Systems (4)

Part A:

- Carbohydrates: Monosaccharide, polysaccharides, Mutarotation, Anomeric effects.
- Amino acids and Protein structure
- Fatty acid biosynthesis and degradation pathways
- Introduction to metabolism and bioenergetics.
- Oxidation and Reduction pathways in biological system.
- Chemistry of Garlic and Onion

Part B:

- Elements of life, Role of metal ion in biological functions,
- Metal nucleic acid interactions, Metalloproteins and metalloenzymes,
- Oxygen carrier proteins- Structure and role of haemoglobin, myoglobin, hemerythrin, hemocyanin.
- Electron transport proteins: Iron-Sulfur proteins, cytochromes.
- Redox enzyme: Mo, Fe, Cu, Zn-containing redox enzyme.
- Metal induced toxicity and chelation therapy: Platinum complexes and related anticancer drugs.

Suggested Reading:

- Jeremy Berg, John Tymoczko, and Lubert Stryer *Biochemistry* (5th Edition)
- S. J. Lippard, J. M. Berg *Principles of Bioinorganic Chemistry* University Science Books
- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.

CHM 401: Non-transition Metal Chemistry (4)

Concepts and principles of nontransition metal chemistry: An overview of bonding models in inorganic chemistry, Chemical forces, Bent's rule, Application of molecular orbital theory to polyatomic molecules (localized and delocalized orbitals), Walsh diagrams, Fluxional molecules, Atomic inversion, Berry pseudorotation.

The role of *p*- and *d*- orbital participation in nonmetals, Periodicity, periodic anomalies of the nonmetals, multiple bonding in heavier main group elements, charge transfer complexes.

Representative chemistry of s- and p-blocks: alkali metals, boranes, carboranes, boron clusters, Wade's rules, metallacarboranes, boron nitride, borylene, aminoboranes, organoaluminium compounds, graphite, diamond, fullerene, grapheme, CNT,

organosilicon compounds, silicates and aluminosilicates, zeolites, silylenes and R_3Si^+, Polysilanes, stability and activation of dinitrogen, phosphorus oxides, oxyacids, phosphines, anion chemistry of N, P, As and Sb, singlet and triplet oxygen, oxygen activation, chemistry of chalcogens, polychalcogenides, sulfur-nitrogen compounds, halogens, pseudohalogens, interhalogens, noble gases, CFC

Inorganic rings and polymers: Borazines, heterocyclophosphazenes, siloxanes, stannoxanes and the polymers derived from them.

Chemistry of carbenes, push-pull carbenes, stable heavier carbene analogues (Silicon, Germanium, Tin and lead): synthesis, characterisation and reactivity.

Multiple bonding in heavier main-group elements: Synthesis, structure and reactivity.

Main group organometallic chemistry: Preparation, stability aspects and reactions. Structurally diverse π-cyclopentadienyl complexes of the main group elements. Element-Element Addition to Alkynes (Si-Si, Ge-Ge, B-B, S-S, Se-Se, Ge-Sn, Si-B, Sn-B, S-B, Se-P, Si-S).

Interlocked macromolecules: catenanes, rotaxanes, pseudorotaxanes.

Suggested Reading:

- *Inorganic Chemistry-Principles of Structure and Reactivity.* J. E. Huheey, E. A. Keiter, R. L. Keiter, *4th Edn.* Harper-Collins, NY, **1993**.
- *Chemistry of the Elements.* N. N. Greenwood, and Earnshaw, A. *1st Edn.* Pergamon, Oxford, **1989**.
- *Concepts and Models of Inorganic Chemistry.* B. Douglas, D. McDaniel, J. Alexander, *3rd Edn.* John Wiley, New York. **1993**.
- *Advanced Inorganic Chemistry.* F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, *3rd Edn.* John Wiley and Sons Press, **1995**.
- *Modern Inorganic Chemistry.* W. L. Jolly, *2nd Edn.* McGraw-Hill, NY, **1991**.
- *Inorganic Chemistry.* D. F. Shriver, and P. W. Atkins. *3rd Edn.* Oxford University, Oxford, **1999**.
- Journal articles.

CHM 402/602: Applications of Modern Physical Methods (4)

UV-Vis & NIR Spectroscopy: Introduction, principles and applications.

*Infrared Spectroscopy***:** Introduction, identification of functional groups, hydrogen bonding, metal-ligand vibrations.

Nuclear Magnetic Resonance Spectroscopy: Introduction, applications of ^1H and ^{13}C NMR spectroscopy including (COSY, INADEQUATE, HMQC, HSQC, HMBC,

NOESY, HETCOR, ROESY, TOCSY). Techniques in the structural determination of complex organic systems, application in conformational analysis, multinuclear NMR of various inorganic and organometallic compounds.

Electron Paramagnetic Resonance Spectroscopy: Theory, Analysis of EPR spectra of systems in liquid phase, radicals containing single and multiple set of protons, triplet ground states. Transition metal ions, rare earth ions, ions in solid state. Double resonance techniques: ENDOR in liquid solution, powders and in non-oriented solids. Biological applications: Substrate free radicals, flavins and metal free flavin proteins, photosynthesis, heme proteins, iron-sulfur proteins, spin labels.

Mass Spectrometry: Basic concepts, ionization methods ((EI, CI, Field Ionization, FAB, Plasma desorption, Field desorption, Laser desorption, MALDI, Thermospray, API, ESI, APCI, APPI, Atmospheric pressure secondary ion mass spectrometry, inorganic ionization techniques), fragmentation and rearrangements (McLafferty rearrangement) of different classes of organic molecules, isotope effects.

Mossbauer Spectroscopy: Physical concepts, spectral line shape, isomer shift, quadrupole splitting, magnetic hyperfine interaction. Interpretation of Mossbauer parameters of ^{57}Fe and ^{119}Sn. Applications: solid-state reactions, thermal decomposition, ligand exchange, electron transfer, isomerism and biological applications.

Electrochemical Methods: Heterogeneous electron transfer and concept of capacitative and Faradic current. Cyclic voltammogram, instrumentation, CV, DPV and coulometry. Applications of CV in organic and inorganic chemistry.

Suggested Reading:

- *NMR Spectroscopy – An introduction*, H. Gunther, John Wiley, **1980**.
- *Basic one and two-dimensional NMR spectroscopy*, H. Friebolin, VCH, **1991**.
- *Spectrometric identification of Organic Compounds*, R. M. Silverstein, G. C. Bassler and T. C. Morrill, 5th Ed., John Wiley & Sons, New York, **1991**.
- *Electron Paramagnetic Resonance, Elementary theory and Practical Applications*, Weil, John A, J. R. Bolton, and Wertz, J. E, Wiley-Interscience, New York, **1994.**
- *Structural Methods in Inorganic Chemistry*, E. A. V. Ebsworth, D. W. H. Rankin & S. Cradock, 2nd Ed.**1991**, CRC Press, Boca Raton, Florida.
- *Circular Dichroism: Principles and Applications*, Nakanishi, K., Berova, N., Woody, R. W., Eds.; VCH Publishers, Inc.; New York, **1994**.
- *Principles of Fluorescence Spectroscopy*, J. Lackowicz, Plenum Press, New York **1983**.
- *Electrochemical methods – Fundamentals and applications*, A. J. Baird and L. R. Faulkner, Wiley, **1980**.
- *Applications of Physical Methods to Inorganic and Bioinorganic Chemistry*, R. A. Scott, C. M. Lukehart, Wiley, **2007**.

CHM 411/611: Physical Organic Chemistry (4)

Chemical Equilibria and Chemical Reactivity:

- Thermodynamic and kinetic control of reactions
- Correlation of reactivity with structure, linear free energy relationships, Hammond's postulate, Curtin-Hammett principle, substituent constants and reaction constants

Chemical Kinetics and Isotope Effects:

- Various types of catalysis and isotope effects, importance in the elucidation of organic reaction mechanisms

Stereoelectronic Effects in Organic Chemistry:

- Role of stereoelectronic effects in the reactivity of acetals, esters, amides and related functional groups
- Reactions at sp^3, sp^2, and sp carbons, Cram, Felkin-Ahn, Zimmerman-Traxler, Houk, Cieplak, exterior frontier orbital extension (EFOE) and cation-complexation models as applied to π-facial stereoselectivity
- Allylic strain ($A^{1,2}$ and $A^{1,3}$) and other strains

Pericyclic Reactions:

- Conservation of orbital symmetry, Woodward-Hoffmann rules, frontier molecular orbital (FMO) theory
- Orbital overlap effects in cycloadditions, electrocyclizations, sigmatropic rearrangements and chelotropic reactions
- Paterno-Buchi, Norrish type I and II reactions

Suggested Reading:

- Isaacs, N. S. *Physical Organic Chemistry*, Prentice Hall, **1996**.
- Deslongchamps, P. *Stereolectronic Effects in Organic Chemistry*, Elsevier Science, **1983**.
- Carey, F. A., Sundberg, R. J. *Advanced Organic Chemistry, Part A and B*, Springer, **2007**.
- Turro, N. J. *Modern Molecular Photochemistry*, University Science Books, **1991**.
- Anslyn, E. V., Dougherty, D. A. *Modern Physical Organic Chemistry*, University Science Books, **2005**.
- Woodward, R. B., Hoffmann, R. *The Conservation of Orbital Symmetry*, Verlag Chemie, **1970**.
- Lehr, R. E., Marchand, A. P. *Orbital Symmetry: A Problem Solving Approach*, Academic Press, **1972**.

CHM 421/621: Statistical Mechanics (4)

Review of classical thermodynamics: Laws of thermodynamics and thermodynamic potentials, Legendre transforms and derivative relations, conditions of thermodynamic equilibrium and stability.

Elementary probability theory: Definition of probability, distribution functions and moments, average, variance and binomial distribution for large numbers and central limit theorem, statistical concept of uncertainty.

Fundamental principles of statistical mechanics: Macroscopic and microscopic states, fundamental postulates of statistical mechanics, statistical mechanical ensembles and their distribution functions, partition functions, entropy and Boltzmann distribution law, relation between partition functions and thermodynamic quantities in different ensembles, and fluctuations.

Ideal systems: Monatomic, diatomic and polyatomic gases and calculation of partition functions, heat capacities of gases, equipartition theorem and the Maxwell velocity distribution, Gibbs paradox, ortho- and para-hydrogen, blackbody radiation, heat capacities of solids (Einstein and Debye models), chemical equilibrium in ideal gas mixtures, photon and phonon gas systems of quantum particles and concept of different populations (Bose-Einstein and Fermi-Dirac statistics), distribution function of ideal Bose and Fermi gases, classical limits of quantum systems.

Suggested Reading:

- Callen, H. B., *Thermodynamics and an Introduction to Thermostatistics*, Ed. 2nd, Wiley, **1985**.
- Hill, T. L., *An Introduction to Statistical Thermodynamics*, Dover, **1987**.
- McQuarrie, D. A., *Statistical Mechanics*, University Science Books, **2000**.
- Widom, B., *Statistical Mechanics: A Concise Introduction for Chemists*, Cambridge University Press, **2002**.
- Chandler, D., *Introduction to Modern Statistical Mechanics*, Oxford University Press, **1987.**
- Pathria, R. K., *Statistical Mechanics*, Ed. 2nd, Butterworth-Heinemann, **1996.**

CHM 422/622: Molecular Spectroscopy (4)

Basic Concepts: Nature of the electromagnetic spectrum, Born-Oppenheimer approximation, width, shape and intensity of spectral lines, Lambert-Beer law, energy levels of rigid and harmonic oscillator.

Interaction of radiation with matter: Time-dependent perturbation theory – transition amplitudes, dipoles and rates, Fermi-Golden rule, selection rules for vibrational, rotational and electronic transitions and connection to symmetry.

Microwave Spectroscopy: Moments of inertia of molecules, diatomic molecule as a rigid rotor, rotational spectra of diatomic molecules and calculation of molecular parameters, diatomic molecule as the non-rigid rotor, qualitative treatment of rotational spectra of polyatomic molecules.

Infrared Spectroscopy: Mechanism of IR absorption, vibrational spectra of diatomic molecules, diatomic molecule as an anharmonic oscillator, rotation-vibration spectra of diatomic molecules and calculation of molecular parameters, various vibrational modes in polyatomic molecules, Fermi resonance, frequency shifts because of substitutions, isotope effect, applications of IR spectroscopy in structure elucidation.

Raman Spectroscopy: Classical and quantum approach of Raman scattering, characteristic parameters of Raman lines, selection rules for Raman scattering, Raman spectra of diatomic molecules and calculation of molecular parameters, vibrational Raman spectra of polyatomic molecules and some applications.

Electronic Spectroscopy: Electronic spectra of diatomic molecules, vibrational coarse-structure, selection rules, vibrational progression, Frank-Condon principle and its consequences, theory of absorption and emission, Einstein's coefficients and their relation with transition moment integral, concept of lifetime and Einstein's spontaneous emission coefficients, symmetry properties and selection rules.

Nuclear Magnetic Resonance Spectroscopy: Nuclear spin and magnetic moment, classical and quantum mechanical description of the origin of NMR, concept of chemical shifts, effect of electron density, magnetic anisotropy, ring currents, isotope effect, lanthanide shift reagents, spin-spin coupling, coupling between groups of equivalent nuclei.

Suggested Reading:

- Banwell, N., McCash, E. M., *Fundamentals of Molecular Spectroscopy*, Tata-McGraw Hill, **2007**.
- Atkins, P. W., de Paula, J., *Physical Chemistry*, Ed. 9th, Oxford Press, **2009.**
- Engel, T., *Quantum Chemistry and Spectroscopy*, Pearson Education, **2007**.
- Becker, E. D., *High Resolution NMR: Theory and Applications*, Academic Press**, 1991**.
- Wilson, E. B., Decius, J. C., and Cross, P. C., *Molecular Vibrations: The Theory of Infrared and Raman Vibrational Spectra*, Dover, **1980**.
- Harris, D. C., and Bertolucci, M. D., *Symmetry and Spectroscopy: An Introduction to Vibrational and Electronic Spectroscopy*, Dover, **1989**.
- Steinfeld, J. I., *Molecules and Radiation: An Introduction to Modern Molecular Spectroscopy*, Ed. 2nd, Dover, **2005**.
- Berry, R. S., Rice, S. A., Ross, J., *Physical Chemistry*, Ed. 2nd, Oxford Press, **2000**.

CHM 423: Physical Chemistry Laboratory II (3)

Suggested Experiments:

- To Verify the Freundlich and the Langmuir Adsorption Isotherms
- Determination of Fluorescence Quantum Yield of an Unknown Compound Using a Standard Fluorophore
- Determination of Critical Micelle Concentration of Sodium Dodecyl Sulphate by Fluorimetry and Correlation by Conductometry
- Determination of Average Molecular Weight of Polystyrene from Viscosity Measurements
- To determine the formula and stability constant of a complex by spectrophotometery
- Determination of the solubility curve for a ternary system of two non-miscible liquids and a third liquid which is miscible with each of them
- Determination of the solubility of benzoic acid between 25^{o}C and 60^{o}C and calculate the heat of solution
- Calibration of a given burette
- Determination of the variation of miscibility of phenol in water with temperature and estimating the Critical Solution Temperature
- To Study the Nature of the Cyclic Voltammogram for a One Electron Transfer $[Fe^{III}(CN)_6]^{3-}/[Fe^{II}(CN)_6]^{4-}$ System and Calculation of the Diffusion Coefficient of the Ion for the Given System

CHM 602: Applications of Modern Physical Methods (4)

See contents of **CHM 402**

CHM 603: Advanced Inorganic Chemistry (4)

- Brief discussion on bonding, spectra and magnetism of coordination compounds, Outer-sphere mechanism
- C-H Activation, Agostic interaction, orthometallation and their applications (from literature)
- Fluxional molecules, Dynamic NMR of Carbonyls, nitrosyls, phosphines and Alkene complexes of transition metals
- Photochemistry of transition metal complexes: Photosensitization, photogalvanic cells and photocurrent generation and dye sensitized solar cells.
- Water splitting reaction using coordination compounds.
- Artificial photosynthesis, Nitrogen fixation, Dioxygen binding, and mimics
- Recent applications of transition metal catalysts- Grubbs catalyst, Pd catalysts.
- Carbenes, olefin metathesis.
- Electron transfer reaction and metal-organic frameworks.

Suggested Reading:

- *Bioinorganic Photochemistry*, Stochel, G.; Brindell, M.; Macyk, W.; Stasicka, Z.; Szacilowski, K. Wiley, West Sussex, UK, **2009**.
- *Bioinorganic Chemistry*, Lippard, S. J.; Berg, J. M. University Science Books, California, **1994**.
- Discussion on above mentioned topics with relevance to the recent literature.

CHM 605: Bioinorganic Chemistry (4)

- Mineral Origin of life. Archaeal, Eucarial and Bacterial domain.
- Transition metal ions in biology. Metallobiomolecules. Electron carriers, oxygen carriers, enzymes. environment.
- Specific examples: Hemoglobin, Myoglobin, Hemocyanin, Hemrythrin cytochromes, Fe-S proteins, Cytochrome P-450, Nitrophorin, NO-synthase, peroxidase, catalase, Ferritin, cytochrome-C oxidase, cerulplasmin, blue copper proteins, *di*- and *tri*-copper proteins. Other enzymes like, hydrogenase, methane monooxygenase, dioxygenases, dehydratase, nitrogenase, molybdenum containing oxidase and reductase class of enzymes like sulfite oxidase, xanthine oxidase, nitrate reductase, DMSO reductase, tungsten containing formate dehydrogenase and tungsten bearing hyperthermophilic and thermophilic enzymes. Zn enzymes like carbonic anhydrase, carboxypeptidase, DNA and RNA polymerases, Nickel containing F-430, role of manganese in water splitting.
- Active site analogue reaction models and structural models of these enzymes.
- Environmental chemistry, auto exhaust, arsenic and other heavy metal pollutions.
- Forensic chemistry; inorganic chemistry in medicine, platinum complexes, Mo=S complexes as anti-cancer drugs.
- Biochemistry of main group elements.

Suggested Reading:

- *Principles of Bioinorganic Chemistry*, S. J. Lippard, J. M. Berg, University Science Books, **1994**.
- *Bioinorganic Chemistry*, I. Bertini, H. B. Gray, S. J. Lippard, S. J. Valentine, Viva Books, 1st Edition, **1998**.

CHM 607: X-ray diffraction: Principles and Applications (4)

- *Symmetry in the Solid State:* Unit Cell, Crystal Systems, Crystal lattices (2D), Bravais Lattices (3D), Miller planes (crystallographic directions and multiplicities), d-spacing formula (resolution), Point Symmetry and Point Groups, Space groups (equivalent points, Wyckoff positions, site occupancy factor).

- *Elements of X-ray diffraction:* Thomson and Compton Scattering, Interference of Scattered Waves, Scattering by an Atom and Crystal, Bragg's Law, Reciprocal Lattice, Reflecting and Limiting sphere of reflection.
- *Preliminary concepts on Crystals and X-rays*
- *Intensity and Geometric Data Collection and Reduction* statistics, Factors that affect intensities (Lorentz and Polarization corrections), Interpretation of Intensity data, Wilson plot and absolute scale factor.
- *Theory of Structure Factors and Fourier Synthesis:* Calculation of Structure Factor amplitudes (general formula and applications), Friedel's Law, Systematically absent reflections, Anomalous Dispersion
- *Structure Solution and refinement:* Patterson symmetry, Direct Methods, Least Squares Methods, Electron density maps, R-factors, refinement by ΔF synthesis.
- *Crystal structure determination:* Asymmetric Unit, crystal density, unit cell contents, and chemical formula. Thermal Motion, the physical interpretation of molecular (Bond lengths, angles and torsions) and crystal structure (Packing Diagram), Rietveld method in Powder diffraction.

Suggested Reading:

- *A Basic Course in Crystallography:* J. A. K. Tareen & T. R. N. Kutty.
- *Fundamentals of Crystallography:* C. Giacavazzo.
- *Basics of Crystallography and Diffraction:* C. Hammond.
- *X-ray Structure determination:* A practical guide: G. H. Stout and L. H. Jensen.

CHM 609: Transition Metal Organometallic Chemistry (4)

Structure and bonding: Brief overview of transition metal orbitals, electron counting, formal oxidation state, 18-e rule and its exceptions, isoelectronic and isolobal analogies, common geometries for transition metal complexes (Crystal Field Theory, MO description), σ- and π-bonding, types of ligands and their properties, soft vs hard ligands.
Reactions of organometallic complexes: ligand substitution/ exchange/dissociation processes and thermochemical considerations, catalyzed and assisted ligand substitution reactions, oxidative addition (definition, mechanism, thermodynamic consideration), oxidative addition of non-polar and polar electrophilic reagents, reductive elimination (bite angle effects, π-acid effects), transmetallation (definition, mechanism, utility), insertion/de-insertion, nucleophilic and electrophilic attack on coordinated ligands.
Complexes with classic Lewis base donors: Amines, phosphines and other related donors.
Complexes with metal-carbon σ-bonds: **(a)** Metal carbonyl complexes: Synthesis, structure and bonding; IR spectroscopy; Reactions; Related complexes with cyanide, nitrosyl, and dinitrogen ligands. **(b)** Metal alkyl complexes: Synthesis, stability and structure; Reactions; Activation of C-H bonds. **(c)** Alkylidene and alkylidyne complexes: Synthesis; structure and bonding; Reactivity; Olefin metathesis.

Metal-element multiple-bonded complexes: Oxo, sulfido, imido, hydroazido, nitrido-complexes: Synthesis, bonding, structure, spectroscopy, and reactivity.
Complexes with metal-metal multiple bonds: Synthesis, structure and bonding, spectroscopic and magnetic properties, and reactions.
Metal complexes of π-ligands: **(a)** Alkene complexes: Synthesis; Bonding; Reactivity. **(b)** Alkyne complexes: Synthesis; Bonding; Reactivity. **(c)** Cyclopentadienyl complexes: Discovery of 'sandwich' complexes; Bonding; Properties of Cp complexes of 3d metals; Substituted metallocenes; Zigler-Natta polymerization; Half-sandwich complexes. **(d)** Allyl and dienyl complexes: Synthesis; Structure and properties; Reactivity. **(e)** Arene complexes: Bis-arene complexes; Arene half-sandwich complexes; η^2 to η^4 coordinated arenes; Seven and eight-membered ring ligands.
Modern applications of organometallic chemistry: **(a)** Small molecule activation and functionalization: mechanistic and practical view. **(b)** Organometallic materials.

Suggested Reading:

- Crabtree, R. H. *The Organometallic Chemistry of the Transition Metals,* 3rd Ed.; Wiley-Interscience: New York, **2001**.
- Hartwig, J. F. *Organotransition Metal Chemistry From Bonding to Catalysis*, 1st Ed.; University Science Books: Sausalito, CA, **2010**.
- Collman, J.P.; Hegedus, L.S.; Norton, J.R.; Finke, R.G. *Principles and Applications of Organotransition Metal Chemistry*; University Science: Mill Valley, CA, **1987**.
- Spessard, G.O.; Miessler, G.L. *Organometallic Chemistry*. Prentice Hall: Upper Saddle River, NJ, **1996**.
- Huheey, J.E.; Keiter, E.A.; Keiter, R.L. *Inorganic Chemistry: Principles of Structure and Reactivity,* 4th Ed.; HarperCollins: New York, **1993**.
- Jordan, R. B. *Reaction Mechanisms of Inorganic and Organometallic Systems;*2nd Ed.; Oxford University Press: Oxford, **1998**.
- (a) Bochmann, M. *Organometallics 1;* Oxford University Press: New York, 1994. (b) Bochmann, M. *Organometallics 2;* Oxford University Press: New York, **1994**.
- Elschenbroich, C.; Salzer, A. *Organometallics: A Concise Introduction*, 2nd Ed.; VCH: New York, **1992**.
- Shriver, D. F.; Atkins, P. W. *Inorganic Chemistry*, 3rd Ed.; W. H. Freeman: New York, **1999**.
- Attwood, J. D. *Inorganic and Organometallic Reaction Mechanisms,* 2nd Ed.; VCH Publishers Inc.: New York, **1997**.
- Nugent, W. A.; Mayer, J. A. *Metal-Ligand Multiple Bonds*, 1st Ed.; Wiley-Interscience, **1987**.
- Elschenbroich, C. *Organometallics, 3rd, Completely Revised and Extended Edition;*Wiley-VCH Verlag GbmH & Co. KGaA, Weinheim, Germany, **2006**.
- Cotton, F. A.; Murillo, C. A.; Walton, R. A. *Multiple Bonds between Metal Atoms*, 3rd Ed.; Springer Science Inc. New York, **2005**.
- Primary literature (journal articles).

Go to Contents

CHM 611: Physical Organic Chemistry **(4)**

See contents of **CHM 411**

CHM 612: Advanced Organic Chemistry II **(4)**
(Advanced Organic Synthesis)

- Reactions related to synthesis of 3 to 6 membered and higher carbocycles.
- Miscellaneous reactions: (a) tandem/domino reaction, (b) multicomponent reaction (MCR), (c) remote functionalization.
- Philosophy of synthetic design: Retrosynthesis, importance of reactivity, relation between functional groups, regio and stereocontrol, use of functional groups as a guide for retrosynthesis.
- Concepts of atom, step and redox economy.
- Total synthesis of natural products.

Suggested Reading:

- Clayden, J., Greeves, N., Warren, S., Wothers, S. *Organic Chemistry*, Oxford University Press, **2001**.
- Wyatt, P., Warren, S. *Organic Synthesis: Strategy and Control*, Wiley, **2007**.
- Warren, S. *Organic Synthesis: The Disconnection Approach*, Wiley, **1983**.
- Nicolaou, K. C., Sorensen, E. *Classics in Total Synthesis*, Wiley-VCH, **2008**.
- Nicolaou, K. C., Snyder, S. A. *Classics in Total Synthesis-II*, Wiley-VCH, **2003**.
- Corey, E. J., Cheng, X-M. *The Logic of Chemical Synthesis*, Wiley, **1995**.

CHM 613: Advanced Organic Chemistry I **(4)**
(Asymmetric Synthesis)

- Concepts and principles of enantioselective and diastereoselective transformations (including Curtin-Hammet principle, 1,2-induction and 1,3-induction models)
- Asymmetric C-C bond forming reactions (Asymmetric alkylations, Asymmetric additions to C=O, C=N, C=C bonds)
- Asymmetric oxidation reactions (Dihydroxylations, epoxidations, enolate oxidations, chiral sulfoxides, etc.)
- Asymmetric reductions of C=C, C=O and C=N bonds.
- Resolutions (Kinetic, Parallel Kinetic, Dynamic Kinetic resolutions)
- Non-linear effects and autocatalysis.
- Desymmetrization reactions
- Introduction to Organocatalysis (Covalent and non-covalent catalysis)

Suggested Reading:

- Walsh, P. J., Kozlowski, M. C. *Fundamentals of Asymmetric Catalysis*, University Science Book, **2009**.
- Ojima, I. *Catalysis in Asymmetric Synthesis*, Wiley-VCH, **2004**.
- Carreira, E., Kvaermo, L. *Classics in Stereoselective Synthesis*, Wiley-VCH, **2009**.
- Berkessel, A., Groger, H. *Asymmetric Organocatalysis: From Biomimetic Concepts to Applications in Asymmetric Synthesis*, Wiley-VCH, **2005**.
- Hassner, A. *Advances in Asymmetric Synthesis***,** Vol 3, Elsevier, **1999**.

CHM 614: Advanced Organic Chemistry III (**4)**
(Organometallics)

- Concepts (Ligand systems, electron counting and chemical bonding).
- Fundamental aspects (ligand substitutions, oxidative addition/reductive elimination, intramolecular insertions/ eliminations, nucleophilic/ electrophilic addition on coordinated ligands).
- Coupling reactions and their synthetic applications (C-C and C-Heteroatom bond forming reactions).
- Brief introduction to Fischer and Schrock carbene complexes, Metathesis (concepts and catalysts, RCM, ROM, CM, yne-metathesis, ene-yne metathesis and their applications).
- Miscellaneous transition metal catalyzed reactions (C-H and C-F bond activation, carbonylation, click chemistry, hydrosilylation, etc.).

Suggested Reading:

- Crabtree, R. H. *The organometallic chemistry of the transition metals*, John Wiley, **2005**.
- Hegedus, L. S. *Transition metals in the synthesis of complex organic molecule*, University Science Books, **2010** (3rd Ed).
- Grubbs, R. H. (Editor) *Handbook of Metathesis*, (Vol 1-3), Wiley-VCH, **2003**.
- Hartwig, J. H. *Organotransition Metal Chemistry: From Bonding to Catalysis*, University Science Books, **2009** (1st Ed).

CHM 615: Frontiers in Organic Chemistry **(4)**

In this course, ***most recent advances in areas of organic chemistry*** will be discussed. The emphasis will be to discuss ***latest research papers*** and also those published in the ***last 5 years*** so as to give an in-depth exposure to the latest advances in organic synthesis.

Suggested Reading:

- Research article published in National and International journals.
- Carriera, E. M.; Kvaerno, L. *Classics in Stereoselective synthesis*, Wiley-VCH.
- Hudlicky, T.; Reed, J. W. *The Way of Synthesis*, Wiley-VCH.
- Kurti, L.; Czako, B. *Strategic Applications of Named Reactions in Organic Synthesis*, Elsevier.
- Nicolaou, K. C., Sorensen, E. *Classics in Total Synthesis*, Wiley-VCH.
- Nicolaou, K. C., Snyder, S. A. *Classics in Total Synthesis-II*, Wiley-VCH.

CHM 616: Spectroscopy and its Application to Organic Molecules (4)

Infrared spectroscopy: Theory of IR spectroscopy, Modes of stretching and bending, Fourier Transform Spectrometers, Background spectrum, Survey of important functional groups with examples, Chemical environment and chemical shift.
Nuclear Magnetic Resonance: Physical basis of Nuclear Magnetic Resonance spectroscopy, Chemical shift and Spin-spin coupling as functions of structure, Analysis of high-resolution NMR spectra, FT and pulse-NMR, NOE, 2D NMR (COSY, INADEQUATE, HMQC, HSQC, HMBC, NOESY, HETCOR, ROESY, TOCSY).
Mass spectroscopy: Principles of Mass Spectrometry, Ion sources (EI, CI, Field Ionization, FAB, Plasma desorption, Field desorption, Laser desorption, MALDI, Thermospray, API, ESI, APCI, APPI, Atmospheric pressure secondary ion mass spectrometry, inorganic ionization techniques, formation and fragmentation of ions, fragmentation reactions, Mass analyzers (Quadrople, Ion trap, ToF, Orbitrap, magnetic and electromagnetic analyzers), Ion cyclotron resonance and FT-MS.
Application of above techniques to organic chemistry and structural elucidation with exhaustive examples from latest publications.

Suggested Reading:

- Donald L. Pavia, Gary M. Lampman, George S. Kriz, James A. Vyvyan: *Introduction to Spectroscopy*, 4th Edition, Brookes Cole, **2008**.
- Harald Gunther: *NMR spectroscopy, Basic principles, concepts, and applications in chemistry*, 2nd Ed., Wiley, **2001** (reprint)
- Timothy Claridge: *High Resolution NMR Techniques in Organic Chemistry*, 2nd Ed. Elsevier, **2009**
- Edmond de Hoffmann, Vincent Stroobant: *Mass Spectrometry, Principles and applications*, 3rd Edition, Wiley, **2007**
- Robert M. Silverstein, Francis X. Webster, David Kiemle: *Spectrometric identification of organic compounds*, 7th Edition, Wiley, **2005**.

CHM 617: Chemical Biology **(4)**

- *Introduction:* What is Chemical Biology, Basics of Biology: Lipids, DNA, Protein, Sugars - their function and importance.
- Structure of peptides and proteins: Primary, secondary and tertiary structure, Non-covalent interactions, Aggregation, Folding, Misfolding.
- Microscopy and Spectroscopy in Biology: AFM, SEM, TEM, DLS, CD, UV-Vis, Fluorescence and Bioluminescence, NMR, MS.
- Bioorthogonal Ligation techniques: Functional group specific ligation techniques, Strategies for attachment of synthetic molecules to biomolecules, Bioorthogonal ligations, Staudinger Ligation, Native Chemical Ligation, Intein-mediated synthesis, Site selective protein modification.
- Natural and Synthetic Lipids**:** Natural and synthetic membranes, Vesicles. Designing synthetic vectors for DNA and siRNA, Differential Scanning Calorimetry.
- DNA chemistry and its uses: Molecular recognition of DNA**,** Recognition and modulation of DNA, RNA, and proteins with small molecules, siRNA, RNAi and its applications, DNA-based architectures and DNA Nanotechnology.

Suggested Reading:

- Herbert Waldmann, *Chemical Biology: Learning Through Case Studies*; Wiley-VCH, Weinheim **2009**.
- Dobson, Gerrard & Pratt, *Foundations of Chemical Biology*; Oxford Univ. Press; **2002**.
- Miller & Tanner, *Essentials Of Chemical Biology: Structure and Dynamics of Biological Macromolecules*; Wiley; **2002**.
- Waldman & Janning, *Chemical Biology: A Practical Course*; Wiley-VCH; **2004**.
- Greg T. Hermanson, *Bioconjugate Techniques*; Academic Press, **2008**.
- Joseph R. Lackowicz, *Principles of Fluorescence Spectroscopy*; Springer; **2006**.
- Journal Articles

CHM 621: Statistical Mechanics **(4)**

See contents of **CHM 421**

CHM 622: Molecular Spectroscopy **(4)**

See contents of **CHM 422**

CHM 624: Molecular Simulations (4)

- Introduction to scientific programming, brief overview of molecular simulation methods and their application.
- Concept of phase space, statistical ensembles and averages, fluctuations, phase space distribution functions and the Liouville equation.
- Born-Oppenheimer approximation, potential energy surfaces, brief overview of Hartree-Fock theory and the density functional theory, Hellman-Feynman theorem.
- Description of semi-empirical **f**orce-fields and parameterization, techniques for energy minimization and normal mode analysis.

Molecular Dynamics (MD):

- Introduction to molecular dynamics, equations of motion, approximate integration schemes, force calculations, initialization and boundary conditions, potential truncation, stability, simulation of bulk phases with continuous potentials, evaluation of thermodynamic and transport properties.
- Extended Lagrangian, thermostats and barostats, methods of constraints, multiple time-steps. Methods for treating long-range Coulomb interactions, ab-initio molecular dynamics.

Monte Carlo (MC):

- Introduction, importance sampling, Markov chains and detailed balance, Metropolis method.
- Extension to various ensembles (canonical, isothermal-isobaric, grand-canonical, and Gibbs ensemble). Monte Carlo simulation of monatomic fluids and complex molecules, study of phase-equilibria.

Further Advanced Topics and Applications:

- Methods for calculation of free energy, solvation models for use with empirical potentials, advanced sampling techniques and rare events**,** combined quantum mechanical/molecular mechanical (QM/MM) methods**,** coarse-graining and mesoscale simulation methods.
- Brief introduction to commercial simulation software.

Suggested Reading:

- *Molecular Modelling – Principles and Applications*, A. R. Leach, 2nd Ed., Prentice Hall, 2001.
- *Understanding Molecular Simulation*s, D. Frenkel and B. Smit, 2ndEd., Academic Press, 2002.
- *Computer Simulation of Liquids*, M. P. Allen and D. J. Tildesley, Oxford,1987.
- *Essentials of Computational Chemistry: Theories and Models*, C. J. Cramer, 2nd Ed., Wiley, 2004.

CHM 625: Biophysical chemistry (4)

*Structure of Proteins and Nucleic Acids***:** Primary and secondary structure, Ramachandran plot, conformational analysis, tertiary structure, structure of a nucleotide chain, the DNA double helix model, polymorphism.

Molecular Forces in Biological Structures: Electrostatic interactions, hydrophobic and hydrophilic forces, hydrogen bonding interactions, ionic interactions, stabilizing forces in proteins and nucleic acids, steric interactions.

Configurational Statistics of Biomacromolecules: End-to-end distance and radius of gyration of a polymer chain, statistics of random coils, persistence length, rotational isomeric state model, helix-coil transition and the Zimm-Bragg model, cooperativity in ligand binding and folding, allosteric transitions.

Dynamics of Biomacromolecules: Brownian motion and the random walk model, Fick's law of diffusion, friction and diffusion coefficients, Langevin equation and time correlation functions, Kramer's theory of crossing a potential barrier.

Techniques to Study Structure-Function Inter-relationships: Applications of CD, fluorescence, NMR in characterizing biomolecular systems, use of FRET in understanding conformational dynamics.

Suggested Reading:

- Cantor, C. R., and Schimmel, P., *Biophysical Chemistry (parts I, II and III)*, W. H. Freeman, **1980**.
- Jackson, M. B., *Molecular and Cellular Biophysics*, Cambridge, **2006**.
- Serdyuk, I. N., Zaccai, N. R.,and Zaccai, J.,*Methods in Molecular Biophysics: Structure, Dynamics, Function*, Cambridge, **2007**.
- Daune, M., *Molecular Biophysics: Structures in Motion*, Oxford, **199**9.
- Lakowicz, J. R., *Principles of Fluorescence Spectroscopy*, Plenum Press, **2003**.

CHM 626: Physical Photochemistry (4)

Introduction to absorption: Lambert-Beer law and its deviation relation between molar extinction coefficient and absorption cross section, Einstein induced absorption coefficient and integrated Einstein induced coefficients, notation of energy levels and electronic transitions

Fluorescence: introduction, Jablonski diagram, kinetic parameters, Einstein's induced and spontaneous emission coefficients, relationship between lifetime and Einstein coefficients (Strickler and Berg' equation) and its limitations, fluorescence quantum yield, Stoke's shift, fluorescence excitation spectrum

Effects of solvents on the fluorescence spectrum: (general effects and specific effects, derivation of the equation), time scales of molecular processes in solutions, applications
Fluorescence quenching: Different mechanism of fluorescence quenching, applications

Radiationless processes: Mechanism for internal and intersystem crossing, effect of temperature of radiationless processes

Phosphorescence: kinetic parameters, origin of triplet state and its formation, different methods of triplet-triplet absorption
Fluorescence Anisotropy and its applications

Resonance Energy Transfer: Different mechanisms of energy transfer (Forster and Dexter mechanism), selection rules for energy transfer, non-vertical energy transfer, Forster Resonance Energy Transfer (FRET), typical examples and choice of dyes

Spectrophotometry and Fluorometry: principles and instrumentation; choice of light sources, monochromators, choice of optical filters and various detector systems used, Concept of Time Correlated Single Photon Counting: Basic principles and instrumentation

Fluorophores and dyes used in spectroscopy: intrinsic and extrinsic fluorophores, protein labeling.

Suggested Reading:

- Lakowicz, J. R., Principles of Fluorescence Spectroscopy; Ed. 3rd, Plenum Press, 2003.
- Birks, J. B., "Photophysics of Aromatic Molecules"; Wiley-Interscience, 1970.
- N. J. Turro, N. J., Ramamurthy, V., J. C. Scaiano, J. C., Principles of Molecular Photochemistry: An Introduction, University Science Books, California.
- C. A. Parker; "Photoluminescence of Solutions"; Elsevier Publishing Company, 1968.

CHM 628: Electrochemistry: Fundamentals and Applications (4)

Introduction and Overview of Electrode processes: Electrochemical Cells and Reactions, Nature of Electrode-Solution Interface, Faradaic Reactions, Mass Transfer Controlled Reactions, Coupled Chemical Reactions.

Electrochemical Thermodynamics: Basics of Electrochemical Thermodynamics, Liquid Junction Potentials.

Kinetics of Electrochemical Reactions: Arrhenius Equation, Transition state theory, Butler Volmer model, Marcus Theory.

Electrochemical Methods: Linear Sweep Voltammetry, Cyclic Voltammetry, Square wave Voltammetry, Chronoamperometry, Chronopotentiometry, Rotating Disk Electrode, Rotating Ring-disk Electrode, AC impedance, Spectroelectrochemistry.

Applications of Electrochemistry: Electron Transfer, Characterization of Inorganic Complexes, Catalysis, Supercapacitors and Batteries.

Suggested Reading:

- Electrochemical Methods: Fundamentals and Applications, Allen J Bard and Larry R. Faulkner, 2nd Edition, John Wiley and Sons
- Modern Electrochemistry Ionics: Volume 1, John O'M. Bockris and Amulya K. N. Reddy, 2nd Edition, Plenum Press.
- Recent Research Publications.

CHM 629: Advanced Molecular Spectroscopy (4)

Basic Concepts: Einstein's coefficients and their relation with transition moment integral, time-dependent perturbation theory, various kinds of transitions and selection rules, notations of energy levels and electronic transitions

Fluorescence: Introduction, Jablonskii diagram, kinetic parameters, relationship between lifetime and Einstein's coefficients (Strickler and Berg equation) and its limitations, fluorescence quantum yield, Stokes' shift, analysis of a fluorescence spectrum, effect of solvent on fluorescence, (general effects and specific effects), Lippert equation and its applications, fluorescence excitation spectra, time scales of molecular processes, fluorescence quenching, different types of mechanisms associated with fluorescence quenching and their applications, fluorescence anisotropy and its applications

Radiationless processes: Mechanism of internal conversion and inter-system crossing, effect of temperature on radiationless processes

Phosphorescence: Kinetic parameters, origin of triplet state and its formation, different methods of triplet-triplet absorption, factors affecting the rate of phosphorescence

Resonance Energy Transfer: Different mechanisms of energy transfer (Forster and Dexter), selection rules for energy transfer, non-vertical energy transfer, FRET and its applications, typical examples and choice of dyes.

Spectrophotometry and Fluorometry: Principles and instrumentation, choice of light sources and detectors, monochromators, optical filters and choice of filters, fluorophores and dyes used in spectroscopy, intrinsic and extrinsic fluorophores, protein labeling
Lasers and its applications: Principles of lasers, multi-photon ionization processes in molecules, dynamics of reactions in liquids, spectroscopy of single molecules, concept of time-resolved spectroscopy, Confocal microscopy, FCS and FLIM.

Suggested Reading:

- Atkins, P. W., and de, Paula, J., *Physical Chemistry*, 8th Edition, Oxford Press, **2008**.
- Levine, I., *Physical Chemistry*, McGraw-Hill, **2008**.
- Lakowicz, J. R., *Principles of Fluorescence Spectroscopy*, Plenum Press, **2003**.
- Dogra, S. K., and Randhawa, H. S.; *Atom, Moleculeand Spectrum*, New Age International Pvt. Ltd., **2011**.
- Turro, N. J., Ramamurthy, V., and Scaiano, J. C., *Principles of Molecular Photochemistry: An Introduction*, University Science Books, **2009**.
- Selvin, P. R., and Ha, T., *Single Molecule Techniques: A Laboratory Manual*, Cold Spring HarborLaboratory Press, **2008**.

CHM 630: Advanced statistical mechanics (4)

Basic postulates and ensembles: Distributions, partition functions and calculation of thermodynamic properties in various ensembles.

Classical Statistical Mechanics: Classical partition function (rotational, vibrational and translational) as the high-temperature limit of its quantum counterpart, microscopic equations of motion, phase space, phase space vectors and Liouville's theorem, the Liouville equation and equilibrium solutions, ergodic theory.

Theory of imperfect gases: Cluster expansion for a classical gas, evaluation of cluster integrals, virial explansion of the equation of state, evaluation of the virial coefficients, law of corresponding states.

Theory of the liquid state: Definition of distribution and correlation functions, radial distribution function, Kirkwood integral equation, potential of mean force and the superposition approximation, Ornstein-Zernicke equation, Percus-Yevick and hypernetted-chain approximations., density expansion of the pair functions, perturbation theory of the van der Waals' equation.

Critical phenomena: Critical behaviour of the van der Waals equation, Ising model, lattice-gas model and binary alloys, broken symmetries, mean-field theories, Landau-Ginsburg theory, scaling and universality, introduction to renormalization group theory.

Suggested Reading:

- Chandler, D., *Introduction to Modern Statistical Mechanics*, Oxford, **1987**.
- McQuarrie, D. A., *Statistical Mechanics*, University Science Books, **2000**.
- Hansen, J. P., and McDonald, I. R., *Theory of Simple Liquids*, Ed. 3rd, Academic Press, **2006**.
- Pathria, R. K., *Statistical Mechanics*, Ed. 2nd, Butterworth-Heinemann, **1996**.
- Stanley, H. E., *Introduction to Phase Transitions and Critical Phenomena*, Oxford, **1971**.

CHM 631: Electronic Structure (4)

Review of quantum chemistry – Molecular Schrodinger equation, Born-Oppenheimer approximation, variational principle, many-electron wavefunctions, Hartree-Fock theory and electron correlation.

Some early density-functional theories– Thomas-Fermi model, Slater approximation of Hartree-Fock.

Modern Density-functional theory – Introduction to functionals and functional calculus, Hohenberg-Kohn theorems, Kohn-Sham approach, meaning and utility of the Kohn-Sham orbitals and eigenvalues, approximate exchange-correlation functions.

Practical DFT – Introduction to basis sets – localized and periodic basis sets, all-electron versus pseudopotential approximations, self-consistent methods to solve the Kohn-Sham equations. Hellmann-Feynman theorem and computation of forces, computation of electronic and structural properties.

Introduction to a DFT code and some simple examples and case-studies

Suggested Reading:

- W. Koch and M. Holthausen, *A chemist's guide to density-functional theory*.
- A. Szabo and N. S. Ostlund., *Modern Quantum Chemistry*.
- R. Martin, *Electronic Structure.* R.G. Parr and W. Yang, *Density-functional theory of Atoms and Molecules.*

CHM 632: Physical Chemistry of Polymers (4)

Introduction: Basic concepts, types of polymers, molecular weights, determination of molecular weights.

Polymerization kinetics: Stepwise & chain growth kinetics, Carothers equation, kinetic chain length, copolymerization and emulsion polymerization.

Structure of Polymer Chain: Chain isomerism, stereoregularity, configurations, and conformations, NMR characterizations, radius of gyration.

Polymer solutions and blends: Thermodynamics and statistical thermodynamics, lattice model, Flory-Huggins theory, osmotic pressure, phase separation, properties of dilute polymer solutions: intrinsic viscosity.

Polymer viscoelasticity and glass transition (T_g): Stress-strain behavior, Stress relaxation, Maxwell-Voigt mechanical models, glass and melting transition, thermodynamic aspects of T_g, determination of T_g (calorimetry, dynamic mechanical analysis), factors affecting T_g.

Networks, gels and rubber elasticity: Gel point, rubbery elastic states of polymers, thermodynamics of polymer elasticity-equation of state, ideal elastomers.

Crystalline state of polymers: Polymer Crystallization, thermodynamics and kinetics of crystallizations, semi-crystalline structures, experimental methods.

Applications and emerging technologies: Conducting and semi-conducting polymers in organic electronics, liquid crystalline polymers, self-assembly, Merrifield resins, polymer nanocomposites, plasticizers, antioxidant, adhesives.

Suggested Reading:

- *Polymer Chemistry*, P. C. Hiemenz and T.P. Lodge, 2nd Edition, CRC Press, 2007.
- *Introduction to Physical Polymer Science*, L.H. Sperling, Wiley-Interscience, 2006.
- *Principles of Polymer Chemistry*, P.J. Flory, Cornell University Press, 1953.

CHM 633: Quantum Chemistry (4)

Review of the postulates of quantum mechanics. Introduction to Hilbert spaces and bra-ket algebra. Symmetry and conservation laws, Ehrenfest theorem and quantum-classical correspondence. Electron spin angular momentum, spin operators and eigenfunctions. Addition of angular momenta, spin-orbit coupling.

Many-electron systems, antisymmetry principle, Slater determinant wave functions, Pauli exclusion principle. The Independent particle approximation to many-electron atoms, atomic term symbols for ground and excited states. Molecular Hamiltonian, Born-Oppenheimer approximation.
The independent particle approximation applied to molecules, MO treatment of H2+ molecular ion, LCAO approach to polyatomic molecules, Huckel and extended Huckel theories and simple applications.

Electron-electron correlations, Hartree-Fock theory and the SCF method, Koopmans' theorem, Brillouin's theorem, restricted and unrestricted approaches, Gaussian basis sets and pplications to simple molecules.

Correlation energy, a survey of post-HF and semi-empirical methods. Introduction to density-functional theory, Hohenberg-Kohn theorems, Kohn-Sham equations, exchange-correlation functionals and some applications.

Suggested Reading:

- Levine, I., *Quantum Chemistry*, Ed. 6th, Pearson Press, **2009**.
- McQuarrie, D. A., *Quantum Chemistry*, Ed. 2nd, University Science Books, **2008**.
- Atkins, P. W., Friedman, R. S., *Molecular Quantum Mechanics*, Oxford University Press, **2008**.
- Szabo, A., Ostlund, N. S., *Modern Quantum Chemistry: Introduction to Advanced Electronic Structure Theory*, Dover, **1989**.

CHM 635: Mathematical Methods for Chemists (4)

Linear algebra and vector spaces; matrices, eigenvalues and eigenvectors; vector calculus; curvilinear coordinates and coordinate transformations; functions of a complex variable; special functions; ordinary and partial differential equations; orthogonal polynomials.
Fourier series, integral transforms; calculus of variations; statistics; introduction to approximation methods and numerical techniques.

Suggested Reading:

- McQuarrie, D. A., *Mathematical methods for scientists and engineers*, University Science Books, **2003**.
- Arfken, G., Weber, H., and Harris, F., *Mathematical methods for physicists*, Academic Press, Ed. 7th, **2012**.
- Boas, M. L, *Mathematical methods for the physical sciences*, Kaye Pace, Ed. 3rd, **2006**.
- Matthews, J., and Walker, R. L., *Mathematical methods of physics*, Addison Wesley Longman, Ed. 2nd, **1971**.

CHM 637: Chemistry and Physics of Materials (4)

Structure and Bonding in Materials: Ideal structures, types of interactions and bonding, experimental determination of structure, defects and disorder in solids.

Review of Basic Concepts: Quantum mechanics, thermodynamics and statistical mechanics, electricity and magnetism, interaction of radiation with matter.

Properties of Materials: Electronic properties of solids, transport properties, thermal conductivity, lattice dynamics and structural phase transitions, absorption and scattering of radiation by crystals, electro-optic and photovoltaic effects, and elastic phenomena.

Structure and Properties at the Nano-scale: Optical, electronic and structural properties of confined systems, principles of electron microscopy and other experimental tools for nano-science.

Surface Science: Introduction to surface structure, electronic states, adsorption, reactivity of surfaces, surface free energy and stress.

Functional Materials

Suggested Reading:

- The Physics and Chemistry of Materials – Joel I. Gersten, Fredrick W. Smith.
- Introduction to Nano-science and Nano-technology – Massimiliano DiVentra, *et al.*
- Solid State Physics – Guiseppe Grosso and Guiseppe Pastori Parravicini.

CHM 641: Symmetry and Group Theory **(4)**

See contents of **CHM 301**

CHM 642: Principles of Quantum Chemistry **(4)**

See contents of **CHM 322**

CHM 651: Chemical Dynamics and Non-adiabatic Interactions **(4)**

The Born-Oppenheimer Approach – The Time Independent Framework: (a) The Adiabatic Representation; (b) The Diabatic Representation

Mathematical Introduction: (a) The Hilbert Space and the Curl-Div Equations; (b) First Order Differential Equations along contours; (c) Abelian and non-Abelian Systems.

The Adiabatic-Diabatic Transformation (ADT). On the Single-valuedness of the newly formed Diabatic Potentials and the Quantization of the Born-Oppenheimer (BO) non-adiabatic coupling (NAC) matrix. Singularities, Poles and Seams characterizing the BO-NAC terms.
Molecular Fields as formed by Lorentz Wave-Equations.

The Jahn-Teller Model, The Renner-Teller model, the mixed Jahn-Teller/Renner-Teller model. The Privileged ADT phase and the corresponding Topological (Berry/Longuet-Higgins) phase.

The Extended Born-Oppenheimer Equation including Symmetry

The Born-Oppenheimer Approach – The Time Dependent Framework (emphasizing Field-dependent non-Adiabatic Coupling terms).

The interaction between molecular systems and electromagnetic fields: (a) The Classical treatment of the field (b) The Quantum treatment of the Field (based on Fock states).
If time allows various subjects related to Quantum Reactive Scattering Theory will be introduced. Among other things the concept of arrangement channels and decoupling of arrangement channels employing Absorbing Boundary conditions will be discussed.

Selected Readings:

- M. Baer and C-Y. Ng, (eds), State-Selected and State-to-State Ion-Molecule Reaction Dynamics. Ser. Advances of Chemical Physics, Vol. 82, Part 2, John Wiley, Hoboken, N.J. (1992)
- M. Baer and G.D. Billing (eds), The Role of Degenerate States in Chemistry, Ser. Advances of Chemical Physics, Vol. 124; John Wiley, Hoboken, N.J. (2002)

- W. Domcke, D.R. Yarkony and H. Koeppel, Conical Intersections, Advances Series in Physical Chemistry Vol. 15 (World Scientific, Hong-Kong (2004).
- Farad. Discussions, Non-Adiabatic Effects in Chemical Dynamics, Vol. 127 (R.S.C.), University Oxford, (2004)
- M. Baer, Beyond Born-Oppenheimer: Electronic Nonadiabatic Coupling Terms and Conical Intersections, Wiley Interscience, Hoboken, N.J., (2006).
- G.C. Schatz and M. A. Ratner, Quantum Mechanics in Chemistry, Prentice-Hall, Englwood Cliffs (1993)
- J.D. Jackson, Classical Electrodynamics, 2nd Edition, John Wiley, New York (1975)
- J. Z. H. Zhang, Theory and Application of Quantum Molecular Dynamics, World Scientific, Hong-Kong (1999)

Earth and Environmental Sciences

EES 102: Introduction to Earth Sciences (3)

Introduction to Earth Sciences - Disciplines of Earth science; Integration across other disciplines.

Overview of the Universe - The Big Bang; Nucleosynthesis and formation of stars; Nebular condensation and formation of the Solar System; Planets, meteorites, comets, asteroids.

Interior of the Earth - Earth's topography; Continental and oceanic crust; Mantle and its discontinuities; Core.

Plate Tectonics - Lithospheric plates; Divergent boundaries; Continental rifting; Convergent plate boundaries; Transform faults and hotspots; What drives plate tectonics?

Mineralogy – Definition and physical properties of minerals; Bonding and crystal structure; Important mineral groups.

Structural Geology - Concepts of stress, strain and deformation; Techniques of measuring and mapping geologic features; Mechanisms of faults, fractures, folds.

Volcanoes and Earthquakes - Types of volcanoes and their products; Predicting and controlling volcanic activity; Effect of volcanoes on climate and environment; Earthquake nomenclature; Mercalli Scale; Earthquake prediction.

Rock cycle and Petrology – The rock cycle; Classification of igneous rocks; Bowen's reaction series; Sediments and the sedimentary cover; Classification of sedimentary rocks; Sedimentary structures and bed forms; Metamorphism and associated changes; Classification of metamorphic rocks.

Concept of Time - Geologic time; Relative versus absolute age; Principles of stratigraphy; Geologic time and life; Radiometric dating; The age of the Earth;

Life on Earth - Early life; Species, evolution, and natural selection; How fossils form; Evolution and extinctions.

Mineral and Energy Resources - Formation, exploration, and production of Ore deposits; Global mineral needs; Fossil fuels, coal, oil and natural gas; Alternative energy.

Hydrogeology - Hydrologic Cycle; Artesian system; Hot-springs and geysers; Groundwater contamination.

Physical Geology - Types and causes of mass movement; Work of Running Water; Oceans and Coasts; Deserts; Glaciers and Ice Ages; Global Change.

Remote Sensing and GIS – Basic concepts of remote sensing; Data acquisition and image Processing; Geographic Information System; Global Positioning System.

Suggested Reading:

- *Earth: Portrait of a Planet* (4th Ed) by Stephan Marshak
- Essentials of Geology (third edition) by Stephan Marshak
- Earth: Portrait of a Planet (fourth edition) by Stephan Marshak

EES 202: Atmospheric Sciences (3)

Introduction: Significance of studying atmospheric sciences in the regional and global contexts, prediction of weather and climate change, identification and remediation of environmental threats. Atmospheric sciences as an inter-disciplinary area of study, evolution and progress in the discipline. Recent trends and emerging frontiers

Earth's atmosphere: Sun and its origin, spectrum of radiation of the sun and earth, evolution of the earth and its atmosphere. Atmospheric elements and compounds, chemical structure and reactivity, lifetime of chemicals. Structure and composition of the atmosphere, Global circulation patterns

Atmospheric radiation: Quantitative description of radiation, blackbody radiation, Planck function, local thermodynamic equilibrium, absorption and emission by atmospheric gases, scattering by air molecules and particles, absorption by particles, Beer-Lambert law

Atmospheric thermodynamics: Basic definitions, Absolute temperature, Boyle's law, Dalton's law. Hydrostatic balance, First law of thermodynamics. Air parcel concept. Moisture in the atmosphere, measure and description of moist air, isobaric cooling, saturated adiabatic lapse rate.

Vertical mixing, vertical stability in the atmosphere, stability analysis and conditions

Tropospheric chemistry: Composition of tropospheric air, sources, transport, and sinks of important trace gases (O3, CO, OH , NOx, and VOCs). Tropospheric aerosol, sources, composition, -size distribution and concentrations, transport, residence times, and sinks. Urban pollution episodes, smog formation

Stratospheric chemistry: Overview, Chapman mechanism for ozone formation and destruction,

NOx cycle, and halogen cycles. Ozone hole. Stratospheric aerosols

Suggested Reading:

- Atmospheric Science: An introductory survey (2nd edition), John M. Wallace and Peter V. Hobbs, Academic Press (2006).
- Atmospheric Chemistry and Physics: From Air Pollution to Climate Change (2nd edition), John
- Seinfeld, Sypros N. Pandis, Wiley-Interscience (2006)
- An Introduction to Atmospheric Thermodynamics (2nd edition), Anastasios A. Tsonis, Cambridge University Press (2007)

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EES 305/605/606: Mineralogy (4)

Structure of the course, introduction to the subject and history of mineralogy.

7 crystal system, symmetry operations and the fourteen Bravais Space Lattices. 32 crystal classes & their Hermann Mauguin (HM) Notation.

Laws of Crystallography; Miller Indices; Absence of 5-fold symmetry. Crystal growth and twinning.

Principles of optical Mineralogy and optical Properties.

Nature of X-ray, X-ray crystallography. Bragg Equation and its application in mineralogy.

Crystal chemistry, chemical affinity and classification of elements. Mineralogy of the solar system.

Chemical bonding, coordination polyhedra, radius ratio, and Pauling's Rules. Major and Minor trace elements in minerals. Isomorphism, polymorphism, phase transformations and crystalline defects.

Mineralogical Phase Rule, Phase Diagrams (Binary Eutectic, Peritecti, Solid Solutions, Exsolutions), Phase Equilibria and introduction to the state mineral assemblages of rocks. Systemic Mineralogy: Native elements, sulfides and sulfosalts. Oxides, Hydroxides and Halides with emphasis on the Spinel group. Carbonates, sulfates and Phosphates.

Silicate structure, classification and Bowen's Reaction Series. Nesosilicates, Inosilicates, Tectosilicates: chemical structure, classification and mode of occurrence.

Suggested Reading:

- Wenk, H.-R. and Bulakh, A., *Minerals – Their constitution and origin.* Cambridge University Press.
- Nesse, W.D., *Introduction to Mineralogy*. Oxford University Press.
- Klein, C., and Hurlbut, C.S., M*anual of Mineralogy*. John Wiley and Sons.
- Mottana, R. Crespi, and G. Liborio, *Simon and Schuster's guide to rocks and minerals*. Fireside Books

EES 308/609/610: Microstructure and Thermodynamics of Rock Forming Minerals (4)

Introduction: Structure of the course, Introduction to rock forming minerals and chemical thermodynamics. Importance of mineral microstructure.

Overview of mineralogy: Introduction. Systematic classifications of minerals. Silicate Minerals: classification, chemical structure, mode of occurrence. Optical properties of rock forming minerals.

Petrology: Introduction. Classification of rocks: igneous, sedimentary and metamorphic rocks, example and characteristic mineral assemblages in each rock type. Plate tectonics and the rock cycle.

Deformation and flow of minerals: Basic terminology, stress and strain, homogeneous, inhomegeous flow and rheology of minerals, relationship between strain, stress and deformation.

Deformation mechanisms: Types of deformation mechanism and recovery of minerals. Different types of creep and processes of re-crystallization of minerals. Flow laws and deformation mechanism maps of minerals.

Deformation of rocks: Mineral microstructure and deformation mechanism in a) igneous, b) sedimentary and, c) metamorphic rocks. Formation of shear zone. Overview of earthquake mechanism.

Introduction to thermodynamics: Free energy in the form of heat and work. First and second laws of thermodynamics. Entropy, enthalpy and third law of thermodynamics. The Gibbs free energy and mineralogical phase rule. Phase transformation and polymorphism. Elementary phase diagrams for common rock forming minerals.

Thermodynamics of solutions: Concept of solid solution in mineralogy. Conservative and non-conservative components of solutions. Chemical potential, chemical equilibrium, fugacity and activity of a component in solution.

Thermodynamics for igneous system: Lever rule for igneous system. Correlation of mineral microstructure and Gibbs free energy in a) binary and b) ternary system. Introduction to MELTS family of algorithm.

Thermodynamics of metamorphic system: Definition, condition and type of metamorphism. Primary mineral assemblage and mineral paragenesis in metamorphic rock. Graphical representation of mineral para-genesis and free energy of metamorphic reactions. Examples of metamorphic phase diagrams. Calculation of Gibbs energy to identify the different deformation and metamorphic processes.

Suggested Reading:

- Bucher, K., and Grapes, R (2011), Petrogenesis of Metamorphic Rocks, Springer, 8th Edition
- Nesse, W. D. (2011), Introduction to mineralogy. Oxford University Press, 2nd Edition

- Patino Douce, A. (2011), Thermodynamics of the Earth and Planets, Cambridge University Press, 1st edition
- Passchier, C.W. and Trouw, R (2005), Micro-tectonics, Springer, 2nd Edition
- Philpotts, A. and Ague, J. (2009), Principles of Igneous and Metamorphic Petrology, Cambridge University Press, 2nd edition
- Vernon, R.H. (2004), A Practical Guide to Rock Microstructure, Cambridge University Press, 1st edition

EES 313/613/614: Science of Sustainability: Managing Earth Resources (4)

Introduction: Introduction to the concept of sustainable development/industrial ecology, historical development of industrial ecology, linking industrial activity with earth resources.

Analogy between ecosystems and industrial systems: Biological and industrial organism/systems, similarities and differences, concept of metabolism: biological and industrial organisms, industry-earth interactions, utility of the ecological approach, and discussion of practical symbiotic cases from a sustainability perspective.

Materials and the environment: Adopting a systems perspective, defining system boundaries, life cycle of materials, definitions and terminology, assessing material and energy flows, eco-efficiency, pollution prevention principles, cradle to grave approach - waste and recycling, resource dissipation, and cradle to cradle approach. Case studies.

Life-cycle Analysis (LCA): Introduction – history and definition of LCA, LCA stages – definition of goal and scope, level of detail for boundaries, natural ecosystem boundaries, LCA inventories, input/output assessment, LCA impact and interpretation, identifying issues in the results, drawing conclusions and recommendations, prioritizing recommendations, comparative LCA modeling. Limitations of LCA. Case studies.

*Industrial ecosystems***:** Environmental impact assessment, policy implications**,** Eco-industrial parks, Development of industrial symbiosis, Socio-economic dimensions of industrial symbiosis.

Suggested Reading:

- Ashby, M.F. (2009). Materials and the Environment: Eco-Informed Material Choice. Elsevier Publishers: Amsterdam.
- Graedel, T.E., and Allenby, B.R. (2003). Industrial Ecology (2nd Edition). Pearson Education: Upper Saddle River, New Jersey.

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EES 410/611/612: Aqueous Geochemistry (4)

Fundamentals of aqueous geochemistry- water molecule and hydrogen bonding, hydrological cycle, controls on aqueous geochemistry, surface and groundwater geochemistry, rain water and acid rain

Carbonate and aluminosilicategeochemistry- occurrence and stability of calcium-magnesium carbonates, calcite-dolomite solubility and role of pH and CO_2, influence on the solubility and saturation state of carbonate minerals, congruent and incongruent dissolution, solubility of aluminium and iron oxyhydroxides, magnesium silicates and aluminosilicates, quartz and silica polymorphs, common ion effect

Weathering and water chemistry – chemical weathering, rate of weathering of rock forming minerals, soil formation and processes, geochemistry of clay minerals, sorption and ion exchange

Redox processes- balancing redox reactions, redox ladder, Nernst equation, pe-pH and Eh-pH diagrams, stability fields, fermentation and methanogenesis, redox conditions in natural water

Acid-base over view- acidity and alkalinity, aqueous pH and buffer capacity

Equilibrium thermodynamics- enthalpy, entropy and Gibb's free energy, thermodynamic laws, La Châtelier's principle , equilibrium constants and effect of temperature and pressure, equilibrium calculation, activity coefficients, Debye-Hückel, Davis and Truesdell-Jones models

Chemical kinetics- rate laws and effect of temperature on reaction rate, precipitation and dissolution kinetics

Sampling, analysis and presentation of aqueous geochemical data- sampling principles and onsite measurements, analytical techniques- physical vs. chemical, statistical evaluation and graphical presentation, geochemical modelling, forward vs. inverse modelling, aqueous geochemical modelling software

Selected Readings:

- Aqueous Environmental Geochemistry. Donald Langmuir, Prentice Hall, 1997.
- Geochemistry of Natural Waters: Surface and Groundwater Environments. **Drever, James I.**, Prentice Hall, 3rd edition 1997.
- Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters. **Stumm, Werner and James J. Morgan,** John Wiley and Sons, Inc., 3rd edition, 1996.

EES 419/619/620: Environmental Biogeochemistry (4)

Continental environment – Fundamentals and important geochemical processes in environment – acid-base, oxidation-reduction, adsorption-desorption, ion exchange, dissolution-precipitation, gas-water and water-rock interaction geochemical processes.Hydrologic cycle, wreathing and water chemistry, acid mine drainage- Fe-S geochemistry, microbial activities

Environmental mineralogy - alumino silicates and environmental stability, carbonate chemistry, geochemistry of clay minerals and cation exchange, trace element cycling in environment and speciation, radioactive and stable isotopes, radioactive waste disposal, non-metals – C, S N, P and halogens, organomettalic and organomettaloidal compounds

Fluvial, lake, estuarine and marineenvironments–processes and composition of river systems, terrestrial nitrogen and phosphorous cycles; processes (physical vs. biological) and thermal stratification in lakes, pit lakes, classification and chemical vs. biological processes of estuaries, chemistry of sea water and oceanic circulation, biological and chemical processes, chemical budgets of elements.marine sediments

Atmospheric environment- atmospheric gases, aerosols and ozone chemistry, rain water and acid rain, S and N cycles and its effect on rain water, greenhouse gases and climate change, air pollution

Selected Readings:

- Global Environment- Water, Air, and Geochemical Cycles. Elizabeth Kay Berner& Robert A. Berner.2nd edition, 2012, Princiton University Press, p. 444.
- Principles of Environmental Geochemistry. Nelson Eby, 1st edition, 2003, Brooks Cole, p. 514.
- Aquatic Chemistry, Chemical Equilibria and Rates in Natural Waters. Stumm, Werner and James J. Morgan, John Wiley and Sons, Inc., 3rd edition, 1996, John Wiley & Sons.Inc. p. 1022.
- Aqueous Environmental Geochemistry. Donald Langmuir, Prentice Hall, 2nd edition 1997, p.600.
- Geochemistry of Natural Waters: Surface and Groundwater Environments. Drever, James I., Prentice Hall, 3rd edition 1997.P. 436.

EES 421/621/622: Remote Sensing of Natural Environment (4)

Introduction: Structure of the course, development of remote sensing technique, fundamental principle, advantage and limitations of remote sensing.

Electromagnetic radiation: The nature, principle and sources of electromagnetic radiation, the Blackbody radiation, the electromagnetic spectrum, energy available for remote sensing, atmospheric window for remote sensing.

High altitude photography: Interaction between light and matter, Color science, film technology, Aerial photography: vertical and oblique photography.

Spectroscopy of rocks and minerals: Introduction, basic principles of spectroscopy, electronic process and vibrational processes, spectral reflectance of minerals.

Multispectral digital imaging system: Introduction to digital images, imaging sensors and tubes, Optical mechanical line scanner, CCD linear array scanner, digital camera, description of space bourne imagine sensors.

Thermal Remote Sensing: The Earth`s radiant energy, surface, radient temperature and kinetic temperature, Plank`s law and emissivity, interpretation of thermal imagery.

Microwave remote sensing: Introduction to microwave, passive and active microwave remote sensing, RADAR technology, interferometry.

Remote Sensing based on gravity: Gravity of earth and other planetary bodies, GRACE mission. Space borne gravity data for hydrology, geodesy and solid earth science.

Distortion and quality of photographs and images: Geometric distortion, distortions related to a) sensors, b) spacecraft, c) earth`s rotation. Factors affecting image quality.Projection, mosaic resampling of satellite images.

Digital image processing of satellite images: Introduction to digital image processing, radiometric and geometric corrections. Principle component analysis, band ratio and colour enhancement of images.

Geological application of remote sensing data: Digital image processing and satellite imagery for geomorphology, tectonics, coastal and deltaic landforms, monitoring vegetation patterns and desertification, lithology and geological mapping, mineral and oil exploration.

Environmental application of remote sensing data: Detailed description of SPOT and JERS images. Geobotany, Geohydrology and water quality using remote sensing data. Remote sensing of the atmosphere.

Integration of remote sensing data with other geo data: Introduction to GIS, transformation of remote sensing data and other data in GIS format.

Indian Remote Sensing Program: Remote sensing program by Indian Space research organization. INSAT, IRS, Oceansat, Resourcesat and Cartosat data and their applications. Future directions.

Suggested Books:

- Sabins, F.F., (2007), Remote Sensing: Principles and Interpretation, Waveland Press, Incorporated.
- Rencz, A.N., (1999), Remote Sensing for the Earth Sciences.Manual of Remote Sensing, Vol. 3. Wiley.

- Gupta, R.P., (2002), Remote Sensing Geology, Springe Verlag, 2nd edition.
- Ustin, S., (2004), Manual of Remote Sensing, Remote Sensing for Natural Resource Management and Environmental Monitoring. Manual of Remote Sensing, Vol. 4. Wiley.
- Jenson, J., (2006), Remote Sensing of the Environment: An Earth Resource Perspective (2nd Edition). Prentice Hall.

EES 601/602: Aerosol Science (4)

Introduction and aerosol characterization: Definition, parameters for determining particle behavior, particle size, shape and density, aerosol concentrations, number, size, and mass distribution functions (moment distributions), Log-probability graphs, Hatch-Choate conversion equations, statistical accuracy

Uniform particle motion: Newton's/Stoke's law, settling velocity, mechanical mobility, slip correction factor, equivalent diameters, settling at high Reynolds numbers, stirred settling, Instruments based on settling velocity

Straight line acceleration and curvilinear motion: Relaxation time, stopping distance, curvilinear motion, Impaction, cascade and virtual impactors, time-of-flight instruments

Diffusion, Thermal and radiometric forces: Diffusion coefficients, Brownian displacement, diffusion/diffusion batteries, thermophoresis, thermophoretic precipitators, radiometric forces.

Coagulation, condensation, and evaporation: Monodisperse coagulation, polydisperse coagulation, kinematic coagulation, homogenous nucleation, Kelvin effect, condensational growth – growth laws, transported limited growth, aerosol phase, reaction-limited growth, heterogeneous condensation, nucleated condensation evaporation

Experimental methods for aerosol sampling and characterization: Microscopy, condensation particle counters, filtration – single fiber efficiency, deposition mechanisms, filter efficiency, pressure drop, membrane filters, Optical measurement instruments-definitions, extinction, scattering, visibility - nephelometers, transmissometers, electrical properties based instruments – electric fields, mobility, charging mechanisms, corona discharge, charge limits, electrostatic precipitators, differential mobility analyzer.

Atmospheric aerosols: Biogenic and anthropogenic aerosols, general features of ambient aerosol size distributions background aerosol, urban aerosol, chemical composition of urban aerosols

Suggested Reading:

- Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles (2nd edition), William C Hinds, John Wiley and Sons (1999)
- Smoke, Dust, and Haze: Fundamentals of Aerosol Dynamics (2nd edition), Sheldon K. Friedlander, Oxford University Press (2000)
- Atmospheric Chemistry and Physics: From Air Pollution to Climate Change (2nd edition), John H. Seinfeld, Sypros N. Pandis, Wiley-Interscience (2006)

EES 603/604: Solid Earth Geochemistry (4)

- The Earth Systems – The earth System; Nature of the early geological record, Achaean lithological associations; the oldest rocks; How much do we really know about the early Earth?
- Isotopes and radioactivity – Nature of an atom; Mass spectrometry; Radioactivity; Dating by parent isotopes; Dating by parent-daughter isotopes; Radioactive chains.
- Radiometric dating methods – General questions; Rich systems and solutions to the problem of open system; Poor systems and the radiometric isotopic correlation diagram; Mixing and alternative interpretations.
- Cosmogenic Isotopes – Nuclear reactions; Carbon-14 dating; Exposure ages; Cosmic irradiation.
- The origin and differentiation of the Earth – The origin and early history of the Universe; Star formation; the condensation of the Solar System; Earth differentiation.
- Uncertainties and results of radiometric dating – Statistical reminders to calculation of uncertainties; Sources of uncertainty in radiometric dating; Geological timescale; Age of the Earth; The cosmic timescale.
- Radiogenic isotope geochemistry – Sr isotope geochemistry; Sr-Nd isotopic coupling; The continental crust-mantle system; Geochemistry of rare gases; Isotopic geology of Pb; Early history of the Earth.
- The evolution of the Earth's Mantle – Understanding the mantle; The Earth's earliest mantle; Mantle models.
- The origin of the continental crust – Moderns crust formation models and mechanisms; First order constraints on the origin of the continental crust; The secular evolution of the Earth's continental crust; Crust growth during the Achaean; Crust-mantle interactions – reservoirs and fluxes.
- Stable isotope geochemistry – Identifying natural isotopic fractionation of light elements; Modes of isotopic fractionation; Isotopic cycle of water; Oxygen isotopes in igneous processes; Paleothermometry and paleoclimatology; Sulfur, Carbon, and Nitrogen isotopes and biological fractionation.
- The origin of the Earth's atmosphere and oceans – Volatile budget of the modern Earth; Origin of the Earth's atmosphere and oceans; Archaean Atmosphere and oceans.

- Isotopic geology and dynamic system analysis – Basic reservoir analysis, steady states, residence time, and mean ages; Assemblages of reservoirs having reached the steady state; Non-steady states; The laws of evolution of isotope systems.
- The origin of Life – Setting the scene of life; Geochemical signals of biological activity; The geological record of life's origin; The microbial record of life's origin; In the beginning.

Suggested Reading:

- Isotope Geology (C. J. Allègre)
- Early Earth Systems – A geochemical Approach (Hugh Rollinson)
- Isotopes – Principles and Applications (Gunter Faure)
- Essentials of Geochemistry (J. V. Walther)
- Using Geochemical Data – Evaluation, Presentation, Interpretation (Hugh Rollinson)

EES 605/606: Mineralogy (4)

See contents of **EES 305**

EES 607/608: Air Quality Management (4)

Introduction Effects and sources of air pollutants, particulate matter management in India - legislation and regulatory trends. Source apportionment models- dispersion model and receptor models. Introduction to receptor modeling - chemical mass balance method, and multivariate methods.

Ambient air quality monitoring: Introduction, role and objectives of monitoring, air sampling, filter media, quality assurance, quality control, network design, instrument selection, system operation, advanced field analysis techniques, data collection and management.

Chemical analyses: Choice of appropriate filter-analysis methodology combinations. Choice of appropriate analytical techniques to quantify trace elements, anions, cations, carbonaceous aerosol. Overview of applying XRF, INAA, PIXE, PIGE, spectroscopic techniques, chromatography, colorimetry, thermal-optical analysis for chemical characterization of ambient particles.

Chemical mass balance for source apportionment: Introduction and method development, principles of CMB, model assumptions, mathematical framework, input and output data, using the model.

Factor analysis methods: Introduction to factor analysis. Principal components analysis, Absolute principal components analysis, UNMIX, SAFER, positive matrix factorization (PMF), advantages of PMF, mathematical framework of PMF, algorithms, penalty functions, estimation of weights, estimation of the number of factors, factor rotations, mass apportionment.

Trajectory ensemble methods: Potential source contribution function (PSCF), Residence time weighted analysis (RTW), quantitative trajectory bias analysis (QTBA), semi-quantitative trajectory bias analysis (SQTBA)

PM management in India: Applicability of receptor models. Model selection. Case studies, review of recent literature, and future directions.

Suggested Reading:

- Receptor Modeling for Air Quality Management, Philip K. Hopke, Elsevier (1991)
- Fundamentals of Atmospheric Modeling (2nd edition), Mark Z. Jacobson, Cambridge University Press (2005). Label 1

EES 609/610: Microstructure and Thermodynamics of Rock Forming Minerals (4)

See contents of **EES 308**

EES 611/612: Aqueous Geochemistry (4)

See contents of **EES 410**

EES 613/614: Science of Sustainability: Managing Earth Resources (4)

See contents of **EES 313**

EES 615/616: Global Atmospheric Chemistry (4)

Atmospheric Chemistry overview: Structure and properties of the troposphere and the stratosphere, temperature profile, sources of chemicals, concentration profiles, removal pathways, and lifetime of chemical species.

Atmospheric Chemistry of the Troposphere: Tropospheric cycles, hydroxyl radical, ozone, NOx chemistry, and hydrocarbons in the troposphere. Torpospheric aerosols – sources and composition, organic aerosol, secondary organic aerosols.

Urban Smog: History of air pollution, anthropogenic impacts, field studies, and modeling.

Atmospheric Chemistry of the Stratosphere: Stratospheric ozone cycle, polar stratospheric chemistry, an stratospheric aerosols

Chemistry of the Atmospheric Aqueous Phase: Aqueous phase reactions, sulfur chemistry, nitrite and nitrate chemistry, and organic chemistry.

Chemistry of Global Climate Change: Greenhouse gases and aerosol concentrations – historical perspectives, natural cycles, anthropogenic impacts, measurement, modeling and uncertainties. Research topics elucidating the coupling between atmospheric chemistry and climate change.

Suggested Reading:

- *Atmospheric Chemistry and Physics*: From Air Pollution Climate Change (2nd edition). John H. Seinfeld, Sypros N. Pandis, Wiley-Interscience (2006).
- *Chemistry of the Upper and Lower Atmosphere*, B.J. Finlayson-Pitts, J. N. Pitts, Jr., Academic Press (2001)

Papers:
The works of J. Seinfeld, R. Kamesn, U. Baltensperger, J. Pankow, J. Chow, P. Saxena, L. Hildemann and other studies as deemed appropriate from time-to-time.

EES 617/618: Geochemistry – Principles and Applications (4)

Introduction – The Earth's aggregate physical and chemical state; Basic Thermodynamics and phase relations; Chemistry of minerals, water, and rocks; Geological controls on geochemical data.

Methods and errors – Analytical methods in geochemistry; Selecting appropriate analytical techniques; Sources of error in geochemical analyses; Correlation, regression, ratio correlation, triangular diagrams.

Using major element data – Rock classification, variation diagrams, and determination of phase boundaries.

Using trace element data – Controls on trace element distribution; REEs; Multi-elemental plots; PGEs; Modeling trace element processes in igneous rocks.

Tectonics – Discrimination between tectonic environments using major and trace element data; Tectonic controls on magmatic and sedimentary processes.

Principles of Atomic Physics – Nuclear synthesis; Decay modes of radionuclides; Radioactive decay; Geochronometry and related uncertainties

Radiogenic Isotope Geochronometers – Rb-Sr system; K-Ar system; Ar-Ar system; K-Ca system; Sm-Nd system; U-Th-Pb and Pb-Pb systems; Lu-Hf system; Re-Os system; La-Ce system; La-Ba method; Radiogenic isotopes in petrogenesis.

Earth Systems – Mixing theory; Origin of igneous rocks; Water and sediment; The oceans; Chemical geodynamics; Early history of the Earth.

Other radionucleides - Short-lived, cosmogenic and extinct radionucleides

Stable Isotopes – Modes of fractionation; Hydrogen, Oxygen, Carbon, Nitrogen and Sulphur systems; Water-rock interactions; Paleothermometry and Paleoclimatology; Biological fractionation; Boron and other elements.

Conclusions – The combined use of sable and radiogenic isotopes and the construction of a global geodynamic system; Basic steady-state reservoir analyses; Non-steady states; Organic Geochemistry.

Suggested Reading:

- Allégre, C. J., 2005, Isotope Geology, Cambridge University Press, 512 pages.
- Rollinson, H., 2008, Early Earth Systems – A geochemical Approach, Blackwell Publishing, 285 pages.
- Faure, G., and Mensing, T. M., 2004, Isotopes – Principles and Applications, Wiley publications, 928 pages.
- Walther, J. V., 2005, Essentials of Geochemistry, Jones & Bartlett Publishers, 704 pages.

EES 619/620: Environmental Biogeochemistry (4)

See contents of **EES 419**

EES 621/622: Remote Sensing of Natural Environment (4)

See contents of **EES 421**

EES 623/624: Structural Geology and Rock Deformation (4)

Introduction: Structure of the course. Introduction to structural geology and tectonics.Interior of the earth and other planetary bodies. The Earth's crust and plate tectonics. The structure of the continental crust.

Stress, strain and deformation: Stress: Basic definitions, different types of stress tensors, Mohr`s diagram: Graphical analysis of stress. Strain: basic

definitions,.Measurement of strain. Rheology of rocks and minerals: concept of brittle and ductile deformation.

Fracture and joints: Classification of fractures, geometry of fracture system in three dimensions, microscopic features of fractured surfaces.

Faults: Different types of faults, recognition of faults, measurement of fault displacements. Fault Geometry. Orientation *of stress field and fault kinematics.*

Mechanics of fracturing and faulting: Experimental fracturing of rocks and minerals. The Coulomb Fracture Criterion, effect of confining pressure on fracturing and frictional sliding. The Griffith theory of fracture.

Folding: Geometric descriptions of folds, fold scale and attitude, the element of fold styles, the order of folding, common styles and structures associated with folding.

Kinematics of Folding: Folding mechanism: a) flexural folding and shear folding of single layers, b) multilayer folding, c) formation of kink and chevron fold, drag fold.

Foliation and lineation in deformed rocks: Different types of foliations: Compositional, disjunctive, crenulation and continuous. Lineation: Structural and mineral, association of lineation and other structures.

Microscopic aspects of ductile deformation: Mechanisms of low temperature deformation, twin gliding, diffusion and solution creep, linear crystal defects. Microscopic criteria for identification of dislocation and diffusion creep.

Shear zone and progressive deformation: The nature of shear zone, mechanism of formation of shear zone, Strain in shear zone, determining the sense of shear in shear zone, shear zone and active tectonics.

Structural Geology and plate tectonics: Introduction to plate tectonics, different types of tectonic boundaries, development of structures at active plate margins

Measurement techniques and preparations of geological maps in structural geology: Orientation and representations of planer and linear structures, strike and dip of planer structures, pitch and plunge of linear structure, graphical representation of structures, stereographic projections of geological structures, preparation of geological maps. Graphical analysis of structures.

Suggested Books:

- Twiss, R.J and Moores, E.M (2007), Structural Geology, W.H Freeman and Company, 2nd edition
- Ghosh, S.K. Structural Geology (1993): Fundamentals and Modern Developments, Pergamon Press, 1st edition.
- Davis, H., Reynolds, S.J. Kluth, F.C, Structural Geology of rocks and regions, Wiley, 3rd Edition.
- Marshak, S., Mitra, G, (1988), Basic methods of Structural Geology, Printice Hall.

Mathematics

MTH 101: Calculus of One Variable (3)

- Introduction to the real number system, field axioms, order axioms and the completeness axiom
- Sequences and series of numbers, convergence of a sequence, Cauchy's criterion, limit of a sequence, supremum and infimum, absolute and conditional convergence of an infinite series, tests of convergence, examples
- Limits and continuity, definitions, continuity and discontinuity of a function at a point, left and right continuity, examples of continuous and discontinuous functions, intermediate value theorem, boundedness of a continuous function on a closed interval, uniform continuity
- Differentiation, definition and basic properties, Rolle's theorem, mean value theorem, Leibnitz's theorem on successive differentiation, Taylor's theorem
- Integration, Riemann integral viewed as an area, partitions, upper and lower integrals, existence of the Riemann integral, basic properties, fundamental theorem of integral calculus, integration by parts, applications

Suggested Reading:

- G. B. Thomas and R. L. Finney, *Calculus and Analytic Geometry*, 9th edition, Indian student edition, Addison-Wesley, 1998
- T. M. Apostol, *Calculus*, Volumes 1 and 2, 2nd edition, Wiley Eastern, 1980
- R. Courant, F. John, *Introduction to Calculus and Analysis*, Volume 1, Classics in Mathematics, Springer, 1989

MTH 102: Linear Algebra (3)

- Review of complex numbers
- Matrices, matrix operations, special matrices (diagonal, triangular, symmetric, skew-symmetric, orthogonal, hermitian, skew hermitian, unitary, normal), vectors in $\mathbf{R}^n$ and $\mathbf{C}^n$, matrix equation $\mathbf{Ax} = \mathbf{b}$, row-reduced echelon form, row space, column space, and rank of a matrix. Determinants. Systems of linear equations
- Vector space $\mathbf{R}^n$, linear independence and dependence, linear span, linear subspaces, bases and dimensions
- Vector spaces, bases and dimensions, linear transformations, matrix of a linear transformation, rank-nullity theorem
- Inner product spaces, orthonormal bases, Gram-Schmidt orthogonalization, projections
- Eigenvalues and eigenvectors of a linear operator, characteristic polynomial,

diagonalizability of a linear operator, eigenvalues of the special matrices stated above, spectral theorem for real symmetric matrices and its application to quadratic forms, positive definite matrices

Suggested Reading:

- T. M. Apostol, *Calculus*, Volume 2, 2nd edition, Wiley Eastern, 1980
- H. Anton, *Elementary linear algebra and applications*, 8th edition, John Wiley, 1995
- G. Strang, *Linear algebra and its applications*, 4th edition, Thomson, 2006
- S. Kumaresan, *Linear algebra - A Geometric Approach*, Prentice Hall of India, 2000
- R. Rao and P. Bhimasankaram, *Linear Algebra*, 2nd edition, Hindustan Book Agency, 2000
- M. Artin, *Algebra*, Prentice-Hall of India, 1994
- R. Bapat, *Linear Algebra and Linear Models*, HBA, 1999

MTH 201: Multivariable Calculus and Differential Equations (3)

- Vectors in $\mathbf{R}^3$, dot product of vectors, length of a vector, orthogonality of vectors, cross product of vectors
- Lines, planes, and quadric surfaces
- Continuity and differentiability of vector-valued functions, tangent vectors
- Functions of two or more variables, limits and continuity, partial derivatives, gradient, directional derivatives, maxima, minima and saddle points, Lagrange multipliers
- Double and triple integrals, change of coordinates, vector fields, line integrals, surface integrals, Green's theorem, Divergence theorem, Stokes' theorem
- First order ordinary differential equations: variables separable, homogeneous, linear and exact equations

Suggested Reading:

- G. B. Thomas and R. L. Finney, *Calculus and Analytic Geometry*, 9th edition, Indian student edition, Addison-Wesley, 1998
- T. M. Apostol, *Calculus*, Volumes 1 and 2, 2nd edition, Wiley Eastern, 1980
- J. E. Marsden and A. Tromba, *Vector Calculus*, W.H. Freeman & Company, 2004
- R. Courant, F. John, *Introduction to Calculus and Analysis*, Vol. 2, Classics in Mathematics, Springer, 1989

MTH 202: Probability and Statistics (3)

- Algebra of Sets: sets, classes, limit of a sequence of sets, rings, sigma rings, fields, sigma-fields, monotone classes
- Probability: Classical, relative frequency and axiomatic definitions of probability, addition rule and conditional probability, multiplication rule, total probability, Bayes Theorem and independence, problems
- Random Variables: Discrete, continuous and mixed random variables, probability mass, probability density and cumulative distribution functions, mathematical expectation, moments, probability and moment generating function, median and quantiles, Markov inequality, Chebyshev's inequality, problems
- Special Distributions, Joint Distributions: Joint, marginal and conditional distributions, product moments, correlation and regression, independence of random variables, bivariate normal distribution
- Transformations: functions of random vectors, distributions of order statistics, distributions of sums of random variables
- Sampling Distributions: The Central Limit Theorem, distributions of the sample mean and the sample variance for a normal population, Chi-Square, t and F distributions
- Descriptive Statistics: Graphical representation, Summarization and tabulation of data
- Estimation: Unbiasedness, consistency, the method of moments and the method of maximum likelihood estimation, confidence intervals for parameters in one sample and two sample problems of normal populations, confidence intervals for proportions
- Testing of Hypotheses: Null and alternative hypotheses, the critical and acceptance regions, two types of error, power of the test, the most powerful test and Neyman-Pearson Fundamental Lemma, tests for one sample and two sample problems for normal populations, tests for proportions, Chi-square goodness of fit test and its applications

Suggested Reading:

- W. Feller, *An Introduction to Probability Theory and Its Applications,* Volume 1, 3rd Edition, Wiley, 1968
- V. Rohatgi, A. Saleh, *Introduction to Probability Theory and Statistics*, 2nd Edition, Wiley, 2000
- S.M. Ross, *A First Course in Probability*, 6th Edition, Prentice Hall
- A. Craig, R. Hogg, J. McKean, *Introduction to Mathematical Statistics*, 6th Edition, Prentice Hall, 2004
- J.S. Milton and J.C. Arnold, *Introduction to Probability and Statistics*
- P. Hoel, S. Port, C. Stone, *Introduction to Probability Theory*, 1st Edition, Brooks Cole, 1972

- R. Isaac, *The Pleasures of Probability*, Springer (Undergraduate Texts in Mathematics)
- H.J. Larson, *Introduction to Probability Theory and Statistical Inference*

MTH 301: Groups and Rings (4)

- Definition of group, subgroups, normal subgroups, quotient groups
- Basic examples: dihedral, symmetric, alternating, quaternion groups, matrix groups
- Cyclic groups, subgroups of cyclic groups, centralizer, normalizer and stabilizer subgroups
- Simple groups, simplicity of alternating groups
- Homomorphisms and isomorphisms, isomorphism theorems
- Group actions on sets, conjugation, class equation, automorphisms
- Sylow theorems and application on counting groups of a given order
- Direct and semidirect products, groups of small order (if time permits)
- Definition of ring, subrings, ideals, quotient rings
- Basic examples: polynomial rings, matrix rings, group rings, rings of formal power series
- Ring homomorphisms, isomorphisms, Chinese remainder theorem
- Commutative rings, euclidean domains, principal ideal domains, unique factorization domains

Suggested Reading:

- I. N. Herstein, *Topics in Algebra, 2nd Edition*, Wiley, 2006
- T. W. Hungerford, *Algebra*, Springer Verlag, 2005
- M. Artin, *Algebra*, Prentice-Hall of India, 1994
- D. S. Dummit, R. M. Foote, *Abstract Algebra, 2nd Edition*, Wiley
- J. Rotman, *A First Course in Abstract Algebra : With Applications*, Prentice Hall
- J. Rotman, *An Introduction to Theory of Groups*, Springer GTM, 1999
- H. Kurzweil, B. Stellmacher, *The Theory of Finite Groups*, Springer Universitext, 2004

MTH 302: Modules (4)

Pre-requisites: MTH 301 Groups and Rings

- Left and right modules, Representations of rings, Submodules, Quotient modules, Finitely generated modules, Cyclic modules
- Homomorphisms, Kernel and Image, Isomorphism theorems
- Direct sums and Free modules, Simple modules, Schurs lemma
- Structure theorem for finitely generated modules over a PID, applications to finitely generated abelian groups

- Exact Sequences of modules, Artinian and Noetherian Modules, Semisimple modules
- Tensor product of modules, Properties of tensor product, change of scalars
- Projective and Injective modules

Suggested Reading:

- D.S. Dummit, R.M. Foote, Abstract Algebra, 2nd Edition, Wiley
- G. Birkhoff, S. McLane, Algebra (3rd Edition), AMS
- S. Lang, Algebra (3rd Edition), Pears
- C. Musili, Rings and Modules (2nd Edition), Narosa
- M.F. Atiyah, I.G. Macdonald, Introduction to Commutative Algebra (1st Indian Edition), Levant Books
- N. Jacobson, Basic Algebra (Vols - I & II), Hindustan Book Agency

MTH 303: Real Analysis I (4)

- Real number system, limit superior, limit inferior, supremum principle, completeness, Cantor set
- Sequences and series of functions, uniform convergence and its consequences, space of continuous functions on a closed interval, equicontinuous families, Stone-Weierstrass theorem, Arzela-Ascoli theorem
- Taylor's theorem, power series, radius of convergence, exponential, trigonometric and logarithmic functions
- Monotonic functions, functions of bounded variation, rectifiable curves
- Riemann-Stieltjes integral, properties of Riemann-Stieltjes integral, differentiation of the integral, fundamental theorem of calculus, integration by parts, Gamma function

Suggested Reading:

- T. M. Apostol, *Calculus, Volumes 1 and 2* (2nd edition), Wiley Eastern, 1980
- W. Rudin, *Principles of Mathematical Analysis (3rd Edn.)*, McGraw Hill, 1953
- T. M. Apostol, *Mathematical Analysis (2nd Edn.)*, Narosa Publishing, 1985
- R. R. Goldberg, *Methods of Real Analysis*
- H. L. Royden, *Real Analysis (3rd Edn.)*, Prentice Hall, 2008
- Terrance Tao, *Analysis I & II*, TRIM Series, Hindustan Book Agency

MTH 304: Metric Spaces and Topology (4)

Pre-requisites: MTH 303 Real Analysis I

- Definition, open sets, closed sets, limit points, convergence, completeness, Baire's theorem, continuity, spaces of continuous functions
- Compactness, sequential compactness, compact metric spaces, compact-open

topology, Ascoli's theorem
- Completeness, space filling curve, nowhere differentiable functions

Topology

- Definition and examples of topology, base, subbase, weaker and stronger topology
- Order topology, subspace topology, product and box topology
- Continuity, homeomorphisms, quotient topology
- Compact spaces, examples, Tychonoff's theorem and locally compact spaces, limit point compactness, local compactness
- Connected spaces, components, path components, totally disconnected spaces, locally connected spaces, examples
- Countability axioms, separation axioms, completely regular and normal spaces, Urysohn's lemma, Tietze extension theorem, Urysohn embedding theorem, Stone-Cech compacitification

Suggested Reading:

- G. F. Simmons, *Introduction to Topology and Modern Analysis*, Tata McGraw Hill, 2008
- J. R. Munkres, *Topology (2nd Edn)*, Dorling Kindersley, 2006

MTH 305: Foundations of Mathematics and Elementary Number Theory (4)

- Ordinal and cardinal numbers, countable and uncountable sets
- Propositional and quantified logic
- Statements and Proofs: proof by induction, direct proof, proof by contradiction
- Arithmetic functions: Divisor function, Euler phi function, Moebius function
- Fermat's little theorem, Wilson's theorem, Euler's theorem
- Quadratic reciprocity law
- Primitive roots

Suggested Reading:

- W. Rudin, *Principles of Mathematical Analysis* (3rd Edn.), McGraw Hill, 1953
- D. Burton, *Elementary Number Theory* (6th Edn.), Tata McGraw Hill
- Jones and Jones, *Elementary Number Theory*, Springer, UTM
- David Tall and Ian Stewart, *The Foundations of Mathematics*, Oxford University Press, 1977
- I. Niven, H. S. Zuckerman, *An Introduction to the Theory of Numbers* (5th Edn.), Wiley
- E. Mendelson, *Introduction to Mathematical Logic* (5th Edn.), Chapman & Hall

MTH 306: Ordinary Differential Equations (4)

Pre-requisites: MTH 303 Real Analysis I

- First-Order Linear equations: exact equations, orthogonal trajectories, homogeneous equations, integrating factors, reduction of order
- Second-order linear equations: equations with constant coefficients, method of undetermined coefficients, variation of parameters, power series solutions, special functions, applications
- Higher-order linear equations
- Some basic concepts of Fourier series
- Quick review of elementary linear algebra, Picard's existence and uniqueness theorem, Sturm comparison theorem
- Systems of first-order equations, homogeneous linear systems with constant coefficients
- Non-linear equations: critical points and stability, Liapunov's direct method, Poincare-Bendixson theory

Suggested Reading:

- George F. Simmons & Steven Krantz, *Differential equations*, Paperback edition, Tata-McGraw Hill 2009
- G. Birkhoff & G. C. Rota, *Ordinary differential equations*, Paperback edition, John Wiley &Sons, 1989
- E. Coddington & N. Levinson, *Theory of ordinary differential equations*, Paperback edition, Tata-McGrawa Hill, 2008
- W. Hurewicz, *Lectures on ordinary differential equations*, Dover, New York, 1999

MTH 307: Programming and Data Structures (4)

- Programming in a structured language such as C
- Data Structures: definition, operations, implementations and applications of basic data structures
- Array, stack, queue, dequeue, priority queue, double linked list, orthogonal list, binary tree and traversal algorithm, threaded binary tree, generalized list
- Binary search, Fibonacci search, binary search tree, height balance tree, heap, B-tree, digital search tree, hashing techniques

Suggested Reading:

- Donald E. Knuth, *The art of computer programming (*five volumes, 0 - 4*)*, Addison Wesley
- V. Aho, J. E. Hopcroft & J. E. Ullman, *Data Structures & Algorithm*, Addison Wesley
- W. Kernighan, D. M. Richie, *The C Programming Language*, Prentice Hall

MTH 308: Combinatorics and Graph Theory (4)

- *Combinatorics*: Elementary principles of combinatorics (permutations and combinations), binomial coefficients, inclusion-exclusion principle, generating functions, recurrence relation, pigeon-hole principle and Ramsey theory
- *Graph theory*: definition, isomorphisms, degree sequences, connectivity, trees, colourings, Eulerian graphs, directed graphs, network flows

Suggested Reading:

- R. A. Brualdi, *Introductory Combinatorics* (5th Ed.), Prentice Hall
- F. Harary, *Graph Theory*, Westview Press
- Bondy, U. S. R. Murty, *Graph Theory* (1st Ed.), Springer, GTM
- S. M. Cioaba & M. Ram Murty, *A First Course in Graph Theory*, TRIM Series, HBA

MTH 311: Advanced Linear Algebra (4)

- Linear transformations and Determinants : The algebra of linear transformations, Multi-linear functions, The Grassman Ring
- Elementary canonical forms : Characteristic Values, Annihilating Polynomials, Invariant subspaces, Simultaneous Triangulation and Diagonalization, The Primary Decomposition Theorem, S-N Decomposition, Canonical forms and Differential Equations
- The Rational and Jordan Forms : Cyclic subspaces and annihilators, Cyclic decompositions and the Rational form, The Jordan Form, Computation of Invariant factors, Semi-simple operators
- Operators on Inner product spaces : Forms on Inner product spaces, Positive forms, Spectral Theory, Unitary Operators, Normal Operators
- Bilinear forms : Bilinear forms, Symmetric bilinear forms, Skew-symmetric bilinear forms

Suggested Reading:

- K. Hoffman and R. Kunze, *Linear Algebra*, Prentice-Hall, 1961
- Serge Lang, *Linear Algebra (2nd Edition)*, Addition-Wesley Publishing, 1971
- M.W. Hirsch and S. Smale, Differential equations, dynamical systems and linear algebra, Pure and Applied Mathematics, Vol. 60, Academic Press, 1974
- P. Halmos, Finite dimensional vector spaces (2nd Edition), Undergraduate texts in Mathematics, Springer-Verlag New York Inc., 1987
- Serge Lang, Algebra, Graduate Texts in Mathematics (3rd Edition), Springer-Verlag New York Inc., 2005

MTH 401: Fields and Galois Theory (4)

Pre-requisites: MTH 301 Groups and Rings

- Polynomial rings, Gauss lemma, Irreducibility criteria
- Definition of a field and basic examples, Field extensions
- Algebraic extensions and algebraic closures
- Classical Straight hedge and compass constructions (optional)
- Splitting fields, Separable and Inseparable extensions
- Cyclotomic polynomials, Galois extensions
- Fundamental theorem of Galois theory
- Composite and Simple extensions, Abelian extensions over Q
- Galois groups of polynomials, Solvability of groups, Solvability of polynomials
- Computations of Galois groups over Q

Suggested Reading:

- D. S. Dummit, R. M. Foote, *Abstract Algebra* (2nd Ed.), Wiley
- S. Lang, *Algebra* (3rd Ed.), Pears

MTH 403: Real Analysis II (4)

Pre-requisites: MTH 303 Real Analysis I

- Vector-valued functions, continuity, linear transformations, differentiation, total derivative, chain rule
- Determinants, Jacobian, implicit function theorem, inverse function theorem, rank theorem
- Partition of unity, Derivatives of higher order
- Riemann integration in $\mathbf{R}^n$, differentiation of integrals, change of variables, Fubini's theorem
- Exterior algebra, simplices, chains of simplices, Stokes theorem, vector fields, divergence of a vector field, Divergence theorem, closed and exact forms, Poincare lemma

Suggested Reading:

- David Widder, *Advanced Calculus*, second edition, Dover, 1989
- M. Spivak, *Calculus on manifolds*, fifth edition, Westview Press, 1971
- J. Munkres, *Elementary Differential topology*, Princeton University Press, 1966

MTH 404: Measure and Integration (4)

Pre-requisites: MTH 403 Real Analysis II

- Topology of the real line, Borel, Hausdorff and Lebesgue measures on the real line, regularity properties, Cantor function
- σ-algebras, measure spaces, measurable functions, integrability, Fatou's lemma, Lebesgue's monotone convergence theorem, Lebesgue's dominated convergence theorem, Egoroff's theorem, Lusin's theorem, the dual space of C(**X**) for a compact, Hausdorff space, **X**
- Comparison with Riemann integral, improper integrals
- Lebesgue's theorem on differentiation of monotonic functions, functions of bounded variation, absolute continuity, differentiation of the integral, Vitali's covering lemma, fundamental theorem of calculus
- Holder's, inequality, Minkowski's inequality, convex functions, Jensen's inequality, $\mathbf{L}^p$ spaces, Riesz-Fischer theorem, dual of $\mathbf{L}^p$ spaces

Suggested Reading:

- W. Rudin, *Real and Complex Analysis*, third edition. Tata-McGraw Hill, 1987
- H. Royden, *Real Analysis*, third edition, Prentice-Hall of India, 2008
- R. Wheeden, A. Zygmund, *Measure and Integral*, Taylor and Francis, 1977
- J. Kelley, T. Srinivasan, *Measure and Integral*, Volume I, Springer, 1987
- Rana, *An Introduction to Measures and Integration*, Narosa Publishing House
- E. Lieb, M. Loss, *Analysis*, Narosa Publishing House

MTH 405: Partial Differential Equations (4)

Pre-requisites: MTH 306 Ordinary Differential Equations

- First-order equations: linear and quasi-linear equations, general first-order equation for a function of two variables, Cauchy problem, envelopes
- Higher-order equations: Cauchy problem, characteristic manifolds, real analytic functions, Cauchy-Kovalevski theorem, Holmgren's uniqueness theorem
- Laplace equation: Green's identity, Fundamental solutions, Poisson's equation, Maximum principle, Dirichlet problem, Green's function, Poisson's formula
- Wave equation: spherical means, Hadamard's method, Duhamel's principle, the general Cauchy problem
- Heat equation: initial-value problem, maximum principle, uniqueness, regularity

Suggested Reading:

- F. John, *Partial differential equations*, 4th edition, Springer, 1982
- G. B. Folland, *Introduction to Partial differential equations*, 2nd edition, Princeton University Press, 1995
- J. Rauch, *Partial differential equations*, Springer, GTM 128, 1991
- L. Evans, *Partial differential equations*, American Mathematical Society GSM series, 1998

MTH 406: Differential Geometry of Curves and Surfaces (4)

Pre-requisites: MTH 306 Ordinary Differential Equations

- Curves: curves in space, tangent vector, arc length, curvature, torsion, Frenet formulas
- Surfaces: parametrization, tangent plane, orientability, first fundamental form, area, orientation, Gauss map, second fundamental form, Gauss curvature, ruled and minimal surfaces
- Geodesics, isometries of surfaces, Gauss' Theorema Egregium, Codazzi-Mainardi equations
- Gauss-Bonnet theorem for compact surfaces

Suggested Reading:

- Pressley, *Elementary Differential Geometry*, Springer, Indian reprint, 2004
- Manfredo do Carmo, *Differential Geometry of Curves and Surfaces*, Prentice Hall, 1976
- D. J. Struik, *Lectures on Differential Geometry*, Dover, 1988
- Barrett O'Neill, *Elementary Differential Geometry*, Second edition, Academic Press (Elsevier), 2006

MTH 407: Complex Analysis I (4)

Pre-requisites: MTH 303 Real Analysis I

- Complex numbers: powers and roots, geometric representation, stereographic projection
- Complex differentiability: limits, continuity and differentiability, Cauchy Riemann equations, definition of a holomorphic function
- Elementary functions: sequences and series, complex exponential, trigonometric, and hyperbolic functions, the logarithm function, complex powers, Mobius transformations

- Complex integration: contour integrals, Cauchy's integral theorem in a disc, Cauchy's Integral Formula, Liouville's theorem, Fundamental Theorem of Algebra, Morera's theorem, Schwarz reflection principle
- Series representation of analytic functions: Taylor series, power series, zeros and singularities, Laurent decomposition, open mapping theorem, Maximum Principle
- Residue theory: residue formula, calculation of certain improper integrals, Riemann's theorem on removable singularities, Casorati Weierstrass theorem, the argument principle and Rouche's theorem
- Conformal mappings: conformal maps, Schwarz lemma and automorphisms of the disk and the upper half plane

Suggested Reading:

Texts

- Elias M. Stein, Rami Shakarchi, *Complex Analysis (Princeton Lectures in Analysis)*, Princeton University Press, 2003
- Theodore W. Gamelin, *Complex Analysis*, Springer Verlag, 2001
- John B. Conway, *Functions of one Complex Variable I*, Springer, 1978
- E. Freitag and R.Busam, *Complex Analysis*, Springer, 2005

References

- Lars Ahlfors, *Complex Analysis.* McGrawHill, 1979
- R. Remmert, *Theory of Complex Functions.* Springer Verlag, 1991
- C. Caratheodory, *Theory of Functions of a complex variable*, AMS Chelsea, 2001

MTH 408: Numerical Analysis (4)

Pre-requisites: MTH 303 Real Analysis I

- Round off errors and computer arithmetic
- Interpolation: Lagrange interpolation, divided differences, Hermite interpolation, splines, numerical differentiation, Richardson extrapolation
- Numerical Integration: trapezoidal, Simpsons, Newton-Cotes, Gauss quadrature, Romberg integration, multiple integrals
- Solution of linear algebraic equations: direct methods, Gauss elimination, pivoting, matrix factorizations
- Iterative methods: matrix norms, Jacobi and Gauss-Siedel methods, relaxation methods
- Computation of eigenvalues and eigenvectors: power method, householders method, QR algorithm
- Numerical solutions of non-linear algebraic equations: bisection, secan and Newton's, zeroes of polynomials

Suggested Reading:

- R. L. Burden, D. J. Faires, *Numerical Analysis*
- E. K. Blum, *Numerical Analysis and Computation, Theory and Practice,* Dover, 2010
- S. D. Conte, C. De Boor, *Elementary Numerical Analysis*, third edition, McGraw-Hill, 1980
- D. M. Young, R. T. Gregory, *A Survey of Numerical Mathematics*, volumes 1 and 2, Dover, 1988

MTH 409: Optimization Techniques (4)

Pre-requisites: MTH 303 Real Analysis I

- Maxima and minima, Lagrange multipliers method, formulation of optimization problems, linear programming, non-linear programming, integer programming problems
- Convex sets, separating hyperplanes theorem, simplex method, two phase simplex method, duality theorem, zero-sum two-person games, branch and bound method of integer linear programming
- Dynamic programming, Bellman's principle of optimality

Suggested Reading:

- Katta G. Murty, *Linear Programming*, Revised edition, Wiley, 1983
- Griva, S. Nash, A. Sofer, *Linear and Non-linear Optimization*, second edition, SIAM, 2008
- M. Bazaraa, H. Sherali, C. Shetty, *Non-linear Programming: Theory and Algorithms*, third edition, Wiley Inter-Science, 2006

MTH 411: Introduction to Lie Groups and Lie Algebras (4)

Pre-requisites: MTH 311 Advanced Linear Algebra, MTH 301 Groups and Rings

- Matrix Lie Groups: Definition and examples; Lie group homomorphisms and isomorphisms, Lie subgroups, polar decomposition.
- Lie algebras: matrix exponential and matrix logarithm, the Lie algebra of a matrix Lie group, Lie subalgebras, complexification of a real Lie algebra, Baker-Campbell-Hausborff formula.
- Representation Theory: standard and adjoint representations, unitary representations, irreducible representations of su(2), direct sum ad tensor product of representations, dual representations, Schur's Lemma.
- Semisimple Theory: Representations of SU(3), weights and roots, the WeyI group. Semisimple Lie algebras, complete reducibility, Cartan subalgebras, root systems.

Suggested Reading:

- Hall, Brian Lie Groups, *Lie Algebras, and Representations. Graduate Texts in Mathematics*, Vol. 222, Springer Verlag, 2003.
- Rossmann, Wulf. *Lie Groups: An Introduction through Linear Groups*. Oxford Graduate Texts in Mathematics 5, Oxford University Press, 2002.
- Humphreys, James E. *Introduction to Lie Alogebras and Representation Theory. Graduate Texts in Mathematics*, Vol. 9, Springer, 1973.
- Baker, Andrew. *Matrix Groups: An Introduction to Lie Group Theory*. Springer Veriag, 2002.

MTH 503: Functional Analysis (4)

Pre-requisites: MTH 304 Metric Spaces and Topology, MTH 404 Measure and Integration

- Banach Spaces: Algebras, Normed linear spaces and Banach spaces, Continuity and boundedness of linear functionals and their norm, semilinear functionals and their extensions, Hahn-Banach theorem, Duality and Natural embedding, revisiting dual of $\mathbf{L}^p$ and Riesz-Fisher theorem, Open mapping and Closed graph theorem, Uniform boundedness theorem, weak* topology, Banach-Alaglou's theorem.
- Hilbert Spaces: Definition and examples, Orthogonal complements, Orthonormal sets and Bessel's inequality, complete orthonormal sets, Gram-Schmidt process, conjugate spaces, Riesz representation theorem, adjoint, self-adjoint, normal and unitary operators, applications to Fourier analysis.
- Spectral Theorem (General discussion): Projections and idempotents, Compact operators, Diagonalization of compact self-adjoint operators, Spectral theorem for compact normal operators.

Suggested Reading:

- G.F. Simmons, Introduction to Topology and Modern Analysis, Tata McGraw Hill, 2008
- W. Rudin, Functional Analysis, McGraw Hill Book Company, 1973
- J.B. Conway, A course in Functional analysis, GTM 96, Springer, 1990
- F. Hirsch and G. Lacombe, Elements of Functional Analysis, GTM 192, Springer
- S. Kesavan, Functional Analysis, TRIM 52, Hindustan Book Agency
- Martin Schechter, Principles of Functional Analysis, Graduate Studies in Mathematics, American Math. Soc. 2nd Ed
- B.V. Limaye, Functional Analysis, New Age books, 2nd Ed

MTH 504/604: Complex Analysis II (4)

Pre-requisites:
Required: MTH 303 Real Analysis I, MTH 407 Complex Analysis
Desirable: MTH 304 Metric Spaces and Topology, MTH 503 Functional Analysis

- Review of elementary concepts: Complex differentiation, Cauchy-Riemann equations, holomorphicity, complex integration, Cauchy's theorem and Cauchy's integral formula, Taylor and Laurent series, residue theorem, definition of a meromorphic function.
- Harmonic functions: definition and properties, Poisson integral formula, mean-value property, Schwarz reflection principle, Dirichlet problem
- Maximum modulus principle: Maximum modulus theorem, Schwarz lemma, Phragmen-Lindelof theorem
- Approximations by rational functions: Runge's theorem, Mittag-Leffler theorem
- Conformal mappings: definition and examples, space of holomorphic functions, Montel's theorem, statement of Riemann mapping theorem
- Entire functions, Infinite products, Weierstrass factorization theorem, little and big Picard Theorems, Gamma function

Suggested Reading:

Texts:
- Stein E.M. and Shakarchi R., *Complex Analysis (Princeton Lectures in Analysis Series, Vol. II)*, Princeton University Press, 2003
- Conway J.B., *Functions of One Complex Variable*, Springer-Verlag NY, 1978
- Rudin W., *Real and Complex Analysis*, McGraw-Hill, 2006
- Epstein B. and Hahn L-S., Classical Complex Analysis, Jones and Bartlett, 2011
- Ahlfors L., *Complex Analysis*, Lars Ahlfors, McGraw-Hill, 1979.

References:
- Carathodory C., *Theory of functions of a complex variable, Vol. I and II*, Chelsea Pub Co, NY 1954
- Remmert R., Classical topics in complex function theory, Springer 1997

MTH 505: Introduction to Ergodic Theory (4)

Pre-requisites: MTH 304 Metric Spaces and Topology, MTH 404 Measure and Integration

- *Discrete Dynamical systems:* definition and examples - maps on the circle, the doubling map, shifts of finite type, toral automorphisms.

- *Topological and Symbolic dynamics:* transitivity, minimality, topological conjugacy and discrete spectrum, topological mixing, topological entropy, topological dynamical properties of shift spaces, circle maps and rotation number.
- *Ergodic Theory:* invariant measures and measure-preserving transformations, ergodicity, recurrence and ergodic theorems (Poincare recurrence, Kac's lemma, Von Neumann's ergodic theorem, Birkhoff's ergodic theorem), applications of the ergodic theorem (continued fractions, Borel normal numbers, Khintchine's recurrence theorem), ergodic measures for continuous transformations and their existence, Weyl's equidistribution theorem, mixing and spectral properties.
- *Information and entropy* - topological, measure-theoretic, and their relationship. Skew products, factors and natural extensions, induced transformations, suspensions and towers. Topological pressure and the variational principle, thermodynamic formalism and transfer operators, applications of thermodynamic formalism: (i) Bowen's formula for Hausdorff dimension, (ii) central limit theorems.

Suggested Reading:

- P. Walters, An Introduction to Ergodic Theory, Springer-Verlag, New York, 1982
- M.G. Nadkarni, Basic Ergodic Theory, Second Edition, Hindustan Book Agency, India
- M. Brin and G. Stuck, Introduction to Dynamical Systems, CUP, 2002
- M. Pollicott and M. Yuri, Dynamical systems and Ergodic theory, CUP, 1998
- P. R. Halmos, Lectures on Ergodic Theory, Chelsea, New York, 1956
- W. Parry, B. Bollobas, W. Fulton, Topics in Ergodic Theory, CUP, 2004
- A.B. Katok and B. Hasselblatt, Introduction to the Modern Theory of Dynamical Systems, Cambridge, 1995

MTH 506/610: Fourier Analysis on the Real Line (4)

Pre-requisites: MTH 404 Measure and Integration, MTH 503 Functional Analysis: Normed linear spaces, completeness, Uniform boundedness principle, MTH 405 Partial Differential Equations: Basic knowledge of Laplacian, Heat and Wave equations

- The vibrating string, derivation and solution to the wave equation, The heat equation
- Definition of Fourier series and Fourier coefficients, Uniqueness, Convolutions, good kernels, Cesaro/Abel means, Poisson Kernel and Dirichlet's problem in the unit disc
- Mean-square convergence of Fourier Series, Riemann-Lebesgue Lemma, A continuous function with diverging Fourier Series
- Applications of Fourier Series : The isoperimetric inequality, Weyl's equidistribution Theorem, A continuous nowhere-differentiable function, The heat equation on the circle

- Schwartz space*, Distributions*, The Fourier transform on **R**: Elementary theory and definition, Fourier inversion, Plancherel formula, Poisson summation formula, Paley-Weiner Theorem*, Heisenberg Uncertainty principle, Heat kernels, Poisson Kernels
- (If time permits/possible project topic) Definition of Fourier transform on $\mathbf{R}^d$, Definition of X-ray transform in $\mathbf{R}^2$ and Radon transform in $\mathbf{R}^3$, Connection with Fourier Transform, Uniqueness

Suggested Reading:

Texts:
- E.M.Stein and R. Shakarchi, *Fourier Analysis: An Introduction, Princeton Univ Press*, 2003
- (For topics marked with a*) W. Rudin, *Functional Analysis*, 2nd Ed, Tata McGraw-Hill, 2006

References:
- J. Douandikoetxea, *Fourier Analysis* (Graduate Studies in Mathematics), AMS, 2000
- L. Grafakos, *Classical Fourier Analysis* (Graduate Texts in Mathematics), 2nd Ed, Springer, 2008

MTH 507: Introduction to Algebraic Topology (4)

Pre-requisites: MTH 301 Groups and Rings, MTH 304 Metric Spaces and Topology

- *The Fundamental Group:* Homotopy, Fundamental Group, Introduction to Covering Spaces, The Fundamental Group of the circle $\mathbf{S}^1$, Retractions and fixed points, Application to the Fundamental Theorem of Algebra, The Borsuk-Ulam Theorem, Homotopy Equivalence and Deformation Retractions, Fundamental group of a product of spaces, and Fundamental group the torus $\mathbf{T}^2=\mathbf{S}^1\times\mathbf{S}^1$, n-sphere $\mathbf{S}^n$, and the real projective n-space $\mathbf{RP}^n$.
- *Van Kampen's Theorem:* Free Products of Groups, The Van Kampen Theorem, Fundamental Group of a Wedge of Circles, Definition and construction of Cell Complexes, Application to Van Kampen Theorem to Cell Complexes, Statement of the Classification Theorem for Surfaces, and Fundamental groups of the closed orientable and non-orientable surfaces of genus g.
- *Covering Spaces:* Universal Cover and its existence, Unique Lifting Property, Galois Correspondence of covering spaces and their Fundamental Groups, Representing Covering Spaces by Permutations – Deck Transformations, Group Actions, Covering Space Actions, Normal or Regular Covering Spaces, and Application of Covering Spaces to Cayley Complexes.

Suggested Reading:

- J. R. Munkres, Topology (2nd Edition), Pearson Publishing Inc, 2000
- Hatcher, Algebraic Topology, Cambridge University Press, 2002
- M. A. Amstrong, Basic Topology, Springer International Edition, 2004
- W. S. Massey, Algebraic Topology: An Introduction , Springer, 1977
- J. J. Rotman, An Introduction to Algebraic Topology, Springer, 1988
- M. J. Greenberg and J. R. Harper, Algebraic Topology: A First Course, Perseus Books Publishing, 1981
- E. H. Spanier, Algebraic Topology, Springer, 1994

MTH 508/608: Introduction to Differentiable Manifolds and Lie Groups (4)

Pre-requisites: MTH 303 Real Analysis I, MTH 304 Metric Spaces and Topology, MTH 306 Ordinary Differential Equations, MTH 403 Real Analysis II

- *Differentiable manifolds*: definition and examples, differentiable functions, existence of partitions of unity, tangent vectors and tangent space at a point, tangent bundle, differential of a smooth map, inverse function theorem, implicit function theorem, immersions, submanifolds, submersions, Sard's theorem, Whitney embedding theorem
- *Vector fields*: vector fields, statement of the existence theorem for ordinary differential equations, one parameter and local one-parameter groups acting on a manifold, the Lie derivative and the Lie algebra of vector fields, distributions and the Frobenius theorem
- *Lie groups*: definition and examples, action of a Lie group on a manifold, definition of Lie algebra, the exponential map, Lie subgroups and closed subgroups, homogeneous manifolds: definition and examples
- *Tensor fields and differential forms*: cotangent vectors and the

  cotangent space at a point, cotangent bundle, covector fields or 1-forms on a manifold, tensors on a vector space, tensor product, symmetric and alternating tensors, the exterior algebra, tensor fields and differential forms on a manifold, the exterior algebra on a manifold
- *Integration*: orientation of a manifold, a quick review of Riemann integration in Euclidean spaces, differentiable simplex in a manifold, singular chains, integration of forms over singular chains in a manifold, manifolds with boundary, integration of *n*-forms over regular domains in an oriented manifold of dimension *n*, Stokes theorem, definition of de Rham cohomology of a manifold, statement of de Rham theorem, Poincare lemma

Suggested Reading:

Texts:

- J. Lee, *Introduction to smooth manifolds*, Springer, 2002
- W. Boothby, *An Introduction to differentiable manifolds and Riemannian geometry*, Academic Press, 2002
- F. Warner, *Foundations of differentiable manifolds and Lie groups*, Springer, GTM 94, 1983
- M. Spivak, *A comprehensive introduction to differential geometry, Vol. 1*, Publish or Perish, 1999

References:

- G. de Rham, *Differentiable manifolds: forms, currents and harmonic forms*, Springer, 1984
- V. Guillemin and A. Pollack., *Differential topology*, AMS Chelsea, 2010
- J. Milnor, *Topology from the differentiable viewpoint*, Princeton University Press, 1997
- J. Munkres, *Analysis on manifolds*, Westview Press, 199
- 01254217
- C. Chevalley, *Theory of Lie groups*, Princeton University Press, 1999
- R. Abraham, J. Marsden, T. Ratiu, *Manifolds, tensor analysis, and applications*, Springer, 1988

MTH 509/609: Sturm-Liouville Theory (4)

Pre-requisites: MTH 306 Ordinary Differential Equations, MTH 404 Measure and Integration

- *Fourier Series:* Fourier series of a periodic function, question of point-wise convergence of such a series, behavior of the Fourier series under the operation of differentiation and integration , sufficient conditions for uniform and absolute convergence of a Fourier series, Fourier series on intervals, examples of boundary value problems for the one dimensional heat and wave equations illustrating the use of Fourier series in solving them by separating variables, a brief discussion on Cesaro summability and Gibbs phenomenon
- *Orthogonal Expansions:* A quick review of L2 spaces on an interval, convergence, completeness, orthonormal systems, Bessel's inequality, Parseval's identity, dominated convergence theorem
- *Sturm-Liouville Systems:* linear differential operators, formal adjoint of a linear operator, Lagrange's identity, self-adjoint operators, regular and singular Sturm-Liouville systems, Sturm-Liouville series, Prufer substitution, Sturm comparison and oscillation theorems, eigenfunctions, Liouville normal form, distribution of

eigenvalues, normalized eigenfunctions, Green's functions, completeness of eigenfunctions

- *Illustrative boundary value problems:* A technique to solve inhomogeneous equations using Sturm-Liouville expansions, one dimensional heat and wave equations with inhomogeneous boundary conditions, one dimensional inhomogeneous heat and wave equations, mixed boundary conditions, Dirichlet problem in a rectangle and a polar coordinate rectangle
- *Maximum Principle and applications:* maximum principle for linear, second-order, ordinary differential equations, generalized maximum principle for such equations, applications to initial and boundary value problems, the eigenvalue problem, an extension of the principle to non-linear equations
- *Orthogonal polynomials and their properties:* Legendre polynomials, Legendre equation, Legendre functions and spherical harmonics, Hermite polynomials, Hermite functions, Hermite equation, Laguerre polynomials, Laguerre equation, zeros of orthogonal polynomials on an interval, and a recurrence relation satisfied by them
- *Bessel Functions:* Bessel's equation, identities, asymptotics and zeros of Bessel functions

Suggested Reading:

Texts:

- Birkhoff, G & Rota G., *Ordinary Differential Equations*, John Wiley & Sons
- Folland, G., *Fourier Analysis & Its Applications*, AMS
- Protter, M. & Weinberger, H., *Maximum Principles in Differential Equations*, Springer

References:

- Brown, J. & Churchill, R., *Fourier Series and Boundary Value Problems*, McGraw-Hill
- Jackson, D., *Fourier Series and Orthogonal Polynomials*, Dover

MTH 601: Algebra I (4)

- Monoids, Groups, group actions, Sylow's theorems, Finitely generated abelian groups.
- Rings and homomorphisms, Chinese remainder theorem, examples as polynomial ring and power series ring, rings of endomorphisms, Universal property of polynomial rings, Principal and factorial rings.
- Modules, quotient modules, direct product and direct sum of modules, Jordan-Hölder theorem, Free, Projective and Injective modules, Dual modules, Modules over PID.

- Category and Functor, Direct and Inverse limit.
- Polynomials in one and several variables, Gauss lemma, Irreducibility criterions, Power series ring, group of units in power series ring.
- Algebraic extensions, Algebraic closure, Splitting fields, Normal extensions, Separable and inseparable extensions, Finite fields.

Suggested Reading:

- S. Lang, Algebra, 3rd Edition, Addison Wesley.
- Jacobson, Basic Algebra I and II.
- Birkhoff and McLane, Algebra.
- D.J.S. Robinson, A course in theory of groups.

MTH 603: Real Analysis (4)

- *Several variable calculus:* A quick overview, the contraction mapping theorem, the inverse function theorem, the implicit function theorem.
- Riemann integration in $\mathbf{R}^n$, $n \geq 1$.
- *Lebesgue measure and integration:* Measures, measurable functions, integration of nonnegative and complex functions, modes of convergence, convergence theorems, product measure, Fubini's theorem, convolution, integration in polar coordinates.
- Signed measures and differentiation, complex measures, total variation, absolute continuity, Fundamental theorem of calculus for Lebesgue integral, the Radon-Nikodym theorem and consequences.
- $\mathbf{L}^p$ spaces, the Hölder and Minkowski inequalities, Jensen's inequality, completeness, the Riesz representation theorem, dual of $\mathbf{L}^p$ spaces.

Suggested Reading:

- G.B. Folland, Real analysis: Modern techniques and their applications, 2nd Edition, Wiley.
- W. Rudin, Principles of Mathematical Analysis, 3rd Edition, Tata McGraw-Hill.
- W. Rudin, Real and Complex Analysis, 3rd Edition, Tata McGraw-Hill.
- E.M. Stein and R. Shakarchi, Functional Analysis: Introduction to further topics in analysis, Princeton lectures in analysis.
- T. Tao, Analysis I and II, 2nd Edition, TRIM Series 37, 38, Hindustan Book Agency.

MTH 604: Complex Analysis II (4)

See contents of MTH 504

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MTH 605: Topology I **(4)**

- *General Topology:* Connectedness, Compactness, Local Compactness, Paracompactness, Quotient Spaces, Topological Groups, Baire Category Theorem.
- *Fundamental Groups and Covering Spaces:* Homotopy, Homotopy. Equivalence and Deformation Retractions, Fundamental Group, Van Kampen Theorem, Deck transformations, Group Actions, Classification of covering spaces.
- Basic Diferential Topology: Differentiable Manifoolds, Vector Fields, Implicit and Inverce Function Theorems, Regular Values Sard's Theorem.

Suggested Reading:

- Hatcher, Algebraic Topology, Cambridge University Press, 2002.
- J. R. Munkres, Topology, Second Edition, Prentice Hall, 2011.
- G. Bredon, Topology and Geometry, Springer, 2006.
- W. S. Massey, A Basic Course in Algebraic Topology, Springer, 2007.
- J. J. Rotman, An Introduction to Algebraic Topology, Springer, 1988.
- J. R. Munkres, Elements of Algebraic Topology, Westview Press, 1996.

MTH 608: Introduction to Differentiable Manifolds and Lie Groups **(4)**

See contents of **MTH 508**

MTH 609: Sturm-Liouville Theory **(4)**

See contents of **MTH 509**

MTH 610: Fourier Analysis on the Real Line **(4)**

See contents of **MTH 506**

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Physics

PHY 101: Mechanics (3)

Kinematics: Introduction to coordinate systems, polar coordinate system, velocity and acceleration in polar coordinate system.

Kinetics: Force, Newton's laws of motion, Frames of reference, Momentum, Momentum of system of particles, Conservation laws, Center of mass, Variable mass system, Collision in laboratory and Center of mass system and Scattering.

Relativity: Axioms of relativity, Lorentz transformation, length contraction, time dilation, relativistic mass energy, Doppler effect.

Rigid body motion: Rigid body, Moment of inertia, Rigid body kinematics, Rigid body kinetics, Motion of gyroscope

Non Inertial Frame: Physics in the rotating coordinate system, Fictitious force.

Central force and Motion of planets and satellites

Oscillations and Waves: Small oscillations, damped harmonic oscillation and forced oscillation, Q factor and resonance. Differential equation of one dimensional wave and its solution, reflection and transmission of waves.

Note: Mathematical tools may be introduced as and when required.

Suggested Reading:

- D. Kleppner and R. Kolenkow, *An Introduction to Mechanics.*
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics* Vol 1.
- C. Kittel, W. D. Knight, M. A. Ruderman, and A. C. Helmholz *Mechanics (Berkeley Physics course) Vol 1.*
- D. Resnick, R. Halliday and K. S. Krane, *Physics, Vol 1, 5th Ed.*
- M. K. Verma, *Introduction to Mechanics.*

PHY 102: Electromagnetism (3)

*Cylindrical and Spherical coordinate systems***:** Line, surface and volume elements

Introduction to vector calculus: Gradient, Divergence and curl of Fields, Divergence theorem, Stokes Theorem, Dirac delta function.

Electrostatics: Coulomb's Law, Gauss's law (integral and differential form) and its applications, Electric potential, Laplace's and Poisson's equations (no solutions), Energy of a charge distribution, , Boundary conditions, Conductors, The uniqueness theorem (statement only), Method of images, Field and Potential due to dipole. Multipole expansion, Polarization in a dielectric, vectors **D**, **P** and **E**, linear dielectrics, force on dielectrics.

Electric currents: Line, surface and volume currents and current densities, electrical conductivity and Ohm's law, equation of continuity, energy dissipation.
Motion of charged particles in electric and magnetic fields
Magnetostatics: Biot-Savart and Ampere's law, divergence and curl of **B,** integral and differential form of Ampere's law, vector potential, Boundary conditions, Magnetic dipoles, Multipole expansion, magnetization in materials, H, B and M, Dia-, para- and ferro-magnetism, B and H in bar-magnet.

Electrodynamics: Electromagnetic induction, motional emf and Faraday's law, inductance and energy in magnetic field, the displacement current, Maxwell's equations.

Electromagnetic Wave: EM wave in vacuum and dielectrics, Poynting's theorem, Reflection, transmission, refraction of EM wave

Suggested Reading:

- D. J. Griffiths, *Introduction to electrodynamics 3rd Ed.*
- E. M. Purcell, *Electricity and Magnetism (Berkeley Physics course) 2nd Ed.*
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics Vol 2.*
- E. Hecht, *Optics, 4th Ed.*
- F. A. Jenkins and H. E. White, Fundamentals of Optics.
- K. Ghatak, *Optics.*
- K. Ghatak, *An introduction to modern optics.*
- K. K. Sharma, *Optics: principles and applications.*
- G. R. Fowles, *Introducton to Modern Optics.*

PHY 103: General Physics Laboratory I **(1)**

- Measurement of length and error analysis
- Gyroscope
- Determination of 'g' by bar pendulum
- Pohl's Pendulum
- Determination of 'g' by free fall
- Shear modulus using Tortional pendulum
- Mechanical hysteresis

- Young's modulus
- Moment of Inertia
- Velocity of sound using resonance tube
- Velocity of sound using Kundt's tube
- Spring constant

PHY 104: General Physics Laboratory II (1)

- Malu's law
- Newton's rings
- Intensity of diffractions due to pin hole diaphragms and circular obstacles
- Magnetic hysteresis loop
- Surface tension by the ring method (Du Nouy method)
- Characteristic curves of a solar cell
- Dielectric constant of different materials
- Charging curve of a capacitor
- Capacitance of metal spheres and of a spherical capacitor
- Magnetic field of paired coils in Helmholtz arrangement
- Electromagnetic induction
- Force of current carrying conductor
- Fresnel's equations

PHY 201: Quantum Physics (3)

*Wave theory and physical optics :*Plane wave in 1 d and 3d, representation of a wave, wave equation, phase velocity and group velocity, light as a wave - nterference, Young's double slit experiment, coherence, diffraction by single slit and circular aperture, polarization

Introduction to quantum mechanics: Photoelectric effect, Compton effect, electron diffraction, de Broglie wavelength, Wave particle duality, Wave function and Born's interpretation, Wave packet, Position and linear momentum, Heisenberg uncertainty principle.
Dynamical variables and corresponding Operators, expectation values, Schrödinger wave equation, stationary states.

Solution of Schrödinger equation in particle in a box, potential barriers and tunneling (eg STM, AFM), Probability current density, bound states of rectangular well potential, simple harmonic oscillator.

Angular momentum, hydrogen atom, spin angular momentum.

Elements of statistical physics: Classical statistics (Arguments leading to Boltzmann Law, $S=k_B \ln\Omega$), Phase space in 2D and 3D (classical and quantum), Identical particles, Bose and Fermi Statistics.

Free electron gas, Fermi energy, Specific heat of metals.
Photon gas, Planck's radiation law and its consequences. Bose Einstein Condensation

Elements of Nuclear Physics: Shell Model, Weizsaecker mass formula, Nuclear fusion and fission.

Suggested Reading:

- Beiser, *Concept of Modern Physics.*
- H. C. Verma, *Quantum Physics.*
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics Vol 3.*
- H. S. Mani and G. K. Mehta: *Introduction to Modern Physics.*

PHY 202: Basic Electronics (3)

Network theorem and its applications, Band theory of solids (basics), Physics of p-n junction, Physics of diodes and transistors, terminal characteristics of diodes transistors and FET's, Simple rectifier and amplifier circuits.

Introduction to analog ICs, Op amps: basics, characteristics and applications (filters, waveform generators etc), instrumentation amplifier, Survey of Op-amps.

Functioning and characteristics of commonly used analog ICs such as voltage regulators and power supplies.

Logic Gates ALUs Flip Flop, overview of commonly used CMOS and TTL chips.

Counters, Shift registers, memory and storage, outline of microprocessor functioning, AD and DA converters

Suggested Reading:

- P. Horowitz and W. Hill, *The Art of Electronics.*
- R. Gayakwad, *Op-Amps and Linear Integrated Circuits, 4th Ed.*
- P. Malvino and D. P. Leach, *Principle of Digital Electronics.*
- T. L. Floyd, *Electronic Devices.*
- D. R. Choudhary and S. B. Jain, *Linear Integrated Circuits.*
- P. Malvino and J. A. Brown, *Digital computer electronics.*

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PHY 203: General Physics Laboratory III **(1)**

- e/m ratio using a pair of Helmhotz coils
- Magnetic torque
- Electron diffraction
- Stefan-Boltzmann's law of radiation
- Coils in AC circuit, capacitor in the AC circuit and RLC circuit
- Dispersion and resolving power of prism and grating spectroscope
- Fine structure, one and two electron spectra
- Balmer series/determination of Rydberg's constant
- Atomic spectra of two-electron systems: He, Hg
- Thermal and electrical conductivity of copper and aluminum
- Determination of Planck's constant
- Rotational Spectra of Iodine vapor

PHY 204: Electronics Laboratory **(1)**

- p-n and Zener characterstics.
- Transistor characterstics.
- CE amplifier and frequency response.
- Hartley and Colpitts oscillator.
- Clipper and clamper circuits.
- JFET and MOSFET characterstics.
- Op-amp: Adder/subtracter,Integrator/differentiator.
- Op-amp:Inverting and non-inverting amplifier.
- Astable and Monostable Oscillator using IC555.
- Analog to digital and Digital to analog converter.
- RS,D and JK flip flop.
- Boolean algebra.
- Binary full adder.
- Multiplexer and demultiplexer.
- Thevenin's and Norton theorem

PHY 301: Mathematical Methods I **(4)**

Vectors analysis in curvilinear coordinates, Tensor analysis (Cartesian only)

Matrices, Eigenvalues and Eigenvectors, Transformation of matrices, Diagonalization of matrices

Review of Complex variables (MTH 202): Multiple valued function, branch cuts and branch points, Evaluation of integrals, saddle point method, Analytic continuation, The Gamma function, Conformal mapping

Ordinary differential equations (with constant coefficients), ODE-singular points, Methods of solutions, Legendre, Bessel, Hermite and Laguire equations and their solutions

Suggested Reading:

- B. Arfken and H. J. Weber, *Mathematical Methods for Physicists, 6th Ed.*
- P. K. Chattopadhyay, *Mathematical Physics.*
- M. L. Boas, *Mathematical Methods in Physical Sciences.*
- S. D. Joglekar, *Mathematical Physics: The Basics.*
- A. K. Ghatak, *Mathematical Method of Physics.*
- H. W. Wyld, *Mathematical Methods for Physics.*
- F. B. Hildebrand, *Methods of Applied Mathematics.*
- A. W. Joshi, *Elements of Group Theory for Physicist.*
- S. Hassani, *Mathematical Physics.*
- P. Dennery and A. Krzywicki, *Mathematics for Physicists.*
- J. Mathews and R. L. Walker, *Mathematical Methods of Physics.*

PHY 302: Mathematical Methods II (4)

Prerequisite: PHY 301: Mathematical Methods I

Sturm-Liouville theory, Orthogonal expansions

Fourier series expansion and Fourier integrals, their use in some simple problems, Fourier and Laplace transforms.

Generalized functions: Dirac delta function

Partial Differential equations, Green's functions, Solution of Laplace and Poisson's equations, Wave equation, Integral equations

Introduction to Groups Representations, Finite Groups, Permutation Groups, Continuous Groups, Lie Algebras, Representation of Unitary and rotation group.

Suggested Reading:

- B. Arfken and H. J. Weber, *Mathematical Methods for Physicists, 6th Ed.*
- P. K. Chattopadhyay, *Mathematical Physics.*

- M. L. Boas, *Mathematical Methods in Physical Sciences.*
- S. D. Joglekar, *Mathematical Physics: The Basics.*
- K. Ghatak, *Mathematical Method of Physics.*
- H. W. Wyld, *Mathematical Methods for Physics.*
- F. B. Hildebrand, *Methods of Applied Mathematics.*
- W. Joshi, *Elements of Group Theory for Physicist.*
- S. Hassani, *Mathematical Physics.*
- P. Dennery and A. Krzywicki, *Mathematics for Physicists.*
- J. Mathews and R. L. Walker, *Mathematical Methods of Physics.*

PHY 303: Quantum Mechanics I (4)

Need for Quantum Theory: (Brief review of PHY 201)

Particle nature of elctromagnetic wave: Photoelectric effect; Blackbody radiation (Rayleigh-Jeans Law); Compton effect
Wave properties of particle: Electron diffraction
Discrete energy levels: Bohr atom

Schrodinger Equation: Uncertainty Principle; Probability interpretation and probability current; Coordinate and momentum representations; Expectation values of dynamical variables; Descriptions of wave packets and its evolution

Principles of Quantum Mechanics: Hermitian operators; Eigenvalues; vector spaces; Classical limit – Ehrenfest's theorem; Stationary states

One Dimensional Problem: Harmonic Oscillator – creation and annihilation operators; Brief descriptions of potential step, barrier and well (already covered in PHY 201) – Ideas of bound states, scattering states and resonances; Dirac-delta potential, Applications to alpha-decay

Formalism: Generalized uncertainty principle; Simultaneous eigenstates of commuting operators; Introduction to Dirac's notation. Theory of Angular Momentum: Orbital angular momentum and eignevalue problem; Spherical harmonics, Spin angular momentum, addition of angular momentum

Central Potential: Bound states in three dimensions; Hydrogen atom

Charged particle in Electromagnetic field: Gauge invariance of Schrodinger equation; Larmor frequency; Brief discussions on normal and anomalous Zeeman effect (Further details in Atomic and Molecular Physics course, PHY 402); Landau levels

Foundational Issues: Measurements and interpretations of Quantum Mechanics; Bell's inequality; EPR paradox

Suggested Reading:

- H. C. Verma, *Quantum Physics* (Surya Publn)
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics Vol 3* (Narosa Publ.)
- J. J. Sakurai, *Modern Quantum Mechanics* (Pearson)
- B. H. Bransden and C. J. Joachain, *Quantum Mechanics* 2nd Ed (Pearson Education)
- D. J. Griffiths, *Introduction of Quantum Mechanics*, 2nd Ed. (Pearson)
- P. A. M. Dirac, The *Principles of Quantum Mechanics*. (4th Ed. Oxford Science Publications)
- C. Cohen-Tannoudji, *Quantum Mechanics, (Vol I and II)* (John Wiley and Sons)
- R. Shankar, *Principles of Quantum Mechanics*, 2nd Ed (Springer)
- A. I. M. Rae, *Quantum Mechanics*, 4th Ed. (IOP publishing)
- E. Merzbacher, *Quantum Mechanics* , 3rd Ed. (Hamilton Printing Company)
- L. D. Landau and L. M. Lifshitz, *Quantum Mechanics Non-Relativistic Theory*. 3rd Ed. (Butterworth-Heinemann)

PHY 304: Quantum Mechanics II (4)

Prerequisite: *PHY 303 Quantum Mechanics I, PHY 301 Mathematical Methods I*

Theory of Spin: Stern-Gerlach experiment; Formulation of spin ½ states; Pauli matrices; Addition of angular momentum

Approximation Methods for Stationary States: Time Independent Perturbation Theory: Formalism; Applications to relativistic corrections ('fine structure corrections') to atom (a) Relativistic K.E, (b) Spin-Orbit couplings, (c) Darwin term; WKB method: Descriptions of tunneling
Variational method: Application to He atom ground state

Time Dependent Phenomena: Formalism; Fermi's Golden rule; Adiabatic approximations; Application to matter-radiation interactions; Emissions and absorptions of photons; Selection rule for electric dipole transitions; Applications to Lasers

Scattering by a Potential: Formalism; Born approximations; Partial wave analysis

Symmetries in quantum mechanics

Relativistic Quantum Mechanics: Klein Gordon Equation; Dirac Equation; Plane wave solutions; Negative energy states; Spin; Magnetic moments; Non-relativistic limit of the Dirac equation

Suggested Reading:

- H. C. Verma, *Quantum Physics*.
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics Vol 3*.
- J. J. Sakurai, *Modern Quantum Mechanics.*
- B. H. Bransden and C. J. Joachain, *Quantum Mechanics.*
- D. J. Griffiths, *Introduction of Quantum Mechanics.*
- P. A. M. Dirac, The *Principles of Quantum Mechanics.*
- C. Cohen-Tannoudji, *Quantum Mechanics, (Vol I and II)*.
- R. Shankar, *Principles of Quantum Mechanics*.
- I. M. Rae, *Quantum Mechanics.*
- E. Merzbacher, *Quantum Mechanics*.
- L. D. Landau and L. M. Lifshitz, *Quantum Mechanics Non-Relativistic Theory*.

PHY 305: Classical Mechanics (4)

Review of Newtonian mechanics.
Lagrangian mechanics, generalized coordinates, calculus of variations, constraints, principle of virtual work, Lagrange's equation.

Symmetry principles, Noether theorem,
Central forces, Planetary motions, Collisions, Scattering, Small oscillations, Normal modes, Forced oscillators, Anharmonic oscillators, Perturbation theory.

Rigid body dynamics, Motion of a top.
Hamilton's equations, phase space & phase trajectories, canonical trans-formations, Poisson brackets.Hamilton- Jacobi theory.

Suggested Reading:

- H. Goldstein, *Classical Mechanics*.
- L. D. Landau and E. M. Lifshitz, *Mechanics.*
- R. G. Takwale and P. S. Puranik, *Introduction to Classical Mechanics*.
- K. C. Gupta, *Classical Mechanics of Particles and Rigid Bodies*.
- N. C. Rana and P. S. Joag, *Classical Mechanics*.
- C. Percival and D. Richards, *Introduction to Dynamics*.
- S. H. Strogatz, *Nonlinear Dynamics and Caos.*
- R. Hilborn, *Caos and Nonlinear Dynamics*.

PHY 306/604: Statistical Mechanics (4)

Prerequisite: PHY 303: Quantum Mechanics I, PHY 301: Mathematical Methods I, PHY 309: Thermal Physics

Review of thermodynamics

Postulates of statistical mechanics.

Phase space, density of states and Liouville's theorem, Ensemble theory (Micro-canonical, Canonical and Grand-canonical), applications to classical ideal gas and simple numerical problems, Gibbs paradox

Introduction to Bose-Einstein and Fermi-Dirac statistics, Maxwell-Boltzmann statistics as a classical limit, Qualitative features of degenerate Fermi and Bose gases, electrons in metals, photon gas.
Fluctuations in canonical and grand canonical ensemble.

Kinetic theory and approach to equilibrium; Boltzmann equation; physical hydrodynamics Langevin equation; Fluctuation-Dissipation theorem.

Phase transition and critical point phenomena, Landau Ginzberg theory. Critical exponents and relations. Scaling and renormalization, Ising model, mean-field theory in zeroth and first approximations, exact solution in one dimension.

Bose Condensation.

Density matrix in statistical mechanics.

Suggested Reading:

- F. Reif, *Fundamentals of Statistical and Thermal Physics*.
- R.K. Pathria, *Statistical Mechanics, 2nd Ed.*
- M. Plischke and B. Bergersen, *Equilibrium Statistical Physics*.
- J. K. Bhattacharjee, *Statistical Physics: Equilibrium and Non-Equilibrium Aspects*.
- Kerson Huang, *Statistical Mechanics.*
- S-K. Ma, *Statistical Mechanics*.
- L. D. Landau and E. M. Lifshitz, *Statistical Physics.*
- R. Kubo, M. Toda and N. Hashitsume, *Statistical Physics I and II.*
- S-K. Ma, *Modern Theory of Critical Phenomena*.

PHY 307: Physics Laboratory I **(3)**

- Franck Hertz experiment
- Planck's constant
- Cavendish experiment
- Chua's circuit
- Ferromagnetic Hysteresis
- Atomic spectra of Iodine vapor
- Inelastic electron collision
- Millikan's oil drop experiment
- Viscosity of Newtonian and non-Newtonian liquids
- Microwave based waveguide measurement.

PHY 308: Physics Laboratory II **(3)**

- STM
- AFM
- Raman Spectrometer
- Characteristics of He-Ne laser.
- Fiber optics
- Spectroscopy with fibers [Ocean optics*]
- Michelson Interferometer
- Fabry Parrot Interferometer
- Optical detection of weak source using a lock-in.
- Laser gyroscope

PHY 309/409: Thermal Physics **(4)**

Review of kinetic theory of gases, laws of thermodynamics.

Basic Concepts and the Postulates: The temporal and spatial nature of Macroscopic Measurements, internal energy, basic problems of thermodynamics, entropy maximum postulates,
conditions of equilibrium, mechanical and chemical equilibrium, Euler equation, Gibbs-Duhem relation, rubber band, magnetic systems, molar heat capacity.

Reversible Processes: Possible and Impossible processes, the Maximum work theorem, Carnot cycle, Measurability of the temperature and of the entropy.

Thermodynamic Functions: Enthalpy, Helmholtz and Gibbs free energies, Legendre transformations, generalized Massieu functions, Maxwell relation, procedure for the reduction of derivatives in single component systems, applied to magnetic systems, stability of thermodynamic systems, Le Chateliers principle.

Phase Transitions: Equilibrium between phases, triple point, gibbs phase rule and simple application, Clapeyron equation, First order phase transition in single component and multi component systems, phase diagrams, critical phenomena, Landau theory, scaling and universality.

Suggested Reading:

- H. B. Callen, *Thermodynamics and an Introduction to Thermostatistics*
- R. H. Dittman and M. W. Zemansky, *Heat and Thermodynamics*
- D. V. Schroeder, *An Introduction to Thermal Physics*
- M. N. Saha and B. N. Srivastava, A *Treatise on Heat*
- E. Fermi, *Thermodynamics*

PHY 310: Waves and Optics (4)

Linear harmonics motion (S.H.M), Superposition of SHMs in parallel and perpendicular directions, Concenpt of Beats, Lissajous figures.

Damped Oscillator, Forced oscillations and resonance, Applications to LCR circuit, Coupled oscillators, Normal modes, Theory of plucked string, struck string.

Waves in a continuous medium, Wave equation, group velocity, phase velocity.

Fermat's principle and its applications to reflection and refraction

Huygen's principle and its application to reflection and refraction

Interference of light – division of wave-front and division of amplitude, Michelson's interferometer, Febry-Perot interferometer, Newton's ring, Colours of thin films

Basic ideas of coherence

Fraunhoffer Diffraction: Single slit, Double slit, Circular aperture, Diffraction grating

Fresnel's Diffraction: Half-period zone, Zone-plate, Diffraction by a straight edge

Polarization: Plane and circularly polarized light, Production of polarized light, Malu's law, Optical activity

Basic ideas of Holography

Suggested Reading:

- French, *Waves and Oscillations*
- Bajaj, N.K, *The Physics of Waves and Oscillations*
- Ghatak, *Optics*
- Jenkins and White, *Fundamentals of Optics*
- Longhurst, *Geometrical and Physical Optics*

PHY 315: Theory of Relativity (4)

Pre-Einstein Relativity: Inertial and non-inertial frames; Galilean relativity; Michelson-Morley experiment; Concepts of aether

Einstein's Relativity: Postulates of the special theory of relativity; Lorentz transformations; Length contraction; Time dilations; Simultaneity; Velocity addition theorem; Aberration; Doppler effect; Mass energy relation

Algebra of Lorentz Transformations: Proper time and the light cone; Intervals; Minkowski metric; Causality; Lorentz transformations as orthogonal transformations in 4 dimensions; 4-vectors and tensors; Covariance of the equations of physics; Relativistic momentum and energy; Variation of mass with velocity

Relativistic Particle Kinematics: Kinematics of decay products of an unstable particle; Centre of momentum transformation and reaction thresholds; Transformation of scattering cross section; Momenta and energies from CM to laboratory systems

Incompleteness of Special Theory of Relativity: Non-intertial reference frames; The Equivalence Principle; Gravitational red shift and time delay; Towards General Relativity

Suggested Reading:

- Resnick - *Special Theory of Realtivity*
- French - *Special Theory of Realtivity*
- Edwin F. Taylor and John Archibald Wheeler - *Spacetime Physics: Introduction to Special Relativity*
- Wolfgang Rindler - *Introduction to Special Relativity*
- S. Carroll - *General Relativity*
- S. Weinberg - *Gravitation and Cosmology*

PHY 401/605: Electrodynamics (4)

Prerequisites: PHY 305: Classical Mechanics, PHY 301: Mathematical Methods I, PHY 302: Mathematical Methods II

Boundary problems, Formal solution with Green functions, Electric fields in matter, Boundary-Value problems with dielectrics, polarizability and susceptibility, Energy density in a dielectric, Multipole expansion.

Vector potential, Magnetic fields of a localized current distribution, Magnetic moment, Force and Torque on and energy of a localized current distribution, Boundary conditions on B and H, Boundary value problems in magnetostatics, Multipole expansion.

Maxwell equations, Gauge transformations, Green functions for the wave equation, Poynting's theorem, Tranformation properties of electromagnetic fields and sources under rotations, spatial reflections, and time reversal
Plane electromagnetic waves and wave propagation, polarization, Stokes parameters, Reflection and refraction of electromagnetic waves at a plane interface between dielectrics, wave propagation in conductors and dielectrics, dispersion, complex refractive index, waveguides
Fields and radiation of a localized oscillating source, Electric dipole fields and radiation, Linear antennas.

Scattering at long wavelengths, Rayleigh scattering

Minkowski space and four vectors, concept of four-velocity, Four acceleration and higher rank tensors, Relativistic formulation of electrodynamics, Maxwell equations in covariant form, Gauge invariance and four-potential, the action principle and electromagnetic energy momentum tensor, Liénard-Weichert potentials, Radiation from an accelerated charge, Larmor formula, bremsstrahlung and synchrotron radiation, multipole radiation, dispersion theory, radiative reaction, radiative damping.

Suggested Reading:

- J. D. Jackson, *Classical Electrodynamics*.
- D. J. Griffiths, *Introduction to Electrodynamics*, 3rd Ed.
- L. D. Landau and E. M. Lifschitz, *Classical Theory of Fields*.
- R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lecture of Physics* Vol 2.
- W. K. H. Panofsky and M. Philips. *Classical Electricity and Magnetism*.
- W. R. Smythe, *Static and Dynamic Electricity*.

PHY 402/606: Atomic and Molecular Physics (4)

Prerequisite: PHY 304: Quantum Mechanics II

Brief review of Hydrogen atom and periodic table; Significance of four quantum numbers; Concepts of atomic orbital

One Valance Electron Atom: Review of [Orbital magnetic dipole moment; Orbital, spin and total angular momenta; Spin-orbit interaction and fine structures]; Intensity of spectral lines; General selection rules; Details of Stark, Zeeman (Normal and anomalous) and Paschenbeck effects

Many Valance Electrons Atom: Two Valance Electrons Atom: Para and ortho states and the role of Pauli's Exclusion principle, He atom, Identical particles, Slater determinant; LS and JJ coupling scheme

Approximation Methods: The Hatree-Fock method; The Thomas-Fermi model of the atom

Width and shape of spectral lines; Hyperfine structure of lines; Lamb shift; Principal of ESR with experimental setup; chemical shift

Molecules: Concept of valance and bonding; Born-Oppenheimer approximation; Hydrogen molecule – Heitler-London method

Molecular orbital and electronic configuration of diatomic molecules (H_2, C_2, O_2, NO, and CN); Vibrational structure and vibrational analysis; Frank-Condon principle; Dissociation energy; Rotational spectra; Raman spectra and influence of nuclear spin

Suggested Reading:

- P. W. Atkins and R. S. Friedman, *Molecular Quantum Mechanics 3rd Ed*.
- W. Demtroder, *Atoms, Molecules and Photons*.
- G. W. Woodgate, *Elementary Atomic Structure*.
- H. S. Friedrich, *Theoretical Atomic Physics*.
- R. Eisberg and R. Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles*.
- H. E. White, *Introduction to Atomic Spectra*.
- B. H. Bransden and C. J. Joachain, *Physics of Atoms and Molecules*.
- H. G. Kuhn, *Atomic Spectra*.
- F. A. Cotton, *Chemical Applications of Group Theory*.
- C. N. Banwell, *Fundamentals of Molecular Spectroscopy*.
- G. M. Barrow, *Introduction to Molecular Spectroscopy*.
- J. M. Hollas, *Modern Spectroscopy*.
- C. A. Coulson, *Valence*.

Go to Contents

PHY 403/607: Condensed Matter Physics (4)

Prerequisites: PHY 306: Statistical Mechanics

Structure of solids, Symmetry, Unit cell, Miller indices, Simple crystal structure, Diffraction of x-rays, Reciprocal lattice, Laue equations and Bragg's law, Brillouin Zones, Atomic scattering and structure factors, Defects and dislocations.

Bonding in solids, van-der Wall and Repulsive interactions, Lennard Jones potential, Cohesive energy and compressibility, Ionic crystals, Madelung potential, Covalent crystals, Metals, atomic and ionic radii.

Vibrations of one dimensional monoatomic and diatomic chain, Normal modes and Phonons,, Phonon spectrum, Long wavelength of acoustic phonons and elastic constants, specific heat capacity, Density of states, thermal expansion and conductivity, Phonons: Vibrational Properties, normal modes, acoutic and optical phonons.

The Drude theory of metals: DC electrical conductivity of a metal; Hall effect and magnetoresistance; AC electrical conductivity of a metal and propagation of electromagnetic radiation in a metal; Thermal conductivity of a metal, The Sommerfeld theory of metals: Density of states; Fermi-Dirac distribution; Specific heat, thermal, and electrical conductivity of degenerate electron gases.

Free electron theory, Kronig-Penney Model, Crystal lattices: Bravais lattices, Periodic potential, Band theory, Tight binding, Classification of metals, insulators and semiconductors, Cellular and pseudopotential methods, Symmetry of energy bands, Density of state, Fermi surface, de Hass-van Alphen effect, Motion of electron in electric and magnetic fields, Hall Effect, Quantum Hall Effect, Magnetoresistance, Superconductivity, Meissner effect, Topological Insulators

Dia-, Para-, and Ferromagnetism, origin of magnetism, Langevin's theory of paramagnetism, Weiss Molecular theory, Ferromagnetic ordering, spin waves, magnons, ferromagnetic domains.

Bose-Einstein distribution and Bose-Einstein condensation.

Suggested Reading:

- L. V. Azaroff, *Introduction to Solids*.
- C. Kittel, *Introduction to Solids State Physics.*
- N. W. Ashcroft and N. D. Mermin, *Solids State Physics.*
- J. Decker, *Solids State Physics.*
- O. Madelung, *Introduction to Solid State Theory*.
- P. M. Chaikin and T. C. Lubensky, *Principles of Condensed Matter Physics.*
- H. Ibach and H. Lutz, *Solid State Physics.*

- J. Weertman and J. R. Weertman, *Elementary Dislocation Theory.*
- M. J. Buerge, *Crystal Structure Analysis.*
- J. Callaway, *Quantum Theory of solid State*.

PHY 404/608: Nuclear and Particle Physics (4)

Prerequisites: PHY 304: Quantum Mechanics II

Properties of nucleon-nucleon interaction, General forms of N-N potential, Description of low energy neutron-proton scattering to show the spin dependence of nuclear force, Ground state properties of deuteron, Simple consideration of deuteron using central potential (square well).

Deuteron problem. Tensor force, S and D states. Neutron-Proton and proton-proton scattering, Effective range theory, Spin-dependence of nuclear forces, Charge independence and charge symmetry of nuclear forces, Isospin formalism.

Nucleon emission, separation energy, Alpha decay and its energy spectrum, Q-value, Gamow's theory of alpha decay (no derivation), Beta decay and its energy spectrum (for example, ^{137}Cs), Need for neutrinos, Q-value for beta decay, Gamma decay, Selection rules for gamma transitions (no derivation).

Outline of interaction of charged particles and of Gamma-rays with matter.

Detectors: Gas Filled counters (ionization Chamber), Scintillation counter, Spark Chambers, Cerenkov detectors.

Accelerators: Ion Sources, Synchrotron, Introduction of Modern Colliders (LHC and RHIC), Storage Ring

Discussion of Direct and Compound nuclear reaction mechanisms, expressions for scattering and reaction cross-sections in terms of partial wave amplitudes. Resonances, Discussions and Applications of Breit-Wigner single-level formula, compound nucleus theory.

Electromagnetic interactions in nuclei, Multipole transitions in nuclei, Parity and angular momentum selection rules, Internal conversion, Fermi theory of beta-decay, Curie plots, Comparative half life. Allowed and forbidden transitions, Detection and properties of neutrino.

Basic interactions in nature, Elementary particles, Quantum numbers and conservation laws, Concept of isospin, Quarks and colors, Quark model, Eightfold way, Mesons and Baryons, Bound states and resonance states.

Suggested Reading:

- S. S. M. Wong, *Introductory Nuclear Physics.*
- V. Devanathan, *Nuclear Physics.*
- B. L. Cohen, *Concepts of Nuclear Physics.*

- B. B. Srivastava, *Fundamentals of Nuclear Physics.*
- H. A. Enge, *Introduction to Nuclear Physics.*

PHY 405: Condensed Matter Physics Lab (3)

- Lattice dynamics
- Abbe refractometer
- Curie Temperature
- Dielectric constant
- Thermal expansion of quartz crystal
- Hall effect
- Thin film preparation and thickness measurement
- Raman effect
- Interfacing a multimeter through GPIB
- X-ray diffraction
- Electro-optic effect (Kerr effect)
- Fabry-Perot and Mach-Zender Interferometer
- Fiber Optics (Estimation of numerical aperture, bending loss)
- Holography

PHY 406: Nuclear Laboratory (3)

- Half life and radioactive equilibrium
- Balmer series/Determination of Rydberg's constant
- GM counter.
- Gamma - Ray Spectroscopy Using NaI (Tl) detector.
- Alpha Spectroscopy with Surface Barrier Detector.
- Determination of the range and energy of alpha partcles using spark counter.
- Study of gamma ray absorption process.
- X-Ray Fluorescence.
- Neutron Activation Analysis Measurement of the Thermal Neutron Flux.
- To Study the Solid State Nuclear Track Detector.
- Fission Fragment Energy Loss Measurements from Cf^{252}.
- Gamma - Gamma Coicidence studies.
- Compton Scattering: Energy Determination.
- Compton Scattering: Cross-Section Determination.
- Determination of energy of mu-mesons in pi-decay using Nuclear Emulsion Technique.
- Identification of particles by visual range in Nuclear Emulsion.
- Study of Rutherford Scattering.

List of Electives to be offered from the Physics Department:

1. Theory of Relativity
2. Fluid Dynamics
3. Introduction to Astronomy and Astrophysics
4. Nonlinear Dynamics and Chaos
5. Plasma Physics
6. Introduction to General Theory of Relativity
7. Computational Physics
8. Advanced Statistical Mechanics
9. Advanced Condensed Matter Physics
10. Experimental Techniques in Physics
11. Soft Condensed Matter Physics
12. Quantum Field Theory-I
13. Quantum Field Theory-II
14. Particle Physics
15. Cosmology
16. Nanotechnology
17. Magnetism and Superconductivity
18. Quantum Optics
19. Advanced Astrophysics
20. Ultrafast Optics
21. Group Theory in Physics
22. Advanced Electronics
23. Thermal Physics
24. Waves and Optics
25. Quantum Information

According to the interest of the students and the availability of faculties, the department will also offer courses those are not mentioned above. In the following we outline syllabus for few elective courses.

PHY 409: Thermal Physics **(4)**

See contents of **PHY 309**

PHY 411/611: Nonlinear Dynamics and Chaos **(4)**

Prerequisites: PHY 305: Classical Mechanics,
PHY 301: Mathematical Methods I

Introduction to Dynamical Systems: Overview, Examples and Discussion

One-dimensional flows: Flows on the line, Fixed points and stability, Population growth, Linear stability analysis, Saddle-node, Transcritical and Pitchfork bifurcations, Flow on the circle
Two-dimensional flows: Linear system: Definitions and examples, Phase portraits, Fixed points and linearization, Limit cycles, Poincare-Bendixson theorem, Lienard systems, Bifurcations revisited: Saddle-node, Transcritical and Pitchfork bifurcations, Hopf bifurcations, Oscillating chemical reactions, Poincare maps, Global bifurcation of cycles, Coupled Oscillators and Quasiperiodicity
Chaos: Lorenz equations: Properties of Lorenz equation, Lorenz Map; One-dimensioanl map: Fixed points, Logistic map, Liapunov exponent, Fractals: Countable and Uncountable Sets, Cantor Set, Dimension of Self-Similar Fractals, Box dimension, Pointwise and Correlation Dimensions; Strange Attractors: Baker's map, Henon map Chaos in Hamiltonian systems

Suggested Reading:

- Steven H. Strogatz, *Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry and Engineering*
- Edward Ott, *Chaos in dynamical systems (Cambridge University Press)*
- R. C. Hilborn, *Chaos and Nonlinear Dynamics (Cambridge Univ. Press. 1994)*
- M. Lakshmanan and S. Rajasekar, *Nonlinear dynamics: Integrability Chaos and Patterns (Springer)*

PHY 412/612: Computational Physics **(4)**

Prerequisites: *PHY 305: Classical Mechanics,*
PHY 306: Statistical Mechanics, Numerical Methods

Introduction: Computer simulations and problems in material science, Numerical methods and programming in Fortran 90/95, A brief review of classical mechanics and statistical mechanics, Quantum mechanics as a starting point.

Monte Carlo simulations: Importance sampling and the metropolis method, basic Monte Carlo algorithm, trial moves, random number generators, estimators.
Applications and hands-on sessions–solid-liquid phase-transition in the Lennard-Jones fluid and the magnetic transition in the Ising model.
Advanced applications–Monte Carlo in various ensembles, Kinetic Monte Carlo, Monte Carlo methods for rigid molecules and polymers.

Molecular Dynamics: The basic idea of MD, numerical integration of equations of motion – Verlet and velocity Verlet algorithms, classical force-fields – bonded and non-bonded interactions, parameterization of force-fields.
Applications and hands-on sessions – determining the diffusion constant and radial distribution functions of a Lennard-Jones fluid using an Anderson thermostat, end-to-end distance and radius of gyration of a solvated polymer using bead-spring model.
Advanced applications – MD in various ensembles – thermostats and baro-stats, constrained MD.

Some Tricks of the trade: Neighbour lists, Multiple time step methods, How to handle long-range forces

Advanced techniques: Biased Monte Carlo Schemes, Rare Event, Brownian dynamics, Dissipative particle dynamics

Suggested Reading:

- D. Frenkel and B. Smit, *Understanding Molecular Simulations* (ed. 2)
- A. R. Leach, *Molecular Modeling*
- M. P. Allen and D. J. Tildesley, *Computer Simulation of Liquids*
- J. M. Thijssen, *Computational Physics*
- T. Pang, *An introduction to computational physics*
- V. Rajaraman, *Computer Programming in Fortran 90 and 95*

PHY 413/503: Introduction to Astronomy and Astrophysics (4)

Introduction: Brief overview of the universe: Solar system and beyond.

Motions in the Sky: the Celestial Sphere, Coordinate Systems, the Ecliptic, Precission of the Equinoxes, proper motion.

Brightness measurements: Flux and UVB system, apparent and absolute magnitudes. Velocity and distance measurements.

Radiative processes in astrophysics: Radiative transfer, Blackbody radiation, Einstein coefficients, Bremsstrahlung, Cylotron & Synchrotron radiation, Thomson & Compton scattering, inverse Compton scattering

Physics of stars: stellar structure and composition, evolution, compact stellar Objects

Interstellar medium: composition, radiative heating and cooling, ISM phases, HII regions

The Milky Way: Structure, kinematics, differential rotation, oort's constant

Normal galaxies: Morphological classification of galaxies, spiral and elliptical galaxies, density wave theory of spiral structure, Galactic dynamics, stellar relaxation, dynamical friction, rotation curves and dark matter, galaxy clusters, gravitational lensing

Active galaxies: active galactic nuclei, classification, unified model of AGN, quasar absorption lines

Cosmology: High redshift universe, CMBR, structure formation

Suggested Reading:

- Binney, J. and Tremaine, S., *Galactic Dynamics*
- L. Sparke and J. S. Gallagher, *Galaxies in the Universe: An Introduction*
- B.W.Carrol and D.A.Ostlie, *An Introduction to Modern Astrophysics*
- Rybicki, G.B. and Lightman, A.P., *Radiative Processes in Astrophysics*
- J. E. Dyson and D. A. Williams, *The physics of the interstellar medium*
- Bohm-Vitense, Erika, *Introduction to Stellar Astrophysics. vol 3 stellar structure and evolution*

PHY 414/614: Advanced Condensed Matter Physics (4)

Prerequisite: PHY 403: Condensed Matter Physics

Review of basic postulates of magnetism, direct and indirect exchange interaction, Zener-double exchange interactions, super-exchange interactions, ferro-, antiferro-, ferri-magnetism, spin glasses.

Oxide based modern magnetic materials: Ferrites and magnetic technology based on it, Giant magnetoresistance: Exchange in magnetic multilayers; Colossal magnetoresistance materials, charge- and orbital-ordering, phase-separation; electric, magnetic and photo control of physical properties.

Dilute magnetic semiconductors, Introduction to spin electronics and technology based on it. Thin film technology of magnetic materials.

Review of basic postulates of superconductivity, High temperature supercondtivity, Josephson junctions, SQUID magnetometer, recent advances in superconductors: MgB_2, Fe-based superconductors, *etc*.

Ferroelectricity, Multiferroicity, magnetoelectricity

Introduction to nanotechnology and nanoscience: Carbon nanotubes and fullerenes.

Suggested Reading:

- Fundamental of Magnetism: Mathias Getzlaff
- Solids State Physics: Ashcroft and Mermin.
- Introduction to Solid State Physics: Madelung.
- Principles of Condensed Matter Physics: Chaikin and Lubensky.
- Solid State Physics – An Introduction to Theory and Experiment: Ibach and Lutz.
- Quantum Theory of solid State: Callaway.
- Introduction to Magnetic Materials: B. D. Cullity
- Magnetic Materials: Fundamentals and Device Applications : Nicola A. Spaldin

PHY 415/615: Quantum Field Theory-I (4)

Prerequisite: PHY 305: Classical Mechanics,
PHY 302: Mathematical Method-II,
PHY 304: Quantum Mechanics-II,
Special Theory of Relativity

Classical Field Theory: Introduction; Lagrangian Field Theory; Lorentz Invariance; Noether's Theorem and Conserved Currents; Hamiltonian Field Theory.

Canonical Quantization: The Klein-Gordon Equation, The Simple Harmonic Oscillator, Free Quantum Fields, Vacuum Energy, Particles, Relativistic Normalization, Complex Scalar Fields, The Heisenberg Picture, Causality and Propagators, Applications, Non-Relativistic Field Theory

Interacting Fields: Types of Interaction, The Interaction Picture, Dyson's Formula, Scattering, Wick's Theorem, Feynman Diagrams, Feynman Rules, Amplitudes, Decays and Cross Sections, Green's Functions, Connected Diagrams and Vacuum Bubbles, Reduction Formula

The Dirac Equation: The Lorentz Group, Clifford Algebras, The Spinor Representation, The Dirac Lagrangian, Chiral Spinors, The Weyl Equation, Parity, Majorana Spinors, Symmetries and Currents, Plane Wave Solutions.

Quantizing the Dirac Field: Spin-Statistics Theorem, Fermionic Quantization, Fermi-Dirac Statistics, Propagators, Particles and Anti-Particles, Dirac's Hole Interpretation, Feynman Rules.

Quantum Electrodynamics: Gauge field, Gauge Invariance, Quantization, Inclusion of Matter - QED, Lorentz Invariant Propagators; Feynman Rules; QED Processes.

Suggested Reading:

- Peskin, Michael E., and Daniel V. Schroeder. An Introduction to Quantum Field Theory. Boulder, CO: Westview Press, 1995. ISBN: 9780201503975.
- Quantum Field Theory by Ryder
- Quantum Field Theory Part 1 by Steven Weinberg

PHY 416/616: General Theory of Relativity (4)

Review of special theory of relativity

Mathematical aspects: Tensor algebra, Transformation of coordinates, Lie derivative, covariant derivative, affine connections, Riemann tensor, Curvature tensior

Inertial frames, Gravitational mass and inertial mass, Equivalance principle: weak form, strong form, Principle of general covariance

Field equations in general relativity: Geodesic deviation, Vacuum Einstein equations.

Action formulation of GTR

Solution of Einstein equations: Tests of GTR, Black holes, Schwarzschild black hole

Penrose diagram of Schwarzschild black hole.

Cosmology: FRW Universe.

Suggested Reading:

- Spacetime and Geometry: An Introduction to General Relativity by Sean Carroll
- General Relativity by Robert M. Vald
- Gravity: An Introduction to Einstein;s General Relativity by James B. Hartle
- Gravitation and Cosmology: by Steven Weinberg

PHY 417/617: Soft Condensed Matter (4)

Introduction and Overview: What is soft condensed matter, forces, energies and timescales in soft condensed matter.

Colloids: A single colloidal particle in a liquid (Stoke's law and Brownian motion), forces between colloidal particles (Van der Waals, electrostatic double layer, stearic, depletion interaction), stability and phase behaviour of colloids (hard sphere, long ranged repulsion, weakly attractive, strongly attractive), flow in concentrated dispersions.

Polymers: Polymeric materials, freely jointed chains and its Gaussian limit, real polymer chains, excluded volume, theta temperature, viscoelastic behaviour of polymers, linear viscoelasticity, time-temperature superposition, entanglements, tube model and theory of reptation.

Liquid Crystals: Types of liquid crystals, characteristics and identification of liquid crystal phases, nematic/isotropic transition, rigidity and elastic constants of a nematic liquid crystal, boundary effects, disinclination, dislocation and other topological defects, polymer liquid crystals.

Amphiphiles: Self-assembled phases in solutions of amphiphilic molecules, spherical micelles and critical micelle concentration, cylindrical micelles, bilayers and vesicles, phase behaviour of concentrated amphiphile solutions, complex phases in surfactant solutions and microemulsions.

Biological Soft Matter: DNA (structure, condensation), proteins (structure, folding, crystallization), membranes (lipid membranes, instabilities).

Experimental Techniques in Soft Matter: Rheology (shear rheometry, microrheology), light scattering (dynamic light scattering, static light scattering), microscopy (optical microscopy, video microscopy and particle tracking).

Suggested Reading:

- Richard A. L. Jones, Soft Condensed Matter, Oxford University Press.
- Ian W. Hamley, Introduction to Soft Matter: Synthetic and Biological Self-Assembling Materials, John Wiley & Sons.
- Thomas A. Witten and Philip A. Pincus, Structured Fluids: Polymers, Colloids and Surfactants, Oxford University Press.

PHY 419/619: Experimental Techniques (4)

Basics of vacuum technique: vacuum generation, gauging

Cryogenics: generation of low temperature and it measurements

Structure and composition analysis by x-ray and electron diffraction based techniques: X-Ray Diffraction, Energy dispersive X-Ray (EDX), Transmission electron microscopy (TEM), X-Ray Fluorescence (XRF)

Electronic structure of Solids: X- ray and ultraviolet photoemission spectroscopy, angle resolved photo-emission spectroscopy, auger electron spectroscopy, and x-ray absorption techniques

Radiation and particle detectors: gas detectors, scintillators detectors and semiconductor detectors

Thin film, polycrystalline and single crystal sample preparation techniques

Magnetometry and electrotransport : ac and dc magnetization techniques, two-probe and four probe resistivity measurements, magnetoresistance, Hall, thermal conductivity, thermopower, and heat capacity

Ultrafast spectroscopy: transient absorption, two photon absorption and terahertz spectroscopy

Neutron and Muons in condensed matter

Suggested Reading:

- Scientific foundations of vacuum technique by Saul Dushman
- Experimental Techniques in Low-Temperature Physics by Guy White, Philip J. Meeson
- Elements of X Ray Diffraction by B. D. Cullity
- Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM by R.F. Egerton
- Handbook of thin-film deposition processes and techniques: principles, methods, equipment, and applications by Klaus K. Schuegraf
- Crystal Growth Technology by Kullaiah Byrappa, Tadashi Ohac
- Photoelectron Spectroscopy by Principles and Applications Stefan Hüfner
- Introduction to Magnetic Materials by B. D. Cullity
- Terahertz Optoelectronics by Kiyomi Sakai
- X-Rays, Neutrons and Muons by Walter E. Fischer, Rudolf Morf

PHY 421/621: Quantum Field Theory II (4)

Prerequisite: PHY 415/615: Quantum Field Theory-I

Introduction: Why should we study "Path integral quantization"?

Review of path integral formulation of quantum mechanics

Path integral formulation of interacting scalar field theory: Correlation functions, Feynman Rules, Functional derivatives, Generating functional.

Path integral for Fermion fields: Anti commutating numbers, the Dirac propogator, Generating functional.

Path inegral for QED.

Non-abelian gauge theories and quantization: Gauge invariance, Yang-Mills action, Feynman rules, Faddeev-Popov ghost fields, BRST.

UV divergences and renormalization: explicit one loop renormalization for interacting gauge theory.

RG: calculation of beta function.

Spontaneous symmetry breaking: Goldstone boson, Higgs mechanism.

Standard model (GSW model, the Lagrangian, different gauge groups, representations and transformation of different fields, Higgs mechanism).

Suggested Reading:

- An introduction to QFT by Peskin and Schroeder
- Quantum Field Theory by Ryeder
- A First Book of QFT by Lahiri and Pal
- QFT: A modern Introduction by M. Kaku
- Relativistic QFT by Bjorken and Drell
- Gauge theory and elementary particle physics by Cheng & Lee
- Quarks and Leptons: An Introductory Course in Modern Particle Physics by Halzen and Martin

PHY 423/523/623: Non-adiabatic Interactions in Physics, Chemistry and Biology (4)

The Born-Oppenheimer Approach – The Time Independent Framework: (a) The Adiabatic Representation; (b) The Diabatic Representation

Mathematical Introduction: (a) The Hilbert Space and the Curl-Div Equations; (b) First Order Differential Equations along contours; (c) Abelian and non-Abelian Systems.

The Adiabatic-Diabatic Transformation (ADT). On the Single-valuedness of the newly formed Diabatic Potentials and the Quantization of the Born-Oppenheimer (BO) non-adiabatic coupling (NAC) matrix. Singularities, Poles and Seams characterizing the BO-NAC terms.

Molecular Fields as formed by Lorentz Wave-Equations.

The Jahn-Teller Model, The Renner-Teller model, the mixed Jahn-Teller/Renner-Teller model. The Privileged ADT phase and the corresponding Topological (Berry/Longuet-Higgins) phase.

The Extended Born-Oppenheimer Equation including Symmetry

The Born-Oppenheimer Approach – The Time Dependent Framework (emphasizing Field-dependent non-Adiabatic Coupling terms).

The interaction between molecular systems and electromagnetic fields: (a) The Classical treatment of the field (b) The Quantum treatment of the Field (based on Fock states).

If time allows various subjects related to Quantum Reactive Scattering Theory will be introduced. Among other things the concept of arrangement channels and decoupling of arrangement channels employing Absorbing Boundary conditions will be discussed.

Selected Readings:

- M. Baer and C-Y. Ng, (eds), State-Selected and State-to-State Ion-Molecule Reaction Dynamics. Ser. Advances of Chemical Physics, Vol. 82, Part 2, John Wiley, Hoboken, N.J. (1992)
- M. Baer and G.D. Billing (eds), The Role of Degenerate States in Chemistry, Ser. Advances of Chemical Physics, Vol. 124; John Wiley, Hoboken, N.J. (2002)
- W. Domcke, D.R. Yarkony and H. Koeppel, Conical Intersections, Advances Series In Physical Chemistry Vol. 15 (World Scientific, Hong-Kong (2004).
- Farad. Discussions, Non-Adiabatic Effects in Chemical Dynamics, Vol. 127 (R.S.C.), University Oxford, (2004)
- M. Baer, Beyond Born-Oppenheimer: Electronic Nonadiabatic Coupling Terms and Conical Intersections, Wiley Interscience, Hoboken, N.J., (2006).
- G.C. Schatz and M. A. Ratner, Quantum Mechanics in Chemistry, Prentice-Hall, Englwood Cliffs (1993)
- J.D. Jackson, Classical Electrodynamics, 2nd Edition, John Wiley, New York (1975)
- J. Z. H. Zhang, Theory and Application of Quantum Molecular Dynamics, World Scientific, Hong-Kong (1999)

PHY 425/625: Quantum Information Theory (4)

- Probabilities
- Classical Information theory
- Review of quantum mechanics
- Bits to Qubits
- Quantum states: mixed states, multipartite states, superposition and entanglement
- Quantum measurements
- Quantum dynamics, open and closed dynamics
- The circuit model
- Quantum entropy and quantum correlations
- Elements of quantum computing

Suggested Reading:

- M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information
- J.Preskill, Quantum Information and Quantum Computation, Available online (Caltech)
- J. J. Sakurai, Modern quantum mechanics Addison-Wesley (1994)

PHY 503: Introduction to Astronomy and Astrophysics (4)

See contents of **PHY 413**

PHY 504/620: Magnetism and Superconductivity (4)

Prerequisite: PHY 304: Quantum Mechanics-II

Magnetism: Orbital and spin magnetism without interactions; Exchange interactions; Ferromagnetism, antiferromagnetism, ferrimagnetism, helical order and spin glasses; Measurement of magnetic order; Broken symmetry, Landau theory of ferromagnetism, Heisenberg and Ising model, consequences of broken symmetry, phase transitions and spin waves; Domains and the magnetization process; Itinerant magnetism of metals; Giant, colossal and tunneling magneto resistance; Nuclear magnetic resonance and technological aspects of magnetic materials.

Superconductivity: Properties of conventional (low temperature) superconductors, Meisnner-Ochsenfeld effect, perfect diamagnetism, London and Pippard equation; Type I superconductors and type II superconductors, vortex state, critical fields, interaction of vortices, magnetic properties, surface superconductivity; Ginzburg-Landau theory; BCS theory of superconductivity- electron-phonon interaction,
ground state of the superconductor, spectrum of elementary excitations, tunnel effects and measurement of
the energy gap; Josephson effect and the quantum interferometers; High Temperature superconductivity.

Suggested Reading:

- S. Blundell, Magnetism in Condensed Matter, Oxford (2001).
- J. M. D. Coey, Magnetism and Magnetic Materials, Cambridge (2010)
- Aharoni, Introduction to the Theory of Ferromagnetism, Oxford (2001)
- M. Tinkham, Introduction to Superconductivity, McGraw-Hill (1996)
- J. F. Annett, Superconductivity, Superfluids and Condensates, Oxford (2004)
- T. P. Sheahen, Introduction to High- Temperature Superconductivity, Plenum (1994)

PHY 506/622: Advanced Topics in Theoretical Condensed Matter Physics (4)

Prerequisite: PHY 303: Quantum Mechanics-I
PHY 304: Quantum Mechanics-II

Second quantization for bosons and fermions.

Lattice vibrations: waves and phonons in graphene. Different bending modes of graphene, Landau levels, oscillations of magnetization (de Haas van Alphen), diamagnetism Landau and magnetic susceptibility of electron gas in graphene.

Graphene: band structure and Dirac spectrum.

Various generalizations: bilayer graphene, edge modes in ribbons, The birth of topological insulators, Berry phase, topological indices, Topological order and the quantum spin hall effect, Addiabatìc transport.

Suggested Reading:

- Condensed Matter Field Theory, Altland and Simon
- Physical properties of carbon nanotubes, R. Saito

PHY 523: Non-adiabatic Interactions in Physics, Chemistry and Biology (4)

See contents of **PHY 423**

PHY 601: Advanced Mathematical Methods for Physics (4)

Vector space and matrices, linear independence, bases dimensionality, Inner product, tensors, parallel transport, linear transformation matrices, inverse, orthogonal and unitary matrices, independent element of a matrix, Eigen values and Eigen vectors, diagonalization.

Theory of complex variables, Cauchy- Riemann condition, analytic functions, Cauchy's theorem, Cauchy integral formula, Laurent series, singularities, branch points and cuts, residue theorem, contour integration, evaluation of definite integrals, method of steepest descent.

Ordinary differential equations, second order linear ODEs with variable coefficients, Solution by series expansion, non-homogeneous differential equations and solution by the method of Green's functions with applications. Eigenvalue methods, up to Strum-Liouville systems. Special functions, Legendre, Bessel, Hermite and Laguerre functions with their physical applications, generating functions, orthogonality conditions, recursion relations, Legendre, Bessel, Hermite, Laguire equations and their solutions. Fourier integral and transforms, inversion theorem, Fourier transform of derivatives, convolution theorem.

Partial differential equations, Solution of Laplace and Poisson's equations, Wave equation

Introduction to Groups, Representations, Finite Groups, Permutation Groups, Continuous Groups, Lie algebras.

Suggested Reading:

- B. Arfken and H. J. Weber, Mathematical Methods for Physicists, 6th Ed.
- P. K. Chattopadhyay, Mathematical Physics.
- M. L. Boas, Mathematical Methods in Physical Sciences.
- S. D. Joglekar, Mathematical Physics: The Basics.
- A. K. Ghatak, Mathematical Method of Physics.
- F. B. Hildebrand, Methods of Applied Mathematics.
- A. W. Joshi, Elements of Group Theory for Physicist.
- S. Hassani, Mathematical Physics.
- P. Dennery and A. Krzywicki, Mathematics for Physicists.
- J. Mathews and R. L. Walker, Mathematical Methods of Physics.

PHY 602: Advanced Classical Mechanics (4)

- Review of Classical Mechanics
- Variational principles- Lagrange's equation and its application,
- Hamilton's equation of motion
- Perturbation theory
- Hamilton Jacobi theory
- Poisson's bracket in Classical Mechanics and its transition to quantum mechanics
- Classical field theory

Suggested Reading:

- Classical Mechanics, John R. Taylor, University science books, 2004
- Mechanics (Volume 1), Landau and Lifshtz, Butterworth-Heinemann (1976), Ed. 3
- Analytical Mechanics, Fowels and Cassiday, Thompson Books (2004) Ed. 7
- Classical Mechanics, Herbert Golstein, Pearson (2011), Ed .3

PHY 603: Advanced Quantum Mechanics (4)

Review of Quantum Mechanics Postulates of quantum mechanics, operator methods, matrix representations, time-dependence, symmetry : Unitary operators: translations in space, translation in time (evolution). Rotations, reflections and parity. Conservation laws.

Solutions to the Schrodinger equation in one dimension. Angular momentum and spin.

Charged particles in electromagnetic fields Hamiltonian for a charged spinless particle in an electromagnetic field. Gauge transformations and gauge nvariance. Aharonov-Bohm effect; Free electron in a uniform magnetic field: Landau levels.

Approximate Methods: Time-independent perturbation theory, first and second order expansion; Degenerate perturbation theory; Stark effect; nearly free electron model. Variational method: ground state energy and eigenfunctions; excited states. The WKB method: bound states and barrier penetration.

Atomic and molecular structure: Revision of the Hydrogen atom. Fine structure: relativistic corrections; spin-orbit coupling; hyperfine structure. Zeeman effects; diamagnetic hydrogen. Multi-electron atoms: central field approximation; LS coupling; Hund's rules. Born-Oppenheimer approximation; H_2+ ion; molecular orbitals; H_2 molecule; ionic and covalent bonding.

Time-dependent perturbation theory: Two-level system, Rabi oscillations, Magnetic resonance. Perturbation series, Fermi's Golden rule, scattering and Born approximation. Radiative transitions, dipole approximation, stimulated emission and absorption, spontaneous emission, Einstein's A and B coefficients, selection rules; Cavity rate equations and lasers.

Scattering by a Potential: Formalism; Born approximations; Partial wave analysis
Relativistic Quantum Mechanics Klein-Gordan and Dirac equations and their solutions. Chirality and helicity.

Suggested Reading:

- Quantum Physics, S. Gasiorowicz
- Quantum Mechanics: Non-Relativistic Theory, Volume 3, L. D. Landau and L. M. Lifshitz
- The Physics of Atoms and Quanta, H. Haken and H. C. Wolf Quantum Mechanics, F. Schwabl
- Principles of Quantum Mechanics, R. Shankar
- Problems in Quantum Mechanics, G. L. Squires
- Quantum Mechanics: A New Introduction, K. Konishi and G. Paffuti
- Quantum Mechanics, F. Schwabl
- Quantum Mechanics, C. Cohen-Tannoudji, B.D. Franck Laloe

PHY 604: Statistical Mechanics **(4)**

See contents of **PHY 306**

PHY 605: Electrodynamics **(4)**

See contents of **PHY 401**

PHY 606: Atomic and Molecular Physics **(4)**

See contents of **PHY 402**

PHY 607: Condensed Matter Physics **(4)**

See contents of **PHY 403**

PHY 608: Nuclear and Particle Physics **(4)**

See contents of **PHY 404**

PHY 611: Nonlinear Dynamics and Chaos **(4)**

See contents of **PHY 411**

PHY 612: Computational Physics **(4)**

See contents of **PHY 412**

PHY 613: Ultrafast Optics and Spectroscopy **(4)**

Basics laser theory: Einstein coefficient and light amplification, laser rate equations, cavity modes, transverse and longitudinal mode selection, coherence properties.

Ultrashort pulse generation: Active and passive mode-locking, mode-locking using optical Kerr Effect.

Ultrafast-pulse measurement methods: Electric field auto-correlations and power spectrum, Intensity autocorrelations, frequency resolved optical gating (FROG).

Manipulation of ultrashort pulses: Pulse shaping techniques.

Ultrafast time-resolved spectroscopy: Forced wave equations, second harmonic generation, Propagation equation for nonlinear refractive index media, nonlinear Schrodinger equation, self-phase modulation, modulation instability and solitons.

Ulatrafast time-resolved spectroscopy: Degenerate and non-degenerate pump-probe transmission measurements, stimulated Raman scattering.

Terahertz electromagnetic radiations: THz generation and detection, THz time domain spectroscopy and imaging.

Introduction to atto-second science.

Suggested Reading:

- Ultrafast Optics by Andrew Weiner
- Laser Spectroscopy edited by Peter Hanna Ford
- Laser Theory and Applications by K. Thyagarajan and A. K. Khatak
- Ultrafast Optics edited by Rick Trebino and Jeff Squier

PHY 614: Advanced Condensed Matter Physics **(4)**

See contents of **PHY 414**

PHY 615: Quantum Field Theory-I **(4)**

See contents of **PHY 415**

PHY 616: General Theory of Relativity **(4)**

See contents of **PHY 416**

PHY 617: Soft Condensed Matter **(4)**

See contents of **PHY 417**

PHY 619: Experimental Techniques **(4)**

See contents of **PHY 419**

PHY 620: Magnetism and Superconductivity **(4)**

See contents of **PHY 504**

PHY 621: Quantum Field Theory II **(4)**

See contents of **PHY 421**

PHY 622: Advanced Topics in Theoretical Condensed Matter Physics **(4)**

See contents of **PHY 506**

PHY 623: Non-adiabatic Interactions in Physics, Chemistry and Biology **(4)**

See contents of **PHY 423**

PHY 625: Quantum Information Theory **(4)**

See contents of **PHY 425**

Computer Science

CS 101/201: Introduction to Computers (3)

- Basic Component of a Computer System: CPU and main Memory; Disk Storage; Input and output units; function of each component.
- Hardware and Software; System Software and Applications Software; Client Server architecture; Desktops, workstations, Server & Clusters.
- Operating systems, Features of a widely used operating environment such as MS WINDOWS; UNIX or LINUX, comparison of operation environments.
- Introduction to computer networking
- Architecture of Networking
- Programming

Suggested Books:

- B Kernighan and D M Ritchie, *The C Programming Language*, Pretice-Hall India, New Delhi.
- H M Deitel and P J Deitel, *C: How to Program*, Prentice-Hall, New Jersey.
- H M Deitel and P J Deitel, *JAVA: How to Program*, Prentice-Hall, New Jersey.
- H M Deitel and P J Deitel, *PYTHON: How to Program*, Prentice-Hall, New Jersey.
- Notes and internet printouts of material on MS WINDOWS, UNIX and LINUX.
- (N.B. The choice of the programming textbook will depend on the programming language to be taught)

Humanities and Social Sciences

HSS 103: Basics of Communication Skills (1)

Communication Skills: Process of Communication, Principles of Communication, Barriers to Communication, Ways to avoid barriers, Oral and Written Communication, Verbal and Nonverbal Communication

Reading Skills: Process of Reading, way to improve reading skills

Reading Comprehension Skills: Discovering structure; identifying themes and sub-themes; understanding and interpreting facts; distinguishing facts from opinions and specific from general statements; searching for information; drawing information and making generalizations.

Language Skills:

(a) Common Grammatical Mistakes: Sentence fragments, Comma splice, Run-together-fused sentences; Faulty agreement and reference of pronouns; Shifts in point of view; Mixed constructions; Omissions; Incomplete and illogical comparisons

(b) Diction: Denotation and connotation; Exactness, appropriateness and effectiveness; Idiomatic usage; Colloquialisms

(c) Strategies: Economy, emphasis, Clarity, concreteness, unity and coherence

Spoken Language Skills: Descriptive, narrative, argumentative and expository techniques in spoken language use

Listening Skills: Importance and Process of Listening, Types of Listening, Barriers to Listening

Role Plays

Selected Readings:

- Andrea J. Rutherfoord, Basic Communication Skills for Technology, Pearson Education. Inc., Eleventh edition, 2010
- Matthukutty M Monippally, Business Communication Strategies, Oxford University Press, Sixth Edition 2011
- Meenakshi Raman & Sangeeta Sharma,Technical Communication, Oxford University Press, Sixth Edition 2011

HSS 104: Oral and Written Communication (1)

Writing Skills: Developing a composition using various techniques like definition, classification, analogy, etc.; Descriptive narrative, argumentative and expository techniques in writing; Technical writing

Report Writing: Types of report, Writing Techniques and Guidelines, Drafting, preparation analysis and interpretation of reports.

Letter Writing: Body Language of a letter, and types of letters, Resume and Job application Netiquettes, Review Writing, Writing Notices, Circulars and Proposals

Speaking Skills: Oral Presentation, Interview Skills, Public Speaking, Kinds of Group Discussion, Debate

Suggested Reading:

- Meenakshi Raman and Sangeeta Sharma, Technical Communication, Oxford University Press, Sixth Edition 2011
- M Ashraf Rizvi, Effective Technical Communication, TMH, 2005
- R C Sharma and Krishna Mohan, Business Correspondence and Report Writing, TMH, 2002

HSS 205: Microeconomics (2)

- Introduction: Households, Firms and Markets
- Households: Utility maximisation; Demand functions
- Firms: Production Functions; Cost Functions; Profit maximisation
- Supply & demand: Types of markets
- Marketing Strategies

Concepts to be covered:

Introduction: Positive and normative economics; total, average and marginal functions; elasticity

Households as consuming units: Indifference curves and the rate and elasticity of substitution; utility maximizing equilibrium; income and substitution effects; demand curves and consumer surplus; Engel curves; demand functions; price, cross and income elasticities of demand

Firms as producing units: Production functions: diminishing returns; isoquants; elasticity of substitution; cost minimisation; cost functions and returns to scale; profit maximization

Supply and demand: Prices as parameters in perfectly competitive markets; competition and price discovery; market equilibrium under monopolistic competition, monopoly and monopsony; oligopoly

Marketing strategies: Marketing functions; objectives of marketing management; levels and patterns of market segmentation; product life cycles

Selected Readings:

Text books:

- Varian, Hal R. Intermediate Microeconomics (W.W.Norton, Eighth edition, 2009)

Suggested books:

- Bernheim, B. Douglas & Whinston, Michael D. Microeconomics (TMH, Second edition, 2013)
- Pindyck, Robert S. & Rubinfeld, Daniel L. Microeconomics (PHI, Eighth Edition, 2012)
- Browning, Edgar K. & Zupan, Microeconomic Theory and Applications (Wiley, Eleventh edition, 2011)
- Kotler, Philip. Marketing Management (Prentice Hall, Fourteenth Edition, 2011)

HSS 207: Macroeconomics (1)

- Introduction
- Consumption, saving and investment functions
- Joint equilibrium in goods and financial markets
- Inflation and unemployment
- Open economy macroeconomics

Concepts to be covered:

Introduction: Macroeconomic aggregates; sectoral contributions to domestic product; international comparisons and purchasing power parity; closed and open economies

Consumption, saving and investment functions: Average and marginal propensities to consume and save; aggregate demand; the simple Keynesian closed economy equilibrium; the multiplier; government consumption and taxation

Joint equilibrium in goods and money markets: Demand for liquidity; the IS-LM model

Inflation and unemployment: Measurement of inflation; inflationary expectations and aggregate demand; the aggregate supply curve; the expectations-augmented Phillips curve; measuring unemployment in India

Open economy macroeconomics: External and internal balance; the Balance Payments; trade tariffs, nominal and effective rates of protection; non-tariff barriers

Selected Readings:

Text Books:

- Dornbusch, Rudiger, Stanley Fischer and Richard Startz. Macroeconomics (TMH, Eleventh edition, 2010).

Suggested Books:

- Olivier Blanchard. Macroeconomics (PHI, Fifth Edition,2010)
- N. Gregory Mankiw. Macroeconomics (Worth Publishers, Seventh edition, 2010)