**Haramaya University**

**VICE-PRESIDENT FOR ACADEMIC AFFAIRS**

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**Syllabi for PHD Programs**

**Compiled By THE OFFICE OF ACADEMIC ProgramS Directorate**

**May 2020**

**Haramaya University**

**College of Natural and Environmental Sciences**

**PhD Programs**

**Department of Biology**

Name of the Program: Doctor of Philosophy in Microbiology

1. **Course Breakdown by Semester**

**Year I, Semester I**

|  |  |  |  |
| --- | --- | --- | --- |
| **S. No** | **Course Code** |  **Course Title** | **Credit Hours** |
| 1 | MICR 741 |  Advanced Medical Microbiology | 3 |
| 2 | MICR 711 | Advanced Food Microbiology | 3 |
| 3 | MICR 611 | Dairy Microbiology(E) | 3 |
| 4 | MICR 601 | Biostatistics  | 2 |
| 5 | MICR 701 | Advanced Molecular and Microbial Genetics (E) | 3 |
| 6. | MICR 721 | Genomics and Bioinformatics | 2 |
| 6 | MICR 751 | Seminar-I | 1 |
| **Total credit hrs** | **12/17** |

E= Elective course

**Year I, Semester II**

|  |  |  |  |
| --- | --- | --- | --- |
| **S.No** | **Course Code** |  **Course Title** | **Credit Hours** |
| 1 | MICR 632 | Advanced Plant Pathology | 3 |
| 2 | MICR 722 | Industrial Microbiology and Microbial Biotechnology | **3** |
| 3 | MICR 832 | Advanced Environmental Microbiology(E) | **3** |
| 4 | MICR 742 | Immunotechnology (E) | **3** |
| 5 | MICR 732 | Soil Microbiology | 2 |
| 6 | MICR 752 | Seminar-II | 1 |
| **Total credit hrs** | **13/15** |

E= Elective course

1. **Course Descriptions**

**Course Title: Advanced Medical Microbiology**

**Course Code:** MICR 741

**Credit Hrs: 3**

**Course objectives**

* To describe the diversity of the pathogenic microorganisms
* To Identify types of infectious and non-infectious microbial diseases and how they affect humans
* To explain the principles of infection and immunity
* To familiarize students with diverse microbial diseases
* To provide the student with detailed insight in epidemiology
* To elucidate the mechanisms of microbial pathogenesis
* To discuss about the variety of host-pathogen interactions
* To learn about the principles and significance of traditional and molecular laboratory methods in the diagnosis of pathogens
* To explain about the mechanism and significance of drug resistance

**Course description**

This course first introduces students with microbial infectious diseases through description of the major bacterial, protozoan, fungal and viral pathogens that cause diseases in humans. It explains basic principles of infection and immunity; the mechanisms of pathogenesis of medically important aerobic and anaerobic pathogenic bacteria, analysis of virulence factors; interactions of pathogens and their products with eukaryotic host cells (cellular microbiology); antigenic variation; contemporary vaccine strategies; bacterial gene regulation (osmoregulation, quorum sensing); bacterial export and secretion; and genetic regulation of bacterial virulence expression. It also attempts to show mechanisms of fungal pathogenesis, superficial and cutaneous mycoses, subcutaneous mycoses, systemic mycoses, opportunistic mycoses, mycotoxicoses; pathogenesis of parasitic diseases including those caused by intestinal and urogenital protozoa, blood and tissue protozoa, microscopic helminthes. Major viral diseases including influenza, measels, mumps, chicken pox, hepatitis A, B, C, D & E, poliomyelitis, AIDS, and diseases caused by human papilloma virus (HPV), rabies, yellow fever, dengue fever and Japanese encephalitis will also be considered. In addition, it addresses some methods of traditional and molecular laboratory diagnosis of bacterial, fungal, parasitological and viral diseases; and the role of molecular detection in outbreak investigation. Finally, the significance of drug resistance among pathogenic bacteria and the methods used to determine their sensitivity to antibiotics will be studied.

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit
* Mini project

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Mini project presentation (15%)
* Final examination (40%)

**Course Title: Advanced Food Microbiology**

**Course Code:** MICR 711

**Credit Hrs: 3**

**Course objectives:**

* To extend the student’s knowledge and understanding of the nature and particular attributes of micro-organisms as a basis for studies in the applied area of food microbiology
* To provide the practical knowledge and skills used in this type of microbiology to give students confidence in modern technical capabilities to analyze food for specific miro-organisms
* To Identify the microflora of different foodstuffs, and how to preserve foods and prevent food poisoning
* To introduce students to the concepts of food safety plans in the food industry
* To explain the microbial principles relating to the production of some fermented foods
* To encourage development of skills in co-operative learning in small groups by using real-life situations and criteria to design methods for microbial food analysis as a team and communicate the decisions of the design to peers.
* To learn about the principles and importance of rapid diagnostic methods

**Course description**

The study of food microbiology involves three major components: foods, microorganisms and hosts. This particular course is designed to help students to build a comprehensive understanding of food-borne microorganisms through studying their interactions with the environment and with the host. Discussions will be focused on critical pathways and mechanisms for microorganisms to survive the environment. Students will be introduced to the applications of micro-organisms in the production of fermented foods. Their implications on human health and food quality will be addressed focusing mainly on microorganisms involved in food-borne diseases, food spoilage, and topics of industrial significance. Particular emphasis will be given to the critical role of fungi (Yeasts and filamentous fungi) in foods, both as agents of spoilage and food processing. The course generally covers the production of food-borne toxins and fungal enzymes. It includes techniques for isolating, culturing, enumerating and identifying foodborne fungi. Genetic and molecular biology approaches important for studying food-borne microorganisms and cutting-edge techniques in solving industrial food microbiological problems will be introduced. Emphasis will be given to modern microbial analysis techniques including rapid methods of determining the microbiological safety and quality of foods, current tools and techniques used in functional genomics of food microorganisms (bioinformatics, RNA interference, gene knockout, TILLING, EST analysis, DNA microarrays, proteomics and metabolomics) and their applications in the development of foods.

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit
* Mini project

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Mini project presentation (15%)
* Final theory examination (40%)

**Course Title: Dairy Microbiology** (E)

**Course Code:** MICR 611

**Credit Hrs: 3**

**Course objectives:**

* To acquaint students with dairy microbiology principles as well as their practical applications
* To describe the major microflora of milk and sources of contamination
* To identify sources of contamination and describe the methods of minimizing contamination
* To practically engage in hazard analysis and identification of critical control points
* To identify and characterize agents of milk-borne infection and intoxication
* To familiarize students with methods of examination of milk and rapid detection of milk-borne pathogens
* To describe methods of milk preservation
* To describe methods of production of fermented dairy products and identify the variety of fermented dairy products
* To explain the role and describe the types of starter lactic acid bacterial cultures
* To discuss about the applications of genetic engineering techniques in starter culture development

**Course description**

The course provides thorough coverage of dairy microbiology principles as well as their practical applications. Primarily, it focuses on the microflora of milk, sources of contamination, and methods of minimizing contamination; the use of a hazard analysis of selected critical control points (HACCP) in the manufacturing process to prevent the contamination of dairy products; updated standards for Good Manufacturing Practice. It discusses new diagnostic techniques that allow a pathogen to be detected in samples in a matter of few hours. Apart from exploring methods of examination of the types of milk-borne infection and intoxication, the course attempts also to study preservation methods including pasteurization and sterilization. Emphasis will also be given to review the type and method of production of fermented dairy products such as butter milk, cream, yoghurt, kefir, kumiss, acidophilus milk and cheese; microbes involved in fermentation; the role and type of starter lactic acid bacterial cultures, the latest developments in dairy starter cultures, and the applications of genetic engineering techniques in starter culture development. Major issues and principles concerning food hygiene and control, food sanitation in food manufacture and in the retail trade, food control agencies and their regulations will be addressed.

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit
* Mini project

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Mini project presentation (15%)
* Final theory examination (40%)
1. **Course Title: Industrial Microbiology and Microbial Biotechnology**

**Course Code:** MICR 722

**Credit Hrs: 3**

**Course objectives:**

* To identify and describe salient features of major fermentation processes
* To discuss in groups major problems and methods of handling of fermentation processes
* To gain knowledge of industrial scale up-stream and down-stream processing
* To examine microbial growth kinetics and learn methods of optimization and modeling of fermentation processes
* To study about bioreactor designs and operations
* To learn about the biotechnological potentials of microalgae
* To discuss about applications of microbial biotechnology in the production of pesticides, herbicides, and insecticides
* To examine the applications of microbial metagenomics in the analysis of microbial diversity

**Course description**

This course encompasses fermentation processes, descriptive layout and components of fermentation process for extracellular and intracellular microbial products; Problems in fermentation process and handling will be thoroughly discussed along with solutions such as the use of immobilized enzymes and cell systems. Fermentation monitoring and control mechanisms; and industrial scale up-stream and down-stream processing as well as product recovery; microbial growth kinetics of different types; optimization and modeling of fermentation processes; single variable design, multivariate screening designs, critical success factor analysis - optimization of designs for two or more factors; and metabolic flux control analysis. It will also attempt to study bioreactor design and operation: classification of reactors; designing parameters for reactors (stirred tank reactor, air-lift reactor, and plug flow reactor); scale-up of bioprocesses: parameters used in scale-up and the associated problems. The course will also deal with issues related to algal biotechnology focusing on the biotechnological potentials of microalgae to serve as sources of food, feed, colorant, fuel and pharmaceutically valuable compounds; microbial pesticides; microbial herbicides, microbial insecticides including bacterial insecticides from *Pseudomonas* sp., *Bacillus* sp.( *Bacillus thrungiensis* toxins - BT cotton), viral insecticides, and entomophathogenic fungi; microbial metagenomics as tools for microbial diversity analysis, indentifying uncultivable microbes from environmental samples, drug discovery, high throughput screening; genome expression and the methods of analysis including - serial analysis, oligonucleotide array technology, cDNA microarrays and micro chips. Additionally, it will enlighten students with the preparation of radio- and non-radioactive probes and microbial diagnostics; introduction to microbial nanotechnology; bio-safety and bioethics

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Final theory examination (55%)
1. **Course Title: Advanced Plant Pathology**

**Course Code:** MICR 632

**Credit Hrs: 3**

**Course objectives:**

* To discuss in groups about occurrence and importance of plant diseases
* To describe the symptomatology, etiology, and pathogenesis of major plant diseases
* To study the epidemiology of plant diseases and identify the control measures for the major plant dides
* To address issues related to the use of some chemical and biological products in plant disease control

**Course description**

The course explores the history of plant pathology; economic importance of plant diseases; symptomatology, etiology, proof of pathogenicity; types of pathogens and their mode of action; plant defense system; constitutive and inducible defense; genetic basis of plant pathogen interaction; R genes and R gene mediated resistance; biochemistry and molecular biology of defense reactions; systemic acquired resistance; role of salicylic, jasmonic acid and ethylene in plant defense; epidemiology and control measures. It also describes the various plant diseases of major economic crops; principles of plant disease control encompassing the theory and practice of plant disease control, quarantine, cropping system, avoidance of disease, physical and chemical control, use of resistant varieties. Particular emphasis will be made in bacterial, fungal, and viral diseases of plants. Apart from these, the course will attempt to cover parasitic plant diseases. Finally, the course will address issues related to the use of some chemical and biological products in plant disease control, diagnosis of plant diseases, and seed pathology.

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit
* Mini project

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Mini project presentation (15%)
* Final theory examination (40%)
1. **Course Title: Soil Microbiology**

**Course Code:** MICR 732

**Credit Hrs: 2**

**Course objectives:**

* To examine the diversity of soil microflora
* To introduce to studentsthe ecology of the major groups of micro-flora and their functions in soils
* To describe the physical and chemical properties of soils
* To describe the nature and function of soil microorganisms in the soil ecosystem
* To discuss about the role of microorganisms in nutrient cycling
* To explain the importance of soil microorganisms in the production of microbial biofertilizers

**Course description**

The course begins with the introductory and historical perspectives of soil microbiology. It studies the physical and chemical properties of soils; the diversity of soil microflora (bacteria, fungi, cyanobacteria and algae) in soils; the nature and function of soil microorganisms in the soil ecosystem, microbial ecology encompassing the rhizosphere and the mycorrhizal symbioses; improvement of soil fertility through the activities of microorganisms. Emphasis will be given to the role of microorganisms in nutrient cycling, particularly in carbon transformation and soil organic matter formation; transformation of nitrogen, biological nitrogen fixation, transformation of sulfur and phosphorus, composition of organic matter; production of microbial biofertilizers through mass cultivation of symbiotic N2 fixing rhizobial species and non-symbiotic N2 fixing microbes such as cyanobacteria (*Spirullina*), *Azolla* and other species

**Methods of course delivery**

* Reading assignment
* Classroom presentation
* Seminar presentation
* Lecture
* Group discussion
* Field visit
* Mini project

**Methods of Assessment**

* Classroom presentation (10%)
* Seminar paper (15%)
* Written assignments (10%)
* Written reports of field visits (10%)
* Mini project presentation (15%)
* Final theory examination (40%)
1. **Course Title: Biostatistics**

**Course Code:** MICR 601

**Credit Hrs: 2**

**Course Objectives**:

* To understand the importance of experimental design and analysis in research
* To be aware of statistical analysis techniques
* To familiarize the different models and methods for analysis the data
* To Identify the proper research design for their research work
* To gain the knowledge about different experimental designs
* To learn about different statistical software and its application

**Course Description**

This course focuses on design and analysis of both experiments and observational studies. It encompasses advanced applied statistical analysis techniques including linear and non-linear models, mixed models, and methods for the analysis of categorical data; regression with several explanatory variables, regression diagnostics; analysis of variance for factorial designs; multiple comparisons; analysis of covariance; repeated measures designs. It will primarily emphasize on teaching Statistics and Experimental Design topics using a conceptual approach, rather than through mathematical derivation. Major experimental designs will be covered, with particular emphasis on Completely Randomized, Randomized Complete Block, and Split Plot Designs, latin square; multi-classification; factorial; nested factorial; incomplete block and fractional replications for 2n, 3n; 2m x 3n; confounding variables; 12 lattice designs; general mixed factorials; analysis of variance in regression models; and optimum design. It also covers a wide range of statistical models and methods for data that are collected at different spatial locations and perhaps at different times (spatial or spatio-temporal data). Students will be also exposed to the entire experimental process from selecting the appropriate design, conducting proper randomization, analyzing data (using SAS), and interpreting the results. Students will read journal articles to see real world examples of well designed and poorly designed experiments. Students will then be asked to critique these experiments with their fellow classmates. Advanced statistical analysis techniques including linear and non-linear models, mixed models, and methods for the analysis of categorical data.

**Methods of Course Delivery**

* Lecture method
* Assignment
* Group discussion
* Mini project work

**Method of Assessment**

* Final Examination (40%)
* Take Home Examination (20%)
* Assignment (20%)
* Oral Examination (10%)
* Mini project work (10%)
1. **Course Title: Advanced Environmental Microbiology** (E)

**Course Code:** MICR 832

**Credit Hrs: 3**

**Course Objectives**:

* To acquaint the presence of different microorganism in the environments
* To distinguish the harmful and beneficial microorganism
* To explain about the aquatic micro flora
* To understand the different types waste water treatment mechanism
* To describe the mechanism of biodegradation
* To enable to understand the concepts of bioremediation
* To gain knowledge about diversification of agro- ecosystem
* To learn about traditional agricultural practices
* To recognize the importance of organic farming and biofertilizers.

**Course Description**

In this course attempts will be made to cover characteristic features of environmental microflora, the beneficial and harmful effects of viruses, protozoa, bacteria, actinomycetes, fungi, algae and nematodes; microorganisms and their environments; aerobiology and aquatic microbiology; waste treatment including the principles and applications of bioaccumulation, biomagnification, and biodegradation of hydrocarbons (with particular emphasis on the biodegradation of oil and petroleum products); bioremediation; microbial leaching; agro-ecosystems mainly focusing on microbial populations in agro-ecosystems, diversification of agro-ecosystems, and interaction between agro-ecosystems and natural ecosystems; sustainable agriculture encompassing traditional agricultural practices and organic farming; biofertilizers.

**Methods of Course Delivery**

* Lecture method
* Field Visit
* Reviewing related research articles and summarizing the content
* Reading Assignment
* Written assignment
* Presentation
* Group discussion
* Mini project work

**Methods of Assessment**

* Final Examination (40%)
* Take home examination (15%)
* Seminar (10%)
* Assignment (10%)
* Oral Examination (10%)
* Mini project report (15%)
1. **Course Title: Advanced Molecular and Microbial Genetics** (E)

**Course Code:** MICR 701

**Credit Hrs: 3**

**Course Objectives**

* To understand current experimentation in the field of molecular biology
* To learn how to read and understand primary publications in molecular biology
* To gain knowledge about microbial genetics
* To explain about the mechanisms of DNA replication
* To explain the mechanism of transcription , translation and RNA processing
* To describe the concept of gene regulation and gene organization in prokaryotes and eukaryotes
* To understand the gene transfer mechanisms

**Course Description**

The course emphasizes the study of DNA replication and repair: Identification of the genetic material, molecular mechanisms of DNA replication , differences in prokaryotic and eukaryotic DNA replication, plasmids, DNA repair mechanisms; transcription and translation: Synthesis of rRNA and tRNA, RNA processing – capping and polyadenylation, genetic code, process of translation, signal sequences and protein transport. It also covers molecular techniques including restriction enzyme digestions, molecular cloning, footprinting, gel-shifts, construction/screening of genomic DNA and cDNA libraries, oligonucleotide synthesis, Southern blotting, northern blotting, western blotting,antibody production, hybrid-select translation, *in vitro* translation, expression systems, reporter genes, yeast two hybrid system, DNA sequencing, PCR, genomics, microarrays, proteomics, bioinformatics, animal transfection and transformation, mammalian cloning, and plant transformation. Concepts of Gene & Gene regulation: Organization of genes in Prokaryotes and Eukaryotes - Operon concept, regulation of gene expression – Transcriptional control, induction and repression, the lactose operon – catabolite repression, tryptophan operon - biosynthesis, translational control, post-transcriptional gene silencing – RNAi; gene transfer mechanisms: transformation, transduction, conjugation, self transmissible and mobilizable plasmids; transposable elements: insertion sequences, complex and compound transposons – T10 , T5, and retroposon, transposons of *E.coli*, bacteriophage and yeast.

**Methods of Course Delivery**

* Lecture method
* Field Visit
* Reviewing related research article and summarizing the content
* Written Assignment
* Presentation
* Group discussion

**Methods of Assessment**

* Final examination (50%)
* Take home examination (15%)
* Seminar (10%)
* Written Assignment (15%)
* Oral Examination (10%)
1. **Course Title: Genomics and Bioinformatics**

**Course Code:** MICR 721

**Credit Hrs: 2**

**Course objectives**

* To familiarize students with most aspects of functional genomics
* To enable students exploit the knowledge of genomics to understand bacterial physiology and pathogenesis so that they can be motivated towards the development of new antibacterials and other biotechnological products
* To enable biological science students without a solid background in computing to gain an understanding of the important concepts underlying bioinformatics together with a thorough grounding in the use of standard computational techniques to analyze biological sequence data

**Course Description**

This course is an introduction to genomics and the use of computers to analyze genomic data. It provides a detailed information about genomics and bioinformatics; principles of genomic characterization and bioinformatic analysis of prokaryotes and eukaryotes, including an overview of analytical platforms, computational tools, experimental design, analysis methods and databases used to study DNA sequence, gene expression and protein levels. Specifically, the course will cover next-generation sequencing, biological databases, sequence alignment, similarity searches, genome browsers, molecular evolution, human disease genetics and proteomics. In the first half of the course students will undertake computer-based practical modules that will provide hands-on experience with the latest on-line genomics and bioinformatics tools. Subsequently, students will choose an elective practical module that provides advanced training in bioinformatics applications in various disciplines. This course is designed to enable biological sciences students without a solid background in computing to gain an understanding of the important concepts underlying bioinformatics together with a thorough grounding in the use of standard computational techniques to analyze biological sequence data.

**Methods of Course Delivery**

* Lecture method
* Reviewing related research article and summarizing the content
* Written Assignment
* Presentation
* Group discussion
* Mini project

**Methods of Assessment**

* Final examination (40%)
* Take home examination (10%)
* Seminar (10%)
* Written Assignment (15%)
* Oral Examination (10%)
* Mini project presentation (15%)
1. **Course Title: Immunotechnology** (E)

**Course Code:** MICR 742

**Credit Hrs: 3**

**Course Objectives**

* To understand the historical perspectives of immunotechnology
* To classify different types of immune responses
* To describe the importance of antigen and antibody molecules
* To understand the concept of MHC molecules and its mode of reaction
* To gain knowledge about vaccines
* To discuss about antibody engineering and hybridoma technology
* To practically known about immunotechniqes
* To learn about immunotechnology and its application
* To familiarize with infectious diseases

**Course Description**

The course begins with the historical perspectives of immunotechnology – discovery, early theories, immunodeficiency conditions, and further describes about lymphocyte traffic, hematopoiesis, innate and adaptive immune response in protection. It also explains the importance of antigen and antibody molecules: antigen engineering for better immunogenicity; use for vaccine development, whole-organism vaccines, recombinant vaccines, DNA vaccines, synthetic peptides, multivalent subunit and anti-idiotype vaccines; antibody engineering, antibody for diagnosis, antibody for therapy, hybridoma technology; MHC molecules, cytokines and complements: structure of MHC molecules, antigen presentation, antigen presentation by non MHC molecules, cytokine structure and their receptors, cytokine therapy, complement proteins, lymphocyte migration and inflammation, hypersensitivity reactions, and auto immunity. Furthermore, the course endeavors to elucidate B and T cell activation: B cell receptor complex, B cell maturation, generation of antibody diversity, understanding self and non-self discrimination, TH cell subpopulation, organization of T cell receptors, cell-mediated responses; immunotechnology and its applications: precipitation techniques, agglutination techniques, radiology in immunotechniqes, Enzyme-Linked Immunosorbent Assay (ELISA), Western blotting, immunofluorescence, flow cytometry and immuno-electron microscopy; infectious diseases - immune system in AIDS, transplantation immunology, cancer and the immune system.

**Methods of Course Delivery**

* Lecture method
* Reviewing related research articles and summarizing the contents
* Reading assignment
* Written assignment
* Presentation
* Group discussion

**Methods of Assessment**

* Final Examination (50%)
* Take home examination (15%)
* Seminar (10%)
* Written assignment (15%)
* Oral Examination (10%)
1. **Course Title: Seminar I**

**Course Code:** MICR 751

**Credit Hrs: 1**

**Course Objectives**:

* To recognize the public understanding of microbiology
* To describe the importance of vaccine development
* To gain knowledge about probiotics and prebiotics
* To discuss about the importance of microbial bioconversion
* To understand the problems and causes of microbial drug resistance

**Course Description**

The focus of this course will be on the public understanding of Microbiology. The issues to be considered will include discussions and debate surrounding vaccine development, microbes as tools of genetic engineering, prospect of gene therapy, significance of microbial biotechnology, bioremediation, development and discussion on the role of probiotics and prebiotics, problems of microbial drug resistance, microbial bioconversion, emerging diseases and other health-, industry-, and agriculture-related issues of public importance. The goal is to examine the communication - understanding gap that exists between scientists and the general public.

**Methods of Course Delivery**

* Presentation
* Group discussion

**Methods of Assessment**

* Oral examination (25%)
* Class presentation (25%)
* Seminar report (50 %)
1. **Course Title: Seminar II**

**Course Code:** MICR 752

**Credit Hrs: 1**

**Course Objectives**

* To familiarize with medical microbiology
* To recognize the importance of dairy microbiology
* To familiarize about food microbiology
* To gain knowledge about soil microbiology and its applications to agriculture

**Course Description**

Students will make extensive review of research articles and present selected topics from any one of the major study areas (sub-disciplines) of the program: Medical Microbiology, Dairy Microbiology, Food Microbiology and Soil Microbiology.

**Methods of Course Delivery**

* Presentations
* Group discussion

**Method of Assessment:**

* Oral examination (25%)
* Class presentation (25%)
* Seminar report (50%)
1. **Course Title: PhD Dissertation**

**Course Code:** MICR 862

**Credit Hrs: 30**

**Course objectives**:

* To generate, document and communicate data on specific problems
* To familiarize and build the capabilities of students in solving problems through scientific investigations

**Course Description**

The goal of this course is to put one’s theoretical knowledge and research proficiency to practical test by carrying out an independent, albeit guided, project producing an original piece of research and making a significant contribution to solving a problem and expanding the knowledge base in the specific discipline. The dissertation should be entirely based on experimental findings in any area and aspect of Microbiology. While research is an ongoing process, in which one is expected to stay on top of the relevant developments in the discipline, the assumption is that students are capable of thinking through the important milestones in the dissertation process and developing a dissertation prospectus that spells out the core concepts and questions as well as the designs of research and the structure of intended dissertation. Designed in a format developed by the School of Graduate Studies, this course is intended to guide students through the formative stages of proposal development to the actual implementation of the proposal in which constant and critical thinking is required. In this process, interaction among the instructor and students is important to transform the latent ideas of students into novel researchable dissertation projects.

**Methods of Course Delivery**

* Review of literature
* Pilot study
* Proposal preparation and defense
* Data generation primarily through experimentation or additionally through the use of other research tools such as questionnaires, interviews, focused group discussion etc.
* Organization and interpretation of data
* Thesis write-up

**Methods of Assessment**

* Progress report
* Review and Approval by Board of Advisors
* Review and Approval by the Department Graduate Council (DGC)
* Open defense examination by Board of Examiners (BoE)
* Review by one or two delegated members of the BoE

**Department of Physics**

Name of the Program: **Ph.D. Program in Environmental and Renewable Energy Physics**

1. **Course Breakdown by Semester**

**Environmental Physics Stream**

For the Environmental Physics stream, the total credit hours required in course work will be 16. Overall credit hours required including seminars and dissertation research makes up to 46.

**Year I; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 751 | Physics principles for Environment | 2 | Core | none |
| EnPhys | 761 | Advanced Environmental Physics | 4 | Core | Phys 566\* & 751 |
| EnREPhys | 741 | Biophysics | 3 | Required |  |
| **Total** |  |  | **9** |  |  |

Phys. 566\* = Environmental physics; M.Sc. level course (for course description see Annex 5, I)

**Year I; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 762\* | Advances in Environmental Physics\* | 4 | Core | EnPhys 761 |
| EnPhys | 742 | Climate dynamics and Environment | 3 | Required |  |
| EnREphys | 722/732 | Modeling and simulation/Instrumentation & meast. | 2 | Elective |  |
| **Total** |  |  | **9** |  |  |

EnPhys 762\* =the two required seminars are implicitly included in this course

**Year II; Semesters I and II: Time for comprehensive exams and proposal development.**

**Year III; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year III; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year IV; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year IV; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| EnPhys | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year I. Other Courses**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Course code** | **Course no.** | **Course Tile** | **Credit hours** | **Course type** |
| EnREPhys | 722 | Modeling and Simulation\* | 2 | Elective |
| EnREPhys | 732 | Instrumentation and Measurement\* | 2 | Elective |
| EnREPhys | 741 | Biophysics\* | 3 | Required |
| EnPhys | 742 | Climate Dynamics and Environment | 3 | Required |

\*= Can be commonly taken by Environmental and Renewable Energy Physics students

**Renewable Energy Physics Stream**

For the Renewable Energy Physics program the total credit hours required in course work will be 18. Overall credit hours required including seminars and dissertation research makes up to 56.

**Year I; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| REPhys | 781 | Physics principles for Renewable Energy  | 2 | Core |  |
| REPhys | 771 | Renewable Energy Physics | 4 | Core | Phys 564\*&751 |
| EnREPhys | 741 | Biophysics\* | 3 | Required |  |
| **Total** |  |  | **9** |  |  |

Phys. 564\* = Renewable energy physics given at M.Sc. level (for course description see Annex 5, II)

**Year I; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Pre-requisite** |
| REPhys. | 772\* | Advances in Renewable Energy Physics | 4 | Core | 771 |
| REPhys | 782 | Semiconductor solar cells | 3 | Required |  |
| EnREPhys | 722/732 | Modeling and simulation/Instrumentation & meast. | 2 | Elective |  |
| **Total** |  |  | **8** |  |  |

REPhys 772\* =the two required seminars are implicitly included in this course

**Year II; Semesters I and II: Time for comprehensive exams and proposal development and defense.**

**Year I. Other courses**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Course code** | **Course no.** | **Course Tile** | **Credit hours** | **Course type** |
| EnREPhys | 722 | Modeling and Simulation\*  | 2 | Elective |
| EnREPhys | 732 | Instrumentation and Measurement\* | 2 | Elective |
| REPhys | 782 | Semiconductor solar cells | 3 | Required |
| EnREPhys | 741 | Biophysics\* | 3 | Required |

**Year III; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| REPhys. | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year III; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of****Course** | **Prerequisite** |
| REPhys. | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year IV; Semester I**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of** **Course** | **Prerequisite** |
| REPhys. | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

**Year IV; Semester II**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Course Code** | **Course No.** | **Course Tile** | **Credit Hours** | **Type of** **Course** | **Prerequisite** |
| REPhys. | 710 | Ph.D. Dissertation Research | 30 | Required |  |
| **Total** |  |  | **30** |  |  |

1. **Course Descriptions**

**Common Core Course for the Two Streams**

**Course title: Physical principles for Energy and Environment (core)**

**Course code: EnREPhys. 751**

**Credit hours: 2**

**Prerequisite: none**

**Course objectives:** This course is designed for students specializing in both Environmental and Renewable Energy Physics. The course tries to give basic physics knowledge that is essential to explain environmental and energy physics problems.

**Course description:** Basic physics theories, Energy transfer, Mass transfer, Momentum transfer mechanisms, Essentials of fluid dynamics and Energy conversion principles

**Course outline**

**1. Basic physics theories**

Stokes law, Bernoulli’s equation, vorticity, potential vorticity, consequences of vorticity conservation, turbulence: turbulent fluctuations, turbulent kinetic energy and Kolmogrov’s turbulence spectrum, turbulent velocity fluctuations, turbulent transport, turbulent viscosity and diffusion, boundary layers, characteristics of boundary layers, logarithmic velocity profile, fluid dynamics, flow near boundaries, flow on large scales, geostrophic approximation, circulation pattern in geostrophic flow, analysis of Navier-Stokes equation, dimensionless numbers, Reynolds number and Reynolds decomposition, boundary layer concept, laminar boundary layer, turbulent boundary layer, viscous boundary layer, Euler Lagrange representation, continuity and incompressible flow, forces in ideal equation, Euler equation, forces in rotating system, Stokes equation, flow separation and large scale flow, flow past a sphere, wakes, friction in pipe flow and lift and drag forces; the Coriolis effect, Coriolis and centrifugal force, horizontal deflection of vertical motion, the Coriolis effect on a rotating planet, Coriolis acceleration, settling of spheres, auto-correlation functions, hydrostatic equation, barotropic and baroclinic conditions, geostrophic motion, geostrophic equilibrium equation, quasi geostrophic equilibrium, Taylor’s theorem, physics of suspended particles.

2. **Energy transfer mechanisms**

**G**as and heat transfer mechanisms between water and air; heat exchange, gas solubility (Henry’s law) and gas exchange (stagnant film model), transfer velocity: dependence on diffusion, Schmidt number, heat circuit analysis, heat transfer mechanisms: conduction, viscosity as diffusion of temperature, convection, free and forced convection, radiative heat transfer, radiative transfer equation, advection, advection diffusion equation, molecular basis of diffusion, mean free path, Fick’s laws, Newton’s law of cooling, radiation exchanges between black surfaces, radiative exchange between grey surfaces, thermal resistance formulation, heat transfer by mass transport, multimode transfer and current analysis; thermodynamic systems, reversible and irreversible processes, equilibrium and non-equilibrium thermodynamics

3. **Mass transfer**

Mass transfer of water and solutes, of atmospheric particles, of water vapor

4. **Momentum transfer**

Fluxes, vertical momentum flux, sensible heat flux, carbon dioxide flux

5. **Energy conversion principles**

Thermodynamic engine cycles**,** direct thermoelectric conversion, magneto hydrodynamic convertor

**Environmental Physics**

**Course title: Advanced Environmental Physics (core)**

**Course code: EnPhys.761**

**Credit hours: 4**

**Prerequisite: Phys. 566 (Environmental Physics) and EnREPhys. 751**

**Course objectives:** This course is designed for students specializing in Environmental Physics and for those who do their dissertation researches in the same stream. The course tries to relate the conceptual knowledge of the students with the underlying physics principles that relate to environmental problems. Such knowledge is imperative for a person who wants to have a deep understanding of the subject, to do practical research or modeling and to make scientific interpretation of the research findings.

**Course description:** Upper Ocean and winds, Environmental Aerosol Physics, Atmospheric Dispersion, Water pollution, Soil pollution, Thermal effects in fluids, Radiation pollution, Sound pollution.

**Course outline:**

1. **Environmental Aerosol and atmospheric scattering**

Properties and sources of aerosols, Size, number, surface area, volume and mass distributions of aerosols, types of aerosols, the role of aerosols in the atmosphere, physics laws as applied to aerosols, settling velocity, mobility and diffusion, residence time, photochemical pollution, aerosol scattering, Lorenz-Mie theory, Rayleigh (dipole) approximation, aerosols and climate change, extinction of radiation passing through the atmosphere

**2. Atmospheric Dispersion**

Derivation of Gaussian plume, solution using Laplace transform, plume properties, emissions from point, line and area sources, time varying sources, height dependent parameters, single source-multiple receptors, multiple source and receptors, time varying unidirectional wind, Pasquill atmospheric stability class, Monin-Obukhov length, Briggs plume rise equation

**3. Fresh water system**

Density, electrical conductivity and ion concentrations; Seasonal stratification and mixing types, ventilation; vertical turbulent diffusivity and mixing dynamics of lakes.

1. **Soil and groundwater**

Porous media, porosity and aquifer types, hydraulic head, matric potential, ground water flow and transport in ground water, capillary tension, Richard’s equation.

1. **The cryosphere**

Cryosphere and hydrology, Glacial dynamics, Mountain glaciers, Sea and lake ice, structure and mass balance of glaciers, ice flow physics, Glen’s law, geometry of glaciers, kinematics of ice flow and age distribution Glacial history

6. **Thermal effects in fluids**

Buoyancy driven convection, the valley wind, buoyant plume from a steady heat source, approximation for small temperature change, selective withdrawal of thermally stratified fluid, the role of water in the atmosphere: interaction processes in the atmosphere, cooling and warming with constant pressure, horizontal mixing, adiabatic expansion or contraction; condensation: effect of curvature and chemical composition, condensation nuclei, accretion, Findeisen effect.

6. **Radiation pollution**

Types of radiations, sources of radiations, radiation physics: radioactive decay, half life, absorption process, Fraunhofer absorption lines, radiation interaction with matter, radiation from point sources, radiation from line sources, radiation from area sources

7. **Sound pollution**

The physics of sound, high, low and infra sounds, sound and atmospheric condition, thermal effects, ground effects, wind effects, noise pollution calculation, types of sound sources- point, line and plane sources, sound fields and directivity index, types of noise, noise reduction, guidelines for community noise.

**Mode of instruction:** The course is offered in lecture form with real life illustrative examples, pictures, figures and tables obtained from journal articles, reliable internet sources, etc. Instructor/s of the course can follow their modes of instruction that they may find more educative.

**Assessment:** A student may be given two or three topics from the chapters learned and asked to summarize and present important points in about 15 minutes (30%). At the end four to five general questions are given which the students are required to work on and submit within specific days. Instructor/s can also follow their preferred assessment methods.

**References:**

* Boeker, E., 1999. *Environmental Physics*, 2nd ed. John Wiley and Sons, England.
* Gnyot, G., 1998. *Physics of the Environment and Climate,* Praxis, England.

**Course title: Advances in Environmental Physics (core)**

**Course code: EnPhys.762**

**Credit hours: 4**

**Prerequisite: EnPhys.761**

**Course objectives:** This course is designed to enable the student to be an independent worker and thinker. Out of cutting edge issues concerning the environment the student is given (by the instructor) one theme on which to focus during a particular week. The student has to find at least four to five articles written in the specific area, read and understand the articles, summarize important concepts and compile them. The student is required to present the summary of the findings in ten minutes presentation every other week followed by a discussion. This gives the student a chance to read at least fifty articles during the semester, for the course. Besides, the student will develop the skill of reading articles, sifting and compiling the information. The biweekly ten-minute presentation would help the student build confidence to organize presentations, ask and answer questions.

**Course theme:** The theme may include: Air pollution; sound pollution; thermal pollution; surface water pollution; (lakes; rivers; manmade reservoirs); groundwater pollution; soil contaminants; urban liquid wastes; urban solid wastes, hazardous wastes; radioactive wastes; agricultural wastes: sources, modes of transfer, mathematical models governing their movement, mechanisms of measurements and mechanisms of control. The readings are on the latest findings in these areas to find new ways of tackling the challenges, and be aware of new technologies, models and approaches.

**Assessment:** During presentation the following points are considered for successive evaluation.

1. List of articles the student has read is compiled in the form they are listed, hard copied and given to the instructor/s so that the instructor/s can check the relevance of the articles to the given title.
2. How the information in the articles are organized for the presentation is checked based on sequence, summary, similarities/differences of the opinions of different authors on the subject and in relation to the point under discussion**.**
3. Ability of the student to present and answer questions by relating what s/he has read and understood.
4. Final conclusion drawn from the work.

Points are collected during each presentation and finally added for final grading.

Such independent work enables the student to get experience in how to get relevant information from articles, relate and discuss on different views based on articles written by different authors, learn on how research ideas could be developed from others’ works and get experience in reading, compiling and sorting information for presentation. Since the areas of these readings are related to the future research area on which the student is planning to do research, the articles help very much in literature review and for developing objectives and methodologies. The biweekly presentation develops the student’s ability to speak in front of people and to answer questions. Hence, the student can build confidence for seminar presentation, proposal and dissertation defenses.

**Textbook:** There is no text book for this course. The student is given a specific area on which to focus during one week during which the student is expected to fetch lists of journal articles pertinent to the area, get concepts of the author/s, summarize and makes his/her own notes. This being an independent work, the student meets with the instructor and other students of the same area and presents his/her work of the four or five articles s/he read biweekly. During the presentation discussion is made with the instructor and with other students (if any). This process repeats every other week for the entire semester. The student is evaluated as mentioned before.

**Course title: Modeling and Simulation (elective)**

**Course code: EnREPhys.722**

**Credit hours: 2**

**Prerequisite: none**

**Course objectives:** This course is intended to give basic understanding on modeling (to help those students who intend to do their research in modeling) and, instrumentation and measurement (for students who intend to do their research by experiment). After taking this course students will have better ideas on their research works and the pitfalls they have to avoid.

**Course description:** Mathematical modeling, Model tools, Modeling examples, Instrumentation, aerosols mass measurement, radiation measurements, sound measurement, physical water quality measurement, multipurpose, Important points in instrumentation, Measurement techniques, Data analysis

**Course outline:**

**1. Mathematical modeling**

Modeling definition, model types: empirical/statistical, conceptual (lumped parameters), process (physics) based; concepts of modeling (conceptual and physical), systems, models, simulations, model tasks, model classifications (empirical, mechanistic), general linear model, stationary and non-stationary models, distributed and lumped models, dynamical model, stochastic and deterministic models, stochastic optimization, model calibration, validation and testing, steps in model building, non-dimensionalization, making assumptions, flow diagrams, choosing mathematical equation, solving the equation analytically and numerically, studying models, roles of experimental and numerical data, state variables and parameters, accuracy, precision and interpretation of results, uses and objectives of environmental models

2. **Model tools**

Difference equations, differential equations, integral equations, algebraic equations

**For environmental physics students**

1. **Common features of environmental systems**

Complex nonlinear interactions, heterogeneity of system features, incompatible scales, inaccessible or unobservable system processes

1. **Types of environmental systems**

Hydrological systems: surface water systems, subsurface water systems, coastal systems;

Climate systems: oceans, atmosphere, land surface

5. **Modeling examples**

1. Fundamentals of isotope methods

Stable and radioactive isotopes, fractionation and physical origin, equilibrium and kinetic fractionation, reaction kinetics, the Reyleigh process,

1. Isotopes and tracers in environmental physics

Stable isotope in the water cycle, stable isotopes in paleo-thermometer, radioisotopes as tracers and dating tools, 14C: calibration of the age scale and applications.

1. Model concepts: box models

Types of models, motivation for models, environmental system analysis, linear 1 box model: constant and variable input.

1. Lumped parameter models

Transit time distribution, higher order linear models, characteristics of solutions

1. Continuous model, numerical and inversion techniques

Continuous models, discretization and numerical solution, climate modeling, inverse problem and parameters estimation, prior knowledge, Bayesian approach

1. **Climate modeling**

Energy balance climate modeling, theory of energy balance climate model, Budyko-Sellers climate model, zero dimensional climate model, 1D climate model, Jormungand model, modeling climate dynamically, paleoclimate modeling

1. **Parameterization**

Definition, need for parameterizations, major parameterizations in models: convective parameterization, cloud parameterization, radiation parameterization, planetary boundary layer, surface layer, effects of clouds, effects of vegetation, effects of soil type, effects of soil moisture; physical parameterization: radiative transfer, convection, clouds, surface fluxes, Monin-Obukhov theory for drag coefficient

Air dispersion modeling, modeling environmental systems, modeling traffic flow, modeling pollutant transport, FEFELOW model (for water flow and solution transport in soils), ADR and TRM models, nonpoint source pollution models, turbulence modeling, CORMIX (for hydrodynamic modeling and diffusion tests); Urban noise pollution modeling (using e.g. sooundPLAN)

**For renewable energy physics students**

1. **Renewable energy modeling tools**

Design options for off-grid and on-grid connected power systems, study of long-term performance of hybrid power systems, estimation of electricity produced with PV array, estimation of electricity produced with small wind turbines, calculation and analysis of solar radiation data, evaluation of energy production, life-cycle costs and greenhouse gas emissions reductions for PV application.

1. **GIS planning and modeling for renewable energy**

Challenges, future research avenues

**Course title: Instrumentation and Measurements (elective)**

**Course code: EnREPhys.732**

**Credit hours: 2**

**Prerequisite: none**

1. A**erosols mass measurement**

Piezoelectric mass monitor, micro-balance, light scattering, aerosol photometer (nephelometer),

For size distribution: optical particle counter, electrostatic classifier, diffusion batteries

For number concentration measurement: condensation nucleus counters, aerosol electrometers

1. **Measurement methods of environmental physics**

Radiometry, mass spectroscopy, spectroscopy (CRDS, DOAS), Eddy covariance measurements, gas chromatography, geophysical and other methods.

3. for **radiation measurements**

Portable dosimeters, electronic survey meter, radon measurement, scintillation counter, GM, PIC, TLDs, spectroscopy, etc.

4. for **sound measurement**

Microphone, sound level meter, frequency analyzer, noise dosimeter, personal sound level meters, recorders, and the use of Matlab to study sound spectrum

5. for **physical water quality measurement**

PH meter, electrical conductivity meter, turbidimeter, thermometer;

Solar radiation measurement tools, wind speed and wind direction measurement, fluid flow measurement, etc.

6. **Important points in instrumentation**

Calibrations, measurements and uncertainty

7. **Measurement techniques**

Real time *(in situ)* measurement, different types of sampling, continuous measurement or grab sampling, iso-kinetic sampling; frequency measurement

8. **Data analysis**

Different types of statistical methods, regression, use of graphs and tables illustrated with real examples.

**Mode of instruction:** The course is offered in lecture or in interactive form with real life illustrative examples, pictures, figures and tables obtained from journal articles, reliable internet sources, etc. Instructor/s of the course can follow their modes of instruction that they may find more educative.

**Assessment:** A student may be given assignments on models or specific instruments. Formal exams can also be given. Instructor/s can also follow their preferred assessment methods.

**References**

* Bellomo, N., De Angelis, E. and Delitala, M. 2007. *Lecture Notes on Mathematical Modeling in Applied Sciences*, Italy
* Pfotenhauer, J.M., *Instrumentation and measurement techniques*, Madison, Wisconsin

**Course title: Climate dynamics and Environment (required)**

**Course code: EnPhys.742**

**Credit hours: 3**

**Prerequisite: none**

**Course objectives:** The purpose of this course is to illustrate how natural forces affect climate and their impacts on the environment. At the end of the course students will know the physical aspects of atmospheric and oceanic circulations and how anthropogenic contributions have impact on these two major forces that maintain dynamic equilibrium of our planet.

**Course description:** Relation between climate dynamics and environment, Climate sensitivity and feedback, Cryosphere and their impacts, Climate reconstruction, Natural environmental cycles, Atmospheric circulation, Oceanic circulation and Ekman theory,

**Course outline**

1. **Climate**

The carbon cycle: carbon dioxide observations and the global carbon cycle (reservoirs and fluxes), carbonate and carbon in the ocean, methane observations, sources and sinks, Climate parameters: air temperature, ground temperature, relative humidity and solar radiation, degree day concept, climate parameters and drought; future ozone level, tropospheric water vapor, local climates, plate tectonics and climate change, climate changes versus agriculture and forests, climate predictions and agriculture, projected changes in future climates, temperature projection, sea level rise, erosion, land slide and precipitation variability, climate analogues

1. **Climate sensitivity and feedback**

Climate sensitivity, sea level and atmospheric carbon dioxide, Climate sensitivity estimated from Earth climate history, Climate sensitivity from temperature reconstruction, Equilibrium sensitivity of Earth’s temperature to radiation changes, Climate sensitivity and response, Radiative forcing and changes in temperature, Methods of relating climate sensitivity and climate sensitivity traced to atmospheric convective mixing, Heat capacity and response time, climate predictions, projections of future climate change: climate forcing and climate response, simulating forced climate change, factors contributing to the response, change in variability, change in extreme events, global mean changes, likely to very likely changes, temperature indicators, hydrological indicators.

1. **Climate variability and Paleoclimate reconstruction**

Variability in climate, natural modes of short-term climate variability (North Atlantic Oscillation (NAO), El-Nino and southern oscillations (ENSA)), long-term climate variability and abrupt changes, Paleoclimate index reconstruction, Paleoclimate variability and extreme events, Holocene climate variability, proxies

**4. Natural environmental cycles**

Milankovitch theory: orbital parameters, obliquity, precession, eccentricity, global cycles of ice ages

**5. Global atmospheric circulation**

Energetics of atmospheric circulation, available potential energy, the role of available potential energy in the atmosphere, Lorenz’s concept of available potential energy, Budget of available potential energy, Generation and release of available potential energy, kinetic energy cycles in the atmosphere, local kinetic energy cycle, partitioning of the kinetic energy cycle, angular momentum and LOD, variations under climate warming, temperature gradient as driver of the circulation, Hadley circulation, convergent and divergent circulation, seasonal variation in global pressure, the effects of seasonal wind migration, longitudinal differences in winds, upper air winds and jet stream Rossby waves, distribution of highs, lows and winds, vertical structure functions, advective diffusive balance, Lorenz’s concept of available potential energy, potential energy budget, generation and release of available potential energy, role of available potential energy, kinetic energy cycle in the atmosphere**,** local kinetic energy cycle, partitioning of the kinetic energy cycle, local circulation, turbulent mixing, atmospheric oscillations, variation in pressure, global pattern of atmospheric pressure, sub-global surface winds, , local winds, monsoon winds, El Nino, NAO, variation of atmospheric angular momentum and its relation to ENSO years and LOD, angular momentum cycle in atmosphere, ocean and solid earth, angular momentum exchange between tropics and mid-latitudes

6. **Oceanic circulation and Ekman Transport**

Wind driven circulation, inertial motion, thermohaline processes, energetics of oceanic circulation, ocean currents, horizontal convection, mixing in stratified fluid, Atlantic meridional overturningcirculation,Ekman’s classic theory, Ekman layer and Sverdrup theory, Ekman layer transport, Ekman pumping and the Sverdrup balance, Coastal upwelling, Case studies of Ekman currents

**Course title: Biophysics (required)**

**Course code: EnREPhys. 741**

**Credit hours: 3**

**Prerequisite: none**

**Course objectives:** This course is designed for students specializing in both Environmental and Renewable Energy Physics. Students specializing in both areas require knowledge of biological systems and the underlying physics as it applies to these biological systems. This is especially important when the students carry out their dissertation researches.

**Course description:** Thermodynamics properties of biomolecules, Intermolecular forces and bonds, Molecular structures, Biophysical principles, Biophysics of colloidal systems, Biophysics of membranes, Physical principles of flows in bio-systems, Light and bio-organisms, Photosynthetic processes, Use of radioisotopes

**Course outline:**

**1. Thermodynamics properties of biomolecules**

 Systems, equilibrium states, enthalpy, entropy, Gibbs free energy, work done in biological systems

2. **Intermolecular forces and bonds**

Atomic orbitals, bond energy, strong and weak bonds, the H-bond in living things

3. **Molecular structures**

Carbohydrates, fats, proteins and nucleic acids, self assembly, primary, secondary and tertiary structures of macromolecules, photon induced molecular energy transfer and energy transformation, thermal molecular movement, distribution of molecular energy and velocity at equilibrium

4. **Biophysical principles**

Biophysical transport mechanisms, passive and active transports

**5. Biophysics of colloidal systems**

Sol and gel states, colloids and electrical double layer, forces between colloidal particles, energy of colloids, colloids in bio-systems

6. **Biophysics of membranes**

Membrane structure, membrane lipids and proteins, dynamic properties of membrane, membrane permeability and transport through membranes

7. **Physical principles of flows in bio-systems**

Flow pressure, viscosity, flow resistance, laminar and turbulent flow, flow in living organisms

8. **Light and bio-organisms**

The electromagnetic theory, effect of light on organisms, photosynthesis, photosensitization, photoperiodism, phototropism, photo-movement,

**9. Photosynthetic processes (PSP)**

Trophic level PS, plant level PSP, absorption of light, structure of leaves, photo-physics, molecular level PS, thermodynamic considerations, light and dark reactions, applied PS, natural and artificial photosynthesis, leaf and plant canopies, radiation flux in natural environments, precipitation and living things, effects of acid rain and isotopes in precipitation,

**Mode of instruction:** The course is offered in lecture form with real life illustrative examples, pictures, figures and tables obtained from journal articles, reliable internet sources, etc.Instructor/s of the course can follow their modes of instruction that they may find more educative.

**Assessment:** A student may be given two or three topics from the chapters learned and asked to summarize and present important points in about 15 minutes (30%). At the end four to five general questions are given which the students are required to work on and submit within specific days. Instructor/s can also follow their preferred assessment methods.

**References:**

* Glaser, R. 2001. *Biophysics,* Springer-Verlag, Berlin.
* Campbell, G. S. and Norman J. M., 1998. *An Introduction to Environmental Biophysics*, 2nd ed. Springer-Verlag, NY Inc.
* Amente, G. 2015. *Textbook of biophysics with principles of biophysical measurements*. AAU Press. Addis Ababa, Ethiopia.

**Renewable Energy Physics**

**Course title: Renewable Energy Physics (core)**

**Course code: REPhys.771**

**Credit hours: 4**

**Prerequisite: Phys. 564 (Renewable energy physics) and EnREphys751**

**Course objectives:** The purpose of this course is to enable students specializing in Renewable Energy Physics the basic understanding of the physics behind renewable energy sources and how the energy is stored. In addition, current developments in the areas of fuel cells and other alternative energy sources are also illustrated. After taking this course students can design, fabricate and study performances of different energy sources or do research on how to improve the performances of existing devices.

**Course description:** Energy from fossil fuels, solar thermal application, Photovoltaics, Wind energy, Principles of hydropower energy, geothermal energy, Fuel cells, Energy Storage Systems, Electricity generation systems

**1. Energy from fossil fuels**

Coal production and its conversion processes, exploration, mining, preparation, storage, transportation and conversion, environmental problems associated with coal; petroleum and natural gas: formation, exploration, and their conversions into energy, environmental problems associated with petroleum and natural gas

2. **Solar thermal application**

Geometry of solar collectors, solar concentrators, solar up-drift power, generation of electricity using solar thermal energy

**3. Photovoltaics**

Physics of p-n junctions, circuit characteristics, different types of solar cells: silicon, polycrystalline, nano, multifunction cell, plastic sheet PV, 3D solar cell, concentrated PV; thin film solar cells, third generation concepts; maximizing efficiency types and adaption of PVs, PV circuit properties, application and systems

**4. Wind energy**:

Wind speed distribution, short and long-term fluctuations, diurnal, seasonal and annual patterns, distribution of wind direction, wind shear, linear momentum and basic theory of wind power, wind speed analysis, probability and prediction, Weibull and Rayleigh distributions, wind speed and direction variation with time, power extraction and energy yield, propeller type convertors, turbine types and technologies, concentrated wind, blade tip wind turbine, high altitude wind power, wind belt, up-wind and down-wind devices, power extraction by a turbine, blade element theory, drag and lift forces in wind turbines, solidity, thrust and axial forces, drag mechanisms, dynamic matching, wind farm efficiency and the wake effect

5. **Principles of hydropower energy**

Principles, requirements for hydropower flow driven convertors, turbine types and the physics behind the different turbines, free stream flow turbines, jet velocity, nozzle size, hydroelectric barrel, challenges of hydropower

6. **Geothermal energy**

Geophysics, dry rock and hot aquifer analysis, harnessing geothermal resources, extraction techniques, thermodynamic principles of geothermal energy

7. **Nuclear Energy**

Principles of nuclear power, from mining to nuclear fuel, nuclear waste management

8. **Fuel cells**

Fuel cell types, proton exchange membrane (PEM), regenerative fuel cell, fuel cell development

9. **Energy Storage Systems**

Biological storage, chemical storage, heat storage, electrical storage, mechanical storage, the physics behind every energy storage mechanisms, high quality energy storage, superconducting magnetic energy storage (SMES), pumped hydro-storage, compressed air storage, etc.

1. **Electricity generation systems**

Photochemical electricity production; biomass and biofuels, biofuel classification, biomass for energy farming, pyrolysis, thermo chemical processes

1. **Energy Resource Assessment**

Spatial mapping of potential renewable energy resources, spatial mapping of environmental/ social/technical constraints, methodology to each resource assessment

**Mode of instruction:** The course is offered in lecture form with real life illustrative examples, pictures, figures and tables obtained from journal articles, reliable internet sources, etc. Instructor/s of the course can follow their modes of instruction that they may find more educative.

**Assessment:** A student may be given two or three topics from the chapters learned and asked to summarize and present important points in about 15 minutes (30%). At the end four to five general questions are given which the students are required to work on and submit within specific days. Instructor/s can also follow their preferred assessment methods.

**References**

* John Twidell and Tony Weir, 2006. *Renewable energy resources*, 2nd Ed. Tyler and Francis, London, NY.
* Sorenson, B. 2007.*Energy conversion, transmission and storage*, Academic Press.
* Klaus, J., Olindo, I., Arno, H. M. S., Rene, A. C. M. M. and Miro, Z. 2014. *Solar Energy fundamentals, technology and systems*. Delft University of Technology.

**Course title: Advances in Renewable Energy Physics (core)**

**Course code: REPhys.772**

**Credit hours: 4**

**Prerequisite:REPhys.771**

**Course objectives:** (Ref. EnPhys 762)

**Course theme:** the theme may include: Latest energy researches and their findings on fuel cells, batteries, nanotechnologies, solar photovoltaics, magneto hydrodynamics, and the like. The readings are on the latest findings in these areas to find new ways of tackling the challenges, and to be familiar with the new technologies, models and approaches.

**Mode of instruction:** (Ref. EnPhys 762)

**Assessment:** (Ref. EnPhys 762)

**Textbook:** (Ref. EnPhys 762)

**Course title: Semiconductor Solar PVs (required)**

**Course code: REPhys.782**

**Credit hours: 3**

**Prerequisite: none**

**Course objectives:** The purpose of this course is to give in-depth knowledge about the latest solar PVs and the science associated with them. It discusses the properties, device equations, principles, I-V characteristics and materials efficiencies among others.

**Course outline:** Basic semiconductor physics,PV fundamentals, Semiconductor properties, Equations of semiconductor devices, Solar cell working principles, solar cell I-V characteristics, Solar cell materials and their efficiencies, Solar cell construction, Types and adaptations of PVs, Third generation concepts, Components of PV, Location issues

**Course description:**

1. **Basic semiconductor physics**

Atomic structure, intrinsic semiconductors, doping, donors and acceptors, carriers concentrations, band gaps, transport properties, generation and recombination of carriers, carrier concentration in non-equilibrium semiconductor junctions

1. **PV fundamentals**

EM theory, EM waves, optics in flat interfaces, optics in absorptive media, Continuity equation, Poisson equation, current density equation

1. **Semiconductor junctions**

Electrons and holes, p-n homojunctions, effect of bias voltage, lifetime of excess minority carriers, junction current, Shockley equation, p-n heterojunctions, metal semiconductor junctions

1. **Solar cell I-V characteristics**

PV circuit properties, solar cell parameters and equivalent circuit,

1. **Solar cell types**

Crystalline silicon solar cells (c-Si), thin film solar cells: Transparent conducting oxides, III-V PV technology. Chaleogenide solar cells, organic PVs, hybrid organic-inorganic solar cells, Tandem solar cells

1. **Solar cell construction**

Fabricating solar cells, module fabrication, antireflection coating

1. **Third generation concepts**

Multi-junction solar cells, multi-exciton generation, intermediate band solar cells, hot carrier solar cells

1. **Components of PV**

PV modules, maximum power point tracking, PV convertors, controllers, batteries, wiring, appliances, system sizing and maintenance

1. **Location issues**

Position of Sun, sun path, equation of time, irradiance on TV module, direct and diffuse irradiance, shadowing

**Mode of instruction:** The course is offered in lecture form with real life illustrative examples, pictures, figures and tables obtained from journal articles, reliable internet sources, etc. Instructor/s of the course can follow their modes of instruction that they may find more educative.

**Assessment:** A student may be given assignments or asked to write paper on certain topics. Formal exams can also be given. Instructor/s can also follow their preferred assessment methods.

**References:**

* Klaus, J., Olindo, I., Arno, H. M.S., Rene, A. C. M. M. and Miro, Z. 2014. *Solar Energy, Fundamentals, Technology and Systems.* Delft University of Technology, the Netherlands
* Chen, C. J. 2011. *Physics of Solar Energy*, John Wiley and Sons, Inc. New Jersey.

**Department of Chemistry**

Program Name: **DOCTOR OF PHILOSOPHY IN CHEMISTRY” (MATERIALS CHEMISTRY)**

* + 1. **Course Breakdown by Semester**

**Year I Sem I**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | Inorganic Materials Chemistry  | Chem 752 | 2  |  |
|  | Nanomaterials | Chem 753 | 2 |  |
|  | Polymer Chemistry  | Chem 755 | 2 |  |
|  | Physical Methods in Materials Chemistry  | Chem 754 | 2 +1 |  |
|  | **Total** | **9** |  |

**Year I Sem II**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | Elective Course I | Chem xxx | 2 |  |
|  | Current Topics in Materials Chemistry I | Chem 757 | 1  |  |
|  | Seminar on Advanced Materials I | Chem 758 | 1  |  |
|  | Surface Chemistry and Catalysis  | Chem 756 | 2  |  |
|  | **Total** | **6** |  |

**Year II Sem I**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | Current Topics in Materials Chemistry II  | Chem 857 | 1  |  |
|  | Seminar on Advanced Materials II  | Chem 858 | 1 |  |
|  | Elective course II | Chem xxx | 2 |  |
|  | **Total** | 5 |  |

**Year II Sem II**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | PhD Dissertation (Proposal Writing and defense) | Chem 950 | 30 |  |
|  | **Total** | 30 |  |

**Year III Sem I**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | PhD Dissertation  | Chem 950 | 30 |  |
|  | **Total** | 30 |  |

**Year III Sem II**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | PhD Dissertation  | Chem 950 | 30 |  |
|  | **Total** | 30 |  |

**Year IV Sem I**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | PhD Dissertation  | Chem 950 | 30 |  |
|  | **Total** | 30 |  |

**Year IV Sem II**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Course Title** | **Course Code** | **Cr. hr** | **Remark** |
|  | PhD Dissertation  | Chem 950 | 30 |  |
|  | **Total** | 30 |  |

* + 1. **Course Descriptions**

**Inorganic Materials Chemistry (Chem. 752) 2 Cr.hr**

Inorganic materials chemistry covers the following topics: Structure and bonding properties of materials at the atomic, molecular, or extended structures (amorphous, crystalline and hybrid solids) and their relationship to desired properties; Chemical synthesis, processing, characterization, and applications of inorganic materials. Molecular precursor routes to inorganic solids. Some specific topics to be covered will include molecular orbital theory and band structure of solids. Carbon-based materials (graphene, fullerenes, diamond), ceramics and zeolites, semiconductors, electronic, magnetic, and optical materials, and materials for energy production and storage (ionic conductors, and mixed electronic/ionic conductors), superconductors

**Polymer Chemistry (Chem. 753) 2 Cr. hr**

This is an advanced level course in modern organic materials chemistry. Emphasis will be placed on the design, synthesis, properties and applications of materials that are useful in the design of optoelectronic devices, such as light emitting diodes (LEDs) and liquid crystal displays (LCDs). Topics to be discussed will include conjugated polymers/semiconducting polymers, liquid crystals, molecular devices, self-assembled systems, bio-conjugates and the assembly of thin film materials as well as recent advances from the literature.

**Physical Methods in Materials Chemistry (Chem. 754) 2+1 Cr. hr**

This course will provide a comprehensive overview of the most important and state of the art methods used in the characterization of materials.  The techniques covered include physical and spectroscopic methods of characterization, highlighting approaches to their use to define important attributes of the atomic, compositional/chemical, and mesoscopic, physical morphological features of materials. The topics to be covered will include: Overview of protocols and probes used in materials characterization; Surface Analysis:  X-ray Photoelectron Spectroscopy (XPS); Auger Electron Spectroscopy (AES); Principles of Microscopy: Scanned Probe Methods: STM and AFM; Electron Microscopy - Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Scanning Transmission Electron Microscopy (STEM); Diffraction Methods: X-ray Diffraction (XRD); Electron Diffraction; Optical and Spectroscopic Methods: X-ray Absorption Spectroscopy; Photoluminescence ; Mass Spectroscopy; Thermal Methods

**Surface Chemistry and Catalysis (Chem. 756) 2 Cr. hr**

Adsorption phenonmena and isotherms; surface areas of solids, solubulization and surfactant action, adhesion and cohesion, nucleation and crystal growth, gel formation, techniques in surface chemistry and surface science. Auger electron spectroscopy, photoelectron spectroscopy, IR and Raman spectroscopy, Colloidal systems, Catalysis

**Current Topics in Materials Chemistry I (Chem. 757) 1 Cr. hr**

Electronic and Magnetic Materials: This will encompass the relationship between the chemistry and the electronic and/or magnetic properties of inorganic, molecular, hybrid and nano materials using both experimental and computational/theoretical approaches. Energy Materials: Encompassing all aspects of Materials Chemistry related to energy conversion, storage and fuel generation; Nanomaterials Chemistry: Encompassing synthesis, characterisation and application of materials whose functionality depends on their nanoscale dimensions.

**Current Topics in Materials Chemistry II (Chem. 857) 1 Cr. hr**

Topics in this course will focus but not limited to Porous Materials: This will encompass the chemistry and properties of porous materials for sorption, storage and separation; Soft Matter Materials Chemistry: Including wide and varied aspects of soft matter materials showing the power of the interplay between a priori design and physical function; Biomaterials Chemistry: Encompassing biomaterials for tissue engineering, biomaterials for healthcare, green biomaterials and advanced synthesis methods of biomaterials

**Seminar on Advanced materials I (Chem. 758) 1 Cr. hr**

This is an independent study on topics of current/recent interest in advanced materials. The topics include but not limited to the following: Molecular and nanoelectronics; Computational approach to materials design and property prediction.

**Seminar on Advanced materials II (Chem. 858) 1 Cr. hr**

Topics of interest include but not limited to advanced materials applicable to energy, sensor, environment, drug delivery and agriculture.

**Computational Materials Chemistry (Chem. 847) 2 Cr.hr**

Topics to be covered include: Classical and quantum mechanics: From Newton to Hamilton to Schrödinger; The Schrödinger equation. Motivation from classical wave equation; correspondence principle; Properties of the wavefunction. Born interpretation; Postulates of quantum mechanics; Mathematical background (Operators, eigenvalue problems, Hermiticity, orthonormality); The variation principle; Wavefunctions for multielectron systems. Pauli principle and antisymmetry; fermions and bosons. Slater determinants; The molecular Schrödinger equation; Separation of nuclear and electronic motion; Born–Oppenheimer approximation. Potential energy surfaces; Self-consistent field method, Hartree–Fock theory; Electron correlation. Approximate methods beyond Hartree–Fock; Density-functional theory.

**Photochemistry (Chem. 845) 2 Cr.hr**

Absorption, excited states, fluorescence, phosphorescence, vibronic coupling, relaxation phenomena, solvent effects. Electron and energy transfer, isomerisation and dissociation reactions. Norrish type I and II reactions, potential energy surfaces, conical intersections. The solar spectrum, antennas, reaction centres, photoprocesses in organic, inorganic, and sensitized solar cells. Excitons, polarons, solitons, semiconductor junctions, photocurrent and photovoltage, quantum efficiencies. Photocatalysis, photodamage and repair, DNA, photodynamic therapy. Atmospheric chemistry, reaction dynamics, metal complexes, higher spin states, applied photochemistry

**Electrochemical Methods (Chem. 846) 2 Cr.hr**

This in-depth course covers advances in: Thermodynamics and potential, electrode kinetics. Potential step and potential sweep methods including hydrodynamic methods. Bulk electrolysis methods. Electrode reactions coupled with homogeneous chemical reactions. Double layer structure and adsorbed intermediates in electrode processes. Digital simulation of electrochemical processes. Scanning probe techniques and spectroelectrochemistry.

**Chemometrics (Chem. 811) 2 Cr.hr**

Introduction; Statistics of repeated measurements; Significant measurements; The quality of analytical measurements; Caliberation methods in instrumental analysis (Regression and correlation); Non-parametric and robust methods; Experimental design and optimization; Multivariant analysis

**Phytochemicals and Biopesticides (Chem. 854) 2 Cr hr**

Advanced treatment on the following topics will be considered. Phytochemical pesticides and their synthetic analogues; Ethnobotanicals of pesticidal importance in Ethiopia; Other bioactive natural products chemicals; Chemistry of insect repellents, attractants, antecedents and hormones herbicide chemistry.

**Agrochemical Technology (Chem. 852) 2 cr hr**

Advanced treatment on the following topics will be covered. Survey of (minor and major) plant nutrients in soil; soil fertility evaluation History of soil fertilization; Nature, purpose and function of fertilizers; Fertilizer-soil-plant relationship; Nitrogen fertilizers, nitrates, cyanamide, ammonia and its synthesis, ammonium based fertilizers; Urea; Phosphorus fertilizers; minor sources; phosphate rock; mining and processing for fertilizer production; single superphosphate fertilizers; phosphoric acid manufacture; Ammonium phosphate; Nitrogen phosphorus compound fertilizers; Potassium fertilizers; mining and proceeding of potash; trace elements in fertilizers; compound fertilizers and granulation including methods of manufacturing dry mixture of compounds (NPK): Liquid fertilizers; Organic fertilizers; slow release fertilizers; composting and compost utilization; pesticide (insecticides, herbicides, fungicides, nematicides, etc) formulation; controlled released formulations and methods; application equipment and methods; the Agrochemical R and D process (targeting, synthesis, screening, evaluation, development, post-sales technical support); Product Safety.

**Biomaterials (Biom. XXX) Cr. hr 2**

Overview of biomaterials; Structure and properties of materials; Metals; Ceramics; Synthetic polymers; Biopolymers; Tissue grafts; Cardiovascular implants and extracorporeal devices; Biomaterials in ophthalmology; Orthopedic implants; Dental materials

**References:** [**Qizhi Chen**](https://www.amazon.com/Qizhi-Chen/e/B00O4NFHAW/ref%3Ddp_byline_cont_book_1) **,** [**George Thouas**](https://www.amazon.com/George-Thouas/e/B00OB57PY4/ref%3Ddp_byline_cont_book_2) **Biomaterials: A Basic Introduction, 1st Edition, 2002**