DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 1: BIOPHYSICS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
Biophysics DSE – 1	**4**	**4**	**0**	**0**	--

LEARNING OBJECTIVES

This course familiarizes the students with the basic facts and ideas of biology from a quantitative perspective. It shows them how ideas and methods of physics enrich our understanding of biological systems at diverse length and time scales. The course also gives them a flavour of the interface between biology, chemistry, physics and mathematics.

LEARNING OUTCOMES

After completing this course, students will

- Know basic facts about biological systems, including single cells, multicellular organisms and ecosystems from a quantitative perspective.
- Gain familiarity with various biological processes at different length and time scales, including molecular processes, organism level processes and evolution.
- Be able to apply the principles of physics from areas such as mechanics, electricity and magnetism, thermodynamics, statistical mechanics, and dynamical systems to understand certain living processes.
- Get exposure to complexity of life at i) the level of cell, ii) level of multi cellular organism and iii) at macroscopic system – ecosystem and biosphere.
- Gain a systems level perspective on organisms and appreciate how networks of interactions of many components give rise to complex behaviour.
- Perform mathematical and computational modelling of certain aspects of living systems.
- Get exposure to models of evolution.

SYLLABUS OF DSE – 1

THEORY COMPONENT

Unit – I **(4 Hours)**

Overview: The boundary, interior and exterior environment of living cells. Processes: exchange of matter and energy with environment, metabolism, maintenance, reproduction, evolution. Self-replication as a distinct property of biological systems. Time scales and spatial scales.

Unit - II **(16 Hours)**

Molecules of life: Metabolites, proteins and nucleic acids. Their sizes, types and roles in structures and processes. Transport, energy storage, membrane formation, catalysis, replication, transcription, translation, signaling. Typical populations of molecules of various types present in cells, their rates of production and turnover. Energy required to make a bacterial cell. Simplified mathematical models of transcription and translation, small genetic circuits and signaling pathways to be studied analytically and computationally.

Unit - III **(16 Hours)**
Molecular motion in cells: Random walks and applications to biology: Diffusion; models of macromolecules. Molecular motors: Transport along microtubules. Flagellar motion: bacterial chemotaxis. Mechanical, entropic and chemical forces.

Unit - IV **(16 Hours)**
The complexity of life: At the level of a cell: Metabolic, regulatory and signaling networks in cells. Dynamics of metabolic networks; the stoichiometric matrix. The implausibility of life based on a simplified probability estimate, and the origin of life problem. At the level of a multicellular organism: Numbers and types of cells in multicellular organisms. Cellular differentiation and development. Brain structure: neurons and neural networks. At the level of an ecosystem and the biosphere: Foodwebs. Feedback cycles and self-sustaining ecosystems. Allometric scaling laws.

Unit - V **(8 Hours)**
Evolution: The mechanism of evolution: variation at the molecular level, selection at the level of the organism. Models of evolution. The concept of genotype-phenotype map.

References:
Essential Readings:

1) Biological Physics: Energy, Information, Life; Philip Nelson (W H Freeman & Co, NY, 2004)
2) Cell Biology by the Numbers; Ron Milo and Rob Phillips (Garland Science, Taylor & Francis Group, NY USA and Abingdon UK, 2016)
3) Physical Biology of the Cell (2nd Edition); Rob Phillips et al (Garland Science, Taylor & Francis Group, NY USA and Abingdon UK, 2013)
4) Evolution; M. Ridley (Blackwell Publishers, 2009, 3rd edition).

Additional Readings:

1) Physics in Molecular Biology; Kim Sneppen and Giovanni Zocchi (Cambridge University Press, Cambridge UK, 2005)
2) Biophysics: Searching for Principles; William Bialek (Princeton University Press, Princeton USA, 2012).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE – DSE 2: NUMERICAL ANALYSIS

Course Title & Code	Credits	Credit distribution of the course			Pre-requisite of the course
		Lecture	Tutorial	Practical	
NUMERICAL ANALYSIS DSE – 2	4	2	0	2	--

LEARNING OBJECTIVES

The main objective of this course is to introduce the students to the field of numerical analysis enabling them to solve a wide range of physics problems. The skills developed during the course will prepare them not only for doing fundamental and applied research but also for a wide variety of careers.

LEARNING OUTCOMES

After completing this course, student will be able to,

- Analyze a physics problem, establish the mathematical model and determine the appropriate numerical techniques to solve it.
- Derive numerical methods for various mathematical tasks such as solution of non-linear algebraic and transcendental equations, system of linear equations, interpolation, least square fitting, numerical differentiation, numerical integration, eigen value problems and solution of initial value and boundary value problems.
- Analyse and evaluate the accuracy of the numerical methods learned.
- In the laboratory course, the students will learn to implement these numerical methods in Python/C++/Scilab and develop codes to solve various physics problems and analyze the results.

SYLLABUS OF DSE – 2

THEORY COMPONENT

Unit – I **(3 Hours)**

Approximation and Errors in computing: Introduction to numerical computation, Taylor's expansion and mean value theorem. Floating Point Computation, overflow and underflow. Single and double precision arithmetic. Rounding and truncation error, absolute and relative error, error propagation.

Unit – II **(8 Hours)**

Linear Systems: Solution of linear systems by Gaussian elimination method, partial and complete pivoting, LU decomposition, norms and errors, condition numbers, Gauss-Seidel

method, diagonally dominant matrix and convergence of iteration methods. Solution of Tridiagonal systems
Eigenvalue Problem: Power method, inverse power method.

Unit – III **(5 Hours)**
Interpolation: Lagrange and Newton's methods (divided difference) for polynomial interpolation, theoretical error of interpolation. Inverse Interpolation. Optimal points for interpolation and Chebyshev Polynomials. Minimax Theorem (Statement only)

Unit – IV **(7 Hours)**
Numerical Integration: Newton Cotes quadrature methods. Derivation of Trapezoidal and Simpson (1/3 and 3/8) rules from Lagrange interpolating polynomial. Error and degree of precision of a quadrature formula. Composite formulae for Trapezoidal and Simpson methods.
Gauss Quadrature methods. Legendre, Lagaurre and Hermite quadrature methods.

Unit – V **(7 Hours)**
Initial and Boundary Value Problems: Solution of initial value problems by Euler, modified Euler and Runge Kutta (RK) methods. Local and global errors, comparison of errors in the Euler and RK methods.
Finite difference and shooting method for solving two-point linear boundary value problems.

References:
Essential Readings:

1) Applied numerical analysis, Cutis F. Gerald and P. O. Wheatley, Pearson Education, India (2007).
2) Advanced Engineering Mathematics, Erwin Kreyszig, 2008, Wiley India..
3) Introduction to Numerical Analysis, S. S. Sastry, 5th Edn., 2012, PHI Learning Pvt. Ltd.
4) Elementary Numerical Analysis, K. E. Atkinson, 3rd Edn., 2007, Wiley India Edition.

Additional Readings:

1) Numerical Recipes: The art of scientific computing, William H. Press, Saul A. Teukolsky and William Vetterling, Cambridge University Press; 3rd edition (2007), ISBN-13 : 978-0521880688 .
2) Applied numerical analysis, Cutis F. Gerald and P. O. Wheatley, Pearson Education, India (2007).
3) Numerical methods for scientific and engineering computation, M. K. Jain, S. R. K. Iyenger, New Age Publishers (2012).

PRACTICAL COMPONENT

(15 Weeks with 4 hours of laboratory session per week)

The aim of this lab is not just to teach computer programming and numerical analysis but to emphasize its role in solving problems in Physics. Assessment is to be done not only on the programming but also on the basis of formulating the problem. The list of recommended programs is suggestive only. Students should be encouraged to do more physics applications.

Emphasis should be given to formulate a physics problem as mathematical one and solve by computational methods. The students should be encouraged to develop and present an independent project. At least 10 programs must be attempted (taking at least two from each unit).The implementation can be either in Python/ C++/Scilab.

Unit 1 - Linear Systems :

a) Solve a system of linear equations using Gauss Elimination method with pivoting (application to electric networks).
b) Solve a system of linear equations using Gauss-Seidel method and study the convergence (application to spring mass system).
c) Determine the inverse of a square matrix using Gauss-Jordan method.
d) Solve a tridiagonal system of linear equations.
e) Study an example of ill-conditioned systematic
f) Find the LU equivalent of a matrix.
g) Determine the largest and smallest eigenvalues using Power and inverse power methods. Consider a case where power method fails.

Unit 2 - Interpolation:

a) Given a dataset (x, y) with equidistant x values, prepare the Newton's forward difference, backward difference and divided difference tables.
b) Given a dataset (x, y) corresponding to a physics problem, use Lagrange and Newton's forms of interpolating polynomials and compare. Determine the value of y at an intermediate value of x not included in the data set. This may be done with equally spaced and non-equally spaced x-values.
c) Given a tabulated data for an elementary function, approximate it by a polynomial and compare with the true function.
d) Compare the interpolating polynomial for a given dataset (following a known form e.g. exponential) with the approximation obtained by least square fitting.
e) Compare the interpolating polynomial approximating a given function in a given range obtained with uniformly spaced points and by Chebyshev points.
f) Compare the Chebyshev and Maclaurin series expansions of an exponential or sinusoidal function.

Unit 3 - Integration:

a) Use integral definition of error function to compute and plot erf(x) in a given range. Use Trapezoidal, Simpson and Gauss Legendre methods and compare the results for a small and large values of x.
b) Use the definition of erf(x) and numerically take the limit x going to infinity to get the value of Gaussian integral using Simpson method. Compare the result with the value obtained by Gauss Hermite and Gauss Lagaurre methods.
c) Verify the degree of precision of each quadrature rule.
d) Use Simpson methods to compute a double integral over a rectangular region.
e) Approximate the value of π by evaluating the integral $\int_0^\infty \frac{1}{x^2+1}dx$using Simpson, Gauss Hermite and Gauss Lagaurre methods.

Unit 4 - Initial Value Problems (IVP):

a) Compare the errors in Euler, RK2 and RK4 by solving a first order IVP with known solution. Reduce the step size to a point where the round off errors take over.

b) Solve a system of n first order differential equations by Euler and RK methods. Use it to solve an nth order IVP. Solve a damped free and forced harmonic oscillator problem using this.
c) Solve a physics problem like free fall with air drag or parachte problem using RK method.
d) Solve a compound spring system (3 springs) by solving a system of differential equations using Euler and RK for a given set of initial conditions.
e) Obtain the current flowing in a series LCR circuit with constant voltage for a given set of initial conditions.

Unit 5 - Boundary value problems (BVP):
a) Solve a linear BVP using shooting and finite difference method and compare the results.
b) Solve a non-linear BVP using the finite differnce and shooting method and compare the results.
c) Determine the temperature distribution along a rod made of two dissimilar materials (of different thermal conductivities) welded together when temperatures at two ends are maintained at given temperatures.
d) Design a physics problem that can be modelled by a BVP and solve it by any method.

References for laboratory work

1) Documentation at the Python home page (https://docs.python.org/3/) and the tutorials there (https://docs.python.org/3/tutorial/).
2) Documentation of NumPy and Matplotlib : https://numpy.org/doc/stable/user/ and https://matplotlib.org/stable/tutorials/
3) Computational Physics, Darren Walker, 1st Edn., Scientific International Pvt. Ltd (2015).
4) An Introduction to Computational Physics, T. Pang, Cambridge University Press (2010).
5) Computational Problems for Physics, R.H. Landau and M.J. Páez, 2018, CRC Press.

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