Syllabus template Physics IV

Semester: VII	
Programme : Physics	
Course: Non-Linear Dynamics & NLD Lab	
Paper code: M2C4PH260142T (Non-Linear Dynamics) & M2C4PH260142P (NLD Lab)	**Credits: 3+1**
Hours/week : 3+2	
Category: Core/MDC/SEC/VAC : CORE (Major)	
Theory / Practical / Composite : Composite	
No of Modules : 2	

Course Overview: Non-Linear Dynamics

This course introduces students to the fundamental ideas of nonlinear dynamics through a progressive journey from simple discrete iterative maps to continuous flows and Hamiltonian systems. Beginning with the logistic map as a prototype, students explore phase space, fixed points, stability, bifurcations, and the emergence of chaos. The course then bridges maps to flows through one- and two-dimensional continuous systems, highlighting attractors and qualitative phase-portrait analysis with classic examples. The geometric nature of chaos is developed through fractals and the quantification of strange attractors using box-counting dimension. Finally, nonlinear oscillators, Poincaré sections, and an introduction to Hamiltonian systems provide a unifying perspective that contrasts integrable motion with chaotic dynamics. The emphasis throughout is on visualization, qualitative understanding, and the geometric structure underlying chaotic behaviour.

Course Overview: NLD Lab

This course introduces computational tools for analyzing data from graphs and symbolic computation using Maxima. Students will explore discrete-time systems through time-series analysis, iterative maps, logistic maps, and bifurcation phenomena. Chaos theory is examined via state-space methods, orbits, and sensitivity to initial conditions. Continuous nonlinear systems such as the damped driven pendulum are studied to understand routes to chaos. Emphasis is placed on the period-doubling route and other nonlinear oscillators.

The lab integrates theory with hands-on computational practice to build strong analytical and modelling skills.

Course Outcome: Non-Linear Dynamics
1. Understand the concept of phase space, fixed points, and stability for discrete and continuous dynamical systems.
2. Analyse the logistic map to identify bifurcations, period doubling, invariant measures, and compute/interpret Lyapunov exponents.
3. Interpret phase portraits of one- and two-dimensional flows and classify fixed, periodic, and strange attractors.

4. Quantify fractal structures of strange attractors using box-counting dimension and relate fractal geometry to chaotic dynamics.				
5. Construct and interpret Poincaré sections and distinguish between integrable Hamiltonian motion and chaotic behaviour in nonlinear oscillators..				
Course Outcome: NLD Lab				
1. Data Analysis Skills : Demonstrate the ability to extract quantitative information from graphical representations and compute distances and areas using analytical tools.				
2. Symbolic Computation Proficiency : Apply symbolic computation techniques using software such as Maxima to model and solve mathematical problems.				
3. Discrete Dynamical Systems Understanding: Analyse discrete-time systems through time-series analysis, iterative maps, cobweb diagrams, and logistic maps, and interpret bifurcation phenomena.				
4. Chaos and Nonlinear Dynamics Insight : Investigate state-space methods, orbits, and sensitivity to initial conditions to understand the emergence of chaos in dynamical systems.				
5. Continuous System Modelling: Explore continuous nonlinear systems such as the damped driven pendulum and other oscillators, explaining routes to chaos (e.g., period doubling) and expected dynamical features.				
Prerequisites:				
SYLLABUS				
UNIT/Module	**CONTENT**	**HOURS or NUMBER OF CLASSES**	**CO Mapping**	**COGNITIVE LEVEL**
I.	<u>**Non-Linear Dynamics**</u> **A) Dynamical Systems, Phase Space and Iterative Maps through the Logistic Map** Dynamical systems introduced through discrete iteration. State variables and phase space. Fixed points and stability by graphical and linear methods. One–dimensional non-invertible maps. Logistic map as prototype: bifurcation, period doubling, routes to chaos, invariant measure, Lyapunov exponent, bifurcation diagram and sensitivity to initial conditions.	**18L**	**CO1, CO2**	**KI,K2,K3,K4,K5**
	B) Maps to Flows: One- and Two-Dimensional Continuous Systems, Bifurcations and Attractors	**8L**	**CO3**	**K2,K3,K4,K5**

	From discrete maps to continuous flows. One- and two-dimensional continuous dynamical systems. Bifurcations in continuous systems. Phase portraits and qualitative behaviour. Henon map and Lorenz equations. Fixed, periodic and strange attractors.			
	C) Fractals and Dimension of Attractors Fractal geometry, self-similar sets, non-integer dimension and box-counting method.	**5L**	**CO4**	**K2,K3,K4.K5,K6**
	D) Nonlinear Oscillators, poincaré Sections and Hamiltonian Systems Damped driven pendulum, phase portraits and period doubling. Construction and interpretation of Poincaré sections, other non-linear oscillators.	**5L**	**CO5**	**KI,K2,K3,K4.K5, K6**
II.	**NLD Lab** **A) Tools of analysis**: Extraction of data from graphs, calculating distances and areas. Symbolic computation using Maxima.	**12L**	**CO1, CO2**	**K2,K3,K5,K6**
	B) Discrete time problems: Time-series analysis, Iterative maps and Cobweb diagrams, The logistic map, Bifurcation, State space methods: orbits, Chaos and sensitivity to initial conditions.	**6L**	**CO3, CO4**	**KI,K2,K3,K4.K5, K6**
	C) Continuous systems: The damped driven pendulum: Expected features, approach to chaos through the period doubling route, other non-linear oscillators.	**6L**	**CO4, CO5**	**K2,K3,K4.K5,K6**
Text Books				

MODULE – A

1. David Feldman — *Chaos and Fractals: An Elementary Introduction* (primary text)
2. Steven H. Strogatz — *Nonlinear Dynamics and Chaos*
3. Heinz-Otto Peitgen, Hartmut Jürgens & Dietmar Saupe — *Chaos and Fractals* (very accessible for fractals, Poincaré sections, visual understanding)
4. Kathleen Alligood, Tim Sauer & James Yorke — *Chaos: An Introduction to Dynamical Systems*

5. Edward Ott — *Chaos in Dynamical Systems*
MODULE – B **1.** Chaotic Dynamics - an introduction, G. L. Baker and J. P. Gollub, CUP **2.** A Maxima tutorial Jaime E. Villate University of Porto, Portugal July 21, 2025
Suggested readings
1. Edward Lorenz (1963) – Deterministic Nonperiodic Flow
2. Benoît Mandelbrot (1982) – The Fractal Geometry of Nature
3. James Yorke & Tien-Yien Li (1975, widely cited in the 1980s) – Period Three Implies Chaos
Web Resources (OER)
1. *Complexity Explorer*. Santa Fe Institute, www.complexityexplorer.org. Accessed 10 Feb. 2026.
2. Rothman, D. (2006). *Nonlinear Dynamics I: Chaos*. MIT OpenCourseWare
3. Strogatz, S. (2014). *Nonlinear Dynamics and Chaos* [Video lectures]. Cornell University, YouTube.
4. Yale University. *MATH 190a: Fractal Geometry*. Yale University Course
Evaluation Theory CIA: 15 (10 + 2/assgn.+ 3/attn.). Semester Exam:45 **Practical (if applicable) CA: 38 + 2/attn.**
Paper Structure for Theory Semester Exam Module : For each module of 45 Marks: 15 Marks from 3 marks questions (5 out of 7) 30 Marks from 10 marks questions (3 out of 4)

Course outcomes (COs) For Non-Linear Dynamics and Cognitive Level Mapping

COs	CO Description	Cognitive levels
CO1	Understand the concept of phase space, fixed points, and stability for discrete and continuous dynamical systems.	K1, K2, K4
CO2	Analyse the logistic map to identify bifurcations, period doubling, invariant measures, and compute/interpret Lyapunov exponents.	K3, K4, K5
CO3	Interpret phase portraits of one- and two-dimensional flows and classify fixed, periodic, and strange attractors.	K2, K3, K4, K5
CO4	Quantify fractal structures of strange attractors using box-counting dimension and relate fractal geometry to chaotic dynamics.	K2, K3, K4, K5, K6
CO5	Construct and interpret Poincaré sections and distinguish between integrable Hamiltonian motion and chaotic behaviour in nonlinear oscillators.	K2, K3, K4, K5, K6

Course outcomes (COs) For NLD Lab and Cognitive Level Mapping

COs	CO Description	Cognitive levels
CO1	Data Analysis Skills: Demonstrate the ability to extract quantitative information from graphical representations and compute distances and areas using analytical tools.	K2, K3, K5
CO2	Symbolic Computation Proficiency : Apply symbolic computation techniques using software such as Maxima to model and solve mathematical problems.	K2, K3, K6
CO3	Discrete Dynamical Systems Understanding: Analyse discrete-time systems through time-series analysis, iterative maps, cobweb diagrams, and logistic maps, and interpret bifurcation phenomena.	K1, K2, K3, K4, K5
CO4	Chaos and Nonlinear Dynamics Insight : Investigate state-space methods, orbits, and sensitivity to initial conditions to understand the emergence of chaos in dynamical systems.	K2, K3, K4, K5, K6
CO5	Continuous System Modelling: Explore continuous nonlinear systems such as the damped driven pendulum and other oscillators, explaining routes to chaos (e.g., period doubling) and expected dynamical features.	K2, K3, K4, K5, K6