PHY 380.03 | # NONLINEAR SCIENCE | **Spring 2016**

Instructor:

Dr. Richard Martin
Moulton Hall 314
rfm@phy.ilstu.edu

Office hours: TBA

Textbook: Nonlinear Dynamics for Undergraduates: Lecture Notes for PHY 380.03

Course Content:

The course will cover the basics of nonlinear science, an interdisciplinary paradigm for investigating problems in many fields which share the property that their mathematical models are nonlinear. We will begin in familiar territory with Newton's second law of motion, then progress through new, often more qualitative, tools and ideas for looking at nonlinear and chaotic systems. The first part of the class will focus on systems with no dissipation ("Hamiltonian systems"), followed by chaotic systems with dissipation ("Dissipative systems"). Selected examples will be used to build your intuition for each stop along the way, and to keep us grounded in the real world.

Here is a rough roadmap of what we'll cover.

I. *Introduction: Nonlinear Dynamical Systems*
- Linear and Nonlinear: What's the difference? Why does it matter?
- Everything "interesting" is nonlinear: some examples
- Newton's 2nd law: dynamical systems described by differential equations
- Some basic ideas: dynamical systems and the geometry of phase space
- Solution of dynamical systems by Integrals of motion
- **Archetypal Example**: the plane Pendulum
- Free pendulum: phase portraits
- Driven and damped pendulum: First return maps and chaos

II. *Nondissipative Systems*
- Hamiltonian systems: a slightly different approach than Newton
- Finding Integrals of Motion: symmetry and luck/experience
- Fixed points, stability and instability
- Effective Potentials
- **Physics Example:** Charged Particles in Magnetic Field Reversals
- Types of orbits: transient, periodic, quasiperiodic, chaotic
- Poincaré surface-of-section: visualizing chaos
- Lyapunov exponents: quantifying chaos
- Perturbation theory: approximate solutions; A taste of KAM theory
- The chaotic hierarchy: from simple harmonic motion to systems as random as a coin toss
- **General Example:** What makes time go forward? Does chaos imply irreversibility?

III. *Dissipative Systems*
- Dynamical systems, attractors, sensitive dependence on initial conditions, delay coordinates
- One-dimensional nonlinear maps: tent, shift, logistic
- Bifurcation diagram, Lyapunov exponent
- **Physics Example:** Chaotic water wheel
- Basin of attraction, fractal dimension
- Lorenz, Roessler, Chua systems
- Plasma, population, neuron systems

With time remaining after these basic topics we can delve into some ***specialized topics***, to be chosen by the class (For example: neural networks, cellular automata, chaotic synchronization, self organized criticality, etc.)

Course Structure and Grading:

The class meets MWF 3:00-3:50 PM. in Moulton 309. We'll assume a level of educational maturity commensurate with senior standing, *i.e.*, you all should be aware by now that learning science is an interplay between the professors' summary of basic material in class, reading the ideas of other scientists (in books, on the web *e.g.*), and working with the tools and methods yourself (by filling in the gaps in lecture and by doing homework problems).

To help you exercise your neural circuits and implement the ideas and methods of the course, there will be approximately weekly homework assignments. This "hands-on" practice with the new material is truly essential to learning. Problems will be designed to explore the lecture material and to go beyond the basics.

A great deal of what we know about nonlinear systems has come from numerical computations and simulations. These can provide physical intuition into the behavior of a complicated system, can yield new insights and ideas for subsequent analytical investigations, and sometimes are the only way of elucidating the physics contained in a mathematical model. To give you a taste of this method of discovery, some of the homework will be computer based. I will do most simulation examples in Mathematica, although I'll accept work in other languages (Python, Fortran, C/C++, mainly). Some assignments may require one particular tool.

As usual in upper division courses, collaboration and exchanging ideas on the homework problems is encouraged, but *copying is not*; each student must hand in original homework solutions. This applies to computer code as well as to homework calculations. All incidences of cheating will be handled via university guidelines for academic dishonesty (http://deanofstudents.illinoisstate.edu/downloads/CodeOfStudentConduct-Revised5.12.pdf). Please see the ISU definition of academic dishonesty in the Appendix of this document.

There will be two exams in the course, one on each half. Your total grade will be determined as follows:

Homework	50%
Mid-term Exam	25%
Final Exam	25%
Total	100%

Late homework

Homework is an integral part of the learning in any advanced physics course. It is most beneficial if it's done when we are doing the topic in class - i.e. in a timely manner! With that in mind we will have the following homework policy:

- 5% reward for handing in one or more days *before* the deadline
- 10% penalty for each late day for a maximum of 5 days
- After 5 days, the penalty is 100%.

To account for possible absences or short illness, one homework grade will be dropped.

Miscellaneous:

ASK QUESTIONS! This is a small class and there will be lots of opportunity for discussion. You're *encouraged* to come for help or general discussion during office hours or any other time the instructor is not otherwise scheduled. In particular, don't beat your head against the wall on a homework or computer problem you're stuck on. More often than not a few words of explanation can clear up the block. If you can't make the scheduled office hours, feel free to make an appointment or stop by and see if I'm available.

APPENDIX: Definition of Academic Dishonesty from the ISU Code of Student Conduct.

1. **Academic Dishonesty**.

Students are expected to be honest in all academic work. A student's placement of his or her name on any academic exercise shall be regarded as assurance that the work is the result of the student's own thought, effort, and study. Violations include but are not limited to:

a. possessing or utilizing any means of assistance (books, notes, papers, articles, etc.) in an attempt to succeed at any quiz or examination unless specifically authorized by the instructor.
b. taking any action with intent to deceive the person in charge as to the student's acting without honesty to complete an assignment, such as falsifying data or sources, providing false information, etc. Students are prohibited from conversation or other communication in examinations except as authorized by the instructor.
c. appropriating without acknowledgement and authorization another' s computer program, or the results of the program (in whole or part) for a computer-related exercise or assignment.
d. plagiarizing. For the purpose of this policy, plagiarism is the unacknowledged appropriation of another's work, words, or ideas in any themes, outlines, papers, reports, speeches, or other academic work. Students must ascertain from the instructor in each course the appropriate means of documentation.
e. submitting the same paper for more than one University course without the prior approval of the instructors.
f. willfully giving or receiving unauthorized or unacknowledged assistance on any assignment. This may include the reproduction and/or dissemination of test materials. Both parties to such collusion are considered responsible.
g. substituting for another student in any quiz or examination.
h. being involved in the unauthorized collection, distribution advertisement, solicitation, or sale of term papers, or research papers, or other academic materials completed by a third party.