UNIVERSITY OF CALGARY
FACULTY OF SCIENCE

Department of Physics & Astronomy
Science B 605
403 220-5385
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COURSE OUTLINE

1. **Course:** PHYS 521, Non-linear Dynamics and Chaos - Winter 2021

   Lecture 01: MWF 09:00 - 09:50 - Online

Instructor	Email	Phone	Office	Hours
Dr Joern Davidsen	davidsen@phas.ucalgary.ca	403 210-7964	SB 505	by appointment

   I will respond to your email inquiries about the course within 24 hrs except on weekends and holidays.

   Online Delivery Details:

   Some aspects of this course are being offered in real-time via scheduled meeting times. For those aspects you are required to be online at the same time.

   To help ensure Zoom sessions are private, do not share the Zoom link or password with others, or on any social media platforms. Zoom links and passwords are only intended for students registered in the course. Zoom recordings and materials presented in Zoom, including any teaching materials, must not be shared, distributed or published without the instructor's permission.

   Lectures:

   Students are expected to review assigned reading and other learning materials each week such that we will only use a subset of the regular lecture times for the synchronous component. The synchronous lectures (via Zoom, not recorded) will typically consist of a mix of regular lectures, group discussions centered on specific questions related to the specific material and a general Q&A part. While attendance of the synchronous component is not mandatory, it is an important learning opportunity and it provides direct feedback on the individual learning progression.

   The technology requirements for the synchronous component are:

   - A device with a supported operating system for Zoom;
   - Webcam/Camera (built-in or external);
   - Microphone and speaker (built-in or external), or headset with microphone;
   - Stable internet connection

   Course Site:

   D2L: PHYS 521 L01-(Winter 2021)-Non-linear Dynamics and Chaos

   Note: Students must use their U of C account for all course correspondence.

2. **Requisites:**

   See section 3.5.C in the Faculty of Science section of the online Calendar.

   Prerequisite(s):
   Physics 381 and 449; and Physics 435 or Mathematics 433.

3. **Grading:**

   The University policy on grading and related matters is described in F.1 and F.2 of the online University Calendar.

   In determining the overall grade in the course the following weights will be used:

Component(s)	Weighting %	Date
Homework assignments (5 or 6)	25	predominantly during the first half of the term
Group presentation/lecture	20	predominantly during the second half of the term
Topic presentation	25	during the last two weeks of classes
Topic paper	30	tentatively April 21

Each piece of work (reports, assignments, quizzes, midterm exam(s) or final examination) submitted by the student will be assigned a grade. The student's grade for each component listed above will be combined with the indicated weights to produce an overall percentage for the course, which will be used to determine the course letter grade.

The conversion between a percentage grade and letter grade is as follows.

	A+	A	A-	B+	B	B-	C+	C	C-	D+	D
Minimum % Required	90 %	85 %	80 %	75%	71%	67 %	63 %	59%	55%	51 %	47 %

4. **Missed Components Of Term Work:**

   The university has suspended the requirement for students to provide evidence for absences. Please do not attend medical clinics for medical notes or Commissioners for Oaths for statutory declarations.

   In the event that a student legitimately fails to submit any online assessment on time (e.g. due to illness etc...), please contact the course coordinator, or the course instructor if this course does not have a coordinator to arrange for a re-adjustment of a submission date. Absences not reported within 48 hours will not be accommodated. If an excused absence is approved, then the percentage weight of the legitimately missed assignment could also be pro-rated among the components of the course.

5. **Scheduled Out-of-Class Activities:**

   There are no scheduled out of class activities for this course.

6. **Course Materials:**

   Required Textbook(s):

   Steven H. Strogatz, *Nonlinear Dynamics and Chaos*: Westview Press / Perseus Books.

   Assignments, and supporting lecture material will be posted on the course D2L website.

   In order to successfully engage in their learning experiences at the University of Calgary, students taking online, remote and blended courses are required to have reliable access to the following technology:

   - A computer with a supported operating system, as well as the latest security, and malware updates;
   - A current and updated web browser;
   - Webcam/Camera (built-in or external);
   - Microphone and speaker (built-in or external), or headset with microphone;
   - Current antivirus and/or firewall software enabled;
   - Stable internet connection.

   For more information please refer to the UofC ELearning online website.

7. **Examination Policy:**

   The topic paper and topic presentation should be completed without consulting with other students.

   Students should also read the Calendar, Section G, on Examinations.

8. **Approved Mandatory And Optional Course Supplemental Fees:**

   There are no mandatory or optional course supplemental fees for this course.

9. **Writing Across The Curriculum Statement:**

   For all components of the course, in any written work, the quality of the student's writing (language, spelling, grammar, presentation etc.) can be a factor in the evaluation of the work. See also Section E.2 of the University Calendar.

10. **Human Studies Statement:**

    Students will not participate as subjects or researchers in human studies.

    See also Section E.5 of the University Calendar.

11. **Reappraisal Of Grades:**

A student wishing a reappraisal, should first attempt to review the graded work with the Course coordinator/instructor or department offering the course. Students with sufficient academic grounds may request a reappraisal. Non-academic grounds are not relevant for grade reappraisals. Students should be aware that the grade being reappraised may be raised, lowered or remain the same. See Section I.3 of the University Calendar.

a. **Term Work:** The student should present their rationale as effectively and as fully as possible to the Course coordinator/instructor within **ten business days** of either being notified about the mark, or of the item's return to the class. If the student is not satisfied with the outcome, the student shall submit the Reappraisal of Graded Term work form to the department in which the course is offered within 2 business days of receiving the decision from the instructor. The Department will arrange for a reappraisal of the work within the next ten business days. The reappraisal will only be considered if the student provides a detailed rationale that outlines where and for what reason an error is suspected. See sections I.1 and I.2 of the University Calendar

b. **Final Exam:**The student shall submit the request to Enrolment Services. See Section I.3 of the University Calendar.

12. **Other Important Information For Students:**

a. **Mental Health** The University of Calgary recognizes the pivotal role that student mental health plays in physical health, social connectedness and academic success, and aspires to create a caring and supportive campus community where individuals can freely talk about mental health and receive supports when needed. We encourage you to explore the mental health resources available throughout the university community, such as counselling, self-help resources, peer support or skills-building available through the SU Wellness Centre (Room 370, MacEwan Student Centre, Mental Health Services Website) and the Campus Mental Health Strategy website (Mental Health).

b. **SU Wellness Services:** For more information, see www.ucalgary.ca/wellnesscentre or call 403-210-9355.

c. **Sexual Violence:** The Sexual Violence Support Advocate, Carla Bertsch, can provide confidential support and information regarding sexual violence to all members of the university community. Carla can be reached by email (svsa@ucalgary.ca) or phone at 403-220-2208. The complete University of Calgary policy on sexual violence can be viewed at (https://www.ucalgary.ca/policies/files/policies/sexual-violence-policy.pdf)

d. **Misconduct:** Academic integrity is the foundation of the development and acquisition of knowledge and is based on values of honesty, trust, responsibility, and respect. We expect members of our community to act with integrity. Research integrity, ethics, and principles of conduct are key to academic integrity. Members of our campus community are required to abide by our institutional Code of Conduct and promote academic integrity in upholding the University of Calgary's reputation of excellence. Some examples of academic misconduct include but are not limited to: posting course material to online platforms or file sharing without the course instructor's consent; submitting or presenting work as if it were the student's own work; submitting or presenting work in one course which has also been submitted in another course without the instructor's permission; borrowing experimental values from others without the instructor's approval; falsification/fabrication of experimental values in a report. Please read the following to inform yourself more on academic integrity:

Student Handbook on Academic Integrity
Student Academic Misconduct Policy and Procedure
Research Integrity Policy

Additional information is available on the Student Success Centre Academic Integrity page

e. **Academic Accommodation Policy:** Students needing an accommodation because of a disability or medical condition should contact Student Accessibility Services in accordance with the procedure for accommodations for students with disabilities available at procedure-for-accommodations-for-students-with-disabilities.pdf.

Students needing an accommodation in relation to their coursework or to fulfill requirements for a graduate degree, based on a protected ground other than disability, should communicate this need, preferably in writing, to the Associate Head of the Department of Physics & Astronomy, Dr. David Feder by email phas.ahugrd@ucalgary.ca or phone 403-220-8127. Religious accommodation requests relating to class, test or exam scheduling or absences must be submitted no later than **14 days** prior to the date in question. See Section E.4 of the University Calendar.

f. **Freedom of Information and Privacy:** This course is conducted in accordance with the Freedom of Information and Protection of Privacy Act (FOIPP). Students should identify themselves on all written work by placing their name on the front page and their ID number on each subsequent page. For more information, see Legal Services website.

g. **Student Union Information:** VP Academic, Phone: 403-220-3911 Email: suvpaca@ucalgary.ca. SU Faculty Rep., Phone: 403-220-3913 Email: sciencerep@su.ucalgary.ca. Student Ombudsman, Email: ombuds@ucalgary.ca.

h. **Surveys:** At the University of Calgary, feedback through the Universal Student Ratings of Instruction (USRI) survey and the Faculty of Science Teaching Feedback form provides valuable information to help with evaluating instruction, enhancing learning and teaching, and selecting courses. Your responses make a difference - please participate in these surveys.

i. **Copyright of Course Materials:** All course materials (including those posted on the course D2L site, a course website, or used in any teaching activity such as (but not limited to) examinations, quizzes, assignments, laboratory manuals, lecture slides or lecture materials and other course notes) are protected by law. These materials are for the sole use of students registered in this course and must not be redistributed. Sharing these materials with anyone else would be a breach of the terms and conditions governing student access to D2L, as well as a violation of the copyright in these materials, and may be pursued as a case of student academic or non-academic misconduct, in addition to any other remedies available at law.

Course syllabus

This class gives an introduction to nonlinear dynamical systems as they arise in a wide range of areas of science and engineering. While the main goal of the class is to present the mathematical concepts and techniques, lectures and problems will also make contact with physical systems wherever possible.

Key topics to be discussed include: Phase space representation, nonlinear oscillators, bifurcations, normal forms, deterministic chaos, attractors, fractals, and synchronization.

Course outline:

1. Vector fields and flows in one dimension: flow on the line, existence and uniqueness theorem, bifurcations, flow on a circle
2. Two-dimensional systems: classification of linear systems, stability, phase plane analysis, Poincare-Bendixson theorem, limit cycles, relaxation oscillators, weakly nonlinear oscillators, bifurcations & center-manifold theorem
3. Chaos: Lorenz model, Poincare maps, one-dimensional iterated maps, Lyapunov exponents, strange attractors, invariant measure, routes to chaos, universality & renormalization, two-dimensional maps, Arnold tongues, fractals & fractal dimensions, Kolmogorov-Sinai entropy

In addition to our textbook, the following are useful reference books:

K.T. Alligood, T.D. Sauer and J.A. Yorke, Chaos, an Introduction to Dynamical Systems (Springer, New York 1996)
H.G. Schuster: Deterministic Chaos - an introduction (VCH, Weinheim 1994)
T. Tel and M. Gruiz: Chaotic dynamics - An introduction based on classical mechanics (Cambridge 2006)

Further references and all course relevant material can be found on D2L.

Homework assignments

There will be about five or six homework assignments predominantly during the first half of the term. These are the backbone of the course in that it is through these assignments that you will build up and apply your understanding of the various concepts and techniques. Please keep the following in mind as you work on and write up your assignments:

- Your main two goals in writing up your homework are **to be clear** (so that it is understandable what you have written) and **to demonstrate insight**. Writing clearly means using readable handwriting. You should avoid tiny script and avoid trying to cram many sentences and equations onto a single page. Leave plenty of space between symbols and between successive lines of equations. Leave plenty of space between the ending of one homework problem and the beginning of the next. Spread your answers out over many pages if necessary. (Paper is cheap compared to the time needed for you to complete the assignments and for me to grade your assignments.) If we cannot read and understand your assignments easily, you will get little or no credit.
- Demonstrating insight means using complete sentences that explain what you are doing and why. Cryptic brief answers like "yes", "no", "24", or "f(x)" will not be given credit. Instead, explain what you are doing and why, e.g., as if to a friend who is not familiar with this course. Your homework must show that you understand how you got your answer and that you appreciate the significance of your answer. A well-written complete answer is one that you will be able to understand yourself a month after you have written the answer, even if you don't remember the original question.

- You are allowed to collaborate on the homework assignments (this is realistic, scientists collaborate all the time in research) but as much as possible you should attempt the assignments on your own since you will learn the most that way. Whether or not you collaborate, **you must write up your homework on your own, in your own words, and with your own understanding. You must also acknowledge explicitly at the beginning of your homework anyone who gave you substantial help, e.g., classmates, myself, or other people.** (Again, scientists usually acknowledge in their published articles colleagues that helped to carry out the research.) Failure to write your homework in your own words and failure to acknowledge help when given can lead to severe academic penalties so please play by the rules.
- The assignments will require typically a mixture of analytical, numerical, and graphical approaches. The mathematical derivations or analyses for the analytical problems should be written out by hand on paper. Please use ink, not pencil. Numerical and graphical answers involve output that are best printed out on a laser printer, then stapled to your handwritten sheets. A hand-sketch of a graphical plot with essential features described is also acceptable.
- Please pay attention to details as you write your assignments. All symbols should be given names the first time you introduce them, e.g., say "the momentum p" or "the flux F" instead of just using the symbols p and F. Physical units should be given for any answer that is a physical quantity, e.g., say "the angular momentum was A=0.02 J-sec" or "the angle was mu=0.32 radians." Numerical answers should have the minimum number of significant digits that is consistent with the given data. For example, if you have a product or ratio of numbers of which the least accurate number has two significant digits, the final answer should have only two significant digits. Graphs should have their axes clearly labeled by the corresponding variables and by the variables' physical units. Each graph should have a title that explains the graph's purpose. A good way to learn how to write effectively is to imitate the style of published articles, e.g., those published in Physical Review Letters.
- If you use using Mathematica or any other software package in a homework assignment, please do not hand in the output of your entire session. Instead, just give us enough output to convince us that you have answered the question correctly. You should also include any code that you write so that we can try to understand how you obtained your answers.

Group presentations/lectures

These group presentations will take place predominantly during the second half of the term. Each group will consist of two or three students and prepare a lecture on a given topic. Each group will have at least a week to prepare the presentation.

Topic presentation and topic paper

Instead of a final exam, each member of the class will write a paper on some topic related to nonlinear dynamics that they are especially interested in. I will provide a list of suggestions around the midpoint of the term. As a first step to prepare for your paper, please make an appointment to meet with me so that I can help you to identify a suitable topic and to make sure that the topic will not take too much time for you to investigate. Note that the topic cannot be related to ongoing or previous research or for a previous course, for which you have already worked out the details of a talk and/or paper.
The paper should be clearly written in prose (no bullet points or numbered lists), and be pitched at the level of fellow students. Referencing must be provided similar to the referencing typical in published scientific papers. The references must be in the style of some journal: identify a preferred journal and strictly follow that journal's style guide. The paper should be 15 to 20 pages in length double space in 12 point font including tables, figures, and bibliography. The paper will be graded on presentation (including equations, figures, tables, and captions), logical flow, discussion, and referencing and bibliography. If the paper is based on reading some research article, on carrying out some simple experiment, or by simulating or analyzing some mathematical model, the paper should include a comprehensive background to the topic. The paper will be due in the week after the end of classes.

Each student will give a 20-minute oral presentation to the class about the chosen topic. Grading will be equally based on content (including logical flow and discussion of material) and on delivery (clear slides that are fully readable at a distance, use of props, eye contact with the audience if applicable, pace and volume of speaking, enthusiasm, avoidance of fillers such as "um", confidence, effectiveness at answering questions).

Course learning incomes

Students taking PHYS 521 are expected to have prior knowledge of ordinary differential equations as covered in the required math courses. Students are also expected to have prior knowledge of (i) simulating ordinary differential equations as covered in PHYS 381, and (ii) the different notions of entropy as covered in PHYS 449.

Course Outcomes:

- The student can characterize the gross dynamics of low-dimensional systems using linear stability analysis and graphical tools.

- The student can explain transitions between different dynamical regimes and characterize the underlying bifurcations including the different routes to chaos.
- The student can summarize the main features of chaotic behavior and quantify it by calculating Lyapunov exponents, fractal dimensions and entropy measures.
- The student is able to identify suitable, reliable and understandable reference material and critique original peer-reviewed literature on nonlinear dynamics and chaos.
- The student can solve problems individually and communicate his/her own understanding of a given topic clearly in written and oral form.

Electronically Approved - Dec 18 2020 18:16

Department Approval

Electronically Approved - Jan 04 2021 11:37

Associate Dean's Approval