Physics 311: Advanced Dynamics
Syllabus – Fall 2022

Instructor:

Malcolm Sanders
Email: Malcolm.Sanders@uvm.edu
Phone: 802-656-0050
Office: Innovation E203B
Office Hours: MW 11:00 AM - 12:00 PM, or by arrangement

Time & Location:

TR 11:40 AM - 12:55 PM L210 Old Mill Annex

Why:

This course on advanced dynamics, builds on the ideas of classical mechanics, as formulated and developed through the work of Newton, Euler, Lagrange and Hamilton. Classical mechanics is the quantitative study of the behavior of mechanical systems that are bigger than atoms, and slower than light (and far away from Black Holes). This is the province of planetary motion, natural and artificial satellites, the dynamics of the atmosphere and of the ocean, and of the earth itself.

The early twentieth century saw a couple of significant revolutions in Physics, one involving the theories of special and general relativistic mechanics as formulated by Einstein, the other being the understanding that the world of atomic physics obeys the principles of quantum, not classical, mechanics (although the derivation of quantum theory relied on the principles of classical mechanics.) So our modern understanding is that classical mechanics is an approximate description of physics, valid only when objects move slowly compared to light, and only for objects that are larger than approximately micron scale in size.

The advent of the new ideas about relativity and about the quantum world had the effect of pushing the study of classical mechanics into relative obscurity, but more recently, the rich and sometimes startling behavior of nonlinear mechanical system, has become a more active topic of interest, and the work of mathematicians such as Poincaré, Lie, Liapounov, Birkhoff, Kolmogorov and others has informed us about the behavior of nonlinear, possibly chaotic systems.

The first few weeks of the class will be a review of (hopefully) familar concepts and methods of classical mechanics. From there we will proceed to look at the behavior of Hamiltonian systems, both linear and nonlinear, and their transitions to chaotic behavior, keeping in perspective, Henri Poincaré's dictum that classical mechanics, essentially boils down to doing geometry in phase space.

Outline:

1. Newtonian Dynamics and Kinematics
    (a) Newton's Laws and their gallelean invariance
    (b) Systems of Particles:
        Linear momentum, angular momentum and energy
        Conservation laws
    (c) Accelerated coordinate systems
2. Lagrangian dynamics

(a) Generalized coordinates
(b) D'Alembert's principle
(c) Lagrange's Equations
(d) Hamiltion's principle of least action
(e) Symmetry principles and conserved quantities – Noether's theroem
(f) Examples: Central fields and Kepler's problem
Lagrangian for particle motion in an electromagnetic field

3. Small Oscillations (Linear systems)

   (a) Equilibrium and linearization of the equations
   (b) Normal coordinates
   (c) Parametric Resonance

4. Hamiltionian Dynamics and Transformation Theory

   (a) Hamilton's canonical equations
   (b) Hamiltonian phase flows and Liouville's Theorem
   (c) Poisson brackets
   (d) Canonical (Symplectic) transformations
   (e) Generating functions
   (f) Hamilton-Jacobi theory

5. Completely Integrable systems

   (a) Separable systems
   (b) Action-angle variables
   (c) Integrable systems and invariant tori
   (d) Integrable invariants of Poincaré-Cartan

6. Regular and Chaotic Motion of Hamiltionian Systems

   (a) Surfaces of section:
   Poincaré mappings
   Fixed points and cycles
   (b) Stability of periodic orbits
   (c) Integrable and ergodic systems
   (d) One-degree of freedom
   (e) Two degrees of freedom – Numerical exploration:
   Invariant curves, islands, chaotic regions
   Examples:
   Henon-Heiles potential
   Quadratic mappings
   (f) KAM theorem
   (g) Many degrees of freedom

7. Mechanics of continuous systems: Strings
   (a) Small oscillations in many degrees of freedom
   (b) Transition from discrete to continuous systems
   (c) Wave equation
   (d) General string equation (homogenous):
   Eigenfunction expansion and Sturm-Liouville theory
   Variational properties:
   (e) Inhomogenous equation:
   Green's function method
   (f) Energy flux

Textbook:

A.L Fetter and J.D. Walecka, *Theoretical Mechanics of Particles and Continua*, Dover Publications, Mineola NY, ISBN 0-486-43261-0 (2003). We'll cover Chaps 1-4,6,7

A.L Fetter and J.D. Walecka, *Nonlinear Mechanics: A Supplement to Theoretical Mechanics of Particles and Continua*, Dover Publications, Mineola NY, ISBN 9780486136998 (2006). This can be found online in PDF form. We'll look mostly at sections I and III

Other Recommended Texts:

H. Goldstein, C. Poole, J. Safko *Classical Mechanics* Third Edition, Addison-Wesley, ISBN 0-201-65702-3 (2002).

L.D. Landau and E.M. Lifshitz *Mechanics*, Addison-Wesley, (1960).

Other references will be posted to Blackboard

Grading:

- Weekly assignments & Quizzes 50%
- Take-home Midterm exam 20%
- Take-home Final exam 30%

Homework Problems:

- Homework problem sets will be posted approximately weekly or biweekly on Blackboard with a due date set at the beginning of a class meeting that is at least one week later than the assignment is posted.

  Please either prepare your assignments on a computer, or else scan all handwritten pages of the homework assignment and submit as a single PDF file to gradescope.com. I will give you instructions about how to do this in advance of the due date for the first assignment.

  The following policy will apply to the maximum possible score for each homework assignment:

On time	100%
One class session late	50%
More than one class session late	0%