PHYS 525 - Survey of Fundamental Device Physics

Course description

This course will introduce students to the underlying physical principles employed by various devices. As in Physics 524, we will introduce students to a broader spectrum of device principles than they will encounter in their Physics 523 projects. There will be two 50 minute classes each week, split into discussion and laboratory exercises. The list of topics—which is not intended to be exhaustive—will evolve, according to the interests of the class and instructors. Material will be clustered into units of varying duration, as indicated below. The lists of suggested readings and references are advisory; a large amount of material of excellent quality is now available on the worldwide web, particularly on the sites of university courses addressing the topics of each unit. There are no formal prerequisites other than prior completion of a rigorous undergraduate major (or minor) in physics, astronomy, or a related field.

Credit and grading

Students must register for this course in the spring semester for a total of 2 credit hours. Grading is by letter.

Learning objectives

As a result of completing this course, students will

- Understand the physical principles and mathematical foundations governing the behavior of some of the devices, tools, and techniques that might be relevant to execution of technical projects.
- Understand the origins of the advantages and limitations of particular laboratory techniques that are imposed by fundamental physical principles.
- Learn to consider the tradeoffs—balancing advantages and disadvantages—associated with technology downselects.

Syllabus: topics covered

Unit 1: Incompressible fluids (1 week)

- Newtonian fluid dynamics and the Navier-Stokes equation;
- Flow rates vs. pressure, geometry, viscosity;
- Turbulence.

Unit 2: Electrodynamics (2 weeks)

- Electromagnetic radiation;
- Antennas, waveguides and transmission lines;
- Diffraction and boundaries in wave propagation;
- Cerenkov radiation.

Unit 3: Continuum mechanics and acoustics (2 weeks)

- Acoustic waves;
- Propagation, scattering, and reflection in continuous (dispersive) media;
- Ultrasonic transducers and sonar;
- Proximity sensing.

Unit 4: Semiconductor physics (3 weeks)

- Band structure;
- PN junctions and diodes;
- Bipolar junction transistors;
- Field effect transistors;
- Switching speed and power consumption;
- Band-gap voltage references;
- Moore's law.

Unit 5: Laser physics (1 week)

- General principles of stimulated emission and amplification;
- Laser phenomenology;
- Practical applications.

Unit 6: Magnetic fields (2 weeks)

- Maxwell's equations and magnetic materials;
- Hall effect;
- Magnetic braking;
- Superferric magnet applications;
- Magnetic shielding.

Unit 7: Superconductivity and cryogenics (3 weeks)

- Mechanisms for superconductivity;
- Superconducting phenomenology;
- Practical cryogenics: insulation, heat transport;
- High field magnets;
- SQUIDs;
- Future uses: power transmission, energy storage.

Readings and other sources

Unit 1 reading and reference material:

- Introduction to Fluid Mechanics, Fox and McDonald, Wiley & Sons.
- Mechanics, 3rd edition, K. R. Symon, Addison-Wesley Publishing, 1971.
- Lectures in Elementary Fluid Dynamics: Physics, Mathematics and Applications, J.M. McDonough, Departments of Mechanical Engineering and Mathematics, University of Kentucky, Lexington, KY (2009): http://www.engr.uky.edu/~acfd/me330-lctrs.pdf.

Unit 2 reading and reference material:

- Classical Electrodynamics, 3rd ed., J.D. Jackson, Wiley & Sons (1999).

Unit 3 reading and reference material:

- Understanding Acoustics, S.L. Garrett, Springer (2017).

Unit 4 reading and reference material:

- Semiconductor Physics And Devices: Basic Principles, D.A. Neamen, (2011).

Unit 5 reading and reference material:

- Laser Physics: From Principles to Practical Work in the Lab, M. Eichhorn, Springer (2014).

Unit 6 reading and reference material:

- Classical Electrodynamics, 3rd ed., J.D. Jackson, Wiley & Sons (1999).

Unit 7 reading and reference material:

- Superconductivity: From Materials Science to Practical Applications, P. Mele et al., Springer (2020).