Physics 205 Modern Physics for Engineers

Instructor

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Physics 205 Course Information

Physics 205 Fall 2009: Modern Physics for Engineers

Description: Introduction to atomic, solid state, and nuclear physics. Prerequisite: Physics 202 or 208. Not open to those who have had Physics 241 or 244.

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Lectures: CHAMBERLIN 2241, 08:50 AM - 09:40 AM, Tues. & Thurs.

Discussion: Chamberlin 2241, 02:25 PM - 03:15 PM, Tues. Textbook exercises will be worked. Additional problems at WEBASSIGN.com are required.

Office Hours: TR 10:00am~11:00am, or by appointment

Text: Modern Physics, by Stephen T. Thornton and Andrew Fox, 3rd Edition. Another good book at a similar level is Tipler & Llewellyn, also titled Modern Physics. For other books, see Library Reserve for texts with "Modern Physics" in the title. Ball, Belsey are also good texts.

Grading: The final grade will be determined from the components listed below.

- Attendance/participation 20%. Participation at lecture/demonstration and discussion is required. Attendance will be recorded.
- Discussion Homework: 20% of grade, self graded 20 points per problem. Discussion will focus on the solution to 5 exercises from the text. You will work in small groups to clarify your understanding and hand in at the end of discussion your individual solutions. Come prepared.
- WEBASSIGN Homework: 20% of grade, various points per problem. Five additional exercises per chapter from the text are assigned at Webassign. Consult the course instructor for the class key to self enroll at webassign.com. If you are unfamiliar with webassign, complete the tutorial during the first week of instructor.
- Midterm Exam: 20% Midterm hour exam in class 22 Oct.
- Final Exam: 20% Final exam emphasizing remaining material 19 Dec.

Cheating: Anyone caught cheating on an exam will receive an F for the course.

Honors: Extra exercises specified on the syllabus are required for honors credit.

Syllabus: http://ical.me.com/duncancarlsmith/Phys205Fall09Syllabus

http://www.physics.wisc.edu/undergrads/courses/fall09/205

http://ical.mac.com/WebObjects/iCal.woa/wa/default?u=duncancarlsmith&n=Physics205Fall09Syllabus.ics
Self enroll at

https://www.webassign.net/login.html

Course ID was sent to you in an email from the instructor.
CHAPTER 1

The Birth of Modern Physics

- 1.1 Classical Physics of the 1890s
- 1.2 The Kinetic Theory of Gases
- 1.3 Waves and Particles
- 1.4 Conservation Laws and Fundamental Forces
- 1.5 The Atomic Theory of Matter
- 1.6 Outstanding Problems of 1895 and New Horizons

*The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote…Our future discoveries must be looked for in the sixth place of decimals.* – Albert A. Michelson, 1894
Mechanics – a theory of the motions of ordinary things

- Galileo (1564-1642)
  - Great experimentalist
  - Principle of inertia
  - Established experimental foundations
Three laws describing the relationship between mass and acceleration.

- **Newton’s first law** (law of inertia): An object in motion with a constant velocity will continue in motion unless acted upon by some net external force.

- **Newton’s second law**: Introduces force ($F$) as responsible for the change in linear momentum ($p$):
  \[
  \vec{F} = m\vec{a} \quad \text{or} \quad \vec{F} = \frac{d\vec{p}}{dt}
  \]

- **Newton’s third law** (law of action and reaction): The force exerted by body 1 on body 2 is equal in magnitude and opposite in direction to the force that body 2 exerts on body 1.
  \[
  F_{21} = -F_{12}
  \]
Electromagnetism

Contributions made by:

- Coulomb (1736-1806)
- Oersted (1777-1851)
- Young (1773-1829)
- Ampère (1775-1836)
- Faraday (1791-1867)
- Henry (1797-1878)
- Maxwell (1831-1879)
- Hertz (1857-1894)

Science is a human process. Many people contribute!
Culminates in Maxwell’s Equations

- Gauss’s law ($\Phi_E$): \[ \oint E \cdot dA = \frac{q}{\varepsilon_0} \] (electric field)

- Gauss’s law ($\Phi_B$): \[ \oint B \cdot dA = 0 \] (magnetic field)

- Faraday’s law: \[ \oint E \cdot ds = -\frac{d\Phi_B}{dt} \]

- Ampère’s law: \[ \oint B \cdot ds = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 I \]
Thermodynamics

Contributions made by:

- Benjamin Thompson (1753-1814) (Count Rumford)
- Sadi Carnot (1796-1832)
- James Joule (1818-1889)
- Rudolf Clausius (1822-1888)
- William Thompson (1824-1907) (Lord Kelvin)
The Laws of Thermodynamics

- **First law**: Heat is random microscopic energy and energy is conserved. The change in the internal energy $\Delta U$ of a system is equal to the heat $Q$ added to a system plus the work $W$ done by the system

  $$\Delta U = Q + W$$

- **Second law**: It is not possible to convert heat completely into work without some other change taking place. Entropy increases.

- **The “zeroth” law**: Two systems in thermal equilibrium with a third system are in thermal equilibrium with each other
Other classical physics

- Fluid mechanics
- Continuum mechanics of solids
- Optics
- Chemistry
- Geophysics and astronomy
- Newtonian Theory of Gravity
- ...

The triumph of classical physics was the demonstration of universal laws connecting diverse phenomena generating faith that the physical universe could be understood! That quest continues.
1.3: Waves and Particles

Two ways in which energy and momentum are transported:

1) Motion of massive particles
2) Wave propagation in continuous medium

The distinction is not clear for visible light! Thus by the 17th century begins the major disagreement concerning the nature of light.
The Nature of Light

Contributions made by:

- Isaac Newton (1642-1742)
- Christian Huygens (1629 -1695)
- Thomas Young (1773 -1829)
- Augustin Fresnel (1788 – 1829)
The Nature of Light

Newton promotes the corpuscular (particle) theory
- Particles of light travel in straight lines or rays
- Explained sharp shadows
- Explained reflection and refraction
The Nature of Light

- Christian Huygens promotes the wave theory
  - Light propagates as a wave of concentric circles from the point of origin
  - Explained reflection and refraction
  - Did not explain sharp shadows
The Wave Theory Advances…

- Contributions by Huygens, Young, Fresnel and Maxwell
- Double-slit interference patterns
- Refraction of light from a vacuum to a non-medium
- Discovery of light speed
- Light is an electromagnetic wave!
The Electromagnetic Spectrum

- Maxwell’s theory predicts that visible light covers only a small range of the total electromagnetic spectrum.
- All electromagnetic waves travel in a vacuum with a speed $c$ given by:

$$ c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \lambda f $$

where $\mu_0$ and $\varepsilon_0$ are the respective permeability and permittivity of “free” space which appear in Maxwell’s equations.
Problems with EM theory

- If light in vacuum is a wave, what is the medium?
- All electromagnetic waves travel in a vacuum with a speed c. How can it be that two observers in relative motion both observe light traveling at the same speed?
- Possible answer. There is a medium in space, and only in its rest frame does light move at speed c.
Birth of special relativity theory

- Michelson and Morley set out to prove this ether theory, and discovered to their surprise that no – the speed of light is the same in all inertial reference frames leading to Einstein’s Relativity Theory of space and time!
What is modern physics

- Relativity theory rationalizes the framework of space and time applicable to all physics.

- Modern physics digs deeper into the structure of matter and energy and unearths the properties of fundamental constituents governed by a new sort of mechanics – quantum mechanics – which unifies matter and light, waves and particles, explaining atomic and nuclear structure.

- Contemporary physics is digging deeper still, discovering new forms of normal matter and light described by a unified theory, and dark matter, dark energy not yet understood.
1.5: The Atomic Theory of Matter

- Initiated by Democritus and Leucippus (~450 B.C.) (first to us the Greek *atomos*, meaning “indivisible”)
- In addition to fundamental contributions by Boyle, Charles, and Gay-Lussac, Proust (1754 – 1826) proposes the law of definite proportions
- Dalton advances the atomic theory of matter to explain the law of definite proportions
- Avogadro proposes that all gases at the same temperature, pressure, and volume contain the same number of molecules (atoms); viz. $6.02 \times 10^{23}$ atoms
- Cannizzaro (1826 – 1910) makes the distinction between atoms and molecules advancing the ideas of Avogadro.
Further Advances in Atomic Theory

- Maxwell derives the speed distribution of atoms in a gas
- Robert Brown (1753 – 1858) observes microscopic “random” motion of suspended grains of pollen in water
- Einstein in the 20th century explains this random motion using atomic theory
Overwhelming Evidence for Existence of Atoms

- Max Planck (1858 – 1947) advances the concept to explain blackbody radiation by use of submicroscopic “quanta”
- Boltzmann requires existence of atoms for his advances in statistical mechanics
- Albert Einstein (1879 – 1955) uses molecules to explain Brownian motion and determines the approximate value of their size and mass
- Jean Perrin (1870 – 1942) experimentally verifies Einstein’s predictions
1.6: The submicroscopic world

- What are atoms anyway? What are they composed of and what explains the properties of the elements – the spectra, the chemistry.
- Modern physics begins with the discovery of the electron and the nucleus and the (quantum) wave nature of these particles.
- Their behavior is explained by a radically new quantum mechanics.
100 years later

- Today we understand normal matter is composed of electrons and up and down quarks (bound in nuclei) can use quantum mechanics and relativity to design and engineer atomic and subatomic processes.
- Today we understand the origin and cosmological evolution of normal matter from the Big Bang to the present.