OSE5312: Light-Matter Interaction

CREOL

College of Optics & Photonics, University of Central Florida

COURSE SYLLABUS

Instructor:	Dr. Romain Gaume	Term:	Spring 2022
Office:	CREOL A339	Class Meeting Days:	Tue, Thu
Phone:	407-823-5683	Class Meeting Hours:	10:30-11:45am
E-Mail:	gaume@creol.ucf.edu	Class Location:	CREOL 102
Office Hours:	Thu 12:00am-1:00pm or by appt (f2f or Zoom)	Class Website:	Webcourses.ucf.edu

I. University Course Catalog Description

Microscopic theory of absorption, dispersion, and refraction of materials; classical and quantum-mechanical description of optical properties.

II. Course Overview

This course discusses the interaction of light with matter. We will find that many important optical properties can be described quite accurately using surprisingly simple models. Initially, we will model atoms as classical dipole oscillators ("electrons on springs"). We will use the calculated behavior of these model atoms together with Maxwell's equations to obtain expressions for the frequency dependent refractive index, absorption, and susceptibility. Using this theory, we will be able to understand the optical properties of gases, liquids and solids, including metals, semiconductors and dielectrics. To improve on our model descriptions, we will discuss the foundations of quantum mechanics and derive a quantum mechanical description of the refractive index. We will include the interaction of light with oscillations of atoms (molecular vibrations and rotations, phonons) and consider how quantum mechanics affects molecular absorption spectra.

List of Topics:

Maxwell's Equations and the Dielectric Function: free charges, meaning of susceptibility and polarization response, bound electron polarization and magnetization, causality & Kramers-Kronig relations, *Optical Properties of Solids, Liquids and Gases:* molecules, liquids, metals, insulators, semiconductors, *Classical Treatment of Light-Matter Interaction:* Lorentz oscillator, Drude model, Debye model, calculation of susceptibility and complex refractive index, Sellmeier equations and Abbe number, electronic transitions in atoms, anharmonic classical oscillator model, second order effects, third order effects, molecular rotational/vibrational transitions in molecules, dipole-active and Raman-active modes, phonons in solids, acoustic modes, optical modes, *Quantum-mechanical description of Light-Matter Interaction:* operators, Eigenfunctions, orthonormal complete sets, Dirac notation, wavefunctions, observables, commutation, ensemble averages, energy Eigenfunctions, time independent Schrödinger equation, infinite and finite wells, barriers, time dependent Schrödinger equation, time dependent perturbation theory, Fermi Golden Rule, expectation value of Polarization, susceptibility, oscillator strength , dopants / impurities in dielectric hosts, Kronig-Penney model and Energy bands, Bandgaps, Excitons, impurities (n- and p-type), blackbody radiation, Einstein coefficients, Thermal distributions (Bose-Einstein, Fermi-Dirac, Maxwell-Boltzmann)

III. Course Objectives

Students will be able to identify materials based on reflection, transmission, absorption spectra, predict optical properties based on dopant concentrations and resonances, predict refractive index spectra based on absorption spectra, and understand the role of quantum mechanics in optical properties.

IV. Course Prerequisites

Graduate standing or consent of instructor.

V. Recommended Texts and Materials

- Course notes (online PDF)
- Optical Properties of Solids — M. Fox (Oxford University Press)
- Quantum Mechanics for Scientists and Engineers — D. A. B. Miller (Cambridge)

VI. Supplementary (Optional) Texts and Materials

- Optical Materials — J. Simmons and K. S. Potter (Academic Press)
- Introduction to Solid State Physics — C. Kittel (Wiley)
- Optical Electronics in Modern Communications — A. Yariv (Oxford)

VII. Basis for Final Grade

The semester's grade will be obtained from the following assessments and weights:

Assessment	Percent of Final Grade
Homework (6)	60%
Midterm	20%
Final Exam	20%
	100%

Plus and minus will be used according to the scale below:

Grading Scale (%)	
94-100	A
90-93	A-
87-89	B+
84-86	B
80-83	B-
77-79	C+
74-76	C
70-73	C-
67-69	D+
64-66	D
60-63	D-
0 - 59	F

VIII. Grade Dissemination

Graded tests and materials in this course will be returned individually only by request. You can access your scores at any time using the Grade Book function of Webcourses. Please, note that scores returned mid-semester are unofficial grades.

IX. Course Policies: Grades

Late Work Policy:

Homework posted in late will be assessed a penalty: a half-letter grade if it is one day late, or a full-letter grade for 2-7 days late. Essays will not be accepted if overdue by more than seven days or after solutions are posted. Makeup exams will only be offered with prior permission from instructor.

Grades of "Incomplete":

The current University policy concerning incomplete grades will be followed in this course. Incomplete grades are given only in situations where unexpected emergencies prevent a student from completing the course and the remaining work can be completed the next semester. Your instructor is the final authority on whether you qualify for an incomplete. Incomplete work must be finished by the end of the subsequent semester or the “I” will automatically be recorded as an “F” on your transcript.

X. Course Policies: Technology and Media

Email: Feel free to email me regarding any question or concern about the class or to request a meeting.

Webcourses: Webcourses will be used to communicate class notes (pdf files), assignments, grades or general messages to the class. You will also upload your assignments on this platform.

Laptop/Tablet Usage: If you like, you are welcome to take notes with your personal laptop or tablet during the lectures.

XI. Course Policies: Student Expectations

Disability Access:

The University of Central Florida is committed to providing reasonable accommodations for all persons with disabilities. This syllabus is available in alternate formats upon request. Students who need accommodations must be registered with Student Disability Services, Ferrell Commons Room 185, phone (407) 823-2371, TTY/TDD only phone (407) 823-2116, before requesting accommodations from the professor.

Professionalism Policy:

Per university policy and classroom etiquette; mobile phones, iPods, *etc*. **must be silenced** during lectures. Those not heeding this rule will be asked to leave the classroom immediately so as to not disrupt the learning environment. Please, arrive on time for all class meetings. Students who habitually disturb the class by talking, arriving late, *etc*., and have been warned may suffer a reduction in their final class grade.

Academic Conduct Policy:

Academic dishonesty in any form will not be tolerated. If you are uncertain as to what constitutes academic dishonesty, please consult The Golden Rule, the University of Central Florida's Student Handbook (http://www.goldenrule.sdes.ucf.edu/) for further details. As in all University courses, The Golden Rule Rules of Conduct will be applied. Violations of these rules will result in a record of the infraction being placed in your file and receiving a zero on the work in question AT A MINIMUM. At the instructor’s discretion, you may also receive a failing grade for the course. Confirmation of such incidents can also result in expulsion from the University.

XII. Important Dates to Remember

Drop/Swap Deadline:	Fri, Jan 14th, 2022
Spring Break:	Sun, Mar 6th to Sun, Mar 13th, 2022
Withdrawal Deadline:	Fri, Mar 25th, 2022
Grade Forgiveness Deadline:	Mon, Apr 25th, 2022
Final Examination:	Thu, May 3rd, 2022, 10:00am-12:50pm

XIII. Schedule

The following dates are tentative and updates will be provided based on course progression.

Tentative schedule - check most recent lecture to see up-to-date info

Day	Date	Subjects covered	Description	Notes	Fox	Miller
T	11-Jan	Introduction - broad overview of topics to be covered		1	1	
Th	13-Jan	Review of Maxwell's equations	continuum	2	2	
T	18-Jan	Wave propagation in dispersive media	continuum	3	2	
Th	20-Jan	Kramers-Kronig relations	continuum	4	2	
T	25-Jan	Dielectrics - the Lorentz model (1)	oscillator (classical)	5	2	
Th	27-Jan	Dielectrics - the Lorentz model (2)	oscillator (classical)	5	2	
T	1-Feb	Metals and doped semiconductors - Drude model	oscillator (classical)	8	7	
Th	3-Feb	More on Lorentz model, anharmonic oscillator and pathways to NLO	oscillator (classical)	15	11	
T	8-Feb	Nonlinear optics; frequency mixing: sum and difference frequency generation	oscillator (classical)	15	11	
Th	10-Feb	Nonlinear optics; frequency mixing: sum and difference frequency generation	oscillator (classical)	15	11	
T	15-Feb	**Midterm Exam**				
Th	17-Feb	QM1 - Introduction to Schrödinger equation, states of an infinite well	quantum	-		2
T	22-Feb	QM2 - States of a finite well	quantum	-		2
Th	24-Feb	QM3 - Time dependence, expectation values, orthonormal complete sets	quantum	-		3
T	1-Mar	QM4 - Example basis sets, Harmonic oscillator, Hydrogen atom	quantum	-		3, 10
Th	3-Mar	QM5 - Time dependent perturbation	quantum	-		7
T	8-Mar	No Class (Spring Break)				
Th	10-Mar	No Class (Spring Break)				
T	15-Mar	QM6 - From time dependent amplitudes to absorption coefficient	quantum	-	B	7
Th	17-Mar	QM7 - From time dependent amplitudes to susceptibility	quantum	-	B	7
T	22-Mar	Molecular vibrations, quantum rotor, vibration - rotation spectra	oscillator (Q & class)	10,7		
Th	24-Mar	Classical and quantum description of vibrations in molecules I	oscillator (classical)	6,10		
T	29-Mar	Classical and quantum description of vibrations in molecules II	oscillator (classical)	6,10		
Th	31-Mar	Vibrations in solids I; phonon dispersion in linear chains of atoms	oscillator (classical)	10	10	
T	5-Apr	Vibrations in solids II; reciprocal space, phonon dispersion in real materials		10	10	
Th	7-Apr	Vibrations in solids III; reciprocal space, phonon dispersion in real materials		10	10	
T	12-Apr	Optical properties of semiconductors - Kronig-Penney Model and Bandgaps	QM & band structure	11	3, C	8
Th	14-Apr	Optical properties of semiconductors - Band structure	QM & band structure	11	3, C	8
T	19-Apr	Optical properties of semiconductors - Interband transitions	QM & band structure	11	3, C	8
Th	21-Apr	Optical properties of semiconductors - excitons, impurities, FCA	QM & band structure	11	4	8
T	26-Apr	Optical properties of semiconductors - excitons, impurities, FCA	QM & band structure	11	4	8
T	28-Apr	No Class				
Th	**3-May**	**FINAL EXAM: 10:00am-12:50 am Room 102**				