

## OPTICS AND WAVE MOTION

PHY 411

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Text: "Optics," E. Hecht (4th Ed.)

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### I. Course Description

A study of the properties of light and its interaction with matter. Topics include geometrical and physical optics, polarization, optical instruments, holography, laser physics, and quantum optics at an intermediate level. Laboratory work involves designing experiments to verify physical models and use of photonics research equipment. The course provides the foundations for imaging, laser physics, and optical spectroscopy techniques.

### II. Course Outline

#### 1. Wave motion.- (Ch. 2)

One-dimensional waves. Harmonic waves. Phase and phase velocity. The superposition principle. The complex representation. Plane waves. Three-dimensional waves.

Homework problems: 16,17,22,30,32,35,36,41, A1, A2,A3.

#### 2. Electromagnetic theory, photons and light.- (Ch. 3)

Basic laws of electromagnetic theory. Electromagnetic waves. Energy and momentum. Radiation. Light and matter. The electromagnetic-photon spectrum.

Homework problems: 2,5,7,15,16,17,18,24,30,31,36,46.

#### 3. The propagation of light.- (Ch. 4)

Rayleigh scattering. Reflection. Refraction. Fermat's principle. The electromagnetic approach. Total internal reflection. Optical properties of metals.

Homework problems: 4,6,7,12,13,14,20,24,25,38,60.

First computer program assigned. (Tentative topic: Reflectivity curves)

#### Test 1

#### 4. Geometrical optics.- (Ch. 5)

Lenses. Mirrors. Prisms. Fiberoptics. Aberrations.

Homework problems: 12,13,14,19,24,27,33,36,38,53,54,58,63,65.

#### 5. Superposition of waves.- (Ch. 7)

Addition of waves of the same frequency. Standing waves. The addition of waves of different frequency. Beats. Group velocity. Fourier analysis of anharmonic waves. Fourier integrals of nonperiodic waves. Pulses and wavepackets. Coherence length.

Homework problems: 5,6,10,13,14,18,19,28,29,35,44, A4.

6. Polarization.- (Ch. 8)

Polarized light. Polarizers. Dichroism. Birefringence. Scattering and polarization. Polarization by reflection. Retarders. Circular polarizers. Optical activity. A mathematical description of polarization.

Homework problems: 1,4,5,10,12,16,18,21,29,32, A5, A6, A7.

Second computer program assigned.

Test 2

7. Interference.- (Ch. 9)

Conditions for interference. Interferometers. Multiple-beam interference.

Homework problems: 6,7,8,9,10,16,26,35,37.

8. Diffraction.- (Ch. 10)

Fraunhofer diffraction. Fresnel diffraction. The diffraction grating.

Homework problems: 8,9,29,31,32,33,35.

9. Modern optics: lasers and other topics.- (Ch. 11)

Lasers and laser light. Raman effect. Imagery - the spatial distribution of optical information. Holography.

Final Exam

III. Laboratory

Lab. 1. Snell's Law.

Lab. 2. Reflection, Refraction, and Polarization of microwaves.

Lab. 3. Lenses and mirrors. Optical systems.

Lab. 4. Polarization. Malus's Law. Circular polarization. Optical Activity.

Lab. 5. Interferometers. Mirrored and multiple beam.

Lab. 6. Discussion of Advanced topics in photonics

Lab. 7. Diffraction- multiple slits, circular slits, and gratings.

Lab. 8. Holography I. Single beam reflection holograms.

Lab. 9. Holography II. Single beam transmission holograms.

Lab. 10. Optical Tweezers.

Lab. 11. Raman Spectroscopy.

Lab. 12. Discussion of Advanced topics in photonics.

IV. Assessment of Student Performance

1. tests (30 points)

2. final exam (25 points)

3. homework problems and computer program (22 points)

4. lab. grade (23 points)

For the laboratory grade students must prepare two formal reports, have at all times in lab a lab notebook in which they must write all calculations, observations and procedures performed during the experiments. Students are expected to be in the lab on time, points will be deducted for tardiness.

Homework is due one week after the corresponding chapter has been completed in the lectures unless otherwise noted. Late homework will not be accepted (each homework problem is worth up to .20 points toward the final grade). The computer program is due four weeks after being assigned (the program is worth up to 5 points towards the final grade).

Grading Scale	
Final Score	Letter Grade
92.5 - 100	A
89.5 - 92.4	A-
86.5 - 89.4	B+
82.5 - 86.4	B
79.5 - 82.4	B-
76.5 - 79.4	C+
72.5 - 76.4	C
69.5 - 72.4	C-
66.5 - 69.4	D+
59.5 - 66.4	D
0 - 59.4	F

#### V. Attendance

Students are expected to attend class. No makeups will be given unless there is an emergency situation. In that case students are expected to contact the instructor no later than 24 hours after the missed lab, test or exam, otherwise they will be given a zero grade for the missed evaluation.

#### VI. Bibliography

Guenther, R., Modern Optics, J. Wiley & Sons, 1990.

Halliday, Resnick and Walker, Fundamentals of Physics, 8<sup>th</sup> Ed., Wiley & Sons, 2005.

Hecht, E., Optics, Shaum's Outline Series, McGraw-Hill, 1975.

Klein, M.V. and Furtak, T.E. Optics, 2<sup>nd</sup> Ed., J. Wiley & Sons, 1986.

Pedrotti, F. L., Pedrotti, L. S., and Pedrotti, L. M., Introduction to Optics, 3<sup>rd</sup> Ed., Pearson-Prentice Hall, 2007.

Serway, R. and Jewett, J., Principles of Physics, 4<sup>th</sup> Ed., Thomson-Brooks/Cole Publishers, 2006.

Young, H.D. and Freedman, University Physics, 11<sup>th</sup> Ed., Addison-Wesley, 2003.

#### Additional Problems

A1. A transverse wave pulse, described by  $y = 4/(x^2 + 2)$  is initiated at  $t = 0$  in a stretched string.

(a) Write an equation for the traveling pulse if it moves with a speed of 2.5 m/s in the negative  $x$ -direction.

(b) Plot (using Excel or Mathematica) the pulse at  $t = 0$ ,  $t = 2$ , and  $t = 5$  seconds.

A2. Consider the following mathematical expressions, where distances are in meters:

1.  $y(z,t) = A \sin^2[4\pi(t + z)]$

2.  $y(x,t) = A(x - t)^2$

3.  $y(x,t) = A/(Bx^2 - t)$

(a) Use the differential wave equation to determine which expressions qualify as traveling waves.

(b) If they qualify, give the direction and magnitude of the wave velocity.

A3. Determine if the following expression represents a traveling wave, if it does, determine its velocity (magnitude and direction), where distances are in meters.

$$y = \frac{100e^{-x^2-20xt+100t^2}}{x-10t}$$

A4. (a) Show in a phasor diagram the following two harmonic waves:

$$E_1 = 2 \sin \omega t \quad \text{and} \quad E_2 = 7 \sin(\omega t + \pi/4)$$

(b) Determine the mathematical expression for the resultant wave.

A5. Specify the polarization mode for each of the following Jones vectors.

(a)  $\begin{bmatrix} 3i \\ i \end{bmatrix}$  (b)  $\begin{bmatrix} i \\ 1 \end{bmatrix}$  (c)  $\begin{bmatrix} 4i \\ 5 \end{bmatrix}$  (d)  $\begin{bmatrix} 5 \\ 0 \end{bmatrix}$  (e)  $\begin{bmatrix} 2 \\ 2i \end{bmatrix}$  (f)  $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$  (g)  $\begin{bmatrix} 2 \\ 6 + 8i \end{bmatrix}$

A6. An important application of the QWP is its use in an "isolator". For example, to prevent feedback from interferometers into lasers by front-surface, back reflections, the beam is allowed to pass through a combination of linear polarizer and QWP, with the optical axis of the QWP at  $45^\circ$  to the TA of the polarizer. Consider what happens to such light after reflection from a plane surface and transmission back through this optical device.

A7. Unpolarized light passes through a polarizer with TA at  $60^\circ$  from the vertical, then through a QWP with SA horizontal, and finally through another linear polarizer with TA vertical. Determine using Jones matrices the character of the light after passing through (a) the QWP and (b) the final linear polarizer.