

ELECTROMAGNETIC WAVES AND OPTICS

PHY 411

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

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I. Course Description

Properties of electromagnetic waves are studied, with a focus on visible light. Topics include wave motion, interaction of electromagnetic waves with matter, 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 foundation 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, A4.

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, A5, A6, A7, A8, A9, A10, A11.

Computer program assigned. (Tentative topic: Ray diagrams)

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, 44, A12.

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, A13, A14, A15.

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. Geometrical Optics I

Lab. 3. Geometrical Optics II

Lab. 4. Microwaves Optics.

Lab. 5. Reflectance Curves.

Lab. 6 Polarization I. Malus's Law. Circular polarization. Optical Activity.

Lab. 7. Interferometers. Mirrored and multiple beam.

Lab. 8. Diffraction I. Multiple slits, circular slits, and gratings.

Lab. 9. Discussion of Advanced topics in photonics

Lab. 10. Diffraction II. Spectroscopy.

Lab. 11. Holography I. Single beam reflection holograms.

Lab. 12. Holography II. Single beam transmission holograms.

Lab. 13. Advanced labs in photonics: Faraday's Effect or Optical Tweezers

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. 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 but if they choose not to this will have no negative effect on their grade. Students that do attend and participate or show effort in class may receive extra credit on their tests.

No makeup labs, tests, or exams 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 or test; otherwise they will be given a zero grade for the missed evaluation.

TCNJ's attendance policy can be found at: <http://www.tcnj.edu/~recreg/policies/attendance.html>

VI. Academic Integrity Policy

Academic dishonesty is any attempt by the student to gain academic advantage through dishonest means, to submit, as his or her own, work which has not been done by him/her or to give improper aid to another student in the completion of an assignment. Such dishonesty would include, but is not limited to: submitting as his/her own a project, paper, report, test, or speech copied from, partially copied, or paraphrased from the work of another (whether the source is printed, under copyright, or in manuscript form). Credit must be given for words quoted or paraphrased. The rules apply to any academic dishonesty, whether the work is graded or ungraded, group or individual, written or oral.

TCNJ's academic integrity policy is available on the web:
<http://www.tcnj.edu/~academic/policy/integrity.html>.

VII. Americans with Disabilities Act (ADA) Policy

Any student who has a documented disability and is in need of academic accommodations should notify the professor of this course and contact the Office of Differing Abilities Services (609-771-2571). Accommodations are individualized and in accordance with Section 504 of the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1992.

TCNJ's Americans with Disabilities Act (ADA) policy is available on the web:
<http://www.tcnj.edu/~affirm/ada.html> .

VIII. Bibliography

- Guenther, R., Modern Optics, J. Wiley & Sons, 1990.
Halliday, Resnick and Walker, Fundamentals of Physics, 8th Ed., Wiley & Sons, 2005.
Hecht, E., Optics, Shaum's Outline Series, McGraw-Hill, 1975.
Klein, M.V. and Furtak, T.E. Optics, 2nd Ed., J. Wiley & Sons, 1986.
Pedrotti, F. L., Pedrotti, L. S., and Pedrotti, L. M., Introduction to Optics, 3rd Ed., Pearson-Prentice Hall, 2007.
Serway, R. and Jewett, J., Principles of Physics, 4th Ed., Thomson-Brooks/Cole Publishers, 2006.
Young, H.D. and Freedman, University Physics, 11th 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) Animate (using Mathematica) the pulse from $t = 0$ to $t = 10$ 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 and animate with a 10 second notebook.
- A3. Determine if the following expression represents a traveling wave, if it does, determine its velocity (magnitude and direction), where distances are in meters and provide an animation using Mathematica..

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

A4. Show that the lateral displacement s of a ray of light penetrating a rectangular plate of thickness t is given by $s = \frac{t \sin(\theta_1 - \theta_2)}{\cos(\theta_2)}$ where θ_1 and θ_2 are the angles of incidence and refraction, respectively. Find the displacement when $t = 3$ cm, $n = 1.50$, and $\theta_1 = 50$.

A5. A concave mirror forms an image on a screen twice as large as the object. Both object and screen are then moved to produce an image on the screen that is three times the size of the object. If the screen moved 75 cm in the process, how far is the object moved? What is the focal length of the mirror?

A6. One side of a fish tank is built using a large-aperture thin lens made of glass ($n = 1.50$). The lens is equiconvex, with radii of curvature 30 cm. A small fish in the tank is 20 cm from the lens. Where does the fish appear when viewed through the lens? What is its magnification?

A7. A diverging thin lens and a concave mirror have focal lengths of equal magnitude. An object is placed $(3/2)f$ to the left of the diverging lens, and the mirror is placed a distance $3f$ on the other side of the lens. Determine the final image of the system (as observed by someone to the left of the object), after two refractions using (a) a ray diagram and (b) the paraxial equations.

A8. (*this problem is worth three times as much as the others*) A small object is placed 20 cm from the first of a train of three lenses with focal lengths, in order, 10, 15, and 20 cm. The first two lenses are separated by 30 cm and the last two by 20 cm. Calculate the final image position relative to the last lens and its magnification relative to the original object when (a) all three lenses are positive, (b) the middle lens is negative, (c) the first and last lenses are negative. Provide ray diagrams for each case.

A9. A convex thin lens with refractive index of 1.50 has a focal length of 30 cm in air. When immersed in a certain transparent liquid, it becomes a negative lens with a focal length of 188 cm. Determine the refractive index of the liquid.

A10. A parallel beam of light is incident on a plano-convex lens that is 4 cm thick. The radius of curvature of the spherical side is also 4 cm. The lens has a refractive index of 1.50 and is used in air. Determine where the light is focused for light incident on each side.

A11. An airplane is used in aerial surveying to make a map of ground detail. If the scale of the map is to be 1:50,000 and the camera used has a focal length of 6 inches, determine the proper altitude for the photograph.

A12. (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.

A13. Specify the polarization mode for each of the following Jones vectors.

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

A14. 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° 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.

A15. Unpolarized light passes through a polarizer with TA at 60° 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.