

PHYS 202 OUTLINE FOR PART III LIGHT & OPTICS

Electromagnetic Waves

A. Electromagnetic waves

S-23,24

1. speed of waves = $1/(\mu_0\epsilon_0)^{1/2} = 3 \times 10^8 \text{ m/s} = c$
2. waves and frequency: the spectrum
 - (a) radio
 - (b) microwave & radar
 - (c) infrared
 - (d) visible ----- colors
 - (e) ultraviolet
 - (f) x-ray and gamma ray

red
orange
yellow
green
blue
violet

Supplementary Problems (S-):

23. Given the wavelength of an electromagnetic wave, identify its type (e.g., given a wavelength of $5.5 \times 10^{-7} \text{ m}$, the type is visible (yellow)).

24. a) What is the speed of light in air? b) What is the speed of light in water (index of refraction of water = 1.33)? c) If red light of wavelength 630 nm (in air) is used, what is the frequency of this light in air? On entering the water, does the light: d) change color? e) change frequency? f) change wavelength? (If YES to any of the above three question, tell what it changes to.)

Answers to Supplementary Problems:

24. a) $3.0 \times 10^8 \text{ m/sec}$; b) $2.26 \times 10^8 \text{ m/sec}$; c) $4.76 \times 10^{14} \text{ Hz}$; d) No; e) No; f) Yes, 474 nm.

Reflection and Refraction of Light

A. Reflection & Refraction

S-25 to 28

1. reflection: $\theta_i = \theta_{refl}$
2. refraction: Snell's law: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$
 - (a) index of refraction: $n \equiv c/v$
 - (b) total internal reflection - fiber optics
 - (c) apparent depth

Supplementary Problems (S-):

25. A ray of light coming from air hits the surface of a swimming pool. (The index of refraction of water is 1.33, remember.) The angle the ray makes with the SURFACE is 70° . a) What is the incident angle? b) What is the refracted angle?

26. If the critical angle for a certain plastic is 42° , what is its index of refraction?

27. The velocity of sound is 350 m/sec in AIR and 1400 m/sec in WATER. a) What is the critical angle for a sound wave incident on the surface between air and water? b) Which medium has the higher "index of refraction" for sound?

28. a) Can sound in air "critically reflect" from water or can sound in water "critically reflect" from air? b) Can light in air "critically reflect" from water or can light in water "critically reflect" from air?

Answers to Supplementary Problems:

25. a) 20.0°; b) 14.9°.

26. 1.49 .

27. a) 14.5°; b) Air.

28. a) Sound in air can "critically reflect"; b) Light in water can "critically reflect".

Mirrors and Lenses

A. Thin Lenses

S-29,30

1. focal length

2. lens makers eq: $1/f = [(n_{\text{material}} - n_{\text{medium}})/n_{\text{medium}}] [(1/R_{\text{front}}) + (1/R_{\text{rear}})]$

signs in above equation: convex lens: $R_{\text{front}} > 0$; $R_{\text{rear}} > 0$

concave lens: $R_{\text{front}} < 0$; $R_{\text{rear}} < 0$

3. thin lens equation: $1/f = (1/s) + (1/s')$

4. Magnification: $M = h'/h = -s'/s$ [+M means right-side-up; -M means up-side-down]

5. aberrations

B. Applications

S-31,32,33

1. camera and projector: $s > f$; $M < 0$; inverted, real image;

camera: $s \gg f$, $s' > f$, $|M| < 1$; projector: $s > f$, $s' \gg f$, $|M| > 1$

2. magnifying glass: $s < f$; $s' \approx -25$ cm; upright, virtual image

Supplementary Problems (S-):

29. A lens is made from a glass of index of refraction = 1.46, and has radii of curvature of -10 cm and +5 cm. a) What is the focal length of this lens? b) Is this a converging or diverging lens? c) If the radii were changed to +10 cm and -5 cm, would the focal length change, and if so what would it be? d) Is this a converging or diverging lens?

30. Design a lens that has a focal length of 5 cm.

31. A 35 mm camera has a lens of focal length 55 mm. a) A picture of a mountain one mile away is to be taken. How far away should the film be from the lens? b) A picture of a person 5 meters away is to be taken. How far away should the lens be from the film? c) A close-up picture of a person 60 cm away is to be taken. How far away should the lens be from the film? d) In part b, if the person is 5'11" (1.80 m) tall, how big will his image be on the film? e) In part c, if the person's face is 25 cm long, how big will the image be on the film?

32. A magnifying glass has a focal length of 4 cm. a) Draw a diagram showing the object, lens, image and eye. Include the focal point of the lens in your diagram. b) What should the image distance be if it is used properly? c) What is the magnification of this lens when used properly?
33. A person can see things well only if they are at least 75 cm away (the person is farsighted). a) Draw a diagram showing the eye, the lens, the object and the image. b) What focal length glasses should this person wear?

Answers to Supplementary Problems:

29. a) 21.7 cm; b) Converging; c) Yes, -21.7 cm; d) Diverging.
 30. Many possible answers.
 31. a) 55.002 mm; b) 55.6 mm; c) 60.6 mm; d) 20.0 mm; e) 25.25 mm.
 32. b) -25 cm; c) 7.25 X.
 33. b) $f = +37.5$ cm

Wave Optics

A. Interference

S-34

1. Youngs double slit: $n_{\max} \lambda = d \sin(\theta_{\max})$; [for $\theta < 1$ rad, $\sin\theta \approx \tan\theta = y/L$]
2. diffraction grating: same formula as Youngs; sharper dots
3. thin films: depends on n of all three media
 - a) what do you want: constructive (bright): then need 0 or 360° phase difference
 destructive (dim): then need 180° phase difference
 - b) if $n_{\text{air}} < n_{\text{film}} < n_{\text{base}}$, then have no phase difference due to reflection
 if $n_{\text{air}} < n_{\text{film}} > n_{\text{base}}$, then have 180° phase difference due to reflection
 - c) now determine what the phase difference due to $2t$ is:
 if want 360° phase difference, then have: $2t = \lambda_{\text{film}} = \lambda_{\text{air}}/n_{\text{film}}$
 if want 180° phase difference, then have: $2t = \lambda_{\text{film}}/2 = \lambda_{\text{air}}/2n_{\text{film}}$

B. Diffraction: (same as for sound):

S-35,36

1. slit: $n_{\min} \lambda = w \sin(\theta_{\min})$ (where w is the slit width)
2. circular opening: $1.22 n_{\min} \lambda = D \sin(\lambda_{\min})$ (where D is the diameter)

C. Polarization

1. by absorption (polaroid sunglasses)
2. by reflection (why polaroid sunglasses are especially useful)
3. by double refraction (different n_i in different directions)
4. by scattering

D. Seeing color: how the eye operates

Supplementary Problems (S-):

34. Laser light of wavelength 632 nm is directed through a double slit with slit separation of 0.1 mm. What is the distance between adjacent maxima on a screen 4 meters away?

35. A laser light of wavelength 633 nm shines through a crack and the resulting diffraction pattern on a screen 2 meters away shows the central maximum to have a width of 1.2 cm. How wide is the crack?

36. A low frequency (50 Hz) sound wave ($v = 350$ m/s in air) is incident on a door of width one meter. (a) What is the angle for the first minimum as the sound spreads out due to the diffraction effects of the door? (b) What if the frequency is 500 Hz?

Answers to Supplementary Problems:

34. 2.53 cm.

35. 0.211 mm.

36. a) no minimum; b) 44.4° .

OPTICAL INSTRUMENTS

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|----------------------------------------------------------------------------------------------------|---------|
| A. Cameras | S-37,38 |
| 1. f-stop = f/D | |
| 2. time: amount of light proportional to time and area (D^2) | |
| 3. diffraction effects proportional to $1/D$ [$1.22 \lambda = D \sin(\theta_{\text{limit}})$] | |
| 4. thin films for minimizing reflection (see above) | |
| B. The eye | S-39 |
| 1. focusing | |
| 2. acuity | |
| C. Telescope: magnify angle since $h' \ll h$: $MP = \theta_{\text{with}}/\theta_{\text{without}}$ | S-40 |
| 1. astronomical: $M = f_o/f_e$; $L = f_o + f_e$ | |
| 2. terrestrial: use f_o to form image (projector); use f_e as magnifying glass | |
| D. Microscope: magnification $\gg 1$ ($h' \gg h$) | S-41 |

Supplementary Problems (S-):

37. A 35 mm camera has a 50 mm lens (the focal length is 50 mm and the film is 35 mm long and 24 mm wide). (a) What is the diameter of the opening to the lens when an f-stop of 2.0 is used? (b) If a time of 1/60 second was used correctly with this f-stop, what time should be used for the same exposure when the f-stop is changed to 1.4? (c) Which f-stop setting would give the smallest diffraction effects? (d) Which of the two f-stop settings would give the best overall focus including foreground and background? (e) If an object of length 1 meter is to be photographed and is to exactly fit on the long side of the film, how far away should the object be from the camera? (f) How far should the film be from the lens for this?

38. Answer the questions in problem 37 above for the case where a 135 mm lens is used instead of the 50 mm lens.
39. What is the minimum angle (according to the Rayleigh Criterion) that a person with good eyesight can resolve? (Estimate the diameter of the opening to the eye [pupil] and use the middle of the visible spectrum for the wavelength of the light.)
40. C.B.U. has an 8 inch telescope with an objective lens of focal length 2.0 meters. (a) If a magnification of 50X is desired, what focal length lens should be used as an eyepiece? (b) What is the maximum useful magnification that this telescope can provide? (c) What size focal length eyepiece would give this?
41. Design a microscope that gives a magnification of exactly 340X.

Answers to Supplementary Problems:

37. (a) 25 mm; (b) 1/120 sec; (c) the 1.4 setting; (d) the 2.0 setting; (e) 1.478 m; (f) 51.75 mm.
38. (a) 67.5 mm; (b) 1/120 sec; (c) the 1.4 setting; (d) the 2.0 setting; (e) 3.992 m; (f) 139.72 mm.
39. for a pupil diameter of 4 mm, $\theta_{\text{limit}} \approx 0096^\circ \approx \frac{1}{2}$ arc-minute.
40. (a) 4.0 cm; (b) about 500 X; (c) about a 4 mm lens.
41. Many answers possible.