Jan 5

Concepts

- Form of 1-D and 3-D wave equation
- Mathematical form of a disturbance moving with constant shape
- Meaning of complex amplitude of a wave
- 1-D waves and 3-D plane waves are the only waves that can move with unchanging profile (with dispersion, even these don't)
- In spherical and cylindrical waves the amplitudes must decrease
- Wavefronts: surfaces of constant phase
- Why $\vec{k}\cdot\vec{r} = \text{constant}$ represents a plane
- Wavefront surfaces on cylindrical and spherical waves
- Full plane wave form $\vec{E} = \vec{E}_o e^{i(\vec{k}\cdot\vec{r}-\omega t)} = \left(E_{ox}\hat{x} + E_{oy}\hat{y} + E_{oz}\hat{z}\right)e^{i(k_x x + k_y y + k_z z - \omega t)}$

Skills

- Determine which functions obey the wave equation
- Complex representation of waves
  - Find amplitude and phase delay
  - Represent on phasor diagram
  - Add two or more waves with phasor diagrams and complex numbers
- Construct a plane wave given propagation direction, and info such as λ, ω, v.

Jan 7

Concepts

- Physical (wave optics) vs geometrical optics regimes
- Relation between dielectric constant K, electric permitivity ε
- Recognize the integral and derivative forms of each of Maxwell's equations (in a vacuum for now)
  - Faraday's Law, Ampere's Law, Gauss's Law-electric, Gauss'Law-magnetic
- Describe the physical content of each law above in own words, for integral and derivative forms.
- Write E/M wave equations in general vector form and in Cartesian form for each component
- Radiation comes from accelerating charges (nonuniform motion)
- Radiation is strongest perpendicular to acceleration
- Synchrotron radiation searchlight pattern. Role of magnetic field in stellar synch. rad.
- Electric dipole radiation
  - Field: 1/r behavior vs $1/r^2$ of static field; k^2 or ω^2 behavior
  - Intensity: $1/r^2$ behavior; k^4 or ω^4 behavior
  - $\sin\theta$ behavior
  - Conceptually, how an accelerating charge creates a transverse E field, and a B field perpendicular to this; how this propagates.

Skills

- Curl and divergence

Derivations

From Maxwell's equations show $\vec{k}\times\vec{E} = \omega\vec{B}$ and $\vec{k}\times\vec{B} = -\mu_o\varepsilon_o\omega\vec{E}$, and from this argue why E, B must be perpendicular to k vector and to each other, and that $B_o = \frac{E_o}{c}$

Jan 9

Concepts

Energy
Energy quantities always involve square of amplitude (field)
Energy density u of a field
Poynting vector's magnitude is what physical quantity?
Book uses term "irradiance" for intensity
How is energy distributed between E, B fields in plane wave?
In plane waves of typical intensities, which exerts more force on an electron, E or B ?
Simple relationship between energy density and intensity (Fig 3.16 and discussion)
Average of $\cos^2\omega t$, $\sin^2\omega t$ over one period
sinc function definition

Photons
Oscillating field amplitudes are quantized and so are energy densities
All E/M waves exchange energy in quanta as photons are created or destroyed.
Many photons together exhibit behavior of a classical wave optics on average.
Lecture: Photons have a wavefunction ψ. $|\psi|^2$ is probability of finding photon in a given spot, and is proportional to $|\vec{E}(\vec{r},t)|^2 \propto u \propto I$
Different photon states: fields of different polarizations, different frequencies, or phase.
Do photons exclude others from the same state, congregate in the same state, or are they oblivious of each other?
Energy $\mathcal{E}$ of one photon $\mathcal{E} = h\upsilon = \hbar\omega$
How is momentum of one photon related to $\vec{k}$ and to $\mathcal{E}$**?**

Pressure $\mathcal{P}$ of plane wave
How is $\mathcal{P}$ related to u and I (no pun intended)?
Why different for perfectly absorbing vs perfectly reflecting surfaces?

Emission from atoms – this section is a review of 222 concepts

Optical cooling how do they arrange it so atoms absorb light only if they are moving *toward* the laser beam, and hence get slowed by the incoming momentum of light?

Skills

Find number of photons given P, I, u in a wave or total energy in a pulse.

Derivations

Simple relationship between energy density and intensity (Fig 3.16 and discussion)
Show that intensity drops as $1/r^2$ for a spherical wave (or in a dipole emission pattern)
Pressure of wave on surface from $\mathcal{P} = F/A$ and $F = \frac{\Delta p}{\Delta t}$

Jan 12

3.5 Matter and index

Concepts

- magnetic effects are usually negligible in optics

- same wave equation as vacuum, but ε is different from ε_o in matter (see appdx if want details)
- n determined by ε, K
- Both absorption (loss) and elastic scattering (loss-free) increase as we approach a transition (resonance). This gives an index that changes with frequency.
- Polarization P: dipole moment per volume
- Lorentz model: electron mass – spring oscillator resonances matching quantum frequencies
- for optical frequencies, motion of valence electron cloud gives the dipole motion
- other resonances of charge motion affect $\varepsilon(\omega)$ and $n(\omega)$ in other ranges: microwaves, IR, xrays
- normal vs anomalous dispersion
- Can index be less than 1? ($v_{phase} > c$)
- Lecture: Damping and complex n, ε, K needed near resonance.
- Lecture: Phase of response determines effect on wave.
- Lecture: decaying wave from complex n: absorption coefficient

Skills

Analyze driven damped oscillator with complex method

Derivations

from wave equation find relation between n, ε, K
decaying wave from complex n: absorption coefficient

Jan 14

4.1-3, 4.11.2

Concepts

- why sky is blue, sunsets red: Rayleigh scattering and thermal fluctuations
- Rayleigh scattering obeys dipole emission formula
- When scattering objects are further apart than λ, lateral scattering is strong
- When scattering objects get closer, lateral scattering is weaker and goes to zero for
- Interference (phasor) arguments for two previous statements.
- Mie scattering (whitish) vs Rayleigh (bluish): size of scatterers vs λ, and which frequencies are scattered most
- Forward is the only direction all scattered wavelets add constructively, so forward direction is still strongest propagation
- Phase delays of secondary emission by atoms slows the waves down; advances speed it up
- Photons always propagate at speed c, even when $n \neq 1$
- photons are immediately scattered by an atom (when there is no absorption), but the *phase* in their wavefunction is altered
- In reflection, atoms to a depth of about $\lambda/2$ participate
- Internal reflection vs external reflection have π relative phase shift
- rays direction of radiant energy, perpendicular to wavefront
- plane of incidence contains: surface normal, incident, reflected and transmitted rays
- specular vs diffuse reflection, and surface irregularities vs λ
- photon momentum conservation parallel to surface yields law of reflection, refraction
- Lecture: ε in wave equation assumes a *continuous* medium over scales much less than λ. So wave equation cannot describe scattering

- Lecture: the continual reduction of lateral scattering with increasing density is the transition between the random scattering view and unscattered wave motion in a dense medium which the wave equation describes.

Skills

Calculate the relative scattering strength for different λ’s for dipole (Rayleigh) scattering

Derivations

Law of reflection, refraction from photon momentum conservation of component parallel to interface.

Jan 16

4.4-5 Refraction, Fermat

Concepts

note: ignore 4.4.3

- how rays turn toward or away from normal
- beams get wider as they turn toward the normal (how does this affect intensity?)
- frequency is unchanged as n varies; λ, v change
- Huygen’s principle
- Fermat’s principle
- Optical pathlength definition and relation to time to trace path,
- Lecture: Optical pathlength and relation to phase shift along path
- Mirages and Fermat. Thermal vs gravitational effects on n(height)
- Lecture: turning of wavefronts in gradually varying $n(\vec{r})$ (e.g mirage and Fig 4.33)
- Fermat’s principle, stationary phase and constructive interference along paths.

Skills

Apparent depth and refraction

Derivations

Snell’s law from movement of points on wavefronts (Fig 4.19)

Snell's and reflection law from Fermat's principle

Jan 21

4.6

Concepts

- Boundary conditions on E and B: parallel components conserved (just as in momentum)
- 4.6.2: read derivation to the depth you wish. See last paragraph: signs give vector directions relative to conventions in figs 4.39 and 4.40.
- Light is "in-phase" with incident light if E and B look the same when viewed as the light comes directly toward you: i.e. viewed looking in the direction of $-\vec{k}$.
- There is often a phase shift ε_r and ε_t for refl., trans. vs incident. They become the *signs* of the relative amplitudes r and t.
- normal incidence r,t; R,T easy from Fresnel: phase shift on reflected E if going from low to high index
- Lecture: complex n can be used in same Fresnel equations when there is absorption, which give general phase shifts, not just 0 or π (sign change). Transmission amplitude obtained is that *right* at the surface, as it decreases moving into the material. Snell’s law involves only the real part of $\tilde{n}$.

- E-field polarization directions ⊥ and || vs plane of incidence. Lecture: … s and p polarization respectively.
- 4.6.3: Correction in 4.46 and right above: $\theta_i=0$ should be $\theta_i \approx 0$. "Polarization angle" is Brewster's angle.
- Lecture: Brewster's angle and dipole radiation direction
- R, T proportional to intensities. T must include beam broadening factor related to angle.

Skills

From Fresnel equations get amplitude and phase shifts for real or complex n. Relate to field directions

Derivations

From equ 4.17 (phase continuity at the interface) derive frequency (photon energy) conservation, laws of reflection and refraction.

Jan 23

4.7,8 Internal reflection, metals

Concepts

note: ignore 4.4.3

- Fig 4.42: Brewster's angle also exists for internal reflection
- above critical angle for total internal reflection, θ_t and r become complex, but |r| = 1.
- Evanescent wave decays away from surface, but travels along it.
- QM analogy to TIR: Lecture: photons penetrate barrier and turn back
- QM analogy to FTIR: Lecture: photons penetrate barrier some tunnel through
- In a metal, conduction electrons are free, and so don't have resonances. Free electrons reflect all frequency equally, up to plasma frequency. Bound electrons still have resonances, and this affects spectrum some.
- Plasma frequency: below it, light is essentially all reflected and above it, light is essentially all transmitted.
- Lecture: complex n from free electrons in metals results in reflection, not absorption. Phase of these electrons' motion is π vs E-field, so they can't absorb

Skills

Use complex n in Fresnel equations to find percent reflected, in a thick metal, and by energy conservation, how much absorbed.

Derivations

Propagation and decay properties of the evanescent wave (eq. 4.73), in terms of θ_i

Jan 26

5.1,2 Lenses

Note: this is a long section, and I want you to **focus on the following portions**, rather than reading it all. Some are just one or two things on a page. You might want to mark these portions with pencil.

Concepts

5.2.1 through pg 151: (1.5 pgs)

- ideal glass shape to convert light from a point source in air to a plane wave is ___________.
- ideal glass shape to convert light from a point source in glass to a plane wave in air is _______.

5.2.2 through definition of paraxial rays (2 pgs)

- eq 5.8 and relation to fig 5.6: focusing by a single surface
- paraxial rays stay close to the ________ axis, so that in Snell's law the small _________ approximation holds.

5.2.3 pg 156

- fig 5.12: types of simple spherical lenses

5.2.3 pg 158

- review eqs 5.16, 17

5.2.3 all of pg 162-165

- Newtonian form of thin lens equation and Fig 5.22
- Transverse magnification

5.2.3 pg 168

- Definition of front and back focal length

5.2.3 pg 169

- eq 5.38, 5.39: result of putting thin lenses in contact with each other

5.2.3 all of pg 170 to end of 5.2.3 (1 and ¼ page)

- A lens or any imaging system focuses many rays in many directions from one point to another. All of these rays travel paths that are the same ________________. See fig 5.32

Tables, convention

- Table 5.1 Signs conventions
- Table 5.2 Physical meanings of signs of imaging parameters
- Table 5.3 Images of real objects. Check each one of these with simple ray diagrams to review s

Skills

Basic imaging with thin lenses, as in Phys 123, including with more than one lens. Real and virtual images. Magnification.

Derivations

Jan 28

5.3,4 Stops, mirrors

Concepts

- Field (FS) and aperture stops (AS)
- entrance pupil: the image of the aperture stop as seen from the (axial) *object* location
- exit pupil: the image of the aperture stop as seen from the (axial) *image* side. Eye placed here for visual instruments. Exit pupil should be as big as eye pupil.
- chief ray: one from every off-axis object point. Goes through center of AS, so it heads toward the center of the EP.
- marginal ray: axial object point headed toward edge of entrance pupil (barely makes it by the AS). Likewise the marginal ray hits the axial image point as though it came from the edge of the exit pupil.
- relative aperture
- f-number
- Intensity at image proportional to square of _______
- a “fast lens” is has a _________ small/large f-number.
- mirror imaging systems avoid dispersion and absorption problems
- shape of mirror for converting a point source into plane waves (or vice versa in focusing) is ______________.
- shape of mirror for focusing light from one point to another is ____________________
- shape of mirror for focusing light from one point to another is ____________________
- Fig 5.52, 5.53 to review ray drawing techniques

- Table 5.5…play with a shiny spoon to review.

Skills

Basic imaging with thin lenses, as in Phys 123, including with more than one lens. Real and virtual images. Magnification.

Derivations

Derive the mirror imaging relation eq 5.48, (and hence the focal length), given Figure 5.50. Note the essential use of small angle approximations.

Jan 30

5.5,6 Prisms, Fibers

Concepts

5.5.1 through pg 188:

- apex angle (we'll focus on isosceles triangle prisms)
- angle of minimum deviation

5.5.2 through definition of Porro prism, and then fig 5.68

- note difference in how light goes through a reflecting prism vs diffracting prism:
- reflecting isosceles triangle prisms are achromatic: dispersion at first interface is reversed at the final interface.
- right angle prism vs Porro prism: note orientation of prism and which one flips RH to LH, due to number of reflections
- fig 5.68: example of erecting system, e.g. for flipping inverted images in binoculars without left-right flip.

5.6 all

- attenuation in fibers much lower than copper. Lecture: importance of choosing ω for low loss
- purpose of cladding
- coherent bundles are used for ______________
- step index vs GRIN fiber
- ray picture valid only for $D \gg \lambda$. Lecture: mode picture from wave optics
- intermodal dispersion and how a single mode fiber avoids this
- Lecture: group velocity dispersion
- capillary optics use principle of __________________________ to direct x-rays.

Skills

Derivations

acceptance angle eq 5.62

intermodal dispersion eq 5.68