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Homework assignments

CLASS 25:

9.3.1: ELECTROMAGNETIC WAVES IN MATTER

Now for the practical stuff. A few sections ago we developed equations for electromagnetic waves in free space, where there are neither charges nor current. And yet a lot of optics deals with the motion of electromagnetic waves through matter such as glass or water. (Optics would be pretty dull if we only considered light travelling in a vacuum.) How do we cope?

We can rewrite Maxwell's equations in terms of the two vector fields $\vec{E}$ and $\vec{B}$, and two new fields, the displacement field, $\vec{D}$, and $\vec{H}$ (which is often referred to as “the magnetic field”, with $\vec{B}$ being referred to as the “magnetic induction”. We will not spend enough time with $\vec{H}$ in this course for this distinction to be worth the effort.). If we do this, Maxwell's equations in matter appear similar to the equations in free space, only with μ_0 being replaced by μ and ε_0 being replaced by ε. (The latter is just a change by the factor of the dielectric constant, κ.) This leads to only two fundamental changes. First of all, the speed of light changes from $c = (\mu_0\varepsilon_0)^{-1/2}$ to $v = (\mu\varepsilon)^{-1/2}$. In the laboratory we describe this by saying that the speed of light slows down by a factor of n, the *index of refraction*, where $n=c/v$. The other change is that B_0 / E_0 is altered by this same factor of n:

$$B_0 = E_0 / v = nE_0 / c .$$

Cool! Since μ nearly equals μ_0 for most transparent materials,

$$n^2 = \varepsilon:$$

the index of refraction and the dielectric constant (optics and electrodynamics) are very, very closely related.

9.3.2-3: FRESNEL'S EQUATIONS

Now we are finally ready to deduce the laws governing light traveling between two transparent media. This is done in your book in sections 9.3.2 and 9.3.3, however, I will provide you with a two-page summaries (1) that show the derivation of the resultant equations, Fresnel's equations. Look these over before class.

A few issues come up once we have derived Fresnel's equations. For one, they produce the interesting (and not surprising) result that, if there is no change in the index of refraction, there is no reflection. This is called 'index matching', and it is very handy to know about. Hopefully your instructor will put together some cool demonstrations of it. If not, be sure to ask him about: (a) Making a pyrex test tube 'disappear' in oil, (b) the appearance of a white hair under a microscope, both with and without immersion in an index-matching solution, and (c) using index-matching (matching the index of refraction, “n”) to destroy the iridescence of butterfly wings. He'll welcome the chance to digress.

Index matching with iridescent butterfly wing
http://www.youtube.com/watch?v=jeUd_ittNns&feature=channel_page

Another physical phenomenon which occurs is the Brewster angle, the angle at which a certain polarization of light passing between two transparent media is totally transmitted with no reflection. (Anti-reflection sunglasses, anyone?) We will introduce this phenomenon through the Fresnel equations, but we will also show its origin in a much easier to visualize way. (Maybe next class)

One last very useful rule of thumb about Fresnel's equations. If you solve for the reflection between air and glass (*n=1.5*), you get *r=0.2* (ratio of the reflected electric field to the incident electric field), or a reflection (ratio of reflected *energy* to incident *energy*) of $R = (0.2)^2 = 4\%$. Ever notice that you see your reflection clearly when you look into a storefront window at night, but not during the day? Compare this 4% reflection to the transmission of light from *inside* the window.

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CLASS 26:

11.1.2 DIPOLE RADIATION

The only thing I want to cover in Chapter 11 (as fate would have it, there's little time left to cover anything else in it...) is the material in Section 1.2 on dipole radiation. The rest of the chapter covers other types of sources of radiation, so why do I insist on covering this one? (a) It is the simplest example to study, and would help us should we decide to tackle the other types of sources, and (b) it allows us to understand two interesting physical systems: the linear antenna -- as either an emitter or receiver -- and the individual oscillating atoms and/or molecules that give rise to the *Rayleigh scattering* that makes the Earth's sky appear blue.

We will cover the derivation given in this section of the book. Look over it. The important thing about this derivation is the notion of 'retarded potentials' ('delayed potentials' might be an apter name). These potentials arise because you need to account for the fact that the field one light year away from a dipole, for example, is the result of the dipole's condition *one year ago*, and not of its present condition: it takes an electric field time to propagate through space. When we take the perfect dipole approximation limit, this derivation leads to an electromagnetic wave whose power is proportional to the fourth power of the frequency at which the dipole oscillates. Hence the scattering will be much larger for blue visible light than for red.

What the book doesn't supply is the rationale for assuming that molecules in the sky behave as oscillating dipoles. ***We will show*** that the mathematics for the electron cloud distribution in a molecule is the same differential equation as for the driven and damped harmonic oscillator: this is a resonance phenomenon. The chief thing to remember here, though, is that we are looking at the behavior far away from resonance. Resonance for these molecules is well into the ultraviolet part of the electromagnetic spectrum. The other thing to remember is that, if the scatterer is close to the same size as the wavelength of what is being scattered, different parts of the molecule will be scattering *out of tune* with each other and cancel out. This is why water droplets in clouds appear white (wavelength-nonspecific scattering) while the molecules in the air make the sky appear blue (Rayleigh scattering): water droplets in clouds are just too damn large ($>>\lambda$). We will discuss other examples of Rayleigh scattering and non-Rayleigh scattering.

One last item about scattering. Scattered light can be highly polarized. This is the result that polarization is always perpendicular to the direction of motion of light. In fact, this is why the zero reflection at the Brewster angle occurs. You should go outside in the daytime with polarizers and observe the sky and see whether the [hopefully] blue sky is polarized in certain directions. Which ones? Or, if you wear polarized sunglasses, tilt your head one way or the other as you look at a cloudless sky. In which directions is the sky highly polarized?

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Assorted relevant physics music:
Haverford: Magnetic Monopoles Song
The Physics chanteuse: Maxwell's equations in song