Chapter 33: Electromagnetic Waves
Questions and Example Problems

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \theta_c = \sin^{-1} \frac{n_2}{n_1} \quad I = \frac{P_s}{4\pi r^2} \quad p_r = \frac{I}{c} \]

\[ v = \frac{c}{n} \quad \lambda_n = \frac{\lambda}{n} \quad \theta_B = \tan^{-1} \frac{n_2}{n_1} \quad I = \frac{1}{2} I_0 \quad I = I_0 \cos^2 \theta \]

Example 33.1
a. H.G. Wells, in his novel “The Invisible Man,” described a concoction that would render the person who drank it invisible. Give arguments to prove that a truly invisible person would be blind.
b. What is a plausible explanation for the observation that a street appears darker when wet than when dry?
c. Fire engines used to be red. Yellow-green is now the preferred color. Why the change?
d. Sunlight or starlight passing through the earth’s atmosphere is always bent toward the vertical. Why? Does this mean that a star is not really where it appears to be? Explain.
e. When light is incident on an interface between two materials, the angle of the refracted ray depends on the wavelength, but the angle of the reflected ray does not. Why should this be?
f. A salesperson at a bargain counter claims that a certain pair of sunglasses has Polaroid filters; you suspect that the glasses are just tinted plastic. How could you find out for sure?
g. How can you determine the direction of the polarizing axis of a single polarizer?

Example 33.2
a. What is the radiation pressure 1.5 m away from a 500 W lightbulb? Assume that the surface on which the pressure is exerted faces the bulb and is perfectly absorbing and that the bulb radiates uniformly in all directions?
b. Radiation from the Sun reaching Earth (just outside the atmosphere) has an intensity of 1.4 kW/m². Assuming that Earth (and its atmosphere) behaves like a flat disk perpendicular to the Sun’s rays and that all the incident energy is absorbed, calculate the force on Earth due to radiation pressure. For comparison, the force due to the Sun’s gravitational attraction on the earth is \(3.6 \times 10^{22}\) N. How do they compare?
Example 33.3
In the figures, unpolarized light is sent into a system of three polarizing sheets. The angles $\theta_1$, $\theta_2$, and $\theta_3$ of the polarizing directions are measured CCW from the positive direction of the $y$ axis (they are not drawn to scale). Angles $\theta_1$ and $\theta_3$ are fixed, but angle $\theta_2$ can be varied. The plot gives the intensity of the light emerging from sheet 3 as a function of $\theta_2$. (The scale of the intensity axis is not indicated.) What percentage of the light's initial intensity is transmitted by the three-sheet system when $\theta_2 = 30^\circ$?

Example 33.4
Light is incident at angle $\theta_1 = 40.1^\circ$ on a boundary between two transparent materials. Some of the light travels down through the next three layers of transparent materials, while some of it reflects upward and then escapes into the air. (a) Physically interpret the refractions for this diagram. (b) Determine the values of $\theta_5$ and $\theta_6$?

Example 33.5
The ray is incident at the critical angle on the interface between materials 2 and 3. Find (a) index of refraction $n_3$ and angle $\theta$. (b) If $\theta$ is decreased, does light refract into material 3?