Interaction of light with matter

(usually $T \leq 1$)

In most cases e-m wave loses energy as it travels through the material: absorption. It can be caused by many different processes, but often can be described by a single parameter

Absorption coefficient β →
or attenuation

$$\frac{dI}{dz} = -\beta I$$

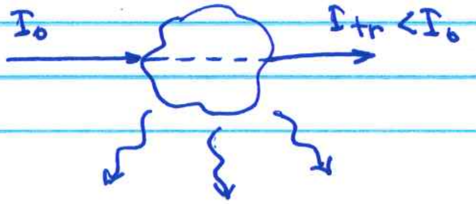
relative reduction of intensity per unit length

$$I_{out} = I_{in}\, e^{-\beta \cdot z}$$

Where absorption comes from and what processes it leads to?

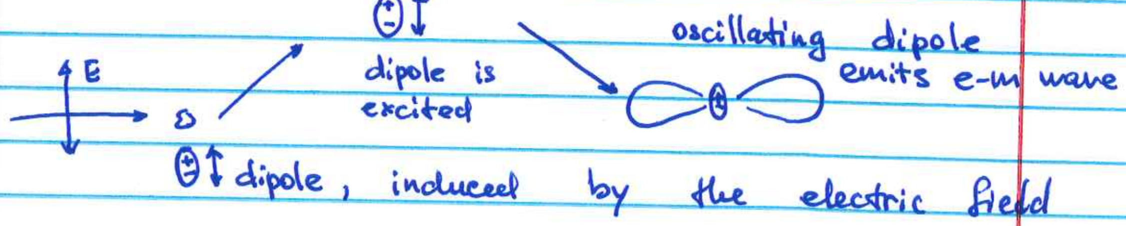
Sometimes by <u>absorption</u> people understand only the loss of em energy when it is converted to some other form (heat, sound, ets)

Often, em energy is absorbed from the original wave, and then re-emitted as another e-m wave



- fluorescence (in all directions)
- scattering

Classical model of scattering
or
why the sky is blue, and the sunset is red, and the clouds are white



Single dipole moment $\vec{p}(t) = \alpha \varepsilon_0 \vec{E}_0 \cos(\omega t)$
α - polarizability, a parameter of "stiffness" of charges within a molecule / particle

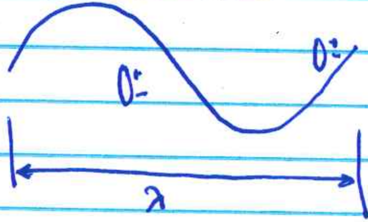
Total power emitted by one oscillating dipole

$$W_{dip} = \frac{\omega^4 \alpha^2 \varepsilon_0 E_0^2}{12\pi c^3}$$

The radiation also has an angular distribution but we won't go too deep into it.

a) Size of a particle << light wavelength

Rayleigh Scattering



Each particle ~ point dipole
N particles / volume
scatter the same way

Number of particle per unit area
$N dz$

~~Energy~~ Power
~~Power~~ emitted per unit area

$$dW = N dz \cdot W_{dip} = N dz \cdot \frac{\omega^4 \alpha^2 \varepsilon_0 E_0^2}{12\pi c^3}$$

The power of the incoming wave

$$W = \frac{1}{2} \varepsilon_0 c E_0^2$$

Power lost from the original wave $\qquad \frac{\omega}{c} = \frac{2\pi}{\lambda}$

$$dW = -N\,dz \, \frac{\omega^4}{c^4} \alpha^2 \frac{1}{6\pi} W = -N\,dz \, \frac{8\pi^3}{3\lambda^4} \alpha^2 W$$

$$\frac{dW}{W} = -\frac{8\pi^3}{3} N \frac{\alpha^2}{\lambda^4} dz$$

or $$\frac{1}{W}\frac{dW}{dz} = -\frac{8\pi^3}{3} N \frac{\alpha^2}{\lambda^4}$$

We can connect polarizability with the average refractive index!

Total polarization $\quad P = p \cdot N \qquad D = \varepsilon_0 \underline{\varepsilon} E = \varepsilon_0 (E + P)$

$$\varepsilon = 1 + \frac{Np}{E} = 1 + N\cdot\alpha$$

$$n = \sqrt{\varepsilon} = \sqrt{1 + N\cdot\alpha} \approx (1 + \frac{N\alpha}{2}) \text{ for } N\alpha \ll 1$$

$$\alpha = \frac{2(n-1)}{N}$$

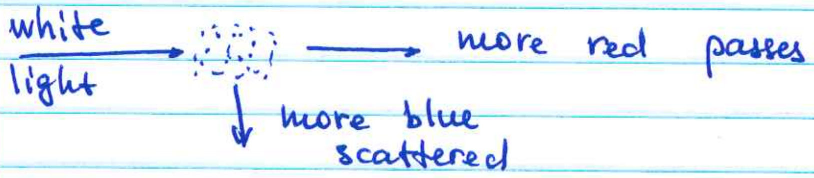
$$\frac{1}{W}\frac{dW}{dz} = -\frac{8\pi^3}{3} \frac{4(n-1)^2}{N\lambda^4} = -\frac{32\pi^3}{3} \frac{(n-1)^2}{N\lambda^4}$$

$$W(z) = W(0)\, e^{-\beta z}$$

$$\beta = -\frac{32}{3}\pi^3 \frac{(n-1)^2}{N\lambda^4}$$ absorption due to scattering

$$\beta \sim {}^{1}/_{\lambda^4} \Rightarrow \beta_{\text{blue}} \approx 16\, \beta_{\text{red}} \;!$$

Blue light is scattered significantly stronger!



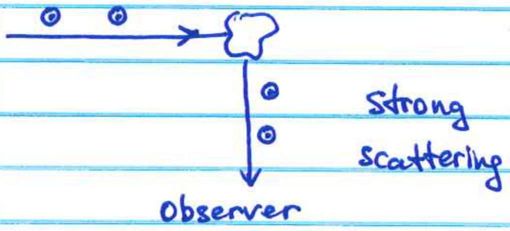
More precise solution — small dialectric spheres of radius a

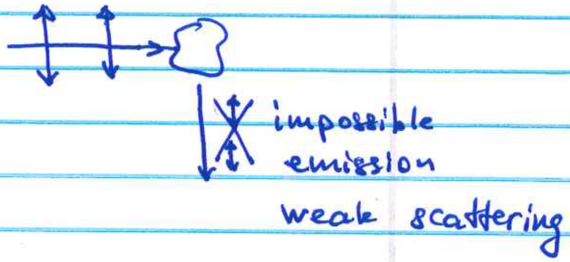
$$\beta = \frac{8\pi}{3}\left(\frac{2\pi}{\lambda}\right)^4 N a^6 \left(\frac{n^2-1}{n^2+2}\right)^2$$

Scattering cross-section $\sigma = \beta/N$

$$\sigma_R = \frac{8\pi}{3}\left(\frac{2\pi}{\lambda}\right)^4 a^6 \left(\frac{n^2-1}{n^2+2}\right)^2$$

Also, because of the anisotropic re-emission pattern, Rayleigh scattering is polarized





That is why sky is partially polarized especially on a very clear day

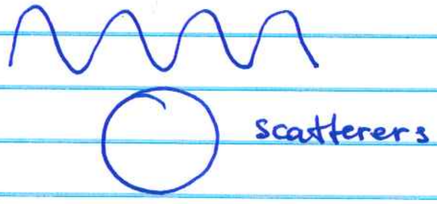
Red sunset → more water vapor and dust particles in the atmosphere b/w the observer and the sun (typical for high pressure region)

Red sky at night, sailor's delight
Red sky in morning, sailor's warning

In northern hemisphere, storms tend to move from west to east

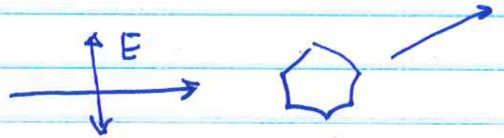
~~A~~ Red sunset – high pressure front is coming (good weather is on its way)
Red sunrise – high pressure system has passed, and may be followed by the lower pressure front, bringing rains and winds.

b) Larger particles (size ~ wavelength)



Much more complicated problem (mathematically)
Need to obey boundary conditions on the surface ⇒ very complicated e-m wave distribution inside, and, thus, complicated emission pattern
Much weaker wavelength dependence
White light scatters white
Also, no polarization dependence

Raman scattering (molecules, in liquids and solids)



re-emitted light is at a differend energy

molecular vibration is excited, using up part of e-m energy

If Ω is a characteristic frequency of a molecular ~~osc~~ vibration mode

$$\omega_{scat} = \omega - \Omega$$

Analysis of a Raman spectrum allows some insight in molecular structure → non-invasive chemical analysis.