13. Egg White

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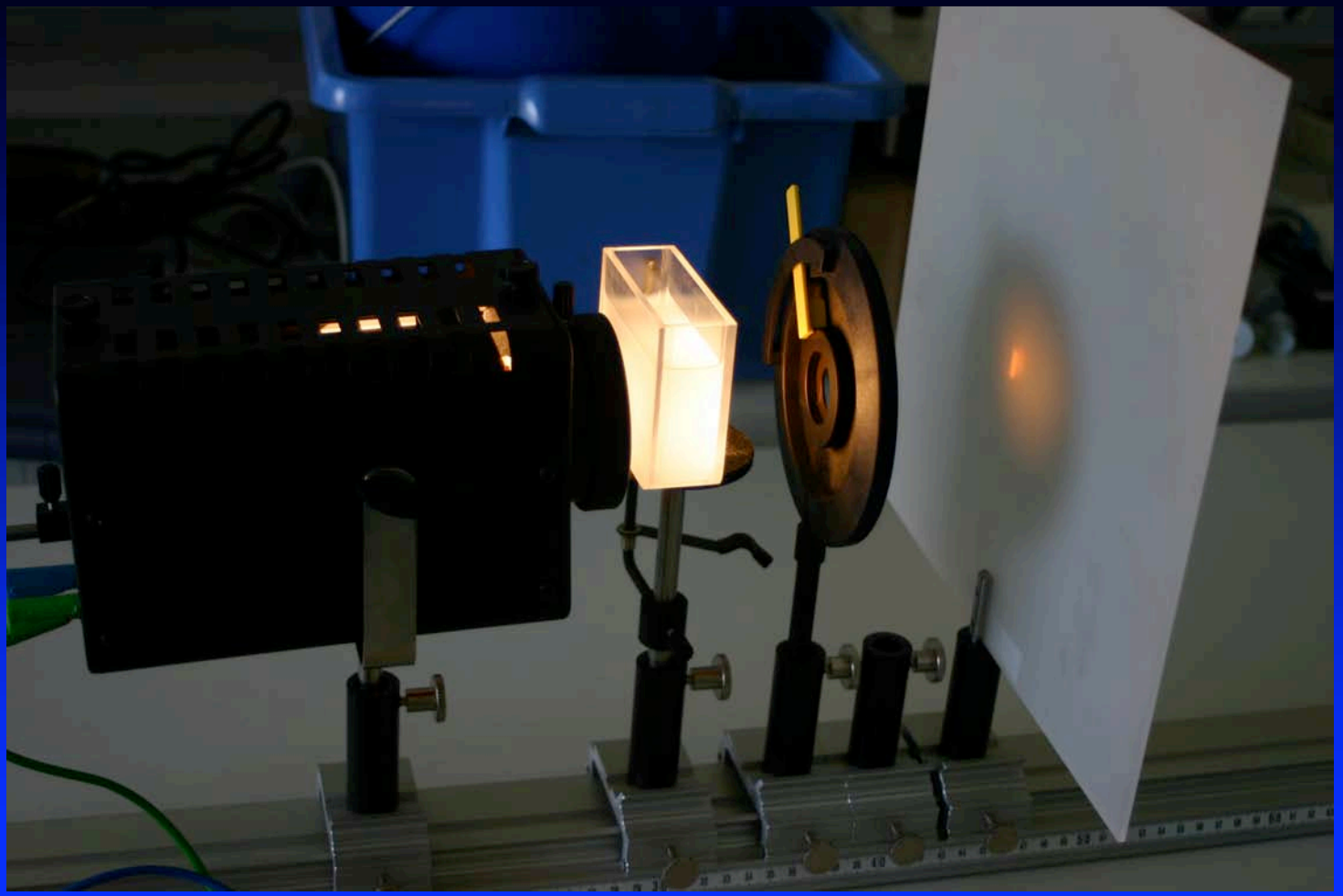
Task

White light appears red when it is transmitted through a slice of boiled egg white. Investigate and explain this phenomenon. Find other similar examples.

Overview

- Experiments
- Structure of Egg White
- Theory
  - Rayleigh Scattering
  - Modified Rayleigh Scattering
- Similar Examples

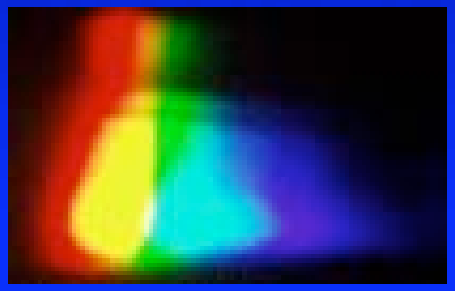
Experimental Setup



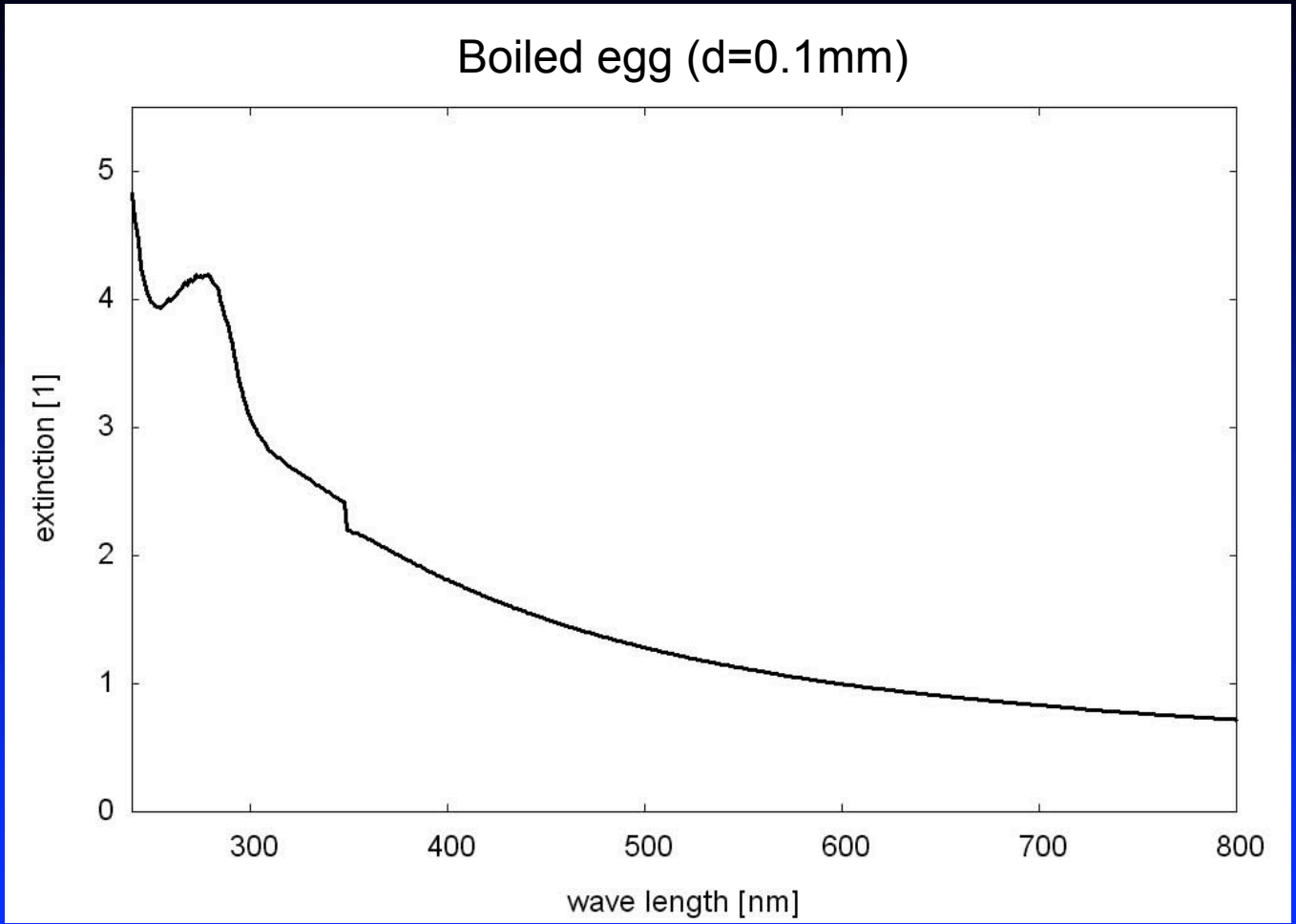
Basic Experiment

- Unpolarized white light
- 0.15 mm solid egg white
  - the screen behind the slice:

- prism
  - spectrum with sample →
    without →



Spectrometer



280nm: absorption maximum

Structure of Egg White

Liquid egg white:

- mixture of proteins in water
- protein: 20 different amino acids

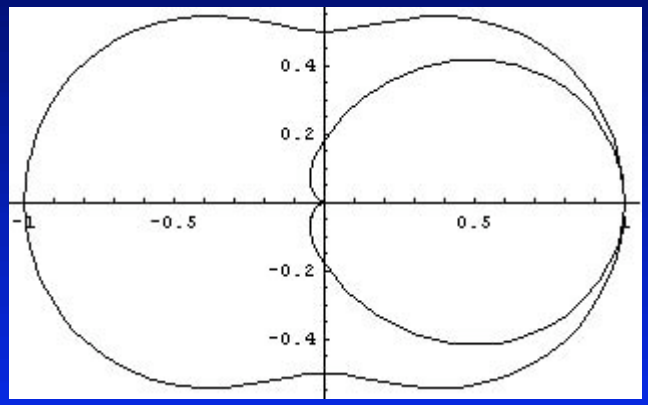
Denaturated egg white:

- unfolding through heat input
- reactions between proteins

→ unstructured network (“random coil”)
→ density fluctuations → scattering

Scattering

- Wave excites particle's oscillation
  - → Hertz's dipole



Scattering fields

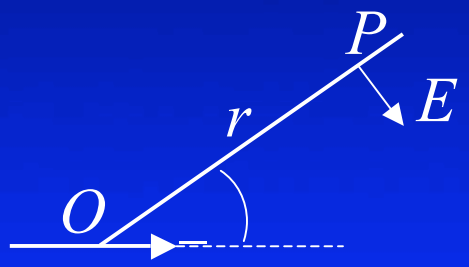
Derivation of E-field

(1) $p = p_0 e^{i\omega t}$

(2) $E \propto \omega^2 E_0 \alpha$ $\quad \omega = \frac{2\pi}{\lambda} \cdot c = k \cdot c$

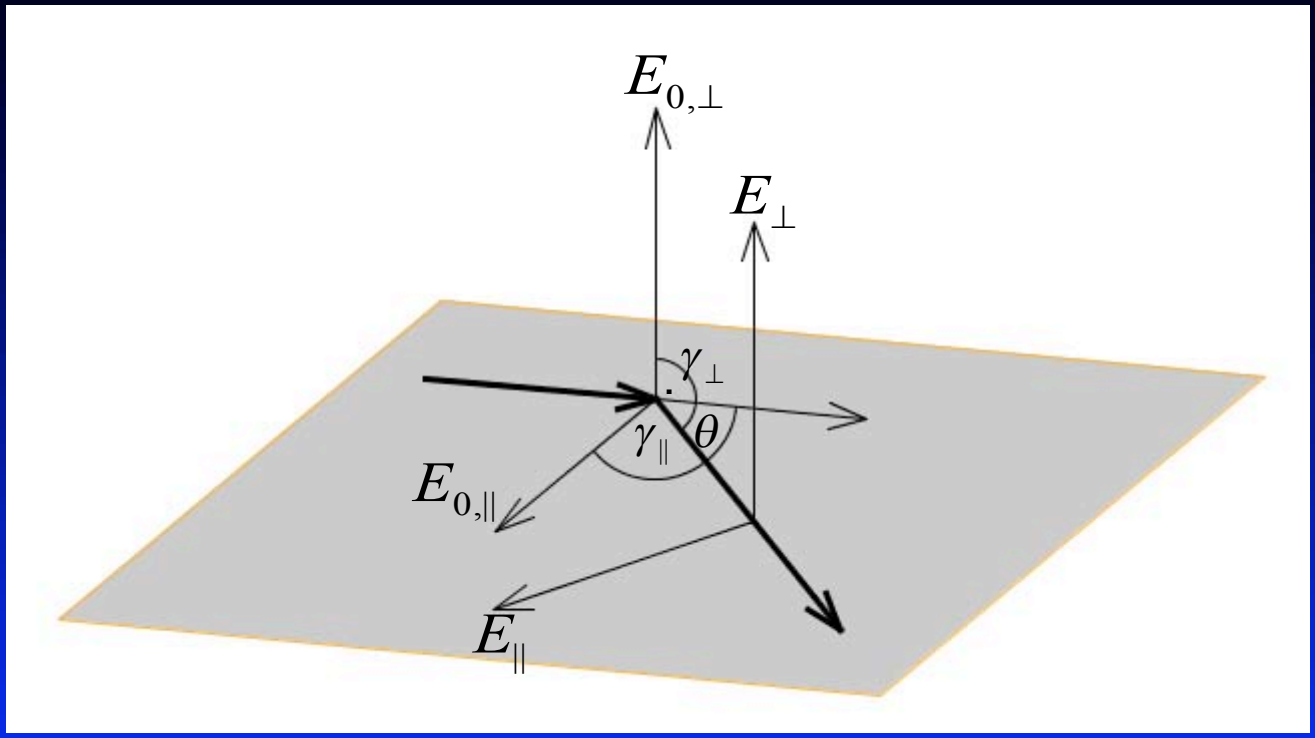
(3) $E \propto \frac{1}{r}$

(4) $E \propto \sin\gamma$



$$\rightarrow \boxed{E = E_0 \frac{k^2}{r} \frac{\alpha}{4\pi\varepsilon_0} \sin\gamma}$$

Unpolarized Light



$$E_{\parallel} = E_{0,\parallel} \frac{k^2}{r} \frac{\alpha}{4\pi\varepsilon_0} \cos\theta \qquad E_{\perp} = E_{0,\perp} \frac{k^2}{r} \frac{\alpha}{4\pi\varepsilon_0} \sin\frac{\pi}{2}$$

Rayleigh Scattering

- $E^2 = E_\perp{}^2 + E_\parallel{}^2 \qquad I \propto |E|^2$

$$\rightarrow I = \frac{k^4}{r^2}\left(\frac{\alpha}{4\pi\varepsilon_0}\right)^2 \frac{(1+\cos^2\theta)}{2} I_0$$

- The radiant power of one particle:

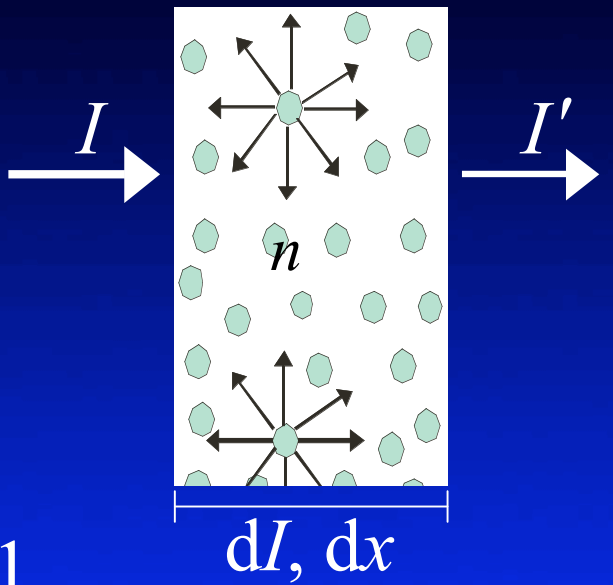
$$P = \int I \cdot r^2 \mathrm{d}\dot{U} \propto k^4 \propto \frac{1}{\lambda^4}$$

Extinction

- Lambert-Beer's Law:

$$I = I_0 \mathrm{e}^{-\alpha x}$$

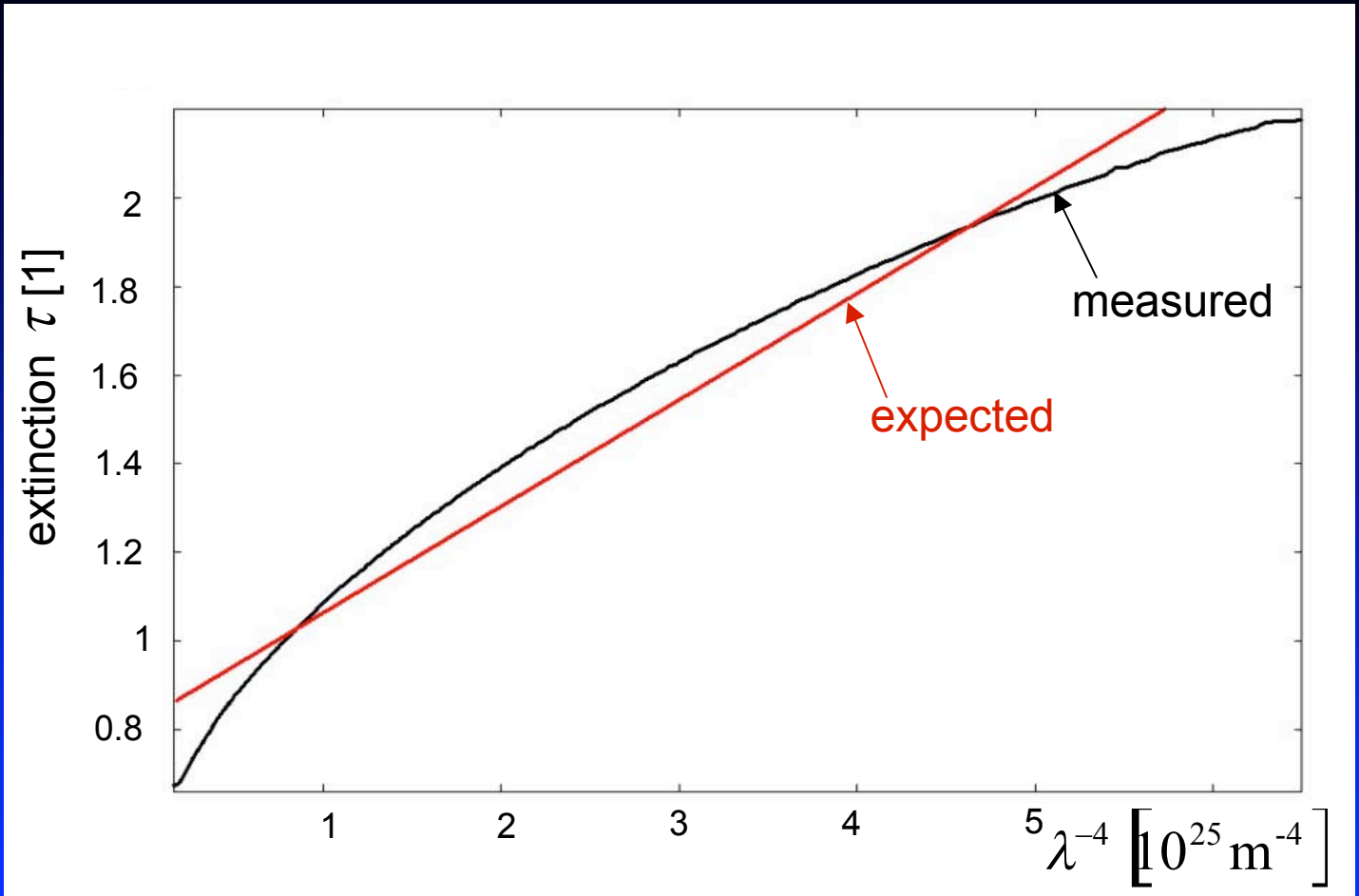
$$\boxed{\alpha \propto nP}$$



- Extinction:

$$\tau = -\ln \frac{I}{I_0} = \alpha \cdot x \propto \frac{1}{\lambda^4}$$

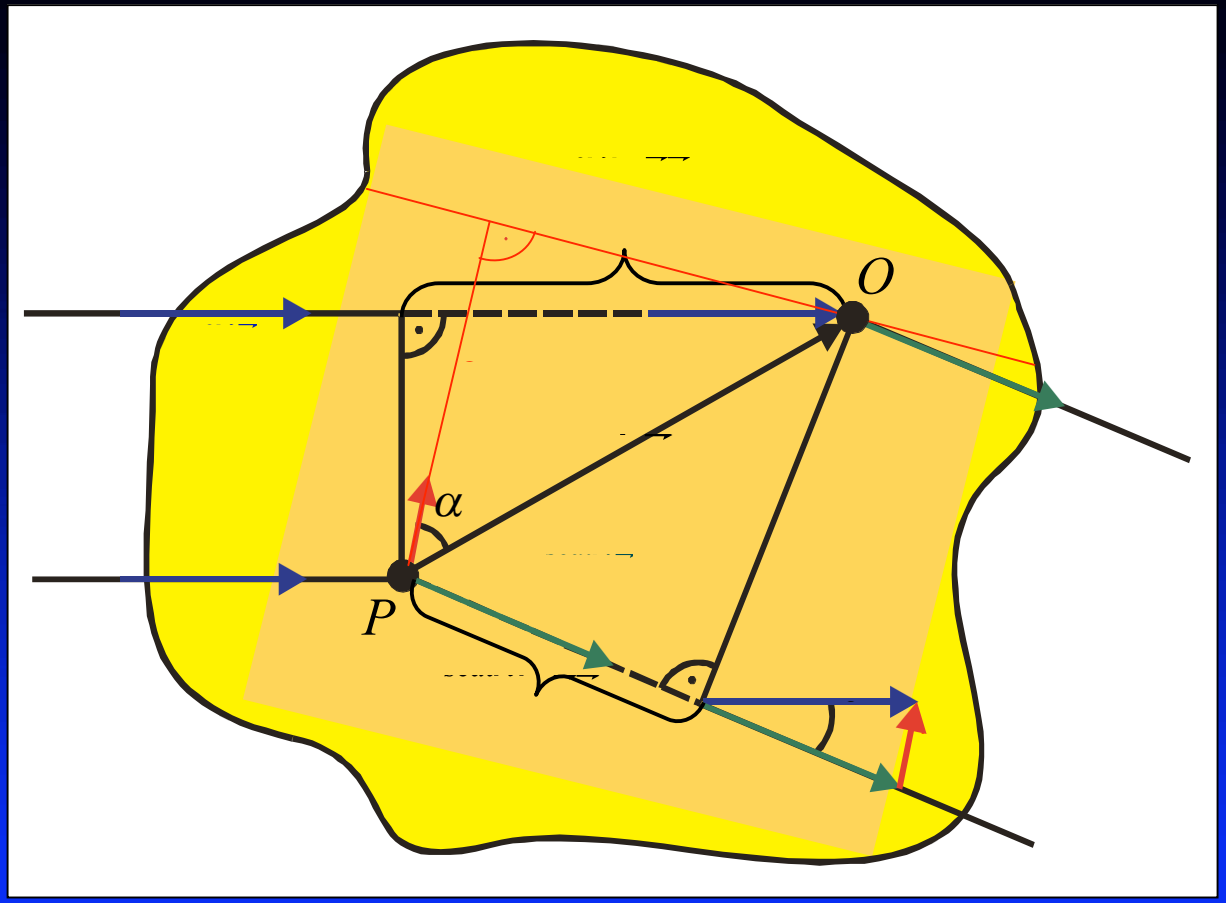
Comparison with Experiment



800nm

350nm

With Interference



$$b = \left|\vec{r}\right| \cdot \cos\alpha$$

$$\delta = \vec{r} \cdot \vec{k}_{\text{inc}} - \vec{r} \cdot \vec{k}_{\text{scat}} = 2bk \sin\frac{\theta}{2}$$

Modified Rayleigh-Scattering

- $$R(\theta) = \frac{1}{Aa}\int_{-a/2}^{a/2} \mathrm{e}^{\mathrm{i}\delta} A \mathrm{d}b = \frac{1}{k}\frac{\sin(ka\sin\frac{\theta}{2})}{a\sin\frac{\theta}{2}}$$
- $$\left.\begin{matrix} E_{\perp} \\ E_{\parallel} \end{matrix}\right\} = E_0 \frac{k^2 \chi V}{4\pi\varepsilon_0 r} R(\theta) \begin{cases} 1 \\ \cos\theta \end{cases}$$

$$\boxed{I = I_{\mathrm{Rlgh}} \cdot \left|R(\theta)\right|^2}$$

Dependence on λ

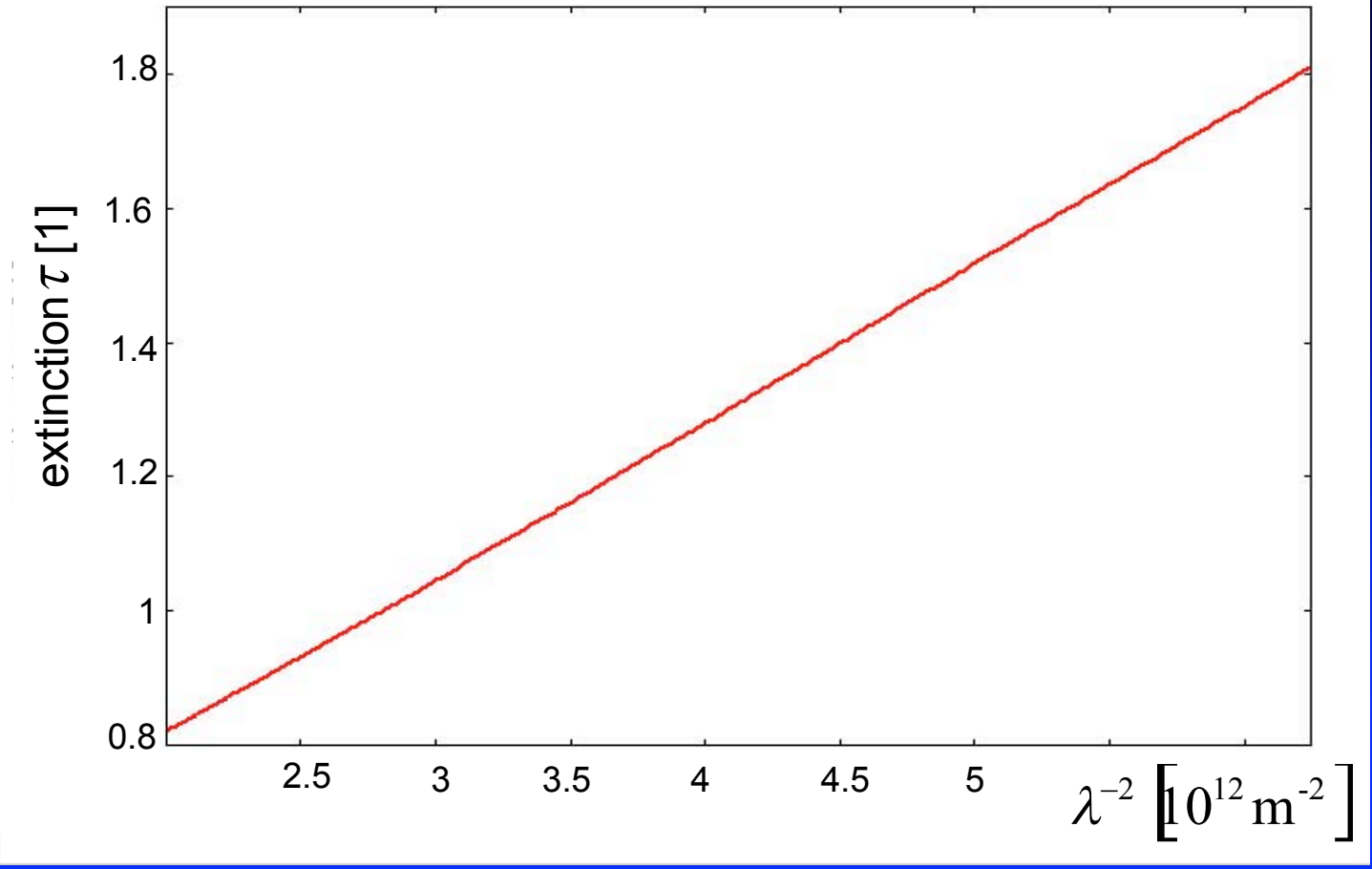
$$P = \int I \cdot r^2 \mathrm{d}\dot{U}$$

$$P \propto \frac{1}{\lambda^2} \underbrace{\int \frac{1+\cos^2\theta}{2} \left(\frac{\sin\left(ka \sin\frac{\theta}{2}\right)}{\sin\frac{\theta}{2}} \right)^2 \mathrm{d}\dot{U}}_{\zeta(k)}$$

- $\zeta(k)$ is only slightly dependant on k

$$\boxed{P \propto \frac{1}{\lambda^2}}$$

Extinction- λ^{-2}-plot



Similar Examples (1)

- Sunset / Lunar eclipse

Similar Examples (2)

- Milk in water

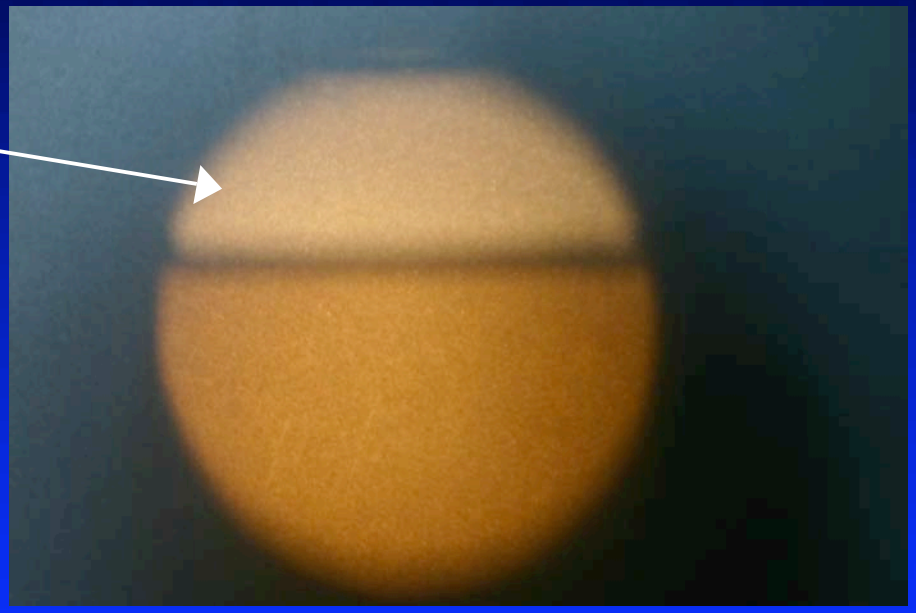
Similar Examples (3)

- Polyethylene: e. g. white plastic bag

Similar Examples (4)

- Ouzo in water

without liquid



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