Optical and Photonic Glasses

Lecture 17:

Light Scattering - Introduction

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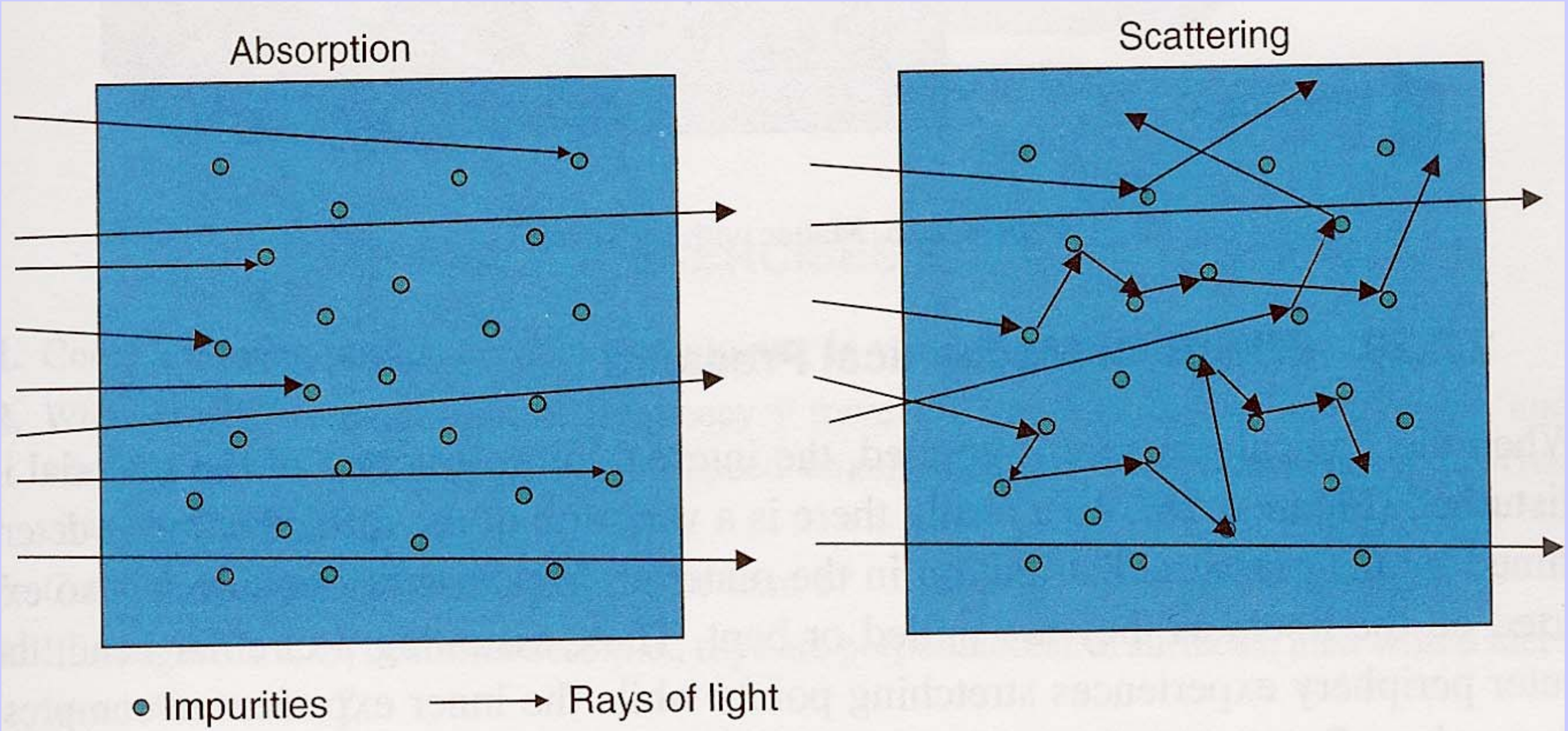
Light scattering

Scattering refers to the interaction of a light beam with small particles, or surface irregularities such as those present on a rough surface, which lead to *fluctuations of the refractive index*. The term “rough” generally applies when the average size of the surface irregularities is $\geq \lambda$ of the incident light, whereas a surface is considered “smooth” if that size is $< \sim \lambda/10$.

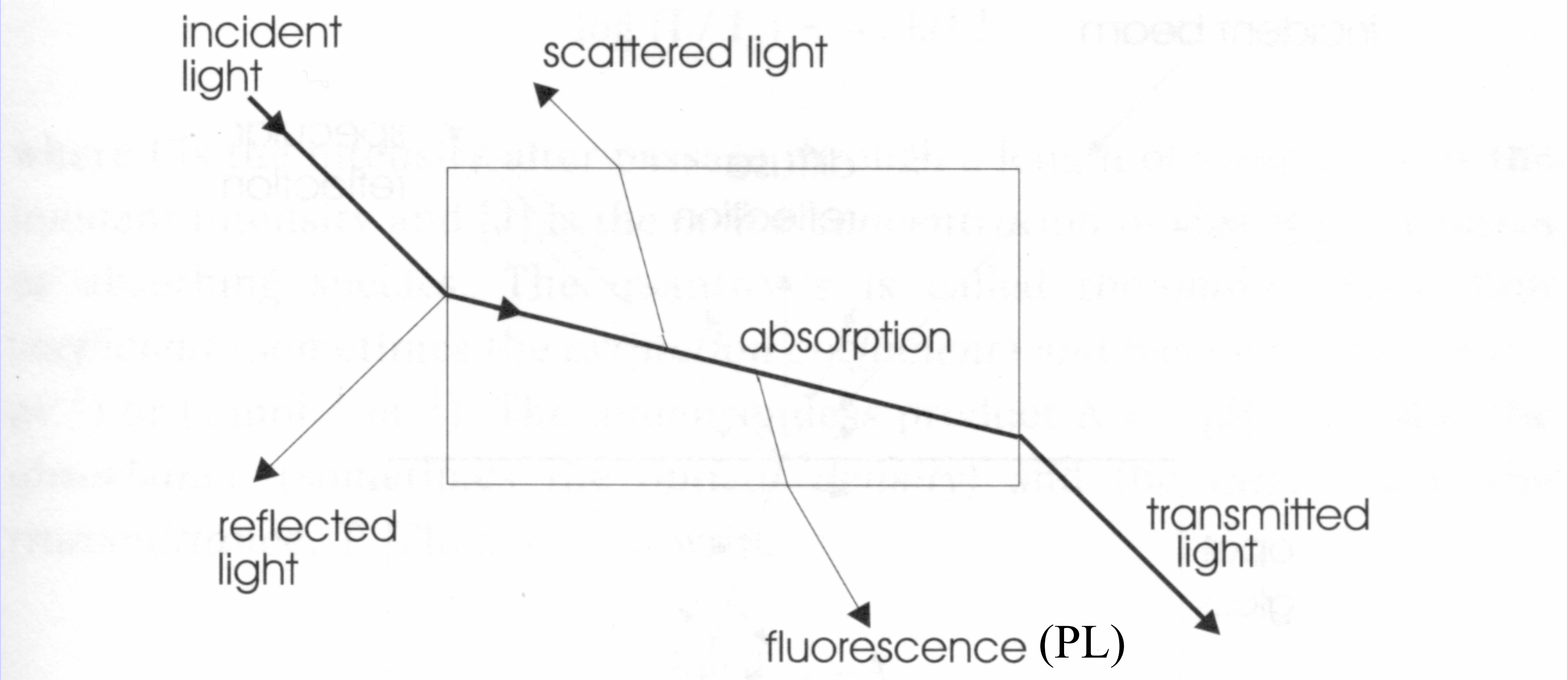


Matter with absorption center and with scattering centers.

(Adapted from: *Introduction to DWDM Technology, S.V. Kartalopoulos, IEEE Press, 2000)*

Interaction of light with a material

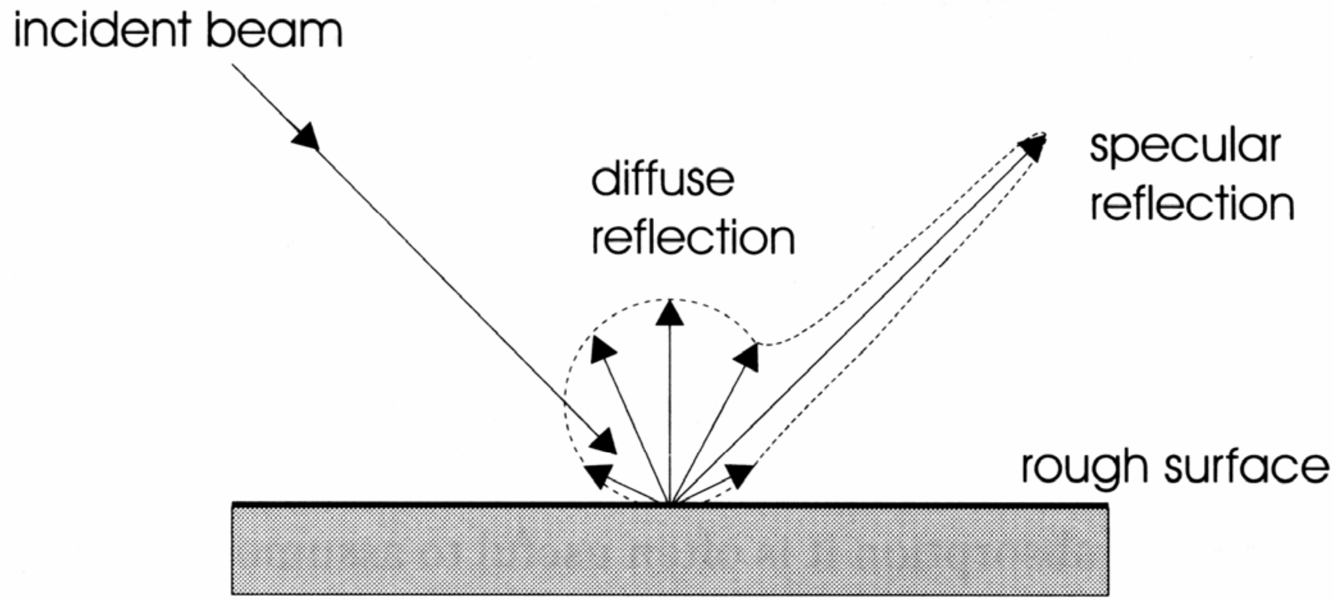
Kirchoff's law: $T(\lambda) = 1 - A(\lambda) - R(\lambda) - S(\lambda) - PL(\lambda)$ (most general form)



The interaction of light with a transparent material. The "bending" of the light ray on entering and leaving the material is called refraction and is discussed in Chapter 2. All of the processes labelled (reflection, absorption, scattering and fluorescence), can lead to colour production

(Adapted from: *Colour and the Optical Properties of Materials*, R. Tilley, John Wiley, 2000)

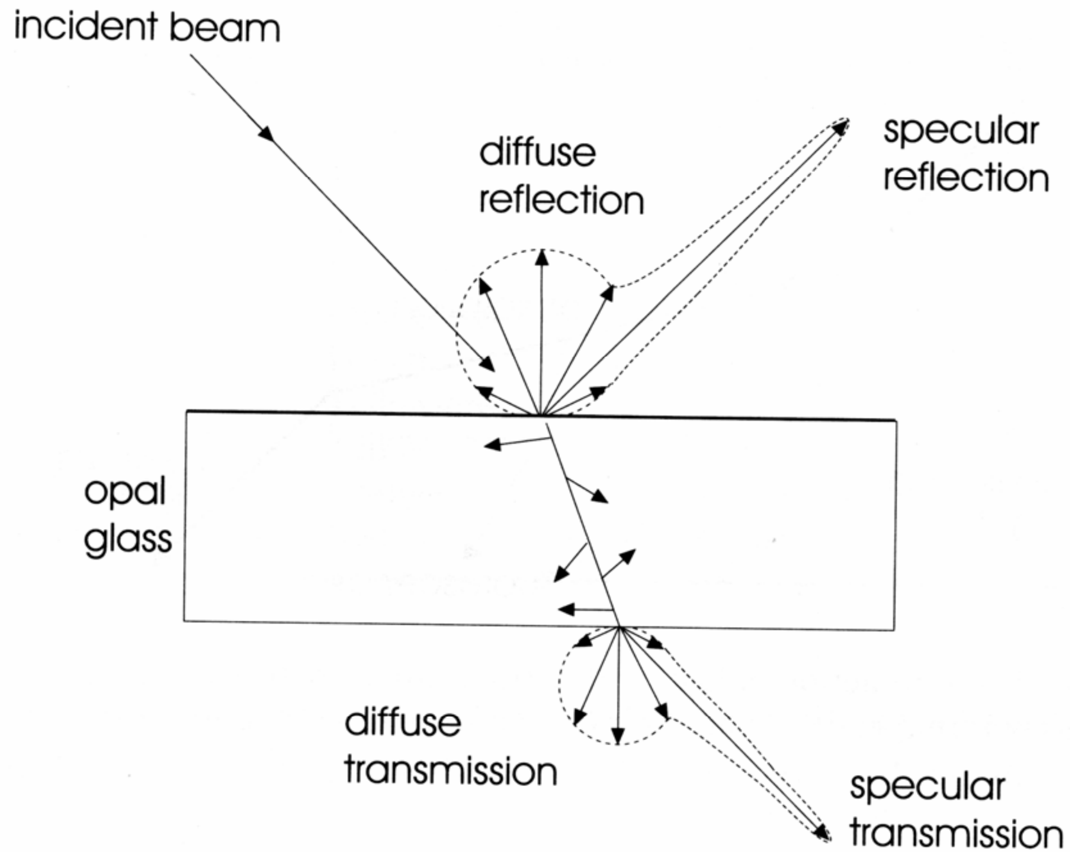
Specular vs. **diffuse reflection**



Reflection of light from a rough surface consists of two components, diffuse reflection and specular reflection. As the surface roughness increases the amount of diffuse reflection relative to the specular reflection increases. The ratio is an indication of surface gloss

(Adapted from: *Colour and the Optical Properties of Materials*, R. Tilley, John Wiley, 2000)

Specular vs. **diffuse reflection** and **transmission**

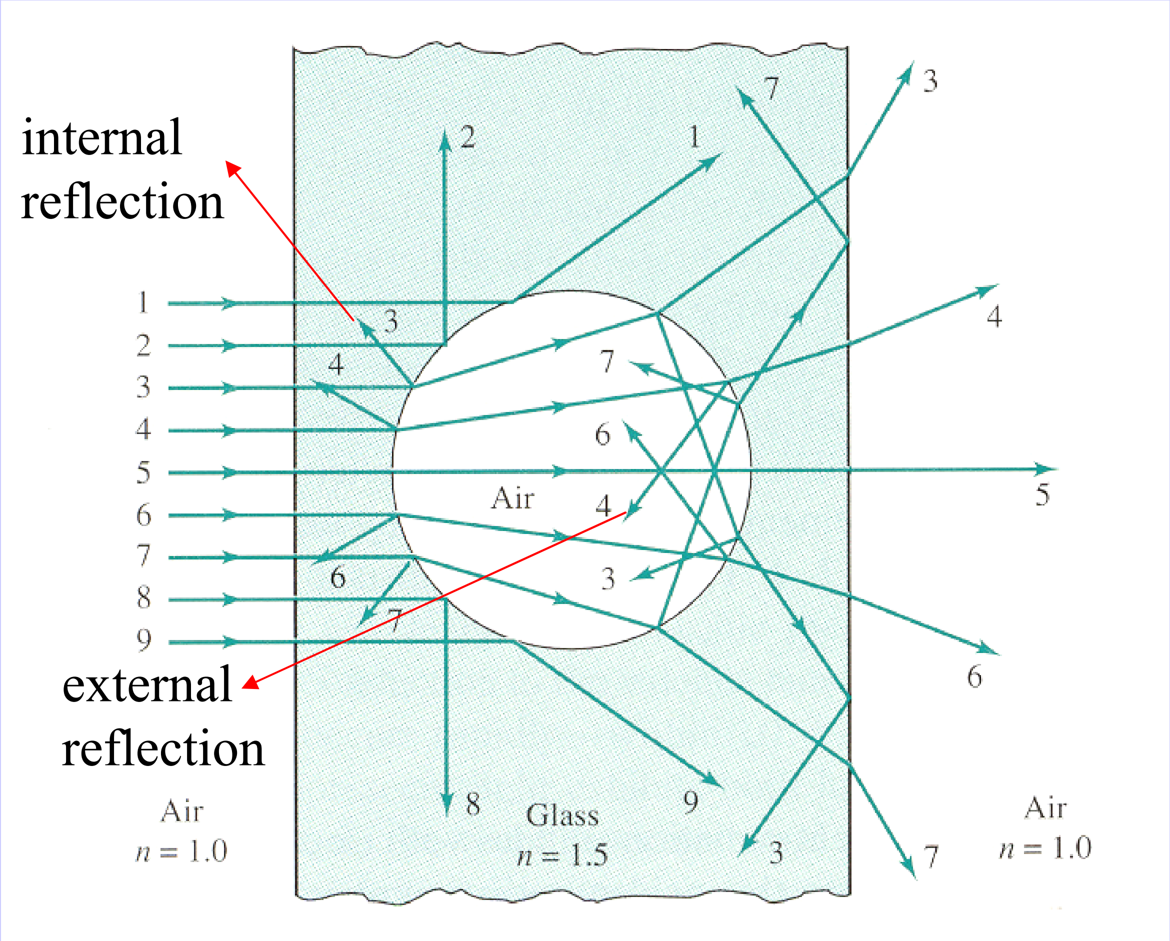


The passage of light through a translucent material containing many scattering centres, such as opal glass. Both the surface reflection and the transmitted light have diffuse and specular components

(Adapted from: *Colour and the Optical Properties of Materials*, R. Tilley, John Wiley, 2000)

Scattering by spherical air bubbles in a homogeneous glass

The presence of bubbles of sizes comparable to λ inside a homogeneous glass leads to light scattering (due to refractive index fluctuations) and to the glass becoming *translucent*, or even *opaque* to the incident light.



(Adapted from: *The science and design of engineering materials*, J.P. Schaffer et al., McGraw-Hill, 1999)

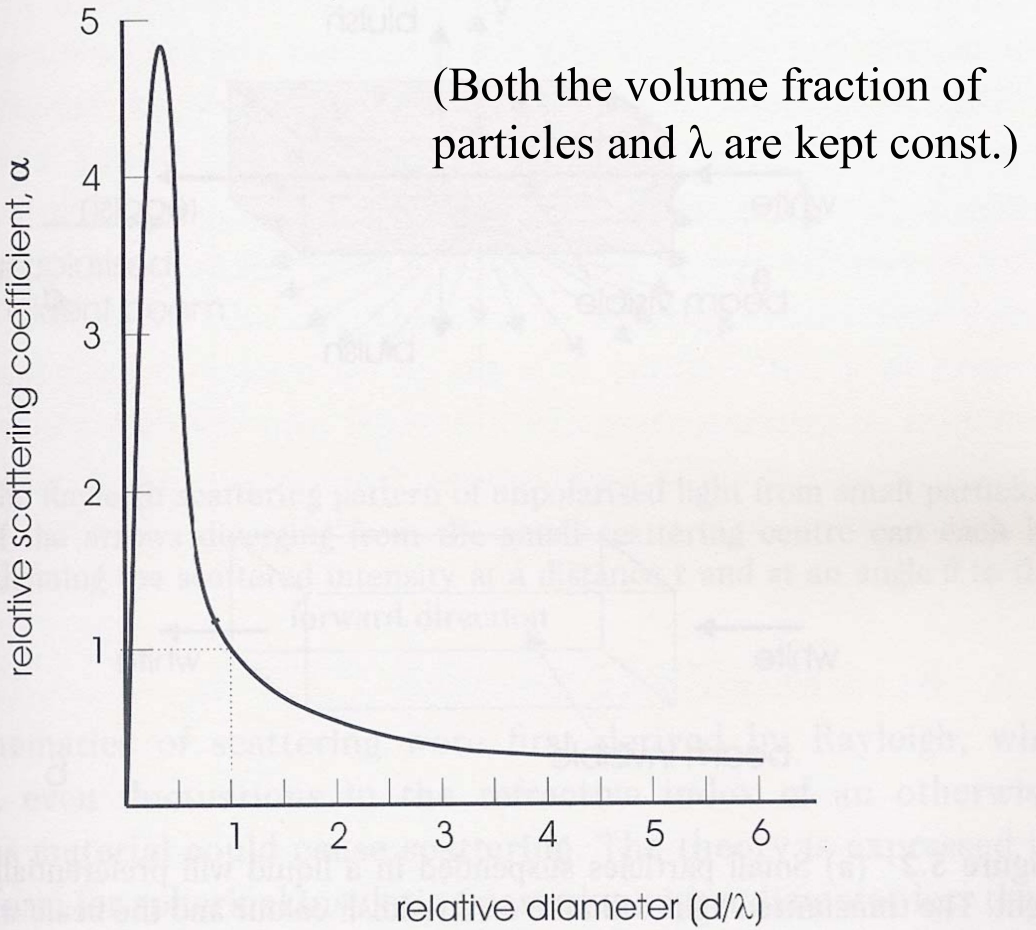
The intensity reduction of a light beam which has traversed a medium of length x, containing scattering centers, is given by an equation similar to Beer's law:

$$I = I_o \exp(-\alpha_s x)$$

where α_s is now the **scattering** (rather than absorption) **coefficient** (in cm^{-1}), which is a function of:

- the number of scattering centers present
- the ratio between the particle diameter and λ
- the ratio between the refractive indices of the particles and the surrounding matrix
- the particle shape

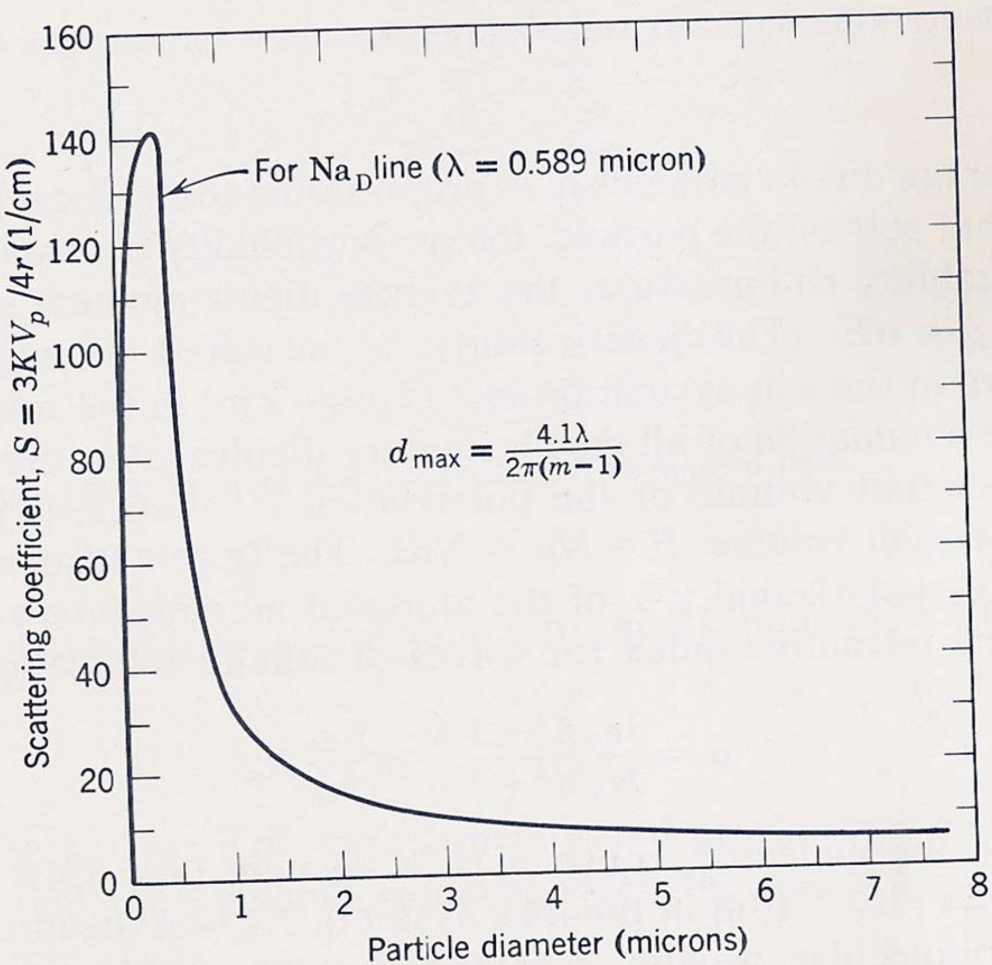
If all these parameters are held constant, with the exception of particle size, and the volume fraction of particles is also held constant, then maximum scattering intensity occurs when the particle size is ~ $\lambda/2$, as illustrated in the next figure.



Schematic illustration of the effect of particle size, expressed as relative diameter (particle diameter, d / wavelength of light, λ) on the relative scattering coefficient, α, expressed as the ratio of the scattering coefficient α_s at the relative diameter of 1.0 to that at other relative diameters. The maximum scattering occurs when the particle diameter is about half the wavelength of the light

(Adapted from: *Colour and the optical properties of materials*, R. Tilley, John Wiley, 2000)

TiO$_2$ particles are frequently added to glass (or plastic materials) to make them translucent or opaque (white).



Effect of particle size on the scattering coefficient ($S = 3KV_p/r4$) of a fixed volume of particles (1.0 vol%) for a relative refractive index of 1.8 (TiO$_2$ in glass).

(Adapted from: *Introduction to ceramics*, W.D. Kingery et al., John Wiley, 1976)