Lecture 13:

Optical Glasses – Absorption, Refraction and Dispersion

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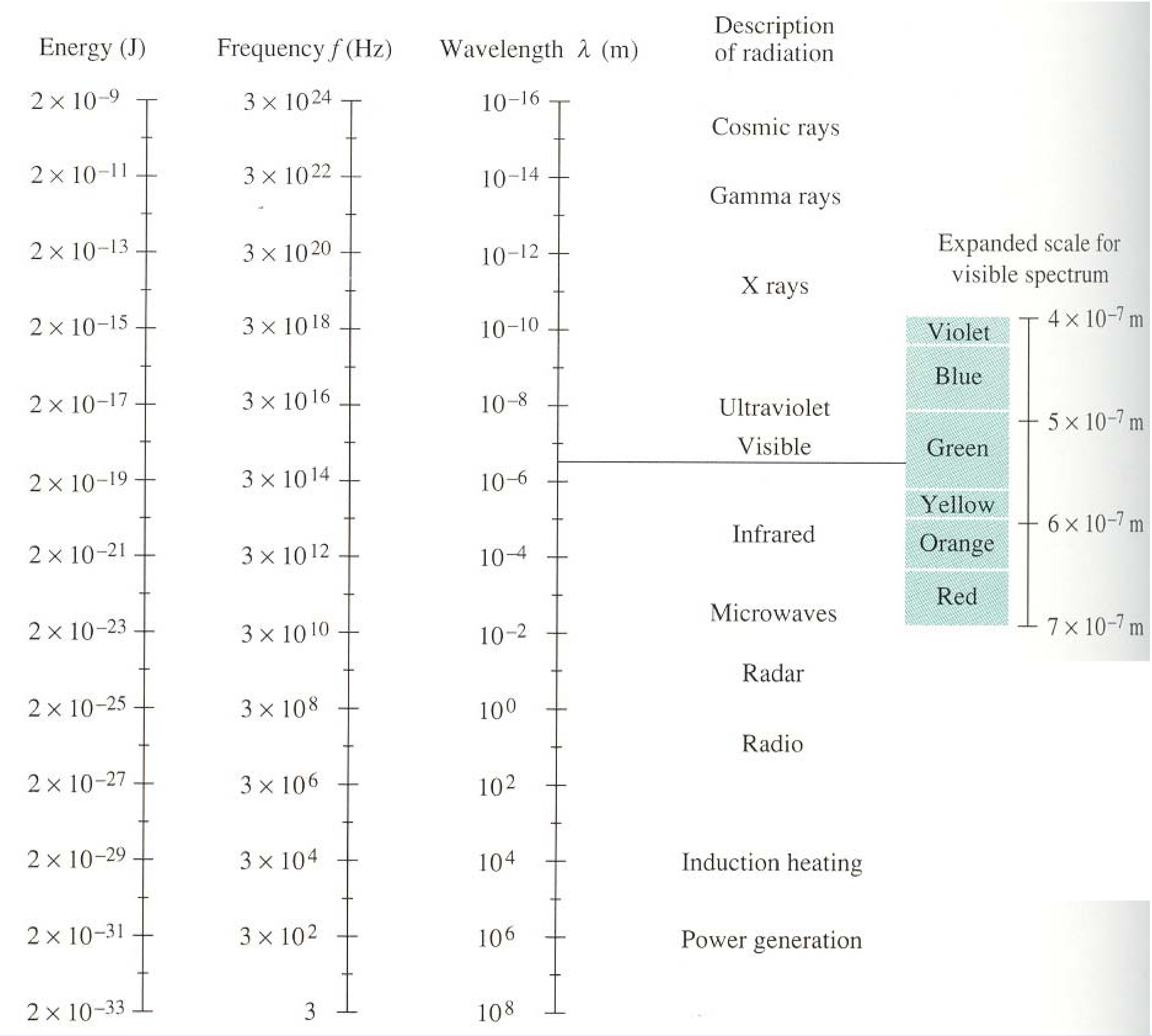
OPTICAL PROPERTIES

The optical behavior of glass, like that of any other material, is the result of the interaction between the electromagnetic radiation and the electrons or nuclei of the constituent atoms or ions.

In the *optical* region of the *electromagnetic spectrum*, **ultra-violet (UV)** radiation ($\lambda \leq 400$ nm) and **visible** radiation ($\lambda \sim 400$-700 nm) usually interact with the *electronic* energy levels, whereas **infrared** (**IR**) radiation ($\lambda \geq 700$ nm) interacts with the atomic nuclei.

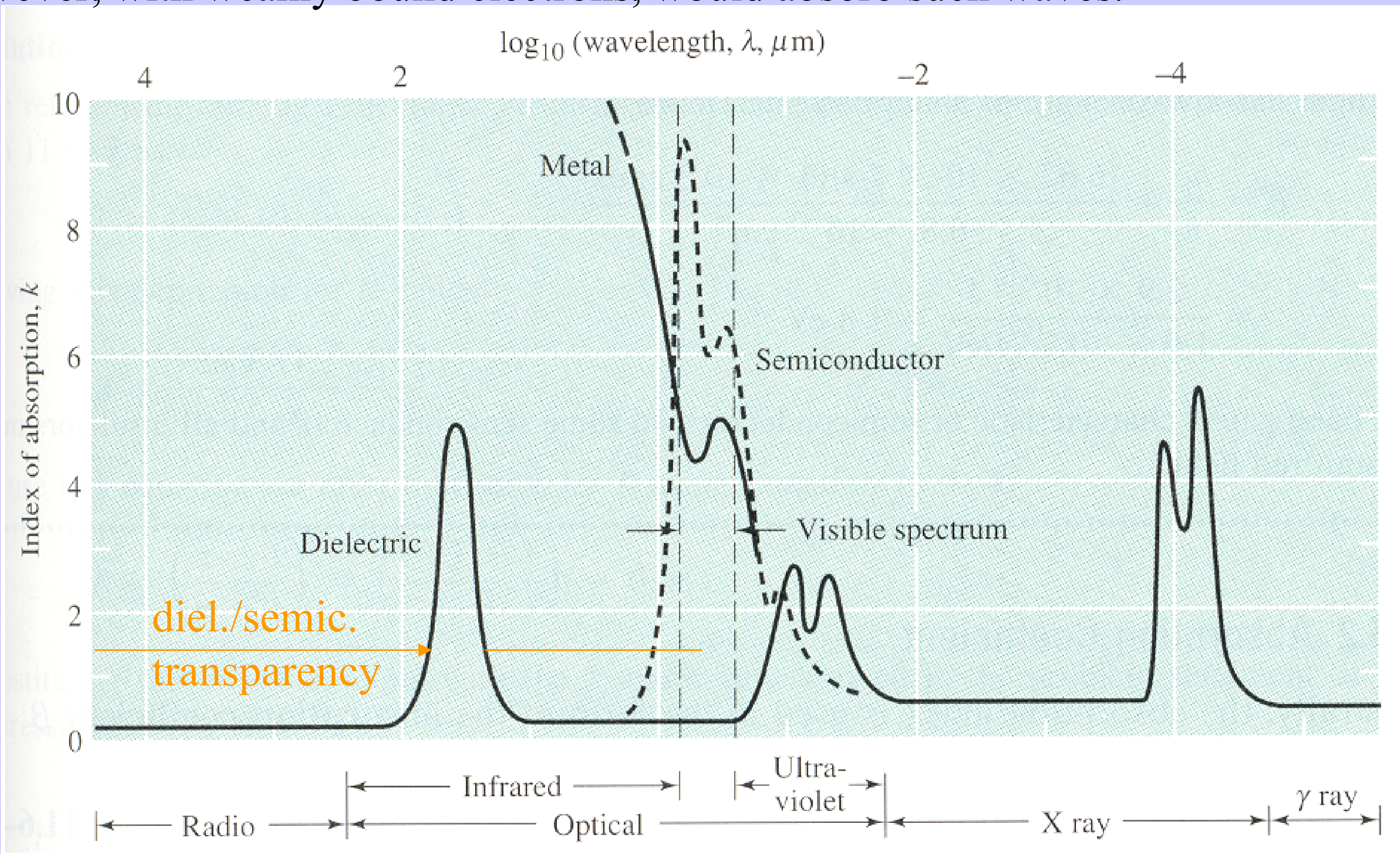
The optical properties considered below include refraction and the refractive index plus its dispersion, reflection (and interference), electronic absorption, infrared absorption (and reflection), Raman scattering and conventional (elastic) light scattering.

Electromagnetic radiation spectrum



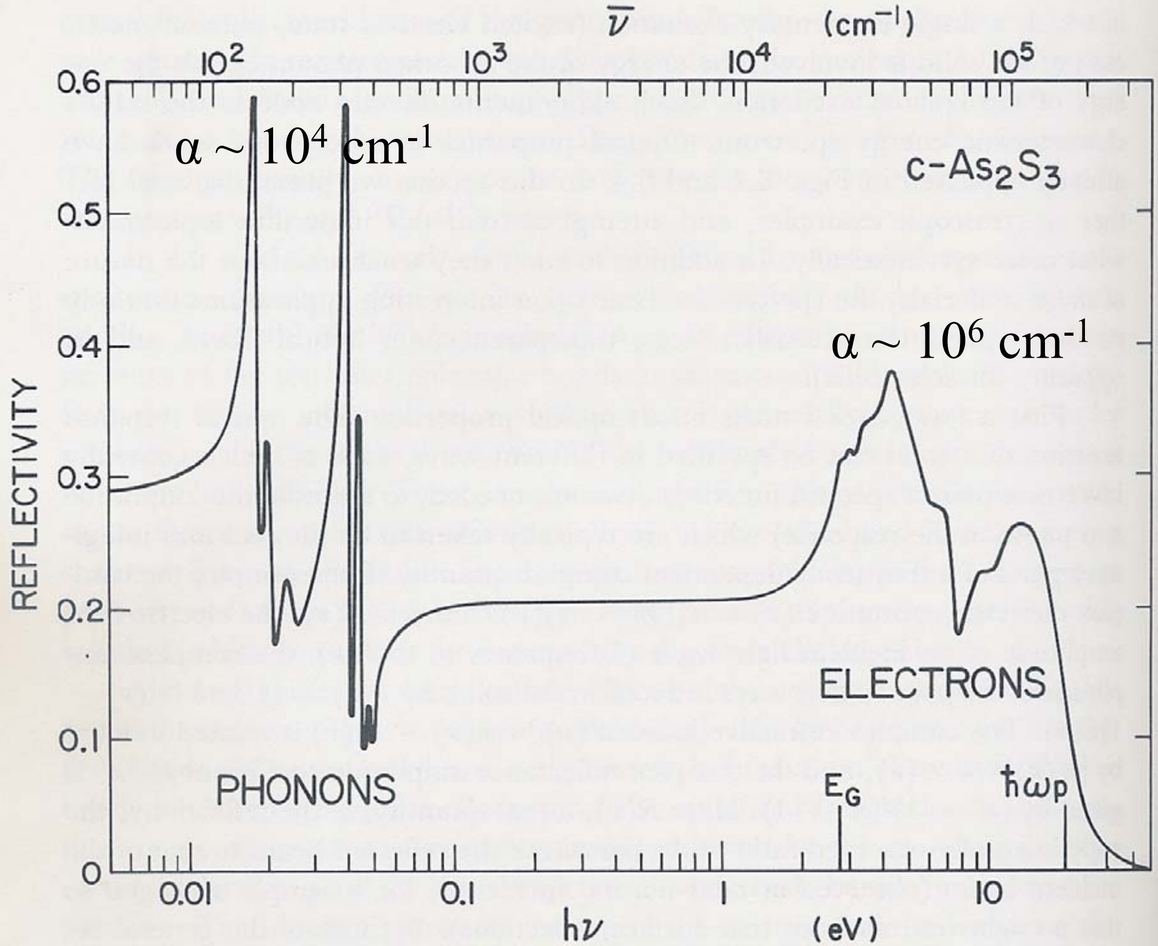
(Adapted from: *The science and design of engineering materials*, J.P. Schaffer et al., McGraw-Hill, 1999)

Example of *absorption* of different materials as a function of the energy of the electromagnetic radiation (E = hc/λ). Radio waves, e.g., are transmitted by dielectric materials like building walls, because the small photon energies cannot cause neither band-to- band electronic transitions, nor vibrational ones. A wall made of metal, however, with weakly bound electrons, would absorb such waves.



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

Example of the optical *reflection* of c-As_2S_3 (a glass former) between 50 eV and 5 meV (70 nm to 40 cm^{-1}; $\lambda \nu = c$). Between ~ 20 eV and E_G (~ 3 eV), the electrons are excited from the valence to the conduction bands. Below ~ 100 meV (or 1000 cm^{-1}), the electric field oscillations become slow enough for the lattice vibrations to respond to them.

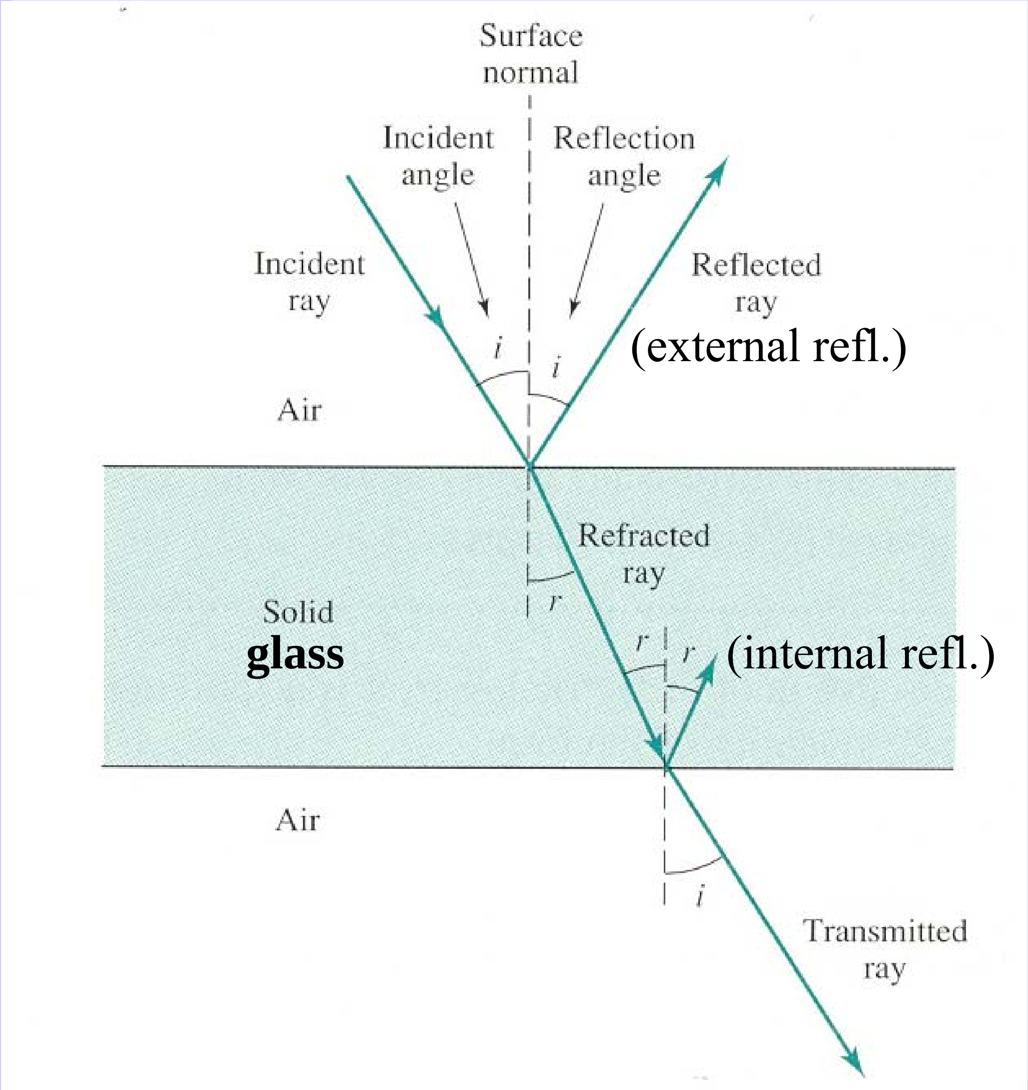


Global overview of the optical properties of crystalline As_2S_3. The reflectivity is shown for one light polarization over a range of photon energies from the far infrared to the far ultraviolet. (Zallen and Blossey, 1976).

(Adapted from: *The Physics of Amorphous Solids*, R. Zallen, John Wiley, 1983)

Refraction and **reflection**

(absorption neglected at this stage)



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

Refraction in terms of geometrical optics: **Snell**'s law

$$[(n^2-1)/(n^2+2)]\, V_M = N_o\, \alpha_t$$

$$n = \frac{v_{vac}}{v_{mat}}$$

$$n = \frac{v_{vac}}{v_{mat}} = \frac{\lambda_{vac}}{\lambda_{mat}} = \frac{\sin i}{\sin r}$$

$$\frac{v_1}{v_2} = \frac{n_2}{n_1} = \frac{\sin i}{\sin r}$$

Refractive indices of materials. **n≥1**

Material	Average refractive index
Air	1.00
Water	1.33
Ice	1.31
Ceramics	
Diamond	2.43
Al_2O_3	1.76
SiO_2	1.544, 1.553
MgO	1.74
NaCl	1.55
$BaTiO_3$	2.40
TiO_2	2.71
Pyrex glass	1.47
Soda-lime-silicate glass	1.51
Lead-silicate glass	2.50
Calcite	1.658, 1.486
Semiconductors	
Ge	4.00
Si	3.49
GaAs	3.63
Polymers	
Epoxy	1.58
Nylon 6,6	1.53
Polycarbonate	1.60
Polystyrene	1.59
High-density polyethylene	1.54
Polypropylene	1.49
Polytetrafluoroethylene	1.30–1.40
Polyvinylchloride	1.54
Poly(ethylene terephthalate)	1.57

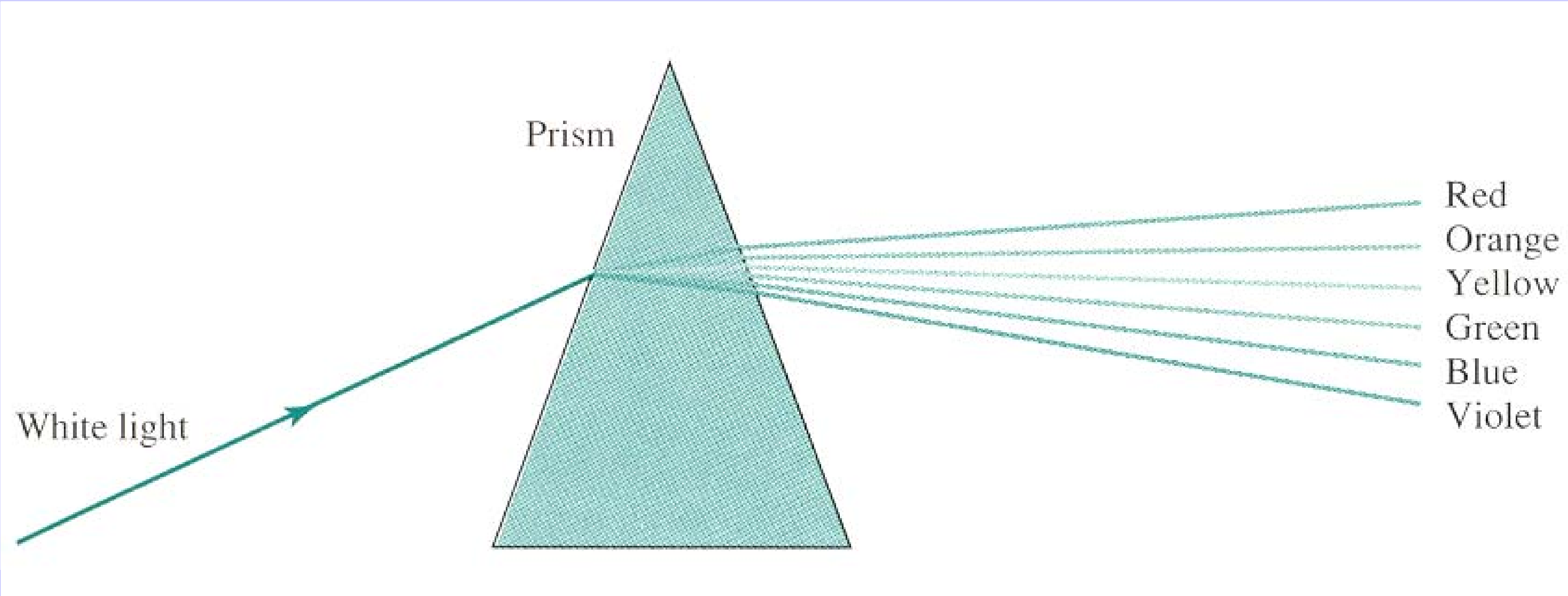
(Adapted from: *The science and design of engineering materials*, J.P. Schaffer et al., McGraw-Hill, 1999)

Refractive indices of some glasses

Glass composition:	n_D
From orthoclase ($KAlSi_3O_8$)	1.51
From albite ($NaAlSi_3O_8$)	1.49
From nepheline syenite	1.50
Silica glass, SiO_2	1.458
Vycor glass (96% SiO_2)	1.458
Soda-lime-silica glass	1.51–1.52
Borosilicate (Pyrex) glass	1.47
Dense flint optical glasses	1.6–1.7
Arsenic trisulfide glass, As_2S_3	2.66
Tellurite glasses (TeO_2-based)	1.8 – 2.3

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

Dispersion is the change in refractive index with the wavelength of light. In the absence of absorption, the (*normal*) dispersion generally corresponds to a decrease of the refractive index with increasing light wavelength, as shown below.

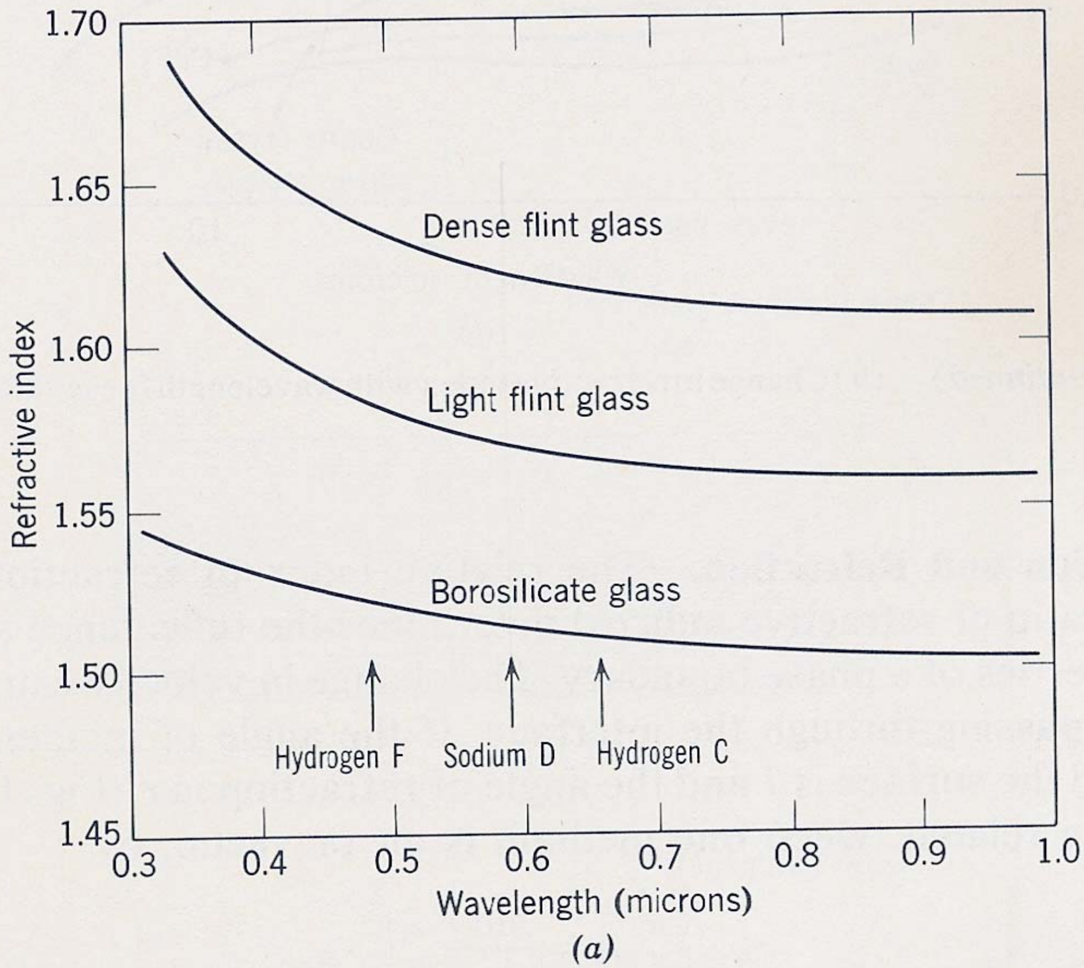


(Adapted from: *The science and design of engineering materials*, J.P. Schaffer et al., McGraw-Hill, 1999)

Examples of refractive index dispersion in optical glasses:

Abbe number: $\nu_D = (n_D - 1)/(n_F - n_C)$

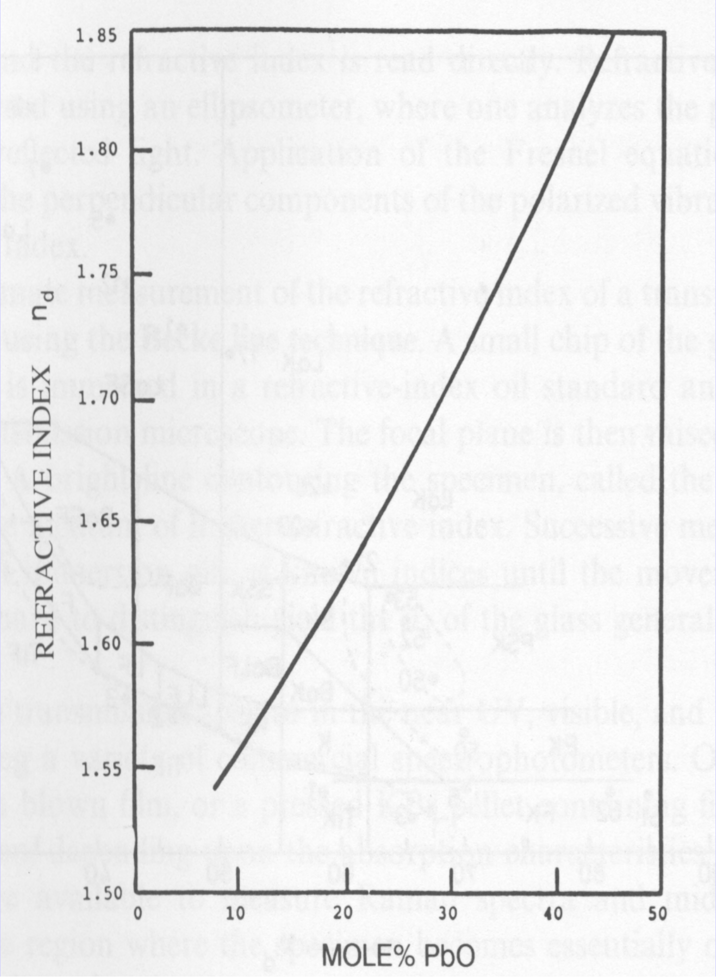
Cauchy equation: $n = A + B/\lambda^2 + C/\lambda^4$



(*a*) Change in refractive index with wavelength for typical glasses in the visible

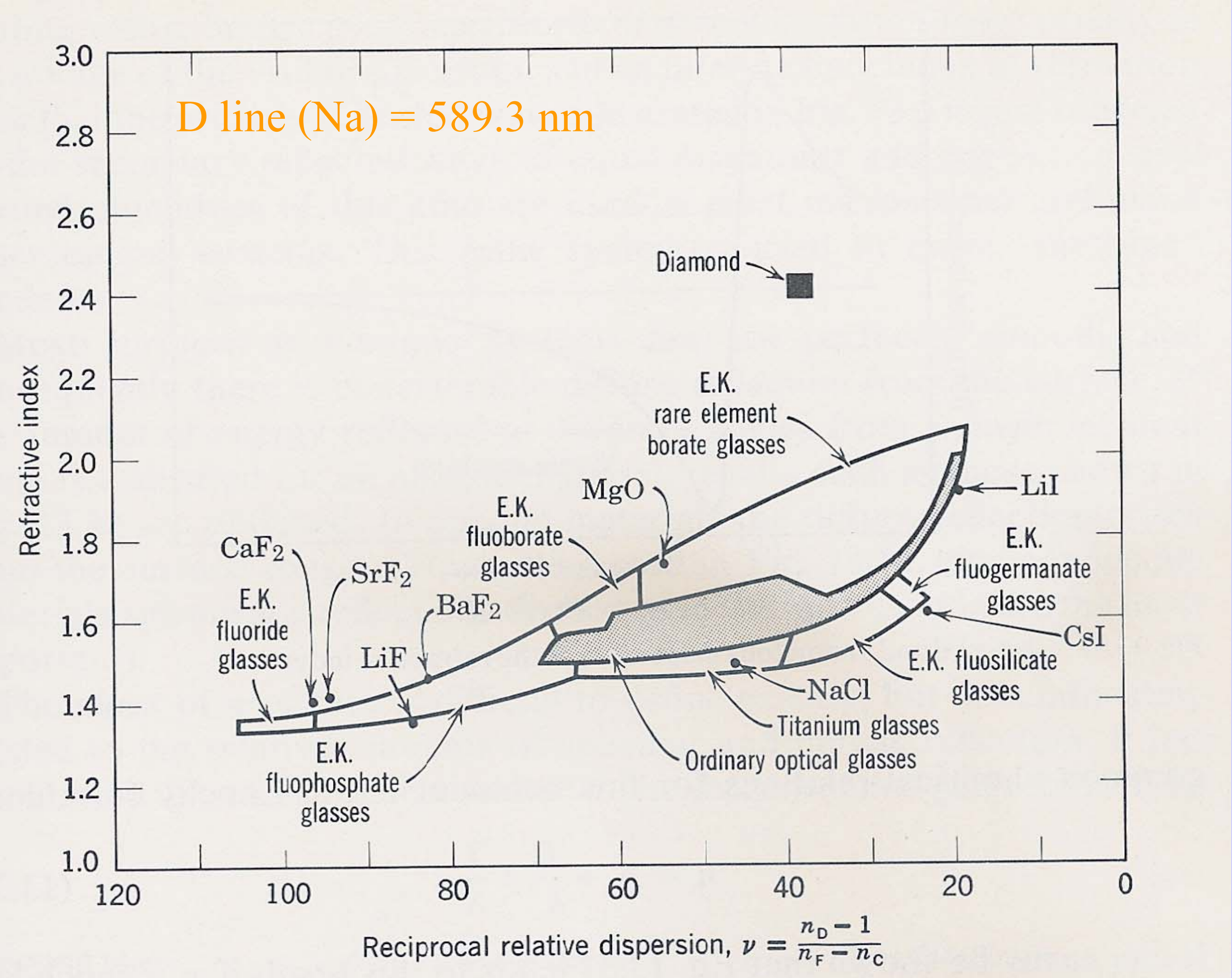
(Adapted from: *Introduction to Ceramics*, W.D. Kingery et al., John Wiley, 1976)

The well known brilliance of "crystal glass" is not only a result of its high refractive index, but especially of its high dispersion.



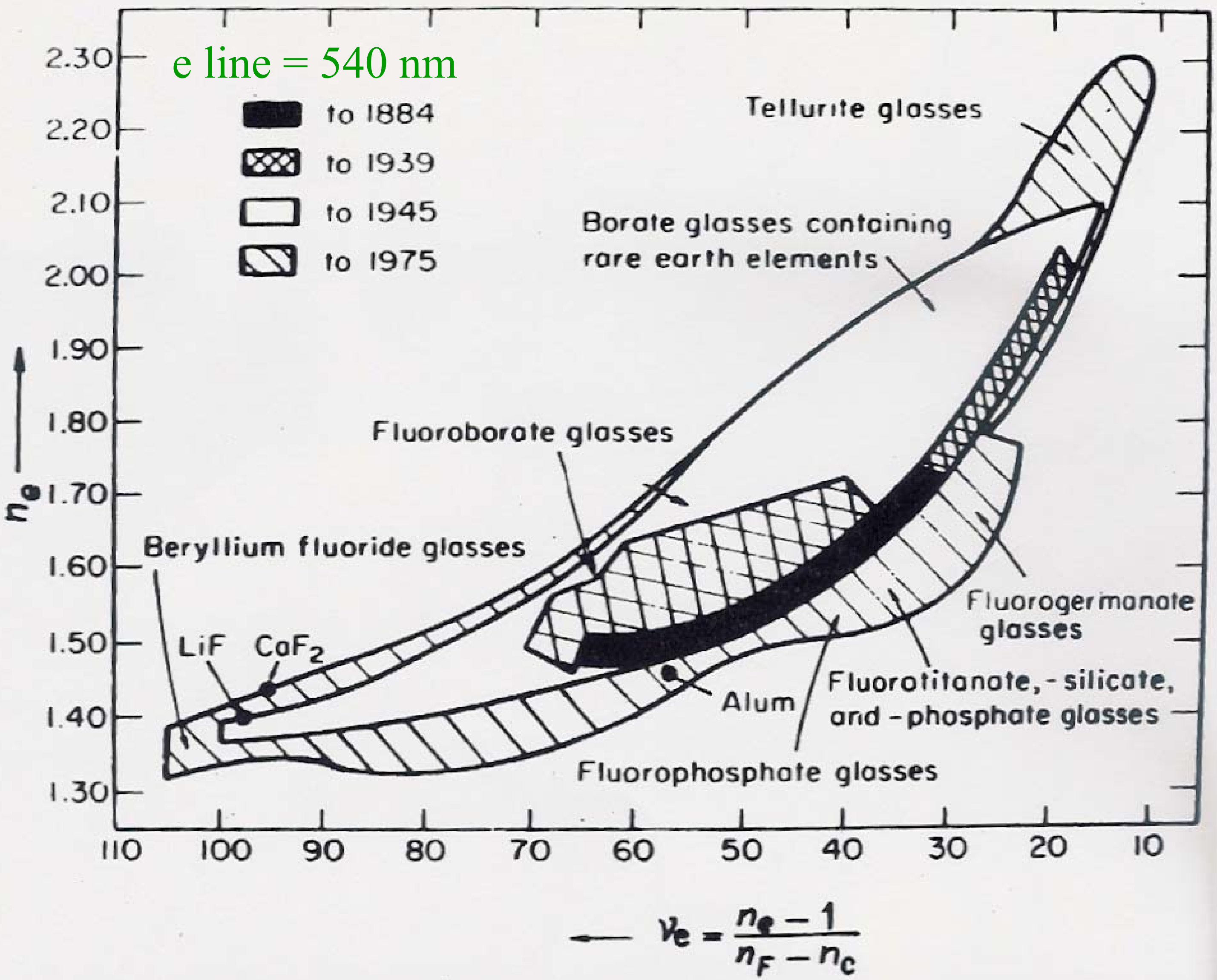
Increase of the refractive index with PbO in R_2O PbO--SiO_2 glasses.

(Adapted from: *Fundamentals of inorganic glasses*, A.K. Varshneya, Academic Press, 1994)



Range of optical properties obtained with crystals and ordinary optical glasses

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



Status of the development of optical glasses characterized by their location in the Ernst Abbe $n_e - \nu_e$ diagram.