3.003
Principles of Engineering Practice

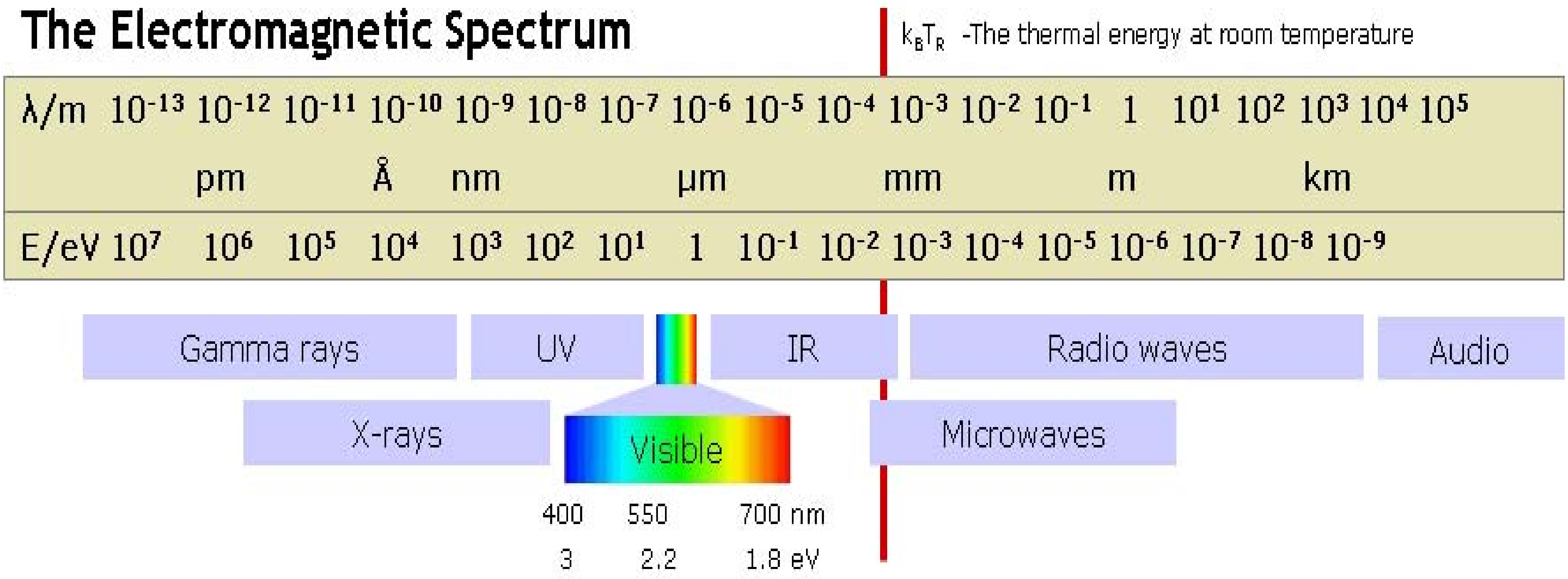
Light

Materials

AR Coatings

Solar Cells

Light is an Electromagnetic Wave



Courtesy of the Opensource Handbook of Nanoscience and Nanotechnology.

Observables

Electromagnetic Field

- voltage, $\vec{E}(\vec{r},t)$
- current, $\vec{H}(\vec{r},t)$

Photonic Materials

- dielectric constant, $\varepsilon/\varepsilon_0$
- index of refraction, n
- absorption, α

- wavelength, λ
- group velocity, $v_g = c_o/N$; N = group index
- power, P

Tool Box (1): Wave Equation

dielectric constant and index of refraction

Wave equation

$$\boxed{\nabla^2 u - \frac{1}{c_0^2}\frac{\partial^2 u}{\partial t^2} = 0}$$

time and spatial variation

$$C_0 = (\epsilon_0 \mu_0)^{-\frac{1}{2}} = 3\times 10^8 m/s$$

ϵ_0 = permittivity of free space

$$= \frac{1}{36\pi}\times 10^{-9} Fm^{-1} \qquad \text{(MKS)}$$

μ_0 = magnetic permittivity of free space

$$= 4\pi \times 10^{-7} Hm^{-1} \qquad \text{(MKS)}$$

n = index of refraction

= c_0/c = 1 (vacuum)

= $(\varepsilon/\varepsilon_0)^{1/2}$ (in a material)

$$\boxed{\epsilon_0 \mu_0 C_0^2 = 1}$$

Harmonic Oscillator

$$F = -kx$$

$$E = \frac{1}{2} k x^2$$

$$\omega = (k/m)^{1/2}$$

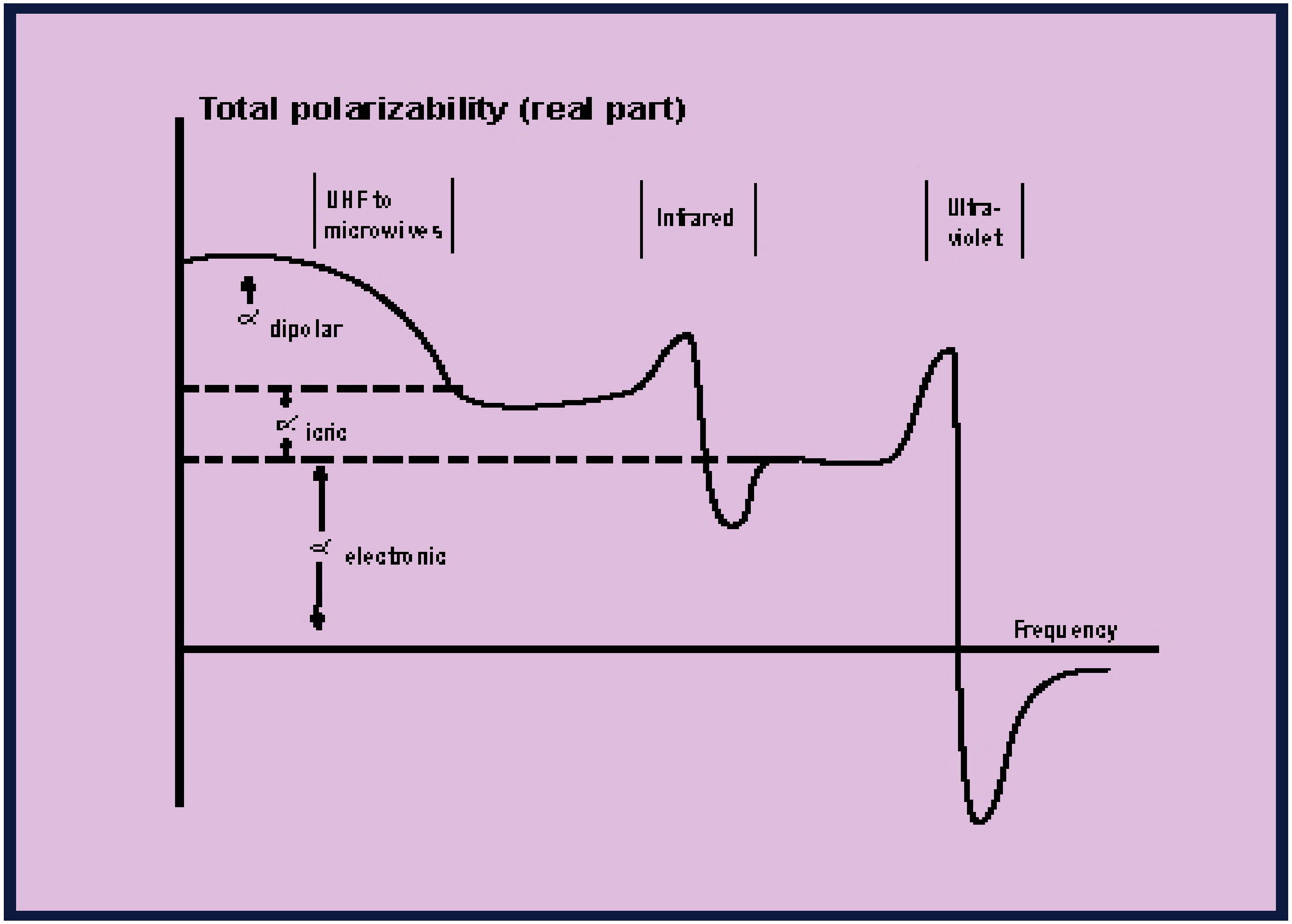
Tool Box (2): Harmonic Oscillator

absorption and dispersion

Dynamic Relation (time dependent) between P(t) and E(t)

$$\bar{E}(t) = a_1 \underbrace{\frac{d^2\bar{P}}{dt^2}}_{\text{accel}} + a_2 \underbrace{\frac{d\bar{P}}{dt}}_{\text{vel}} + a_3 \underbrace{\bar{P}}_{\text{x}}$$

Polarizability, Dielectric Constant, Refractive Index



Dielectric Constant

	$\varepsilon/\varepsilon_0$ (static)
Si	**11.7**
Ge	**16**
$LiNbO_3$	**43**
$BaTiO_3$	**3600**

- Absolute Magnitude
- Materials Trend
- Frequency
- Applications

Refractive index, $(\varepsilon/\varepsilon_0)^{1/2}$

	$\varepsilon/\varepsilon_0$ (static)	n_r (υ)
Si	11.7	3.5
Ge	16	4
$LiNbO_3$	43	2.27
$BaTiO_3$	3600	2.46

'The Chemical Bond' (Pauling)

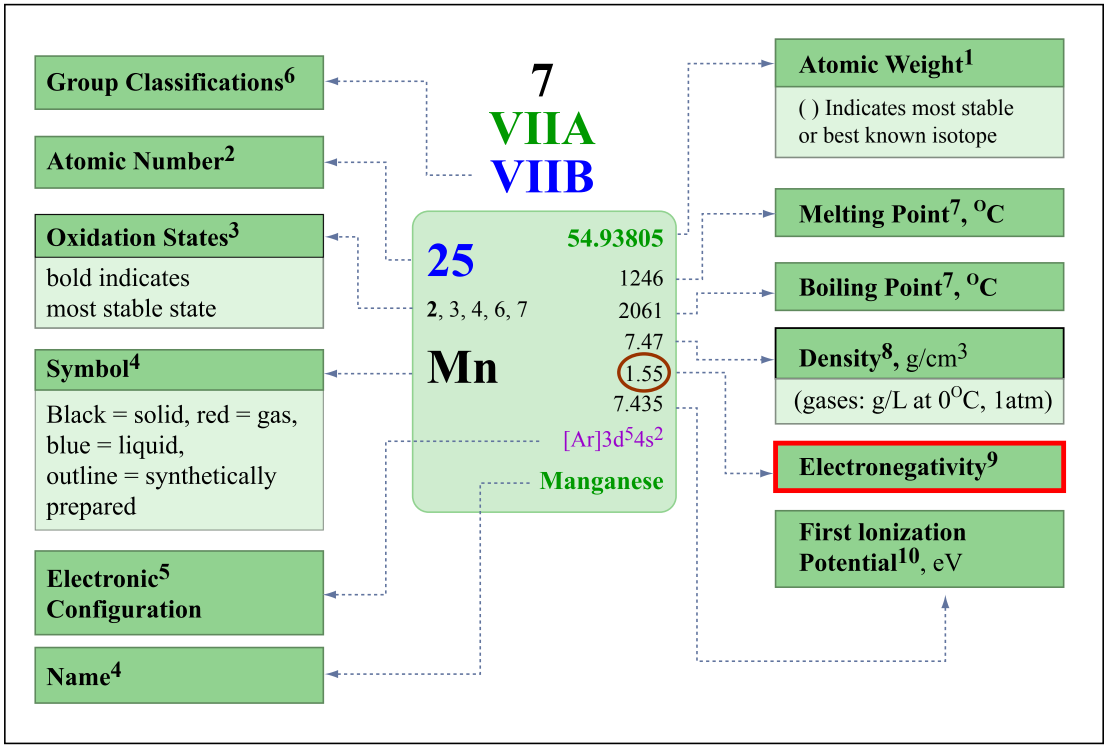


Image by MIT OpenCourseWare.

IIIA	IVA	VA	VIA
10.811 5 2075 4000 3 2.31 2.04 B 8.298 $[He]2s^2p^1$ Boron	12.011 6 4492^{TP} 3825^{SP} 2, ± 4 2.25 2.55 C 11.260 $[He]2s^2p^2$ Carbon	14.00674 7 -210.00 -195.79 2, ± 3,4,5 1.25046 3.04 N 14.534 $[He]2s^2p^3$ Nitrogen	15.9994 8 -218.79 -182.95 -2 1.429 3.44 O 13.618 $[He]2s^2p^4$ Oxygen
26.981539 13 660.32 2519 3 2.702 1.61 Al 5.986 $[Ne]3s^2p^1$ Aluminum	28.0855 14 1414 3265 4 2.33 1.90 Si 8.151 $[Ne]3s^2p^2$ Silicon	30.973762 15 44.15 277 ± 3,4,5 1.82 2.19 P 10.486 $[Ne]3s^2p^3$ Phosphorus	32.066 16 115.21 444.60 ± 2,4,6 2.07 2.58 S 10.360 $[Ne]3s^2p^4$ Sulfur
69.723 31 29.76 2204 3 6.095 1.81 Ga 5.999 $[Ar]3d^{10}4s^2p^1$ Gallium	72.61 32 938.25 2833 4 5.35 2.01 Ge 7.899 $[Ar]3d^{10}4s^2p^2$ Germanium	74.92159 33 817^{TP} 614^{SP} ± 3,5 5.727$^{25°C}$ 2.18 As 9.81 $[Ar]3d^{10}4s^2p^3$ Arsenic	78.96 34 221 685 -2,4,6 4.81 2.55 Se 9.752 $[Ar]3d^{10}4s^2p^4$ Selenium
114.818 49 156.60 2072 3 7.30 1.78 In 5.786 $[Kr]4d^{10}5s^2p^1$ Indium	118.710 50 231.93 2602 2,4 7.28 1.96 Sn 7.344 $[Kr]4d^{10}5s^2p^2$ Tin	121.757 51 630.63 1587 ± 3,5 6.684$^{25°C}$ 2.05 Sb 8.641 $[Kr]4d^{10}5s^2p^3$ Antimony	127.60 52 449.51 988 -2,4,6 6.25 2.1 Te 9.009 $[Kr]4d^{10}5s^2p^4$ Tellurium

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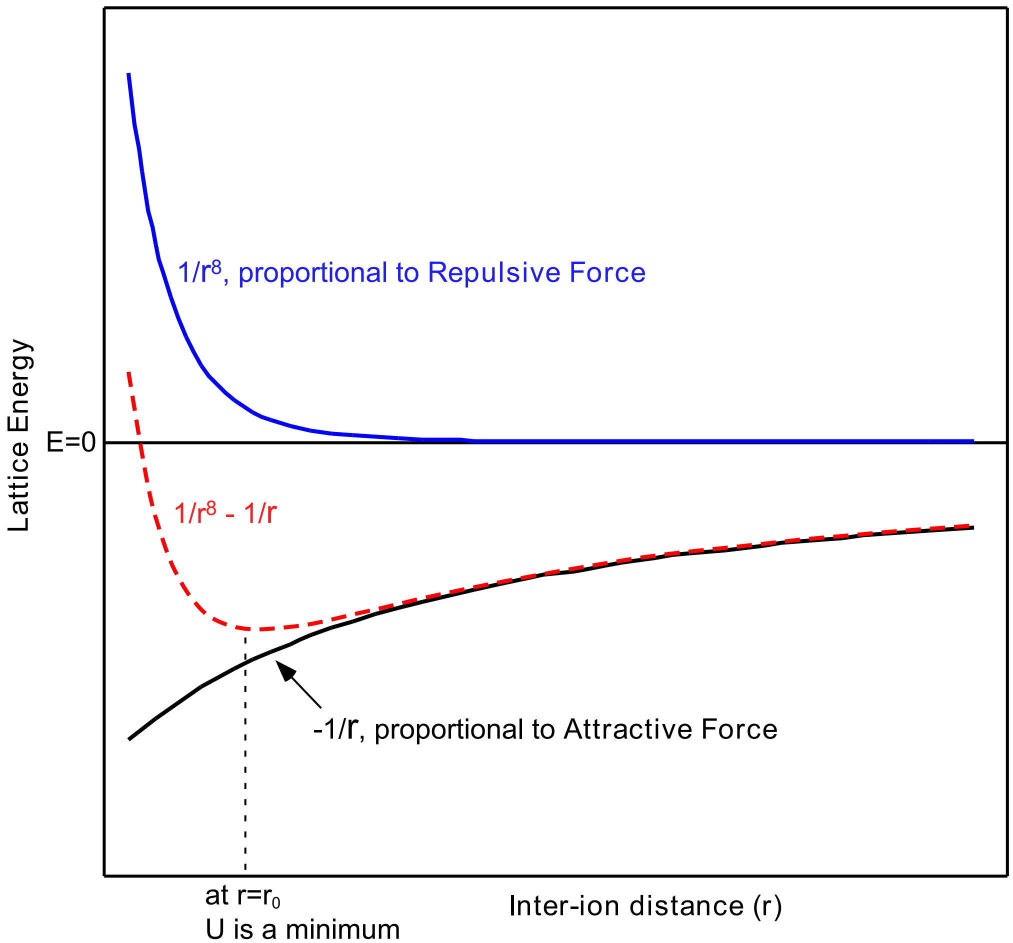
Lattice parameter

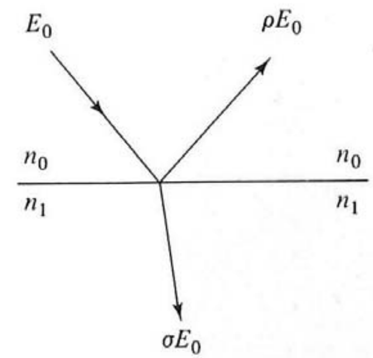


- lattice parameter
- bond stiffness
- coefficient of thermal expansion

Anti-Reflection Coating Design

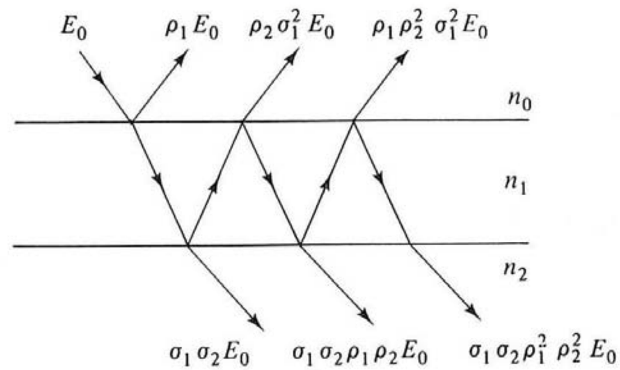
- Reflection (one surface)

  $R_1 = (n_0 - n_1)^2/(n_0 + n_1)^2$



- Reflection (two surfaces: interference)

  phase difference = $(2\pi n_1/\lambda)\ 2t \cos\theta$



$R_2 = (n_1^2 - n_0 n_2)/(n_0 n_2 + n_1^2)$

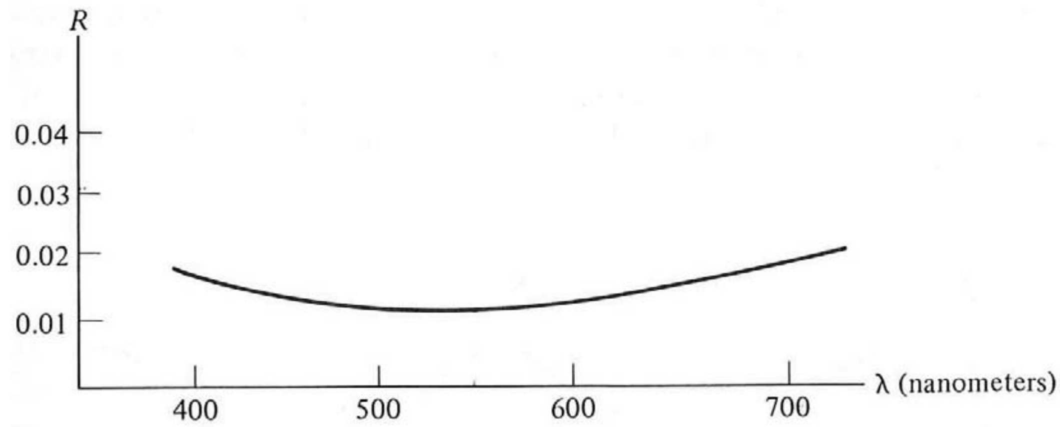
Anti-Reflection Coating Design

- Set R=0

$$n_1 = (n_0 n_2)^{1/2}$$

(index of middle layer is geometric mean of other two indices)

- Sensitivity analysis: f(λ,t,n)



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