

3.003



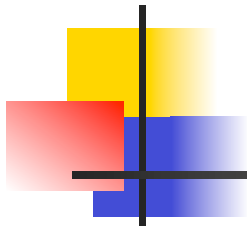
Principles of Engineering Practice

Light

Materials

AR Coatings

Solar Cells

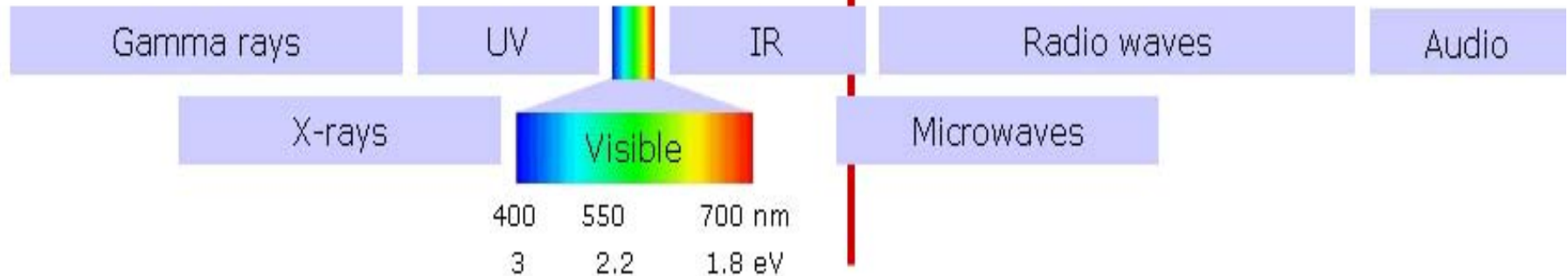


Light is an Electromagnetic Wave

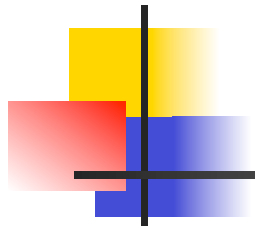
The Electromagnetic Spectrum

$k_B T_R$ -The thermal energy at room temperature

λ/m	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10^1	10^2	10^3	10^4	10^5	
	pm		Å	nm	μm			mm	m		km									
E/eV	10^7	10^6	10^5	10^4	10^3	10^2	10^1	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}			



Courtesy of the [OpenSource Handbook of Nanoscience and Nanotechnology](#).



Observables

Electromagnetic Field

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

- wavelength, λ
- group velocity, $v_g = c_0/N$; $N =$ group index
- power, P

Photonic Materials

- dielectric constant, ϵ/ϵ_0
- index of refraction, n
- absorption, α



Tool Box (1): Wave Equation

dielectric constant and index of refraction

Wave equation

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

time and spatial variation

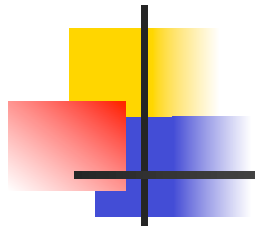
n = index of refraction
= $c_0/c = 1$ (vacuum)
= $(\epsilon/\epsilon_0)^{1/2}$ (in a material)

$$c_0 = (\epsilon_0 \mu_0)^{-1/2} = 3 \times 10^8 \text{ m/s}$$

$$\begin{aligned} \epsilon_0 &= \text{permittivity of free space} \\ &= \frac{1}{36\pi} \times 10^{-9} \text{ Fm}^{-1} \quad (\text{MKS}) \end{aligned}$$

$$\begin{aligned} \mu_0 &= \text{magnetic permeability of free space} \\ &= 4\pi \times 10^{-7} \text{ Hm}^{-1} \quad (\text{MKS}) \end{aligned}$$

$$\epsilon_0 \mu_0 c_0^2 = 1$$

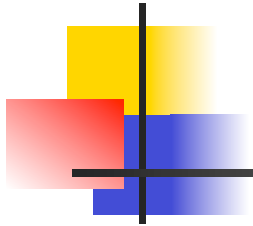


Harmonic Oscillator

$$F = -kx$$

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

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



Tool Box (2): Harmonic Oscillator

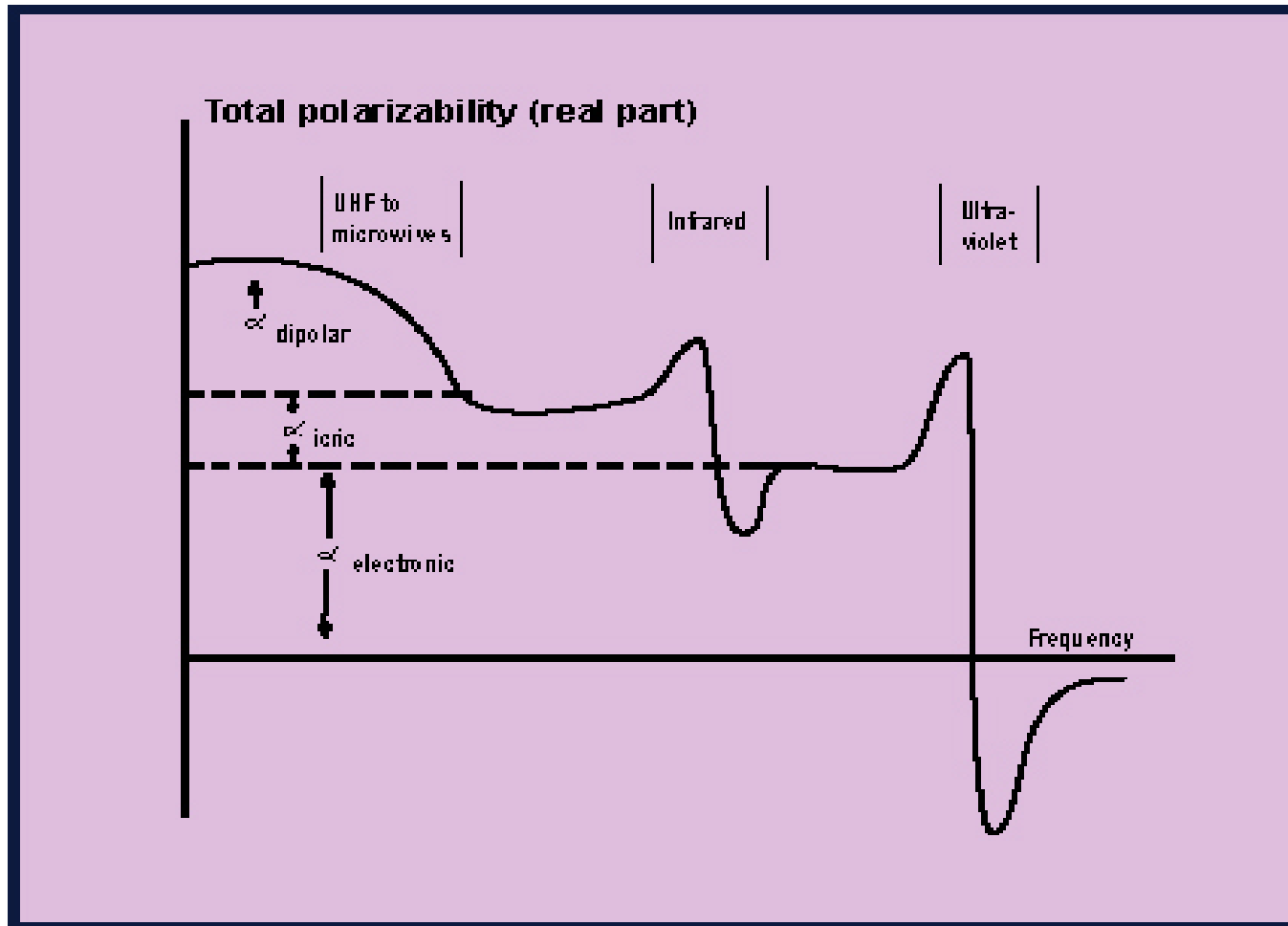
absorption and dispersion

Dynamic Relation (time dependent)
between $\bar{P}(t)$ and $\bar{E}(t)$

$$\bar{E}(t) = a_1 \frac{d^2 \bar{P}}{dt^2} + a_2 \frac{d\bar{P}}{dt} + a_3 \bar{P}$$

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Polarizability, Dielectric Constant, Refractive Index





Dielectric Constant

	ϵ/ϵ_0 (static)
Si	11.7
Ge	16
LiNbO₃	43
BaTiO₃	3600

- Absolute Magnitude
- Materials Trend
- Frequency
- Applications



Refractive index, $(\epsilon/\epsilon_0)^{1/2}$

	ϵ/ϵ_0 (static)	n_r (ν)
Si	11.7	3.5
Ge	16	4
LiNbO ₃	43	2.27
BaTiO ₃	3600	2.46

'The Chemical Bond' (Pauling)

7
VIIA
VIIIB

Atomic Weight¹
() Indicates most stable or best known isotope

Melting Point⁷, °C

Boiling Point⁷, °C

Density⁸, g/cm³
(gases: g/L at 0°C, 1atm)

Electronegativity⁹

First Ionization Potential¹⁰, eV

Group Classifications⁶

Atomic Number²

Oxidation States³
bold indicates most stable state

Symbol⁴
Black = solid, red = gas, blue = liquid, outline = synthetically prepared

Electronic⁵ Configuration

Name⁴

25 **54.93805**

Mn

Manganese

[Ar]3d⁵4s²

1246
2061
7.47
1.55
7.435

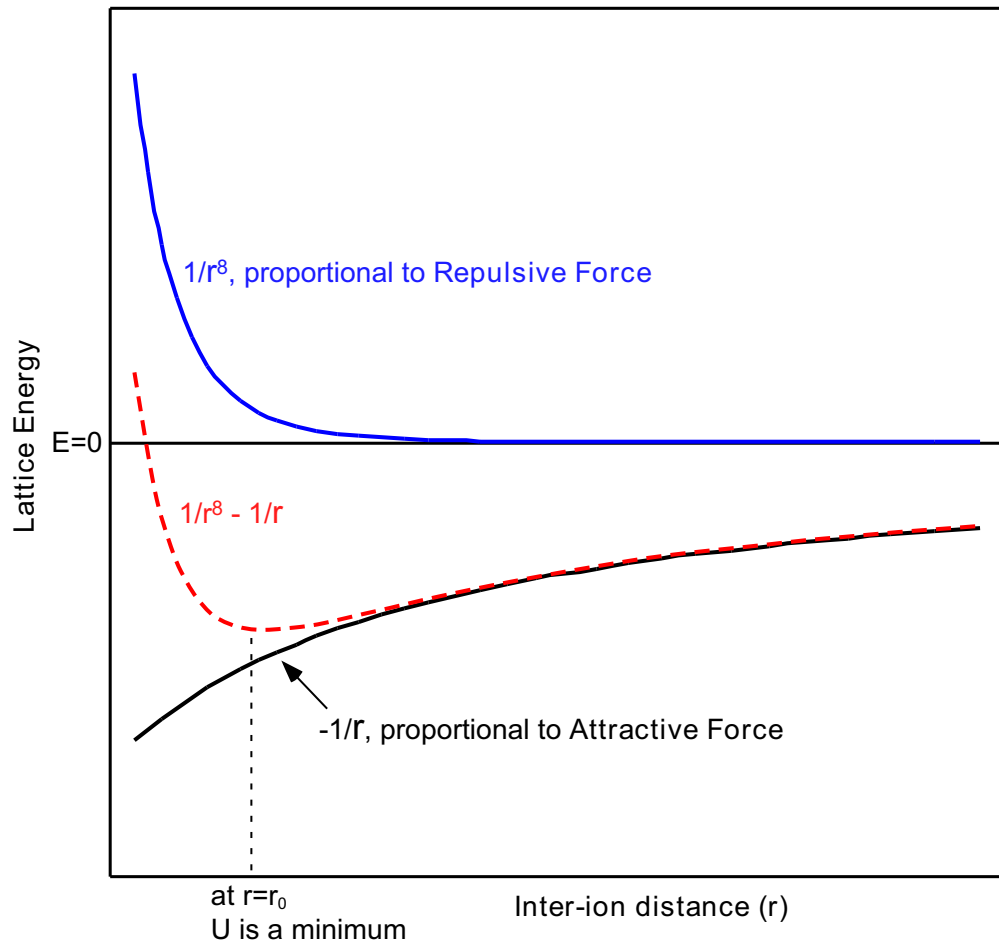
2, 3, 4, 6, 7

Image by MIT OpenCourseWare.

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

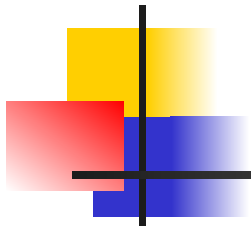
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Lattice parameter



- lattice parameter
- bond stiffness
- coefficient of thermal expansion

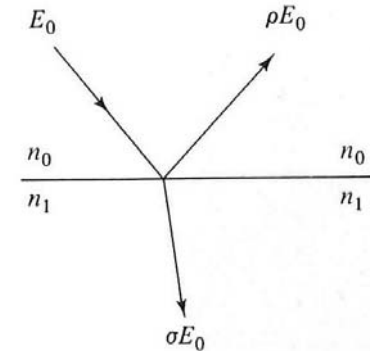
Image courtesy of Frederick Frey. Used with permission.



Anti-Reflection Coating Design

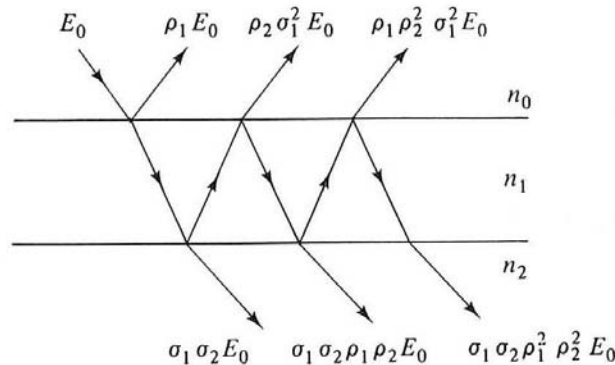
- Reflection (one surface)

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



- Reflection (two surfaces: interference)

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



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

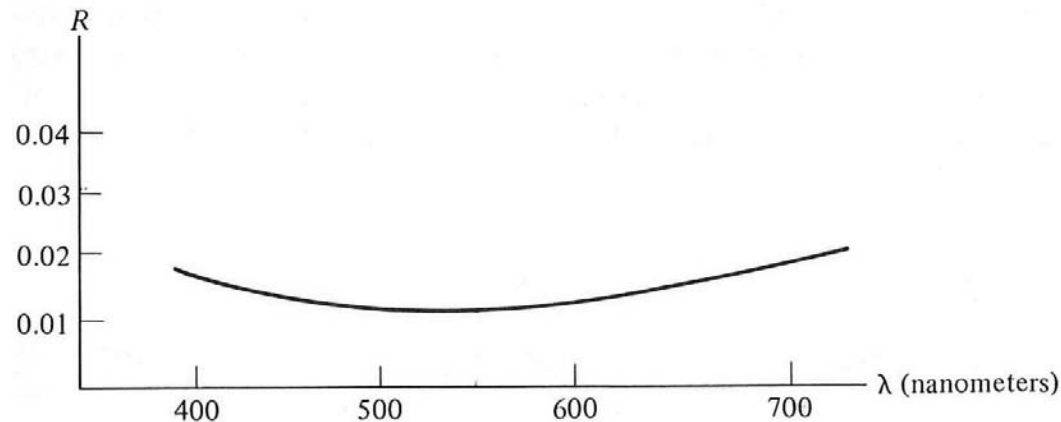
Anti-Reflection Coating Design

- Set $R=0$

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

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

- Sensitivity analysis: $f(\lambda, t, n)$



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3.003 Principles of Engineering Practice
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