Linear Superposition:

⇒ for 2 wave sources vibrating in phase:

$$\Delta L = n\lambda \qquad n = 0,1,2,... \qquad \text{constructive interference}$$

$$\Delta L = \frac{n\lambda}{2} \qquad n = 1,3,5,... \qquad \text{destructive interference}$$

Beats:

$$f_{beats} = |f_1 - f_2|$$

Standing Waves:

⇒ for standing waves on a string fixed at both ends:

$$\lambda = \frac{2L}{n} \qquad f_n = n\left(\frac{v}{2L}\right) \qquad n = 1,2,3,...$$

⇒ for standing waves in a tube open at both ends:

$$\lambda = \frac{2L}{n} \qquad f_n = n\left(\frac{v}{2L}\right) \qquad n = 1,2,3,...$$

⇒ for standing waves in a tube open at only one end:

$$\lambda = \frac{4L}{n} \qquad f_n = n\left(\frac{v}{4L}\right) \qquad n = 1,3,5,...$$

Electromagnetic Waves:

⇒ All electromagnetic (EM) waves travel through a vacuum at the same speed:

$c = 3.00 \times 10^8$ m/s

⇒ for all waves: $\lambda f = v$ also known as the "**Universal Wave Equation**"

⇒ the speed of EM waves through a material is less than in a vacuum:

index of refraction: $n = \frac{c}{v}$ where v is the speed of light in the material

⇒ when a waves passes from one material to another, the frequency remains constant but the wavelength changes:

$\lambda = \frac{\lambda_0}{n}$ where λ_0 is the wavelength in vacuum

Polarization:

⇒ for an EM wave, the direction of polarization is taken to be the direction of the electric field

⇒ when an EM wave passes through a polarizing filter, the intensity of the transmitted light decreases:

$I = \frac{1}{2} I_0$ initially unpolarized light

$I = I_0 \cos^2\theta$ initially polarized light

⇒ after light passes through a filter, it is polarized in the direction of the filter

Reflection of Light:

Law of Reflection: $\theta_r = \theta_i$

Refraction of Light:

Index of Refraction: $n = \frac{\text{speed of light in vacuum}}{\text{speed of light in the material}} = \frac{c}{v}$

Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$

Total Internal Reflection:

⇒ total internal reflection can only occur if $n_2 < n_1$

Critical Angle: $\theta_c = \sin^{-1}\left(n_2 / n_1 \right)$

Thin Lens and Magnification Equations:

thin lens equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ magnification equation: $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

Lenses in Combination:

⇒ the image produced by the first lens serves as the object for the second lens

Interference:

constructive interference: $\Delta L = L_2 - L_1 = m\lambda \quad m = 0,1,2,\ldots$

destructive interference: $\Delta L = L_2 - L_1 = (m + 1/2)\,\lambda \quad m = 0,1,2,\ldots$

Young's Double-Slit Experiment:

bright fringes: $\sin\theta = \frac{m\lambda}{d} \quad m = 0,1,2,\ldots$ *dark fringes:* $\sin\theta = \frac{(m + 1/2)\,\lambda}{d} \quad m = 0,1,2,\ldots$

use $\mathbf{y = L \tan\theta}$ to find the distance between the fringes

Diffraction:

dark fringes for single-slit diffraction: $\sin\theta = m\lambda / W \quad m = 1,2,3...$

Thin Film Interference:

⇒ the wavelength that is important is the wavelength within the film: $\lambda_{film} = \dfrac{\lambda_{vacuum}}{n_{film}}$

⇒ there is a ½ λ phase change when light reflects from a region with a higher index of refraction

⇒ if only one of the waves undergoes a ½ λ phase change:

constructive interference: $2t = (m + 1/2)\lambda_{film} \quad m = 0,1,2,...$

destructive interference: $2t = m\lambda_{film} \quad m = 0,1,2,...$

⇒ if neither of the waves or if both waves undergo a ½ λ phase change:

constructive interference: $2t = m\lambda_{film} \quad m = 0,1,2,...$

destructive interference: $2t = (m + 1/2)\lambda_{film} \quad m = 0,1,2,...$

Photons and the Photoelectric Effect:

Energy of a photon: $E = hf$

$E = hc/\lambda \qquad hc = 1240\,\text{eV}\cdot\text{nm}$

Plank's constant: $h = 6.626\times10^{-34}\,\text{J}\cdot\text{s}$

$h = 4.136\times10^{-15}\,\text{eV}\cdot\text{s}$

Photoelectric Effect: $hf = KE_{max} + W_0$

$W_0 = hf_0 \qquad f_0 = \text{cutoff frequency}$

KE_{max}: max KE of ejected electrons

W_0: work function (minimum energy required to eject an electron)

Momentum of a Photon and the Compton Effect:

Momentum of photon: $p = h/\lambda = hf/c$

Compton Scattering: $\Delta\lambda = \lambda' - \lambda = \dfrac{h}{m_e c}(1 - \cos\theta)$

$$\frac{h}{m_e c} = 2.426\times10^{-12}\,\text{m} = 2.426\,\text{pm}$$

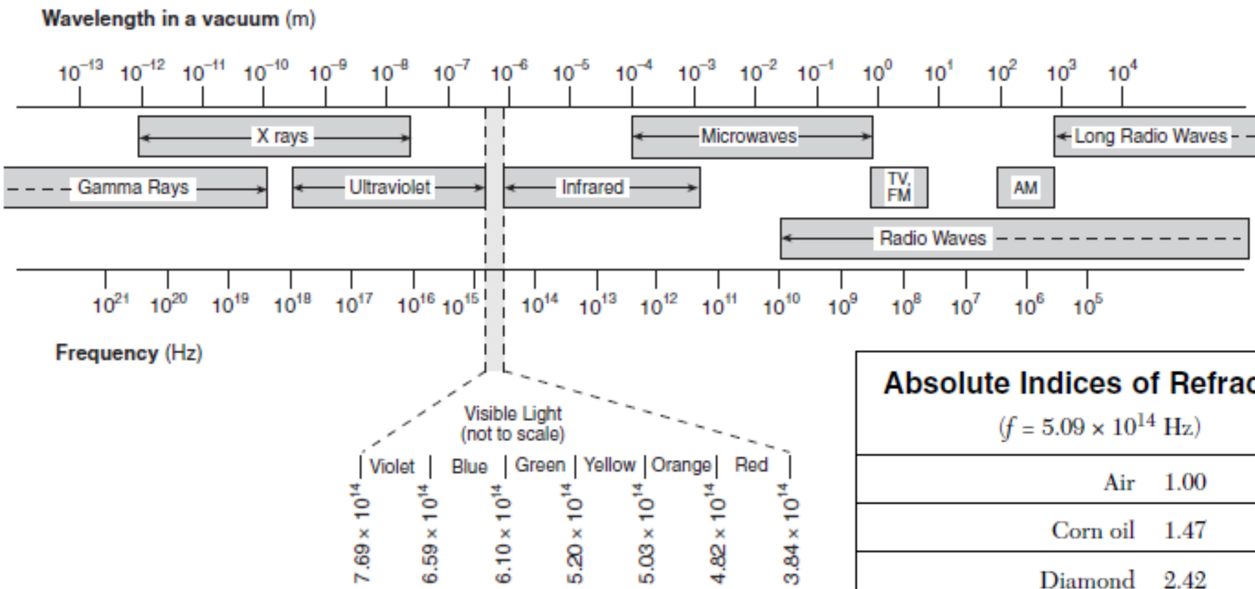
de Broglie Wavelength: *de Broglie Wavelength:* $\lambda = \dfrac{h}{p}$

Heisenberg Uncertainty Principle:

$$(\Delta p_y)(\Delta y) \geq \frac{h}{4\pi}$$

$$(\Delta E)(\Delta t) \geq \frac{h}{4\pi}$$

The Electromagnetic Spectrum



Absolute Indices of Refraction

($f = 5.09 \times 10^{14}$ Hz)

Air	1.00
Corn oil	1.47
Diamond	2.42
Ethyl alcohol	1.36
Glass, crown	1.52
Glass, flint	1.66
Glycerol	1.47
Lucite	1.50
Quartz, fused	1.46
Sodium chloride	1.54
Water	1.33
Zircon	1.92

Particles of the Standard Model

Quarks

Name	up	charm	top
Symbol	u	c	t
Charge	$+\frac{2}{3}$e	$+\frac{2}{3}$e	$+\frac{2}{3}$e
	down	strange	bottom
	d	s	b
	$-\frac{1}{3}$e	$-\frac{1}{3}$e	$-\frac{1}{3}$e

Leptons

electron	muon	tau
e	μ	τ
–1e	–1e	–1e
electron neutrino	muon neutrino	tau neutrino
ν_e	ν_μ	ν_τ
0	0	0

Note: For each particle, there is a corresponding antiparticle with a charge opposite that of its associated particle.

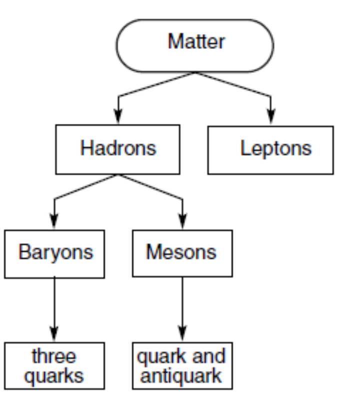
Modern Physics

$$E_{photon} = hf = \frac{hc}{\lambda}$$

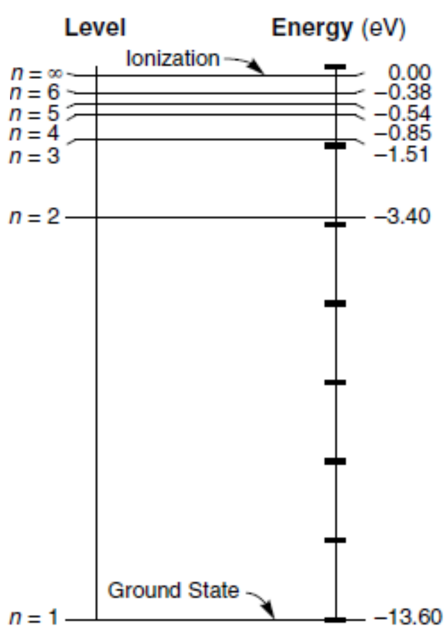
$$E_{photon} = E_i - E_f$$

$$E = mc^2$$

Classification of Matter



Hydrogen



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