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Radiation (energy movement, charge acceleration, energytransport, poynting)

Hypothesis: Accelerated charge causes radiation (analogous to “force”)

I) Optical Radiation spectral range: $\lambda = [100nm, 1mm]$:

1. high frequency: UV spectral range: $\lambda = [100nm, 200nm]$
2. visibility wavelength: light (Photon) range: $\lambda = [380nm, 780nm]$
3. long wavelength: IR spectral range: $\lambda = [5 \cdot 10^4 nm, 10^6 nm]$

II) Heat Radiation invisible (Black Body “B”), $\mathcal{L}_{\lambda,B}(\lambda, T)$

Charge:

$$q = ne_0 \qquad \sum q = Q = I \cdot t \qquad n \in \mathbb{Z} \tag{1}$$

Radiation:

$$\mathcal{S} = \frac{d}{dt}p = \frac{1}{c}\frac{d}{dt}(E_{kin}) = q \cdot a \tag{2}$$

Optical Radiation:

Deviation angle of ray beam after refraction (transmission) and diffraction:

$$\varsigma = \alpha + arcsin\left[sin(\varpi)\sqrt{\eta^2 - sin^2(\alpha)} - cos(\varpi)sin(\alpha)\right] - \varpi = \alpha + \alpha_2 - \varpi \tag{3}$$

where $\varpi = \beta + \beta_2 = const.$

Minimal aberration (minimal projection error):

$\varsigma = \varsigma_{min} \iff$

$$\begin{gathered} \varsigma_{min} \iff \\ \frac{d}{d\alpha}\varsigma = 0 \wedge \\ \varsigma_{min} = 2\alpha - \varpi = 2(\alpha - \beta) \end{gathered} \tag{4}$$

Thermal Radiation:

Spectral Reflection:

$$\mathcal{R}(\lambda) = \frac{d^3\Phi_{\lambda,r}}{d^3\Phi_{\lambda,e}} \tag{5}$$

Spectral Transmission:

$$\mathcal{T}(\lambda) = \frac{d^3\Phi_{\lambda,t}}{d^3\Phi_{\lambda,e}} \tag{6}$$

Spectral Absorbtion:

$$\mathcal{A}(\lambda) = \frac{d^3\Phi_{\lambda,a}}{d^3\Phi_{\lambda,e}} \tag{7}$$

Spectral Emission:

$$\mathcal{E}(\lambda) = \frac{\mathcal{L}(\lambda)}{\mathcal{L}(\lambda, B)} \tag{8}$$

$\mathcal{R}(\lambda) + \mathcal{T}(\lambda) + \mathcal{A}(\lambda) = 1$

Black Body "B":

$$\mathcal{A}(\lambda, T) = \mathcal{E}(\lambda, T) = 1,\ \mathcal{R}(\lambda, T) = 0,\ \mathcal{T}(\lambda, T) = 0 \tag{9}$$

$\Rightarrow$ Heat Radiation (Black Body):

$$\mathcal{L}_B = \frac{c}{4\pi}\langle w_{EM}\rangle = \frac{c}{4\pi} w_B \tag{10}$$

$$\mathcal{L}_{\lambda,B}(\lambda, T) = \frac{\mathcal{L}_\lambda(\lambda, T)}{\mathcal{A}_\lambda(\lambda, T)} \overset{continuum}{=} \frac{2c}{\lambda^4} kT \overset{quantum}{=} \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} = const. \tag{11}$$

$$\mathcal{L}_{\nu,B}(\nu, T) \overset{quantum}{=} \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{hc}{kT}} - 1} \tag{12}$$

$$\mathcal{L}_{\lambda,B}(\lambda_x, T_x) = \left(\frac{T_x}{T}\right)^5 \cdot \mathcal{L}_{\lambda,B}(\lambda, T) \tag{13}$$

$T_x > T \Rightarrow \lambda_x < \lambda$

$$\lambda_{max} \cdot T = \frac{h \cdot c}{5k} \frac{1}{1 - e^{-\lambda_{max} \cdot T}} = b = 2.897773 \cdot 10^{-3} m \cdot K \tag{14}$$

Heat Radiation Transfer (sent from source g to receiver b with areas $\mathcal{A}$):

$$d^2\Phi \overset{vacuum}{=} \mathcal{L} \frac{dA_g \cos(\varepsilon_g)}{R} \frac{dA_b \cos(\varepsilon_b)}{R} = \frac{\mathcal{L}}{R^2} \cdot dA_g \cos(\varepsilon_g) \cdot dA_b \cos(\varepsilon_b) = \mathcal{L} \cos(\varepsilon_b) dA_b d\Omega_b \tag{15}$$

Heat Radiation Return, Reflection Absorbtion (Feedback absorbed "a" at sender g received "e" at receiver b, with areas $\mathcal{A}$ at wavelength λ):

$$d^3\Phi_{\lambda,a,b} \overset{vacuum}{=} \mathcal{A}_b \cdot d^3\Phi_{\lambda,e,b} = \mathcal{A}_b \cdot \mathcal{L}_\lambda \cos(\varepsilon_b) d\mathcal{A}_b d\Omega_b d\lambda = \mathcal{L}_{\lambda,b} \cos(\varepsilon_g) d\mathcal{A}_g d\Omega_g d\lambda = d^3\Phi_{\lambda,b} \tag{16}$$

Energy Density w and Pressure P, Temperature T, Volume V, inner Energy U, Entropy density s, Radiance

$\mathcal{L}_B$:

$$w_B = \frac{\mathcal{L}_B}{c} \int_0^{4\pi} d\Omega = \frac{4\pi}{c} \cdot \mathcal{L}_B = \frac{4}{c} \cdot \mathcal{M}_B = 2 \cdot 2\pi \cdot \frac{\mathcal{L}_B}{c} \overset{oriented}{=} P_{EM} \overset{unoriented}{=} 3w_{EM} = 3\left(\varepsilon_0 \varepsilon_r \mathcal{E}^2\right) = 3P_B = 3\left(-\frac{dW}{d}\right. \tag{17}$$

$$w_{\lambda,B} \overset{continuum}{=} -\frac{dn}{d\lambda}\overline{W} = \frac{8\pi}{\lambda^4} kT \overset{quantum}{=} \frac{8\pi hc}{\lambda^5} \frac{1}{e^{\frac{hc}{kT}} - 1} = 8\pi h\nu \frac{1}{\lambda^4} \frac{1}{e^{\frac{hc}{kT}} - 1} \tag{18}$$

$$w_{\nu,B} \overset{continuum}{=} \frac{dn}{d\nu}\overline{W} = \frac{8\pi\nu^2}{c^3} kT \overset{quantum}{=} \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{hc}{kT}} - 1} = 8\pi h \left(\frac{1}{\lambda}\right)^3 \frac{1}{e^{\frac{hc}{kT}} - 1} \tag{19}$$

where Radiant Exitance (Emittance) $\mathcal{M}_B = \frac{d\Phi}{dA_g} = \sigma T^4$ and proportionality constants:

$a = \frac{2^3}{3 \cdot 5} \frac{\pi^5 k^4}{h^3 c^3} = 7.5657 \cdot 10^{-16} J m^{-3} K^{-4}$ (a = constant from integration)

$\sigma = \frac{1}{4} \cdot a \cdot c = \frac{2}{3 \cdot 5} \frac{\pi^5 k^4}{h^3 c^3} = 5.6704 \cdot 10^{-8} W m^{-2} K^{-4}$ (c = light speed)

$$\frac{d}{d\Omega} P_{EM} \overset{oriented}{=} \frac{d}{d\Omega} w_B = \frac{\mathcal{L}_B}{c} \tag{20}$$

Blackbody Entropy Density $s_B = \frac{4}{3} a T^4$ Blackbody Entropy $S_B = \frac{4}{3} a V T^3$ Blackbody Inner Energy $U_B = aVT^4$ Blackbody Pressure $P_B = \frac{1}{3} a T^4 \overset{unoriented}{=} \frac{1}{3} w_B$