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Thermal Radiation:

Spectral Reflection:

$$\mathcal{R}(\lambda) = \frac{d^3\Phi_{\lambda,r}}{d^3\Phi_{\lambda,e}} \quad (1)$$

Spectral Transmission:

$$\mathcal{T}(\lambda) = \frac{d^3\Phi_{\lambda,t}}{d^3\Phi_{\lambda,e}} \quad (2)$$

Spectral Absorbtion:

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

Spectral Emission:

$$\mathcal{E}(\lambda) = \frac{\mathcal{L}(\lambda)}{\mathcal{L}(\lambda, B)} \quad (4)$$

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

Black Body “B”:

$$\mathcal{A}(\lambda, T) = \mathcal{E}(\lambda, T) = 1, \quad \mathcal{R}(\lambda, T) = 0, \quad \mathcal{T}(\lambda, T) = 0 \quad (5)$$

$\Rightarrow$  Heat Radiation (Black Body):

$$\mathcal{L}_B = \frac{c}{4\pi} \langle w_{EM} \rangle = \frac{c}{4\pi} w_B \quad (6)$$

$$\mathcal{L}_{\lambda,B}(\lambda, T) = \frac{\mathcal{L}_{\lambda}(\lambda, T)}{\mathcal{A}_{\lambda}(\lambda, T)} \stackrel{\text{continuum}}{=} \frac{2c}{\lambda^4} kT \stackrel{\text{quantum}}{=} \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} = \text{const.} \quad (7)$$

$$\mathcal{L}_{\nu,B}(\nu, T) \stackrel{\text{quantum}}{=} \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \quad (8)$$

$$\mathcal{L}_{\lambda,B}(\lambda_x, T_x) = \left( \frac{T_x}{T} \right)^5 \cdot \mathcal{L}_{\lambda,B}(\lambda, T) \quad (9)$$

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

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

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

$$d^2\Phi \stackrel{vacuum}{=} \mathcal{L} \frac{dA_g \cos(\varepsilon_g)}{R} \frac{dA_b \cos(\varepsilon_b)}{R} = \frac{\mathcal{L}}{R^2} \cdot dA_g \cos(\varepsilon_g) \cdot dA_b \cos(\varepsilon_b) = \mathcal{L} \cos(\varepsilon_b) dA_b d\Omega_b \quad (11)$$

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

$$d^3\Phi_{\lambda,a,b} \stackrel{vacuum}{=} \mathcal{A}_b \cdot d^3\Phi_{\lambda,e,b} = \mathcal{A}_b \cdot \mathcal{L}_\lambda \cos(\varepsilon_b) d\mathcal{A}_b d\Omega_b d\lambda = \mathcal{L}_{\lambda,b} \cos(\varepsilon_g) d\mathcal{A}_g d\Omega_g d\lambda = d^3\Phi_{\lambda,b} \quad (12)$$

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

$\mathcal{L}_B$ :

$$w_B = \frac{\mathcal{L}_B}{c} \int_0^{4\pi} d\Omega = \frac{4\pi}{c} \cdot \mathcal{L}_B = \frac{4}{c} \cdot \mathcal{M}_B = 2 \cdot 2\pi \cdot \frac{\mathcal{L}_B}{c} \stackrel{oriented}{=} P_{EM} \stackrel{unoriented}{=} 3w_{EM} = 3(\varepsilon_0 \varepsilon_r \mathcal{E}^2) = 3P_B = 3 \left( -\frac{dW}{dV} \right) \quad (13)$$

$$w_{\lambda,B} \stackrel{continuum}{=} -\frac{dn}{d\lambda} \overline{W} = \frac{8\pi}{\lambda^4} kT \stackrel{quantum}{=} \frac{8\pi hc}{\lambda^5} \frac{1}{e^{\frac{hc}{kT}} - 1} = 8\pi h\nu \frac{1}{\lambda^4} \frac{1}{e^{\frac{hc}{kT}} - 1} \quad (14)$$

$$w_{\nu,B} \stackrel{continuum}{=} \frac{dn}{d\nu} \overline{W} = \frac{8\pi \nu^2}{c^3} kT \stackrel{quantum}{=} \frac{8\pi h \nu^3}{c^3} \frac{1}{e^{\frac{hc}{kT}} - 1} = 8\pi h \left( \frac{1}{\lambda} \right)^3 \frac{1}{e^{\frac{hc}{kT}} - 1} \quad (15)$$

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

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

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

$$\frac{d}{d\Omega} P_{EM} \stackrel{oriented}{=} \frac{d}{d\Omega} w_B = \frac{\mathcal{L}_B}{c} \quad (16)$$

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Blackbody Entropy Density  $s_B = \frac{4}{3}aT^4$

Blackbody Entropy  $S_B = \frac{4}{3}aVT^3$

Blackbody Inner Energy  $U_B = aVT^4$

Blackbody Pressure  $P_B = \frac{1}{3}aT^4 \stackrel{\text{unoriented}}{=} \frac{1}{3}w_B$