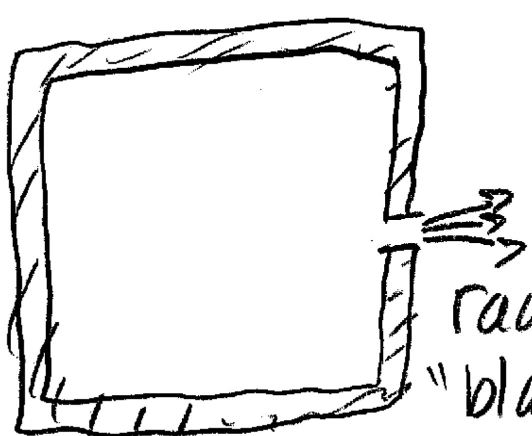
Hot objects emit light.

"red hot", "white hot"

even a "black body" emits radiation when above $T > 0$

↑ Kelvin

empirical work was crucial



$\leftarrow \frac{\text{energy}}{\text{second}} \frac{1}{\text{Area}}$ ↓ "radiant intensity" $I(T)$

radiation

"black body"

↑ box, say, copper heat to temperature T

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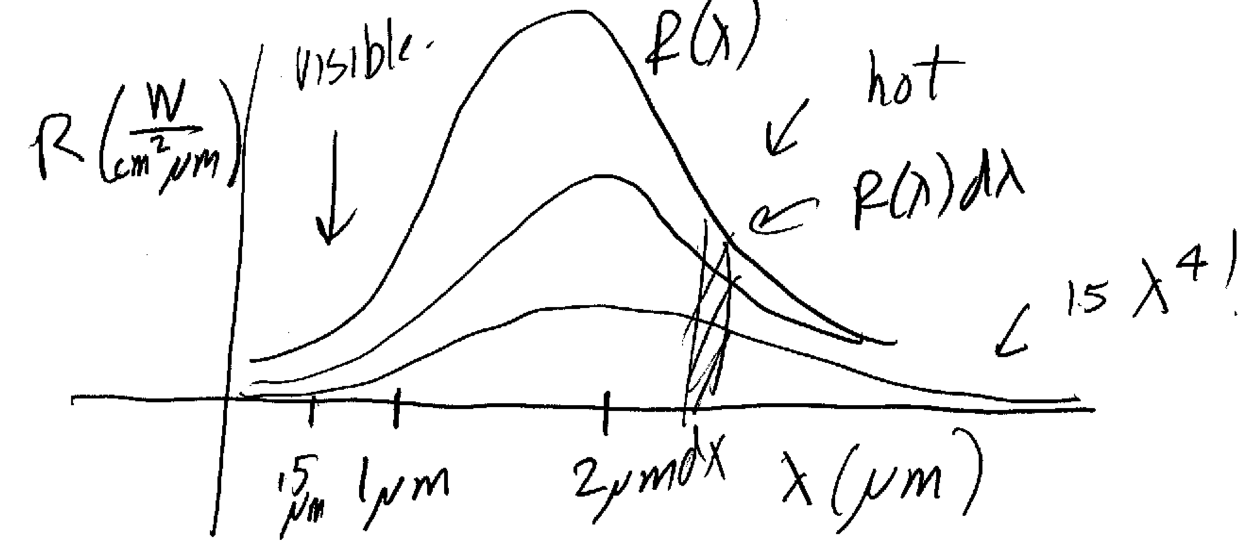
① $I(T) = \sigma T^4$ → explainable by deeper physics.

↑ Stefan-Boltzmann $= 5.67 \cdot 10^{-8} \frac{W}{m^2 K^4}$

(2) Spectral Radiancy

put this radiant intensity in intervals of wavelength...



$$I(T) = \sigma T^4 = \int_0^\infty R(\lambda)\, d\lambda$$

Form a mystery...

Rayleigh - Jeans'

$$R(\lambda) = \frac{2\pi c k T}{\lambda^4}$$

$\rightarrow \infty$ as $\lambda \rightarrow 0$!!

(3) $\lambda_{max} T = 2898 \, \mu m \cdot K$

$$\lambda_{max} = \frac{2898 \, \mu m \cdot K}{T \, (K)}$$

(i) Body $T = 98.6 \simeq 37 \, C$

$\simeq 310 \, K$

$\lambda_{max} \simeq 9.34 \, \mu m$

(ii) Sun, $\lambda_{max} \simeq 500 \, nm \simeq \frac{1}{2} \, \mu m$

$$T = \frac{2898 \, \mu m \cdot K}{1/2} \simeq 5800 \, K$$

Total Radiated power?

body: $I(T) = \sigma T^4$

$\simeq (5.67 \cdot 10^{-8})(310)^4$

$\simeq 524 \, W/m^2$

$\boxed{\text{Body Area}} \simeq 1.6 - 1.9 \, m^2$

$\boxed{\text{Energy Radiated}} \simeq 840 - 1000 \, W$

Sun... $4 \cdot 10^{26} \, W$.

Planck's Radiation Law

Mathematical Fit to Empirical Data

$$R(\lambda) = \frac{a}{\lambda^5} \frac{1}{e^{b/(\lambda T)} - 1}$$

λ really long..

$$e^{b/\lambda T} \sim 1 + \frac{b}{\lambda T}$$

get $R(\lambda) \simeq \frac{a}{\lambda^5} \frac{1}{\frac{b}{\lambda T}}$ Rayleigh

$$\simeq \left(\frac{a}{b}\right) \frac{T}{\lambda^4} \simeq \frac{2\pi c k T}{\lambda^4}$$

$$\frac{a}{b} = 2\pi c k$$

λ really small.

Derivation: atoms oscillators but can only have energies

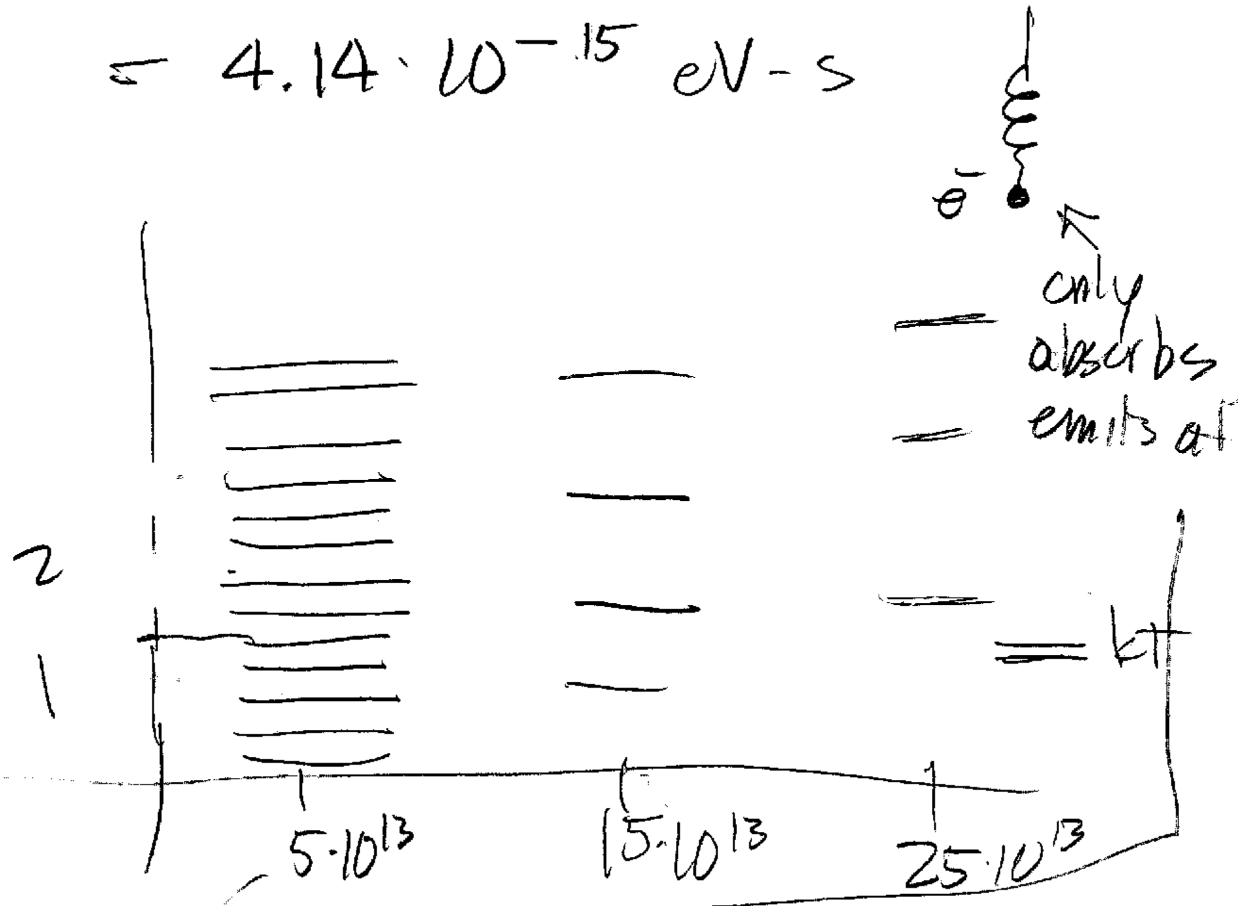
$$E = n h \nu = \frac{n h c}{\lambda}$$

$$\frac{2\pi c^2 h}{hc/k} = 2\pi c k$$

$$R(\lambda) = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k T}} - 1}$$

numerical value of h

$$h = 6.63 \cdot 10^{-34} \ J \cdot s$$
$$= 4.14 \cdot 10^{-15} \ eV\text{-}s$$



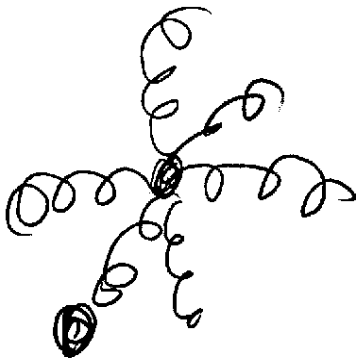
$$e^{\frac{hc}{\lambda kT}} = e^{\frac{h\nu}{kT}}$$ boltzmann factor

$$h\nu = 4.14 \cdot 10^{-15} \cdot 5 \cdot 10^{13}$$
$$\simeq 20 \cdot 10$$

+ time

$$R(\lambda) \sim e^{-h\nu/kT}$$

Heat Capacity of Solids



$$E_{int} = 6 \times \left(\tfrac{1}{2}kT\right) N_A$$

$$= 3RT$$

vibrations

$\nu \rightarrow$ spring constant

crystal prop

quantized, $h\nu_c = kT_E$

$$E_{int} = \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \times 3N_A$$

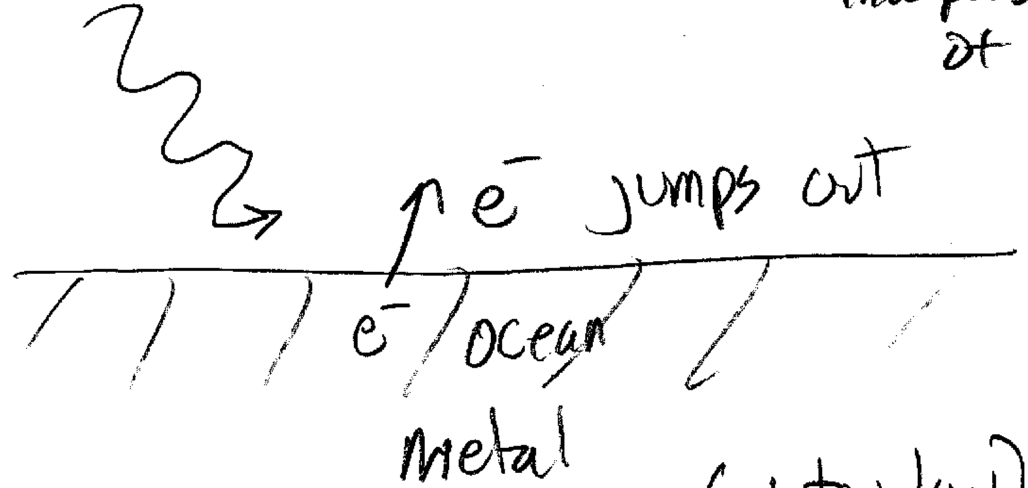
$$= 3RT_E \frac{1}{e^{T_E/T} - 1}$$

$$C_V = \frac{dE_{int}}{dT} = 3RT_E \frac{T_E/T^2}{\left(e^{T_E/T} - 1\right)^2}$$

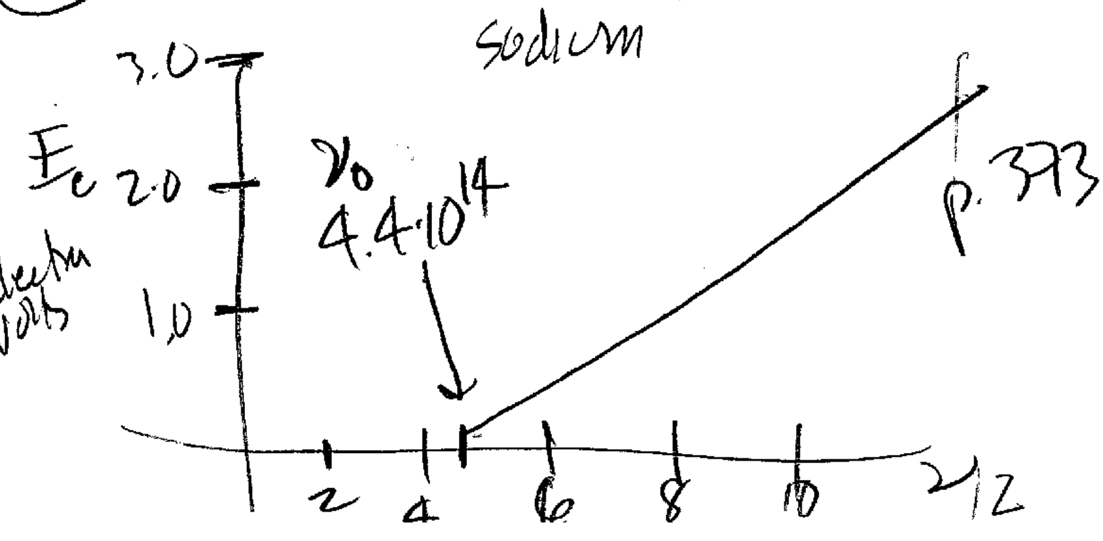
$$= 3R\left(\frac{T_E}{T}\right)^2 \left(\frac{1}{e^{T_E/T} - 1}\right)^2$$

Photo electric Effect (Einstein's Nobel ...)

$\lambda, \nu = \frac{c}{\lambda}$ Classically: $U = \frac{1}{2}(E^2 + B^2)$ independent of λ, ν



1. if λ too long, (ν too low) no amount of intensity makes it happen
2. ν above ν_0, $(\lambda < \lambda_0 = \frac{c}{\nu_0})$, get electrons
3. No time delay
4. most feeble.



$h\nu_0 = \phi$

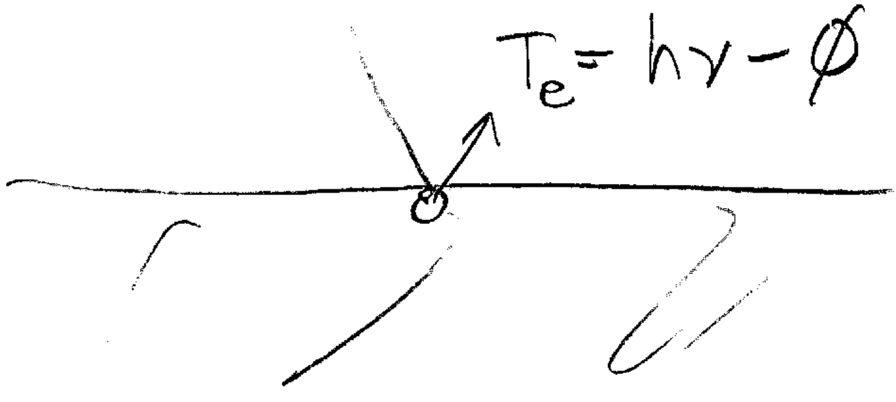
same h — work function.

Picton

each energy $h\nu = \frac{hc}{\lambda}$

table

$T_e = h\nu - \phi$

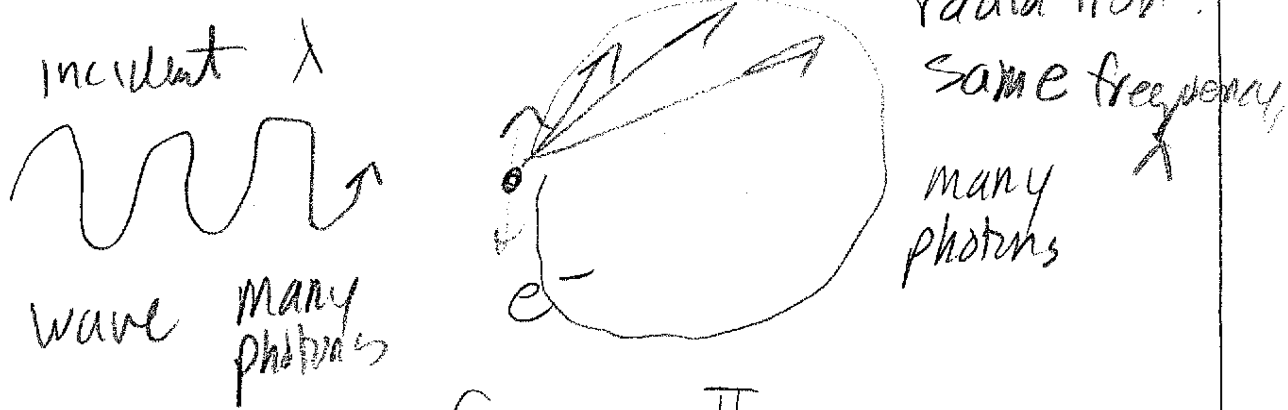


Compton Effect

X-rays behave like particles when they scatter of electrons.

<u>Older</u>: Thomson Scattering.

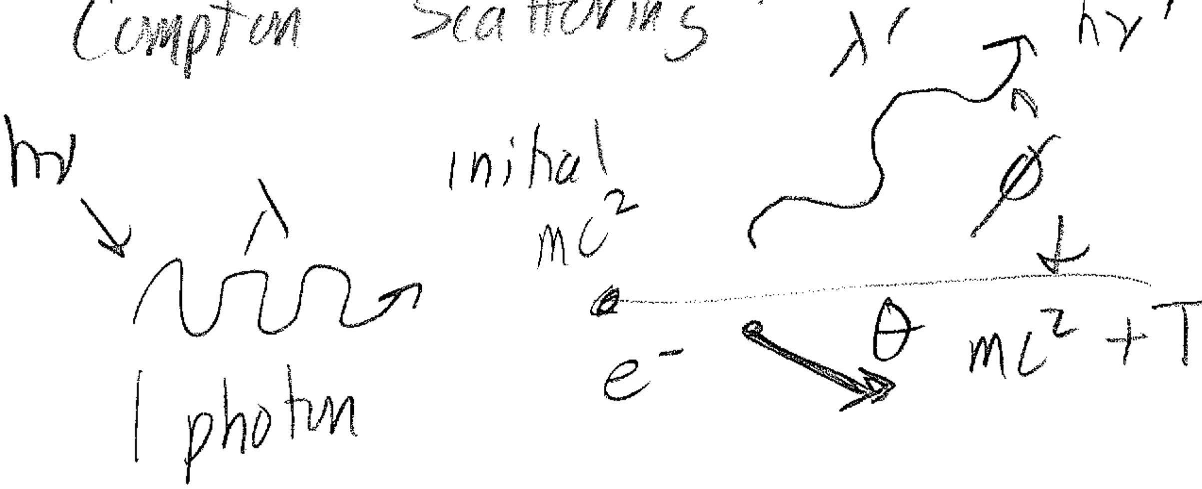
Thomson Scattering



free.. π
out of phase

ELASTIC

Compton Scattering



LOOKS INELASTIC
(actually, wrong frame)

$E_e = \gamma m_e c^2$
$E_e = m_e c^2 + T$

$$h\nu + m_e c^2 = h\nu' + E_e$$

$$\frac{hc}{\lambda} = \frac{hc}{\lambda'} + mc^2(\gamma - 1)$$

no angles!

$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

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Concept: momentum of photons

At rest: $E_e = m_e c^2$

Momentum $|\vec{p}_e|$: $E_e = \sqrt{(m_e c^2)^2 + (c|\vec{p}_e|)^2}$

$$\simeq m_e c^2 + \frac{|\vec{p}_e|^2}{2m_e}$$

↑ no c.

$$E_e^2 - (c|\vec{p}_e|)^2 = m_e^2 c^4$$

→ photon,

$$E_\gamma^2 - (c|\vec{p}_\gamma|)^2 = m_\gamma^2 c^4 = 0!$$

$$E_\gamma = c|\vec{p}_\gamma|$$

$$h\nu = c|\vec{p}_\gamma|$$

$$|\vec{p}_\gamma| = \frac{h\nu}{c} = \frac{h}{\lambda}$$

Momentum conservation in γ-e^- scattering

$$x: \quad \frac{h}{\lambda} = \frac{h}{\lambda'}\cos\phi + |\vec{p}_e|\cos\phi$$

$y: \quad 0 = \frac{h}{\lambda'}\sin\phi - |\vec{p}_e|\sin\phi$

$E_e^2 - (c|\vec{p}_e|)^2 = m_e^2c^4 \qquad (|\vec{p}_e|\cos\phi)^2$

$$= \left(\frac{hc}{\lambda} - \frac{hc}{\lambda'} + m_ec^2\right)^2 - c^2\left(\frac{h}{\lambda} - \frac{h}{\lambda'}\cos\phi\right)^2$$

$$- c^2\left(\frac{h}{\lambda'}\sin\phi\right)^2$$

$$(|\vec{p}_e|\sin\phi)^2$$

Loads of cancellations!

$$\cancel{m_e^2c^4} = \cancel{\left(\frac{hc}{\lambda}\right)^2} + \cancel{\left(\frac{hc}{\lambda'}\right)^2} + \cancel{(m_ec^2)^2}$$

$$-2\frac{h^2c^2}{\lambda\lambda'} + \cancel{2}\frac{hc}{\lambda}m_ec^2 - 2\frac{hc}{\lambda'}m_ec^2$$

$$-\cancel{\frac{h^2c^2}{\lambda^2}} + \frac{2h^2c^2}{\lambda\lambda'}\cos\phi - \cancel{\frac{h^2c^2}{\lambda'^2}\cos^2\phi}$$

$$-\cancel{\frac{hc^2}{\lambda'^2}\sin^2\phi}$$

$$\lambda\lambda' \quad \frac{\overset{hc}{\cancel{h^2c^2}}}{\lambda\lambda'}(1-\cos\phi) = \cancel{hc}\,m_ec^2\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) \times \lambda\lambda'$$

$$\boxed{(\lambda' - \lambda) = \frac{h}{m_ec}(1-\cos\phi)}$$

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$$\frac{h}{m_e c} \equiv \lambda_c = \text{compton wavelength of electron}$$

First appearance... if you squeeze an electron down to smaller than this, an $e^+ + e^-$ pop out!

$$= 2.43 \cdot 10^{-12}\ m$$

$$= 2.43\ pm$$

$$E_\gamma = h\nu = \frac{hc}{\lambda_c} = \frac{hc}{\left(\frac{h}{m_e c}\right)} = m_e c^2 \ !$$

$$E_\gamma \cong 511{,}000\ eV = 0.511\ MeV$$

De Broglie Wavelength

particle momentum p

$$\boxed{\lambda = \frac{h}{p}} \Leftarrow p = \frac{h}{\lambda}$$

photon!

way bigger