HW#1. 1.8, 1.11, 3.4
4.16, 5.13, 5.18

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2/7: Lecture 1

Contents

1. Sylabus explanation
2. Hw, 2 mid terms – one in class, one take home
   focused discussion on global warming
   TA – volunteer

Motivation: when & where radiation is important

a. solar system
   energy fall onto earth:
   Earth diameter 12756.3 km
   Solar flux: 1353 W/m².
   Total energy
   $1353\ W/m^2 \times \frac{\pi}{4} (1.2756 \times 10^7)^2$
   $= 1.78 \times 10^{17}$ W

   Human total use 10^{10} kW
   (10 billion peope 10^{10}) ⇒ 1 kW

b. buildings.
   400 W/m².
   Window 2 × 3 m² ⇒ 2400 W

c. photovoltaics / solar power
d. medical technology
e. Industrial technology

2. Difference of radiatⁿ from conduction/convectⁿ

Conductⁿ : $\vec{q} = -k \nabla T$
convection : Navier-Stokes equatⁿ. } diffusiⁿ
Radiation :

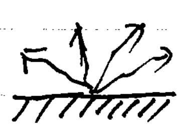
a) ballistic
b) wavelength dependent particle & wave phenomena

↳ very helpful for understanding nanoscale phenomena

3. Blackbody radiation.

Glorious history : M. Planck

Maximum emissive power from a surface



$e_{b\lambda}$

3. What is thermal radiation

a. It is an EM wave
b. It is from an thermal source

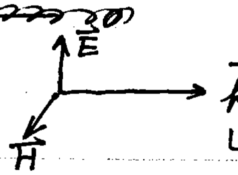
$$c = f \cdot \lambda$$

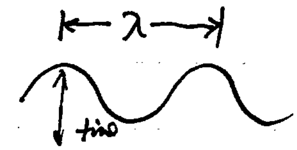
f – frequency [1/s = Hz]

λ – wavelength. [m]

~~wave vector~~

EM wave





└ propagation direction

magnitude of $\vec{k}$ $|\vec{k}| = \frac{2\pi}{\lambda} = k$ wave vector

angular frequency $\omega = 2\pi f = \frac{2\pi}{T}$
└ periodicity in ti…

$$\omega = c k$$

other units in use

energy $E = h\nu = \hbar\omega$

$h = 6.6\times10^{-34}$ J·s $\hbar = \frac{h}{2\pi}$.

wave number $\eta = \frac{1}{\lambda}$ (similar to f).

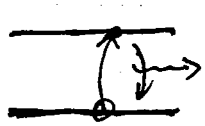
Example: radio frequency 1 MHz = f

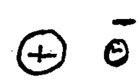
$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{10^{6}} = 300\ m.$$

1 μm $E = 6.6\times10^{-34}\times\frac{3\times10^{8}}{10^{-6}}$ $= 19.80\times10^{-20}$ J $= 1.24$ eV.

Thermal radiation $\lambda \sim$ μm

Atomic energy level

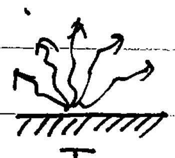




when molecule vibrate
↳ electron motion

4. Blackbody radiation

glorious history : Planck
Einstein



$$E_{b\nu} = \frac{2\pi h \nu^3 n^2}{c_0^2 [e^{h\nu/k_B T} - 1]} \quad \left[\frac{W}{m^2\,Hz}\right]$$

k_B — Boltzmann Constant

n — refractive index $\quad n = \frac{c_0}{c}$

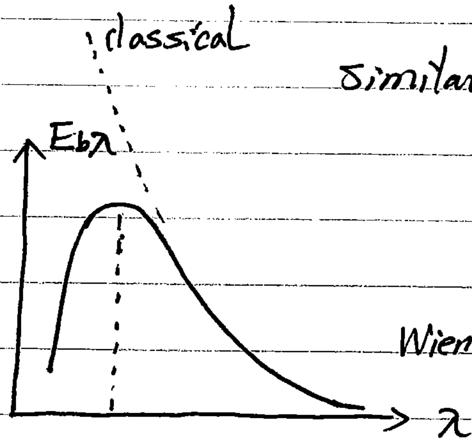
Per unit wavelength $\quad (\nu = \frac{c}{\lambda})$

$$E_{b\lambda} = E_{b\nu} \cdot \frac{d\nu}{d\lambda}$$

$$= -E_{b\nu}\left(-\frac{c}{\lambda^2}\right)$$

$$= \frac{-2\pi h c_0^2}{n^2 \lambda^5 [e^{hc_0/n\lambda kT} - 1]} \quad \text{drop} -$$

Similarly $E_{b\eta}$, $E_{b\omega}$, E_{bE}



$$\frac{E_{b\lambda}}{n^3 \lambda^5} = \frac{C_1}{(n\lambda T)^5 [e^{C_2/n\lambda T} - 1]}$$

Wien's displacement law $(n\lambda T)_{max} = 2898\ \mu m \cdot K$

↑ Vacuum $n = 1$

Sun : $T = 5762\,K$ $\quad \lambda = 0.5\ \mu m$

earth $T = 300\ K$ $\quad \lambda \approx 10\ \mu m$

What Planck said : a) equilibrium

b) curvature/size larger than wavelength

$E = h\nu$

Einstein : a) EM has particle characteristics

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$$p = \frac{h}{\lambda} = \hbar k.$$

b) stimulated emission.

Total $\quad E_b = \int_0^\infty E_{b\lambda}\, d\lambda$

$$= \frac{n^3 T^5}{nT} \int_0^\infty \left(\frac{E_{b\lambda}}{n^3 T^5}\right) \cdot d(n\lambda T)$$

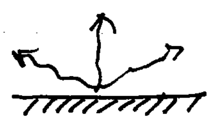
$$= n^2 \sigma T^4$$

σ: $5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

— Stefan–Boltzmann constant

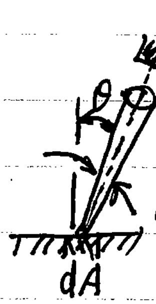
5. Directional properties of radiation : Intensity

Blackbody : isotropic emitter



different directi to view it get different energy.

How we can define directional properties.

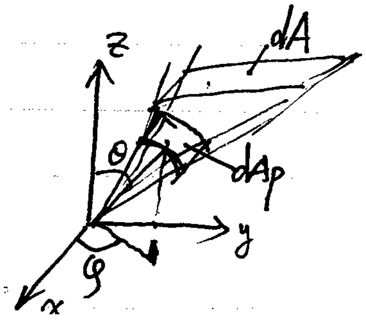


Intensity :

$$I_\lambda = \frac{\text{Power}}{dA_\perp\, d\lambda\, d\Omega} \quad \hookrightarrow \text{solid angle}$$

$$= \frac{\text{Power}}{dA \cos\theta\, d\lambda\, d\Omega}$$

Solid angle :



$$d\Omega = \frac{dA_p}{R^2}$$