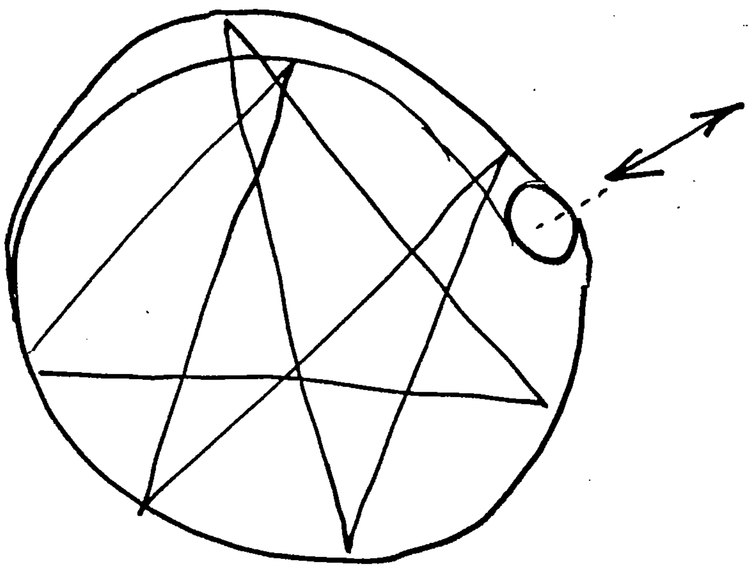
Some Failures of Classical Physics

Consider Black Body Radiation



- Cavity
- ~~exterior~~ insulated
- heat
- Eventually ⟹ Equilibrium
  all energy emitted to cavity is reabsorbed

Wien's Displacement Law

raise temp --→ Color shifts to the blue

$$T \lambda_{max} = \text{Constant}$$

Stefan

$$u = \text{energy density} = \frac{\text{energy}}{\text{unit vol.}}$$

$$u = aT^4$$

for energy summed over all wavelengths

Stefan–Boltzmann Law

M = power emitted/unit area

$$M = \sigma T^4$$

Classical View / Rayleigh; Jeans

- A black body radiator is a Collection of harmonic Oscillators, one for each frequency of light
- Light of a certain frequency - attributed to excitation of osc. of that frequency. --- Continuous function

Equipartition Theorem

Average Energy $= kT$

$\therefore$ The energy density is $\frac{\#\text{ of Osc.}}{\text{unit volume}}$ in range λ to $\lambda + d\lambda$, times the ave. energy

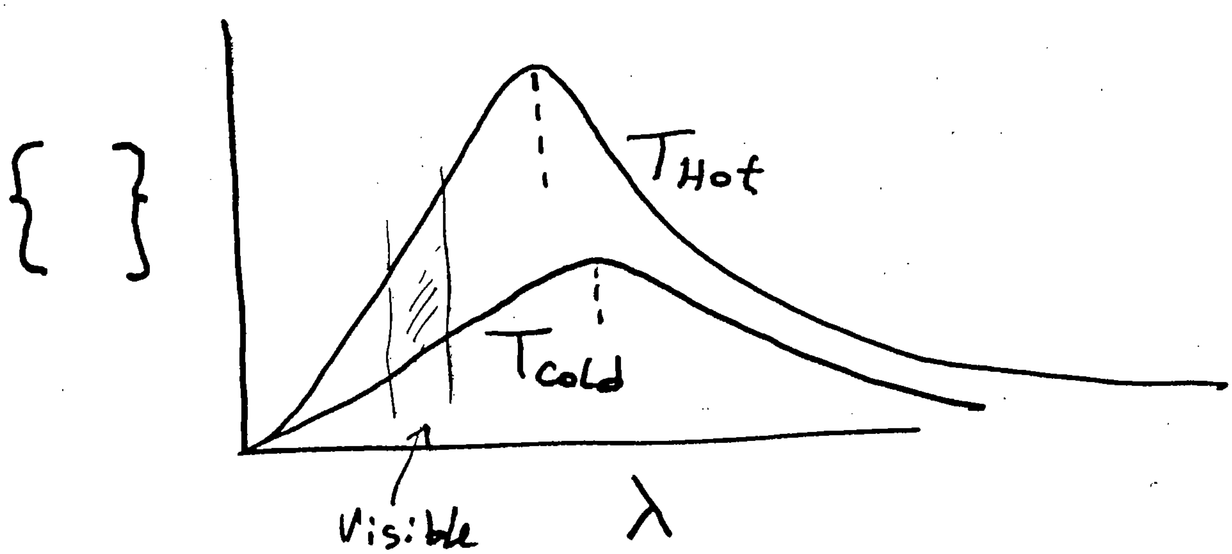
$$d\mathcal{U}(\lambda) = kT\, dN(\lambda)$$

Rayleigh – Jeans Law

$$d\mathcal{U}(\lambda) = \rho(\lambda)\,d\lambda$$

$$= \underbrace{\frac{8\pi kT}{\lambda^4}}_{\left\{\frac{\text{energy}}{\text{unit vol-unit wavelength}}\right\}} d\lambda$$

Observations :



T Hot — peak shifts to the blue

R–J Law Problems ? Big Problems

Rayleigh – Jeans

- $d\mathcal{U}(\lambda)$ does not go through a maximum

- Predicts an infinite energy density at short wavelengths –

  the "Ultraviolet Catastrophe"

  !

Planck's Ideas:

- – an oscillator can only have energy in multiples of $h\nu$
  – if a "ray" carries energy, then # of photons $= E/h\nu$

- – an osc. becomes excited only if it obtains energy equal to $h\nu$

$$d\mathcal{U}(\lambda) = \frac{8\pi hc}{\lambda^5}\left\{\frac{e^{-hc/\lambda kT}}{1-e^{-hc/\lambda kT}}\right\}$$

?E-8 At long wavelengths:

$hc/\lambda kT$ very small – goes to classical result

At short wavelengths: $hc/\lambda kT \Rightarrow \infty$

$e^{-\infty} = 0$

$\ell(\lambda) \Rightarrow 0$

Planck's Ideas

- Energy is "quantized" in $h\nu$

  h = Planck's constant

  $= 6.626 \times 10^{-34}$ JS

- Energy quantization:

  osc. of high energy not excited — don't contribute

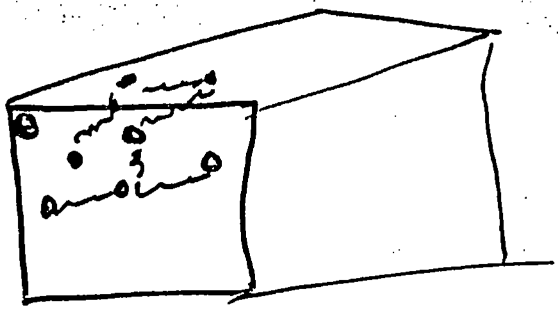
  or

  their contribution is considerably reduced.

Classical Ideas

- all osc. share equally in the energy supplied by the walls of the black body

Heat Capacities – also a problem in classical theory.



Solid – a collection of Oscillators

The atoms of the solid exhibit oscillation & thereby exchange Kinetic & Potential Energy

$T_{osc.}$ $V_{osc.}$

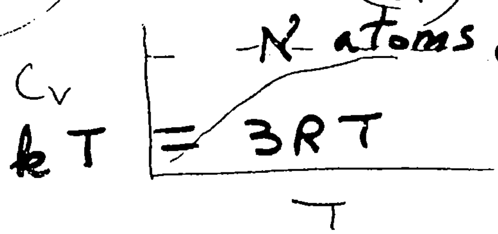
Equipartition – each osc. in 1-D contributes kT of energy.

PE-9

$C_v = \frac{\partial E}{\partial T}$ 3 dimensions

N atoms

$E = 3NkT = 3RT$

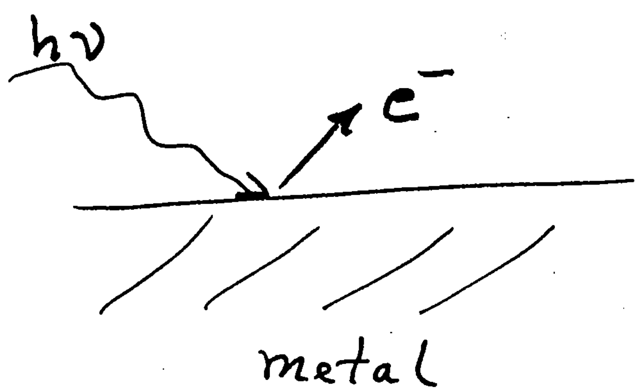


Dulong-Petit Law

Corpuscular Theory of Light

The Photoelectric Effect

Shine ultra violet light on a metal-
— electrons are ejected



1) Regardless of intensity, no electrons unless ν exceeds some threshold

2) then immediate ejection

3) Kinetic Energy of electrons ∝ ν
∴ photons like projectiles

Electron Conservation of Energy

$$\frac{1}{2} m_e v^2 = h\nu - \Phi$$

← Work Function