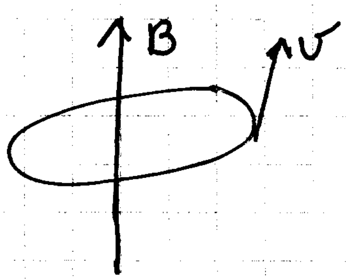
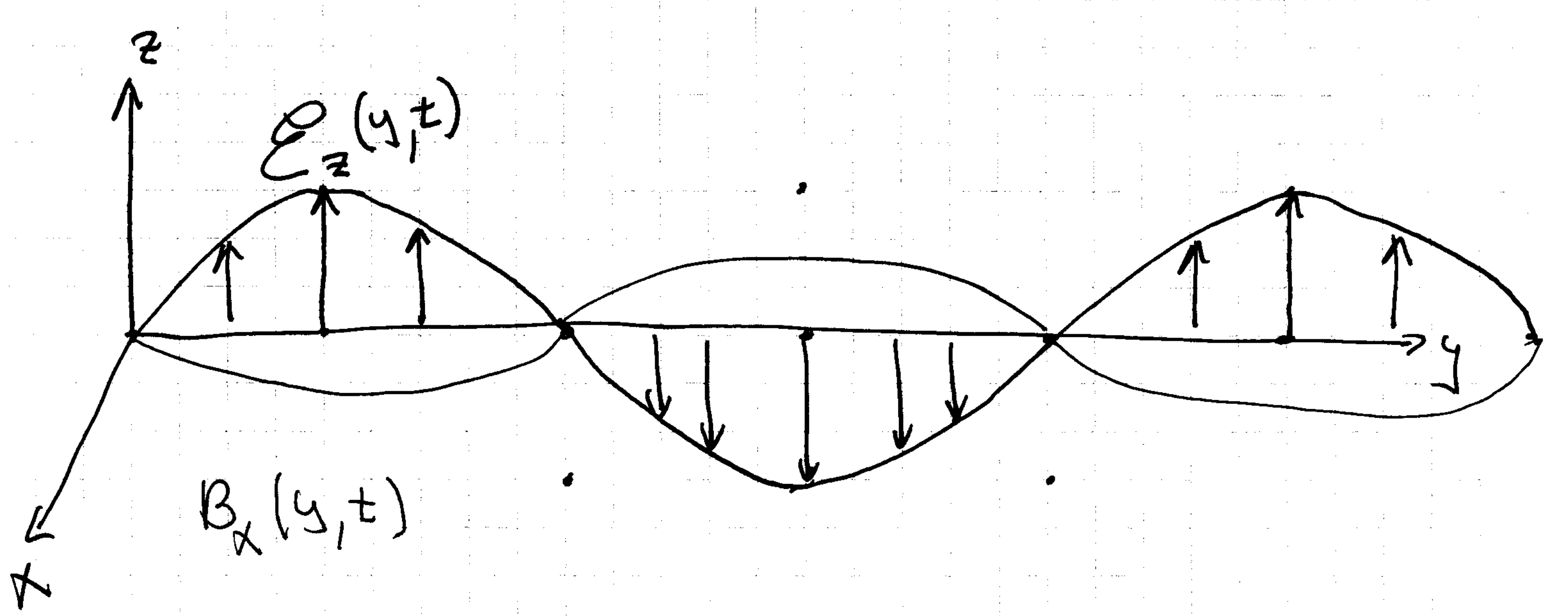
ELECTROMAGNETIC WAVES

E&M WAVES ARE MADE UP OF OSCILLATING ELECTRIC (E) AND MAGNETIC (B) FIELDS AND ARE PRODUCED BY ACCELERATED CHARGES.

E $\longrightarrow$ DISPLACES CHARGE PARTICLES ALONG THE DIRECTION OF THE FIELD

B $\longrightarrow$ ROTATES CHARGE PARTICLES AROUND THE DIRECTION OF THE FIELD





E AND B ARE $\perp$ TO EACH OTHER

$$\mathcal{E}_z(y,t) = \mathcal{E}_0 \sin(ky - \omega t) \quad [\text{UNITS } V m^{-1}]$$

ANGULAR FREQUENCY — ω

$$\omega = 2\pi \nu$$

ν → FREQUENCY (s^{-1})

WAVE VECTOR — k

$$k = \frac{2\pi}{\lambda}$$

λ → WAVE LENGTH (nm)

$$\bar{\nu} \equiv \frac{1}{\lambda} \equiv \text{WAVE NUMBER}$$

$\mathcal{E}_0$ IS THE AMPLITUDE OF THE WAVE

$$B_x(y,t) = \frac{\mathcal{E}_0}{c} \sin(ky - \omega t)$$

$$\lambda \nu = c = \frac{\omega}{k}$$

SINGLE WAVE LENGTH ⟷ MONOCHROMATIC LIGHT

RANGE OF $\lambda \Longleftrightarrow$ E&M WAVES

3×10^{-24} m	10^{32} s^{-1}	COSMIC RAY	4×10^{17} eV
$\downarrow$			
3×10^{6} m	10^{2} s^{-1}	LONG RADIO WAVES	4×10^{-13} eV

E&M RADIATION INTERACTS WITH MATTER

LIGHT GETS SCATTERED

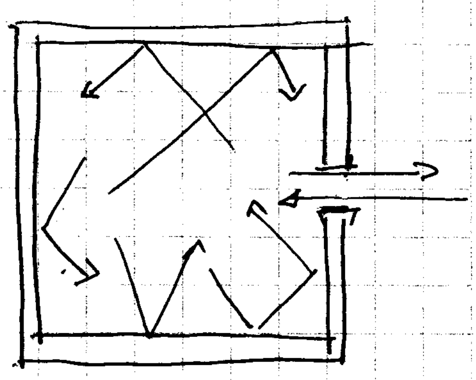
RESULT OF SCATTERING BY

i) MANY CENTERS $\longrightarrow$ DIFFRACTION

ii) FEW CENTERS $\longrightarrow$ INTERFERENCE

BLACKBODY RADIATION

BLACKBODY ≡ IS AN (IDEAL) OBJECT THAT ABSORBS AND EMITS ALL FREQUENCIES



$\rho(\nu, T)$

RADIATION INTERACTS WITH THE WALLS

CHARGED OSCILLATIONS ON THE WALL
$\longrightarrow$ RADIATION

EQUILIBRIUM AT $T \Leftrightarrow$ BLACK BODY RADIATION

DENSITY OF RADIATED ENERGY PER UNIT VOLUME PER UNIT FREQUENCY A TEMPERATURE T

$$\rho(\nu, T)\, d\nu$$

1896 WIEN $\quad \rho(\nu, T) = C_1 \nu^3 e^{-a\frac{\nu}{T}}$

1897 PASCHEN CONFIMED WIEN'S RESULT FOR HIGH FREQUENCIES

1900 LUMMER PRINGSHEIN MEASURED $\rho(\nu,T)$ FOR LOW FREQUENCIES AND REPORTED A FAILURE OF WIEN'S FORMULA

1899 WIEN'S LAW $T\lambda_{max} = \text{CONST.}$
DISPLACEMENT LAW

$R \equiv$ TOTAL ENERGY RADIATED PER UNIT AREA PER UNIT TIME

$R = \sigma T^4$ STEFAN - BOLTZMAN LAW
σ — CONST.

<u>THEORY</u> RADIATION WAS DUE TO HARMONIC OSCILLATORS, ELECTRONS DISPLACING AROUND THE ATOM.

1900 RAYLEIGH

$$d\nu\, \rho(\nu,T) = N_\nu\, d\nu\, \overline{\epsilon}(\nu,T)$$

N_ν NUMBER OF OSCILLATORS PER UNIT VOLUME PER UNIT FREQUENCY

$\overline{\epsilon}$ AVERAGE ENERGY PER UNIT FREQUENCY

$$\left.\begin{aligned} N_\nu\, d\nu &= \frac{8\pi}{c^3}\nu^2\, d\nu \\ \overline{\epsilon}(\nu,T) &= k_B T \end{aligned}\right] \quad \text{(CLASSICAL)}$$

$$\rho(\nu,T)\, d\nu = \frac{8\pi\nu^2}{c^3}\, k_B T\, d\nu$$

1900 <u>PLANCK</u> FROM EXPERIMENTS

AT LOW FREQUENCY $\overline{\epsilon} = \frac{\rho(\nu,T)}{N_\nu\, d\nu} \sim k_B T$

AT HIGH FREQUENCY $\overline{\epsilon} = \frac{\rho(\nu,T)}{N_\nu\, d\nu} \sim \nu e^{-a\frac{\nu}{T}}$

PLANCK PROPOSED

$$\overline{\epsilon}(\nu,T) = \frac{h\nu}{e^{\frac{h\nu}{k_B T}} - 1}$$

$$\rho(\nu,T)\,d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{\frac{h\nu}{k_BT}}-1}\,d\nu \quad (1\text{-}1)$$

h IS A CONSTANT

THIS IS A SEMI EMPIRICAL DERIVATION

FIT THE DATA $\longrightarrow$ VALUE FOR h

$h \equiv$ PLANCK'S CONSTANT

LATER, PLANCK USED THERMODYNAMICS TO CALCULATE S FROM EQ (1-1) AND BOLTZMAN STATISTICAL THEORY. HE FOUND THAT BOTH RESULTS WERE CONSISTENT IF THE OSCILLATOR'S ENERGY SPECTRUM WAS QUANTIZED !

THIS MEANS THAT THE OSCILLATOR COULD ONLY ACHIVED ENERGIES EQUAL TO INTEGER MULTIPLES OF $h\nu$

$$\bar{E}_n = nh\nu$$

EXCELLENT AGREEMENT FOR

$$h = 6.626 \times 10^{-34}\ \mathrm{J\,s}$$

ALSO ONE COULD DERIVE

WIEN'S LAW $\lambda_{max} T = \mathrm{CONST}$

STEFAN-BOLTZMAN LAW $R = \sigma T^4$

$$\bar{\epsilon} = \int_0^\infty E \, P(E) \, dE$$

But

$$P(E) = \frac{e^{-E/k_BT}}{\int_0^\infty e^{-E/k_BT} \, dE}$$

$$\int_0^\infty e^{-E/k_BT} \, dE = k_BT \int_0^\infty e^{-x} \, dx = -k_BT \, e^{-x}\Big|_0^\infty = k_BT$$

$$\bar{\epsilon} = k_BT \int_0^\infty x \, e^{-x} \, dx = k_BT$$

$$\bar{E} \longrightarrow \epsilon_n \equiv n h\nu$$

$$P(\epsilon_n) = \frac{e^{-n\frac{h\nu}{k_BT}}}{\sum_{n=0}^\infty e^{-n\frac{h\nu}{k_BT}}} \equiv \frac{x^n}{\sum_{n=0}^\infty x^n}$$

$$x \equiv e^{-\frac{h\nu}{k_BT}}$$

$$\sum_{n=0}^\infty x^n = \frac{1}{1-x}$$

$$\bar{\epsilon}(\nu,T) = \frac{1}{\frac{1}{(1-x)}} \sum_{n=0}^\infty n h\nu \, x^n = (1-x) h\nu \, x \sum_{n=0}^\infty n x^{n-1}$$

$$\sum_{n=0}^{\infty} n x^{n-1} = \frac{d}{dx}\sum_{n=0}^{\infty} x^n = \frac{d}{dx}\frac{1}{1-x} = \frac{1}{(1-x)^2}$$

$$\bar{\epsilon}(\nu, T) = \frac{h\nu x}{1-x} = \frac{h\nu e^{-\frac{h\nu}{k_B T}}}{1-e^{-h\nu/k_B T}}$$

$$\boxed{\bar{\epsilon}(\nu, T) = \frac{h\nu}{e^{h\nu/k_B T}-1}}$$