So far (More Office hours to 3:30)

- Atoms real.
- Their sub structure

Spectra

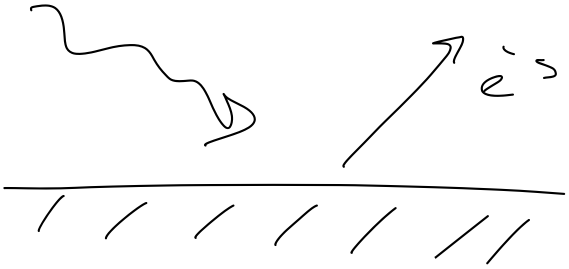
$m_e \ll M_{atom}$

radio activity

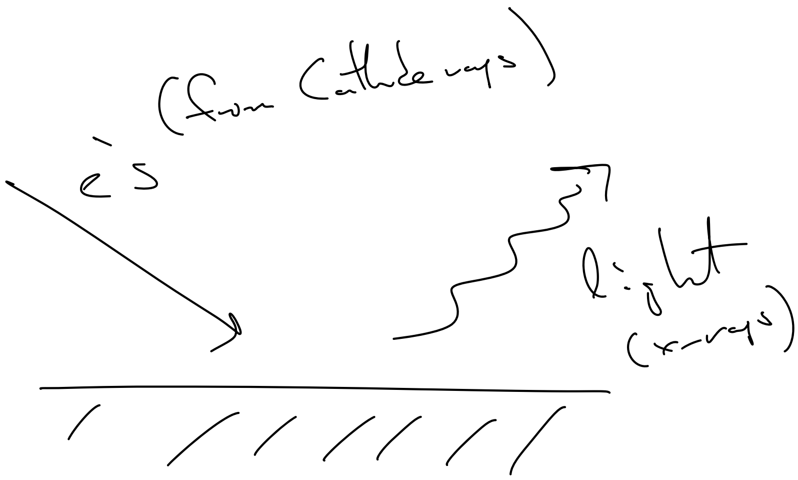
- New forms of radiation X-rays/γ-rays
- Problems w/ Classical Physics

Thermal Radiation / Photo-electric effect

X-rays



"photo electric" Effect



Rontgen's experiment

Rontgen sent in e^-'s w/ kV onto metal

Produced highly penetrating radiation which could

- darken photo paper
- flash fluorescent screens

Not deflected in E + B fields

(Same w/ γ-rays)

(1) Continuous Spectrum

(2) Discrete (~Repeated) Structure

(3) Small wavelength cut off.

Of these (1) predicted by classical physics (Maxwell)

(3) Found empirically that

$$\lambda_{min} = \frac{1240 \text{ nm}}{V(\text{volts})}$$ "Duane-Hunt" Rule

Explained by Einstein.

"Reverse Photo-electric Effect"

Largest KE the X-ray photon can have is the KE of the incoming electron.

$$E_\gamma^{max} = h\nu^{max} = \frac{hc}{\lambda_{min}} = eV$$

$$\lambda_{min} = \frac{hc}{eV} = \frac{1240 \text{ eV nm}}{eV}$$

What about the jagged lines?

found to depend on the material you hit w/ e^-s. (Depends on structure of matter (Next week...)

Again... Hints (Strong Circumstantial Evidence) light quantized, but is this view required

Major Lesson of Physics (Philosophical Interlude)

- When physics forces an interpretation on you you should take it seriously!

We see this again & again in Physics

- Simultaneity Relative.
- Mass is Energy
- $\vec{E}$ & $\vec{B}$ fields same thing
(Comes in Spades w/ QM)
- Atoms.
- We will see more ...

When it comes to Photons can actually do better than Philosophy.

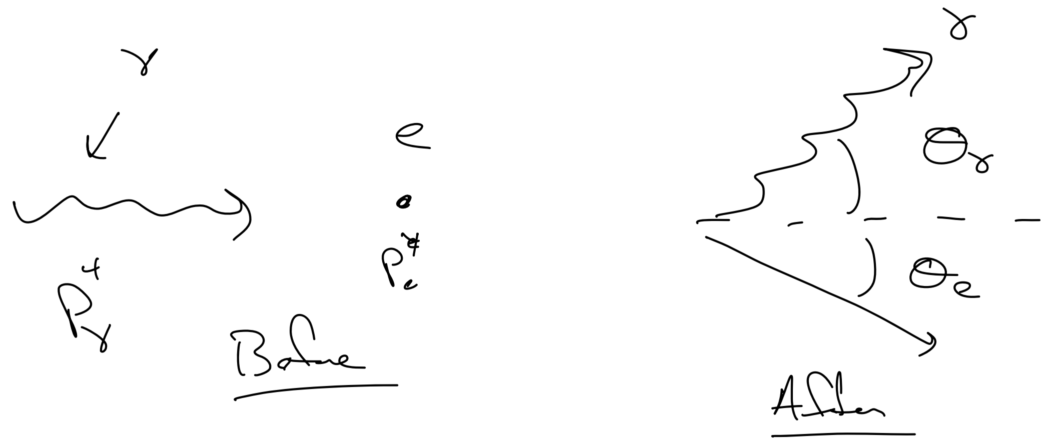
Something we actually already looked at

"Compton Effect"

Scattered X-rays "softer" (lower E_γ)

Suggestion (Now trivial to us... But again this is early days)

X-rays made of γ's & they lose E in collisions w/ e^-'s



$$p^4_\gamma = E_\gamma \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix} \quad p^4_e = \begin{pmatrix} m_e \\ \vec{0} \end{pmatrix}$$

$$\bar{p}^4_\gamma = \bar{E}_\gamma \begin{pmatrix} 1 \\ \cos\theta_\gamma \\ \sin\theta_\gamma \\ 0 \end{pmatrix} \quad \bar{p}^4_e = \begin{pmatrix} \bar{E}_e \\ E_\gamma - \bar{E}_\gamma\cos\theta_\gamma \\ -\bar{E}_\gamma\sin\theta_\gamma \\ 0 \end{pmatrix}$$

Conserves $\vec{p}$ Explicitly

Solve for $\bar{E}_e$

$$E^2 - p^2 = m_e^2$$

$$\bar{E}_e^2 - (E_\gamma - \bar{E}_\gamma \cos\theta)^2 - (\bar{E}_\gamma \sin\theta)^2 = m_e$$

$$\bar{E}_e^2 - E_\gamma^2 + 2E_\gamma \bar{E}_\gamma \cos\theta - \bar{E}_\gamma^2 \cos^2\theta - \bar{E}_\gamma^2 \sin^2\theta = m_e^2$$

$$\bar{E}_e^2 - E_\gamma^2 + 2E_\gamma \bar{E}_\gamma \cos\theta - \bar{E}_\gamma^2 = m_e^2$$

$$\bar{E}_e^2 = m_e^2 + E_\gamma^2 + \bar{E}_\gamma^2 - 2E_\gamma \bar{E}_\gamma \cos\theta$$

Conserve E

$$E_\gamma + m_e = \bar{E}_\gamma + \bar{E}_e = \bar{E}_\gamma + \sqrt{m_e^2 + E_\gamma^2 + \bar{E}_\gamma^2 - 2E_\gamma \bar{E}_\gamma \cos\theta}$$

$$\underbrace{(E_\gamma - \bar{E}_\gamma + m_e)^2} = m_e^2 + E_\gamma^2 + \bar{E}_\gamma^2 - 2E_\gamma \bar{E}_\gamma \cos\theta$$

$$(E_\gamma - \bar{E}_\gamma)^2 + 2(E - \bar{E})m_e + m_e^2$$

$$\cancel{E_\gamma^2} - \cancel{2}E_\gamma \bar{E}_\gamma + \cancel{\bar{E}_\gamma^2} + \cancel{2}(E - \bar{E})m_e + \cancel{m_e^2} =$$

$$\cancel{m_e^2} + \cancel{E_\gamma^2} + \cancel{\bar{E}_\gamma^2} - \cancel{2}E_\gamma \bar{E}_\gamma \cos\theta$$

$$(E_\gamma - \bar{E}_\gamma)m_e = E_\gamma \bar{E}_\gamma (1 - \cos\theta_\gamma)$$ (Saw this Before)

OR

$$\frac{1}{\bar{E}_\gamma} - \frac{1}{E_\gamma} = \frac{1}{m_e}\left(1 - \cos\theta_\gamma\right)$$

$$\frac{\bar{\lambda}}{hc} - \frac{\lambda}{hc} = \frac{1}{mc^2}\left(1 - \cos\theta_\gamma\right)$$

(Boy it sure is a pain in the ass to keep writing all these $\left| \begin{array}{l} h\text{'s} \\ c\text{'s} \end{array} \right.$ ...)

$$\bar{\lambda} - \lambda = \frac{h}{m_e c}\left(1 - \cos\theta_\gamma\right)$$

Comments

- Units $\Rightarrow$ $\frac{h}{m_e c}$ is length $[c] = 1 \Rightarrow [h] = E \cdot l$

- $\frac{h}{m_e c}$ only depends on m_e & physical constants
"Compton wave-length of electron"

λ_c or $r_e \sim 10^{-12}$ m "Size of the electron as seen by γ"

- $\Delta\lambda$ independent of λ

$\Rightarrow$ % change $\quad \frac{\Delta\lambda}{\lambda} = \frac{\lambda_c}{\lambda}\left(1 - \cos\theta_\gamma\right)$

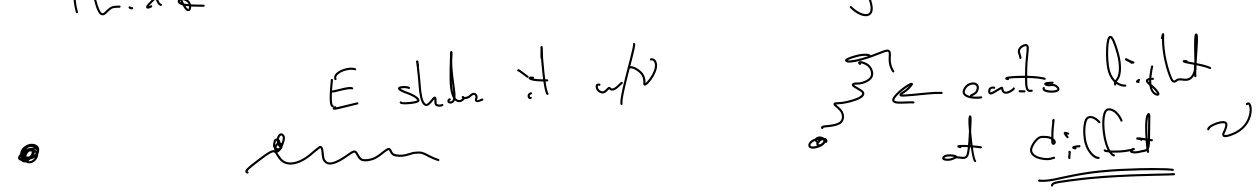
Need λ to be $\sim \lambda_c$ in order to have a big effect.

Long-wavelength light ($\Rightarrow$ Big λ light)

Small effect $\quad \lambda_{vis} \sim 10^3$ nm $\sim 10^{-6}$ m

$$\frac{\Delta\lambda}{\lambda} \sim 10^{-6}$$

4) Think about this "classically" from e's POV



Great resistance to idea. Not Predicted by maxwell.

Direct consequence of $E_\gamma = h\nu$ + Relativity