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In which we learn that EM radiation really must be quantized in packets of E = hf based on two more experiments

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- Atomic spectra
- Bohr Model
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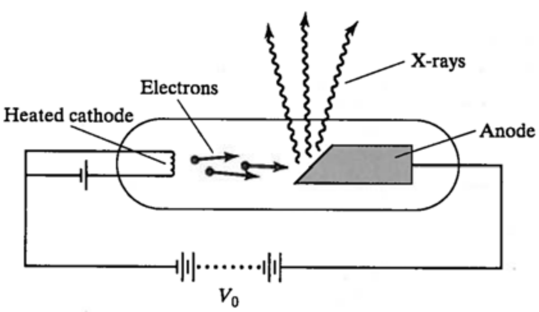
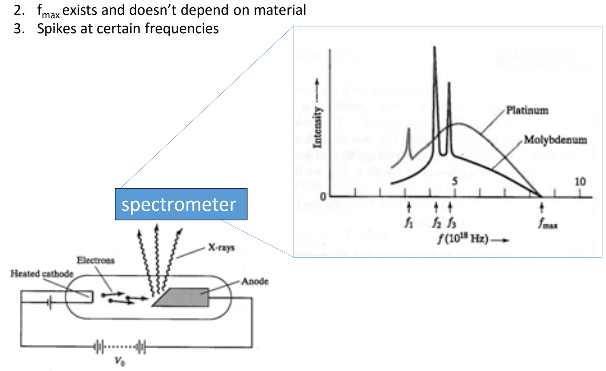
X-Ray Production



X-Ray Spectra

Features of spectra that need to be explained

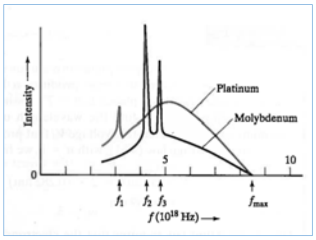
1. Continuous background
2. f_{max} exists and doesn't depend on material
3. Spikes at certain frequencies



X-Ray Spectra

Features of spectra that need to be explained
1. Continuous background
2. f_{max} exists and doesn't depend on material
3. Spikes at certain frequencies

Expect classically
1. Continuous background due to varying rates of deceleration of electrons.
2. No hard value of f_{max}
3. No spikes (explained in Chp 5)



Find the constant in the equation using the data below.

$$f_{max} = \frac{eV_o}{constant}$$

You must use data from both plots.

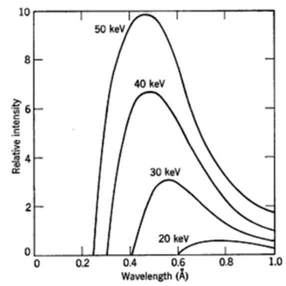


Fig 2- 10 The continuous x-ray spectrum emitted from a tungsten target for four different values of accelerating voltage during x-ray production. From Eisberg and Resnick.

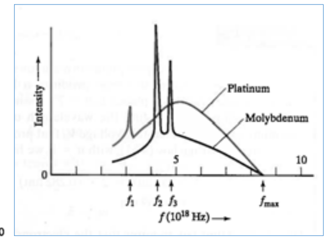
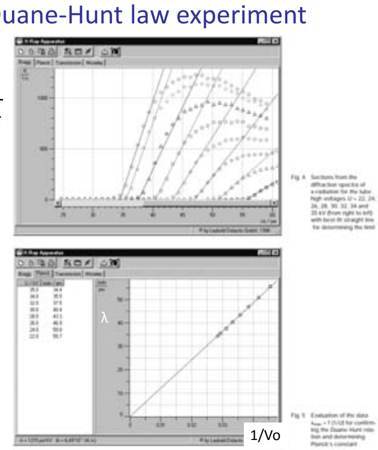


Fig 4.11 x-ray spectra produced by platinum and molybdenum anodes, both made with an accelerating potential of 35kV. From Taylor.

How to do Duane-Hunt law experiment

$$f_{max} = \frac{eV_o}{constant} = \frac{c}{\lambda_{max}}$$

$$\lambda_{max} = \text{constant}\frac{c}{e} * \frac{1}{V_o}$$



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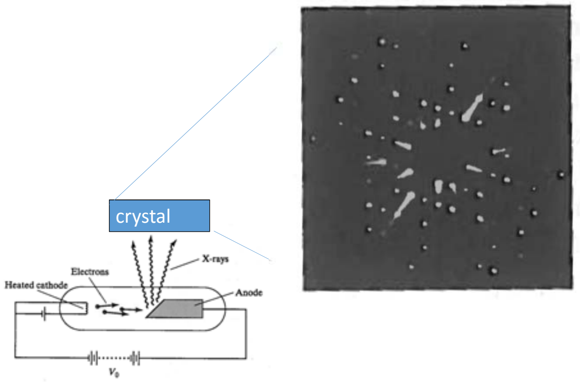
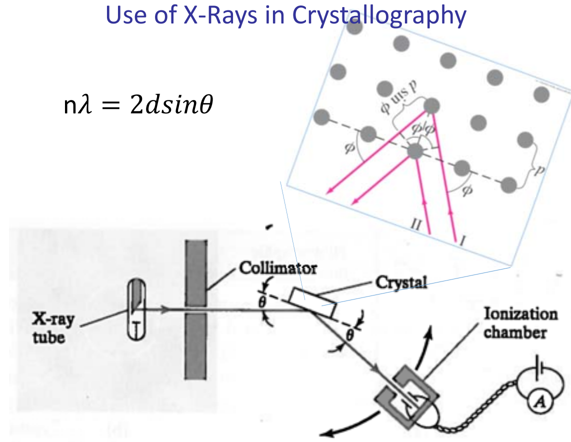
Use of X-Rays in Crystallography



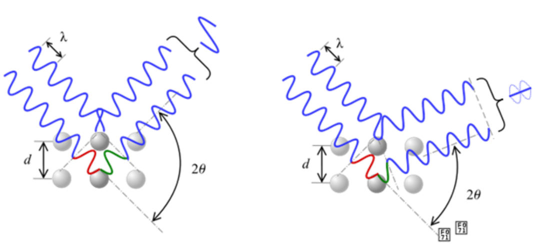
Use of X-Rays in Crystallography

$$n\lambda = 2dsin\theta$$



Crystallography

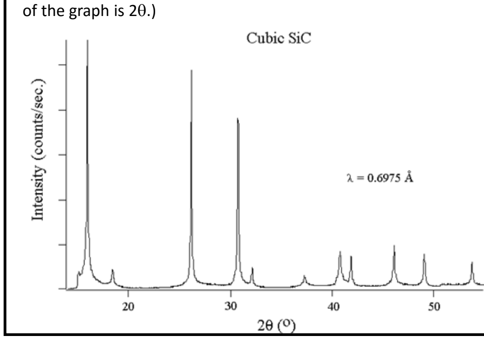
$$n\lambda = 2dsin\theta$$



http://serc.carleton.edu/NAGTWorkshops/deepearth/activities/40414.html. Not there anymore
http://www-pub.iaea.org/MTCD/Publications/PDF/TCS-51/html/topics/235.html

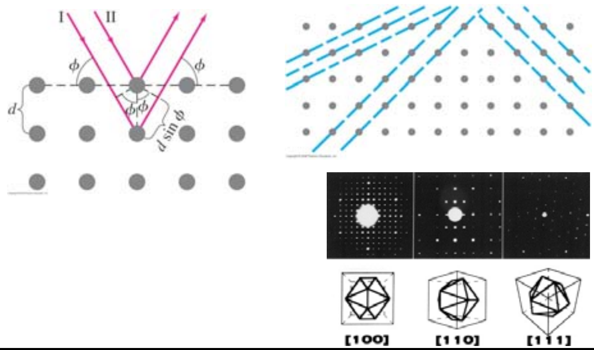
Crystallography Example

The graph below shows the diffraction pattern from cubic SiC. The highest peaks are generally the first order maxima from different sets of planes. The smaller peaks are generally the higher order maxima from those planes. Find the interplane spacing for at least two sets of planes in cubic SiC. (Note that the x axis of the graph is 2θ.)

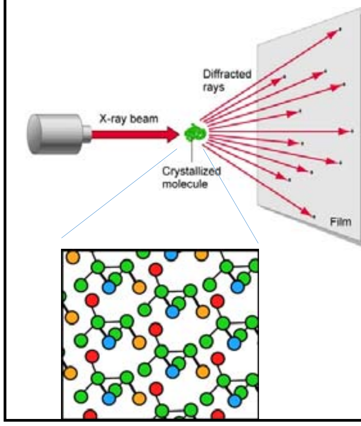


Crystallography Patterns Are Complicated

Diffraction can occur from lots of different sets of planes so crystallography patterns are complicated even for simple crystals like this cubic one.

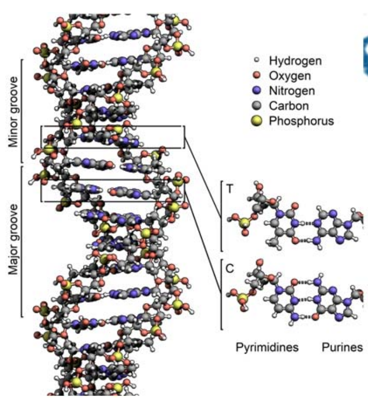


Crystallography in Biology

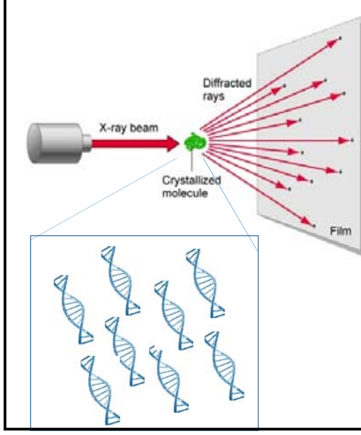


Use a computer to calculate structure of crystallized molecule from extremely complicated diffraction pattern.

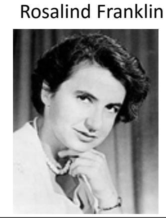
DNA



Crystallography Determined the Structure of DNA



Rosalind Franklin

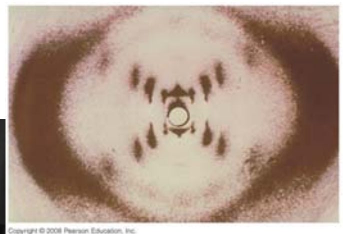


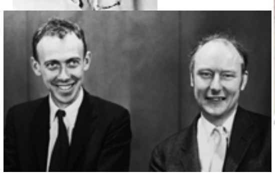
A Tale of Science Discovery

https://www.pbs.org/wgbh/nova/photo51/

Rosalind Franklin

Rosalind Franklin's "Photo 51"
X ray diffraction pattern obtained from DNA





Watson and Crick won the Noble Prize in 1962

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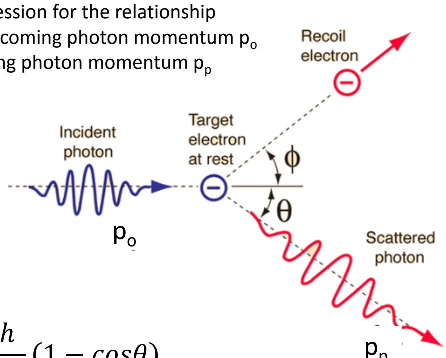
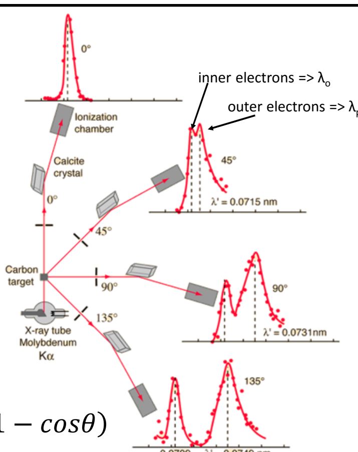
Compton Scattering Setup

Derive an expression for the relationship between the incoming photon momentum p_o and the outgoing photon momentum p_p



$$\lambda_p - \lambda_o = \frac{h}{mc}(1 - cos\theta)$$

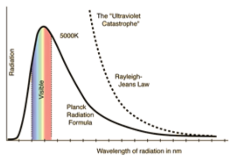
Compton Scattering Data



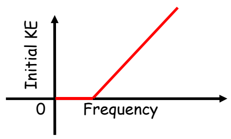
$$\lambda_p - \lambda_o = \frac{h}{mc}(1 - cos\theta)$$

Four Experiments Show E = hf and Prove Photons

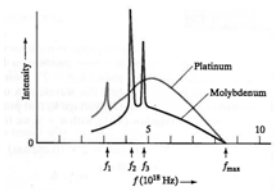
Blackbody Radiation



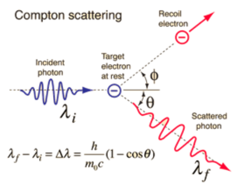
Photoelectric Effect



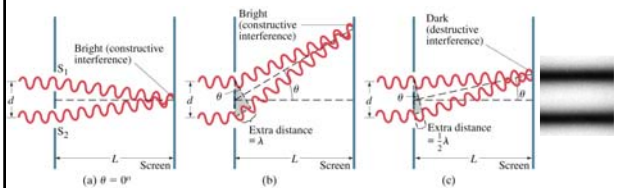
Duane-Hunt Experiment

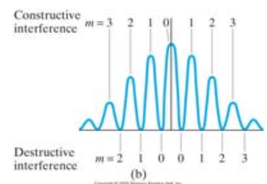


Compton Scattering

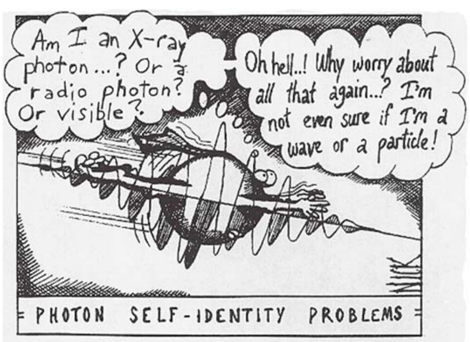


2 slit experiment with light waves





Warticles for sure



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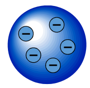
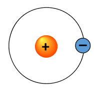
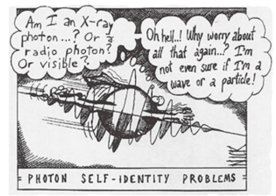
Models of the Atom



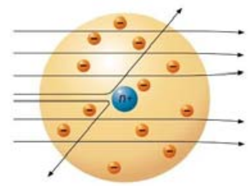
- Thomson – "Plum Pudding"
  - Why? Known that negative charges can be removed from atom.
  - Problem: Doesn't match scattering experiments
- Rutherford – Solar System
  - Why? Scattering showed a small, hard core.



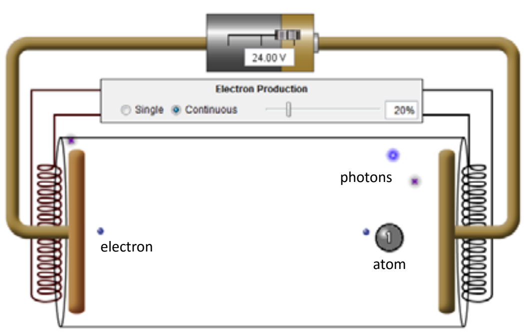
What happens when we combine warticles with Rutherford atoms?



+



Discharge Lamp

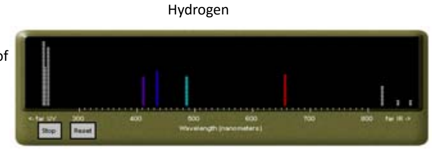


Run simulation:
https://phet.colorado.edu/en/simulation/legacy/discharge-lamps

Atomic Spectra

Hydrogen

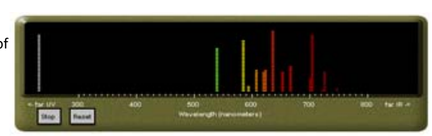
Number of photons



wavelength

Neon

Number of photons



wavelength

Balmer series: A closer look at the spectrum of hydrogen

410.3 434.0 486.1 656.3 nm

Balmer (1885) noticed wavelengths followed a progression

$$\lambda = \frac{91.19\text{nm}}{\frac{1}{2^2} - \frac{1}{n^2}}$$ where n = 3, 4, 5, 6, ….

Balmer used this formula to predict additional lines in the hydrogen spectrum.

Rydberg formula generalization of Balmer's formula

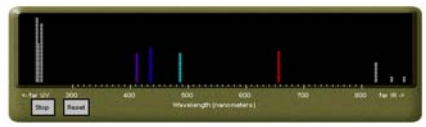
Balmer

$$\lambda = \frac{91.19\text{nm}}{\frac{1}{2^2} - \frac{1}{n^2}}$$

Rydberg

$$\lambda = \frac{91.19\text{nm}}{\frac{1}{m^2} - \frac{1}{n^2}}$$

Rydberg's formula predicted even more of the hydrogen spectral lines.



Obviously these equations describe something about the inner workings of an atom…

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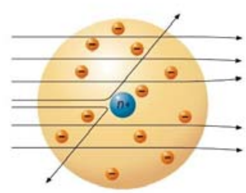
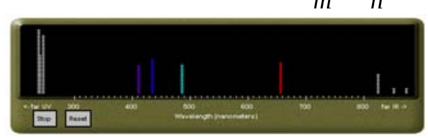
Experimental Observations that Must be Satisfied by Any Atomic Model

Rutherford scattering results



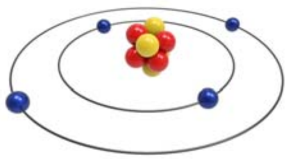
Balmer-Rydberg Formula

$$\lambda = \frac{91.19\text{nm}}{\frac{1}{m^2} - \frac{1}{n^2}}$$



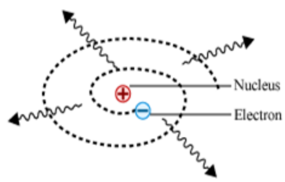
One more experimental observations– Atom is stable

Given solar system model of the atom



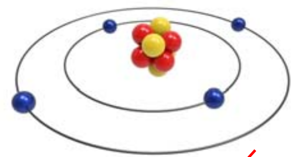
Classical electrodynamics predicts this will happen

decay time ~ 10^{-11} s

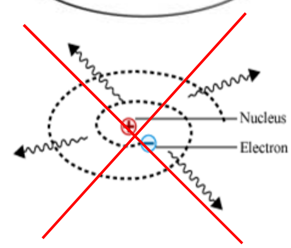


Bohr Model of the Atom

Bohr postulates solar system model of the atom.



Bohr postulates that certain electron orbits are stable and electrons do not radiate if they are in those orbits.

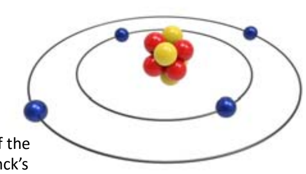


Bohr Atom

Bohr postulates a solar system like atom and uses classical physics to solve it:

- Electron attracted to nucleus by Coulomb force.
- Newton's laws valid so Coulomb force provides centripetal acceleration to make electron go in a circle.
- One non-classical assumption:
  The stable orbits are defined by

$$L = \frac{nh}{2\pi}$$



where L is the angular momentum of the electron, n is an integer, and h is Planck's constant.

By fiat, stable orbits don't radiate.

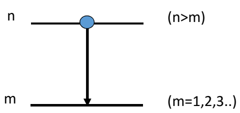
Derive Bohr atom energy levels

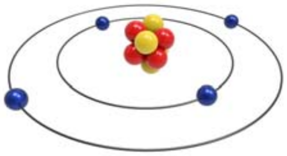
How Rydberg equation and Bohr Atom fit together

Balmer-Rydberg Formula

$$\lambda = \frac{91.19\text{nm}}{\frac{1}{m^2} - \frac{1}{n^2}}$$

Predicts λ of n→m transition:





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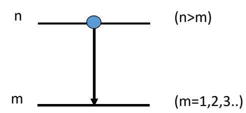
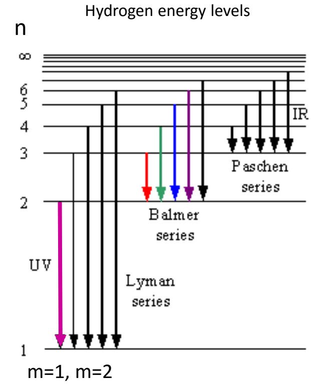
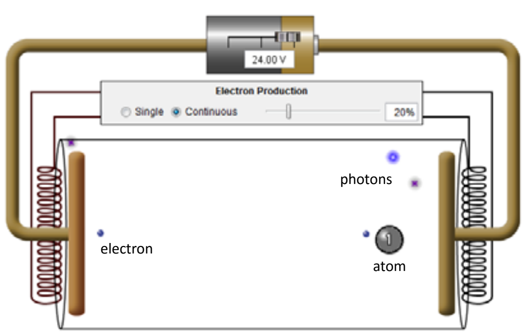




Discharge Lamp



Run simulation:
https://phet.colorado.edu/en/simulation/legacy/discharge-lamps

Do Atomic Spectra and Bohr Atom exercise with Discharge Lamps PHET simulation