PHYS 3313 – Section 001
Lecture #14

Monday, March 4, 2019
Dr. Jaehoon Yu

- The Correspondence Principle
- Importance of Bohr's Hydrogen Model
- Success and Failure of Bohr's Model
- Characteristic X-ray Spectra
- X-ray scattering
- Bragg's Law

Announcements

- Reminder: Homework #3
  - End of chapter problems on CH4: 5, 14, 17, 21, 23 and 45; Due: Monday, March 18
- Reminder: Midterm Exam
  - Covers from CH1.1 through CH4.7 plus the math refresher in the appendices
  - Mid-term exam constitutes 20% of the total
  - **Please do NOT miss the exam! You will get an F if you miss it.**
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations, word definitions or setups or solutions of any problems!
    - No Lorentz velocity addition formula!
    - No Maxwell's equations!
  - No additional formulae or values of constants will be provided!
- Mid-term grade discussions in my office CPB342
  - Monday, March 18 class for the first 45min, from 1:50 – 2:30: Last name starts A – C
  - Wednesday, March 20: 12:30 – 1:00: Last name starts D – K; 1 – 1:30: L – P: 1:30 – 2:00: P - Z
  - Extremely important for you to come and talk to me about the prospect of your grade
- Colloquium this week; 4:00pm Wed. Mar. 6 in SH101
  - Dr. A. Naumov of TCU

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Applications of Carbon Nanomaterials in Biotechnology and Optoelectronics

Anton Naumov
TCU

Wednesday March 6, 2019
4:00 p.m. Room 101 Science Hall

Abstract

Carbon nanomaterials are leading the field of nanotechnology for over 30 years due to their unique physical and electronic properties. They are now used in microelectronics as a basis for nanoscale transistors, they serve as counter electrodes in solar cells or as reinforcement for polymeric materials. Recently carbon nanomaterials have gained a significant attention in the field of biotechnology acting as drug delivery vehicles, therapeutic moieties or nanoscale biosensors. We explore the applications of carbon nanotubes and graphene derivatives as multifunctional agents for transport of molecular anticancer drugs, imaging the pathways of such delivery and detection of cancer. As many chemotherapeutics are toxic, alternative molecular and gene treatment strategies are required to provide effective yet safe treatment of cancer. Many of those involve water-insoluble drugs that are selectively toxic only to cancer cells and non-toxic gene therapies that require a water-soluble platform to deliver those to cancer tumors and protect from degradation in blood. We use carbon nanotubes, graphene oxide and graphene quantum dots for the purpose of such therapeutic delivery that is advantageously combined with imaging of the delivered drugs in cells and animal tissues via the intrinsic fluorescence of those nanostructures. We apply mild physical processing to reduce the toxicity and improve their internalization into biological cells. Additionally, due to their unique redox properties, the fluorescence emission of graphene derivatives and quantum dots helps to detect the presence of cancerous environments. As a result, in our work carbon nanomaterials allow to deliver novel drug and gene therapeutics into cancer cells and animal tissues, trace the location of each drug via intrinsic fluorescence emission from those nanomaterials and detect the presence of cancer cells. Additionally to biomedical applications, carbon nanomaterials developed in our laboratory serve as basis of light-emitting devices and solar cells providing biofrienfdly and cost-effective alternative to current technologies.

Refreshments will be served at 3:30 p.m. in the Physics Lounge

Group Research Projects

- Detailed studies on important discoveries and theories that set the foundation of modern physics
- Final project consists of
  - A 5 – 10 page paper each : 10% of the total
  - A 10+2 minute power point presentation for each group: 5% of total
- Report Due and Presentation Dates
  - Reference cannot have more than 20% direct web link!
  - Presentation: Monday, Apr. 22 and Wednesday, Apr. 24
  - Report Due: At the beginning of the class on Wed. Apr. 24

Group Number	Research Topic	Reseasrch Group Members	Presentation Date and Order
1	Black-body Radiation	Z. Burns, N. Chapagain, A. Contreras, T. Doe, C. Nelson, B. Schuyler	
2	Michelson-Morley Experiment	S. Boucher, J. Breen, R. Contreras, A. Richey, G. Sabine, B. Taylor	
3	The Photo-Electric Effect	I. De Anda, M. Hanna, O. Jagtap, M. Kamerer, C. Morales, T. Nguyen	
4	The Brownian Motion	I. Busch, M. Hail, T. Maxfield, J. Perez, D. Rademacher, P. Williams	
5	Compton Effect	A. Adebayo, E. Alasadi, A. Chaid, T. Freeman, K. Karki, C. Newhouse	
6	Discovery of Electron	C. Garces, E. Glazier, R. Guerra, C. Leferink, E. Ralston, J. Scantlin	
7	Rutherford Scattering	M. Bui, A. Cole, J. Curtis, C. Kizer Pugh, A. Losh, I. Tucker	
8	Super-Conductivity	M. Aquino, J. Bradford, S. Graf, S. Kapoor, M. Liu, M. Smith	
9	The Discovery of Radioactivity	Y. Aryal, B. Garza, G. Hodges, C. Orr, S. Simmonds, R. Wood	

The Correspondence Principle

Classical electrodynamics + Bohr's atomic model

Determine the properties of radiation

Need a principle to relate the new modern results with the classical ones.

Bohr's correspondence principle → In the limits where classical and quantum theories should agree, the quantum theory must produce the classical results.

The Correspondence Principle

- The frequency of the radiation emitted $f_{classical}$ is equal to the orbital frequency f_{orb} of the electron around the nucleus.

$$r = \frac{4\pi\varepsilon_0 n^2\hbar^2}{m_e e^2}$$

$$f_{classical} = f_{orb} = \frac{\omega}{2\pi} = \frac{1}{2\pi}\frac{v}{r} = \frac{1}{2\pi r}\frac{e}{\sqrt{4\pi\varepsilon_0 m_e r}} = \frac{1}{2\pi}\left(\frac{e^2}{4\pi\varepsilon_0 m_e r^3}\right)^{1/2} = \frac{m_e e^4}{4\varepsilon_0^2 h^3}\frac{1}{n^3}$$

- The frequency of the photon in the transition from $n + 1$ to n is

$$f_{Bohr} = \frac{E_0}{h}\left(\frac{1}{(n)^2} - \frac{1}{(n+1)^2}\right) = \frac{E_0}{h}\frac{n^2 + 2n + 1 - n^2}{n^2(n+1)^2} = \frac{E_0}{h}\left[\frac{2n+1}{n^2(n+1)^2}\right]$$

- For a large *n the classical limit*, $f_{Bohr} \approx \frac{2nE_0}{hn^4} = \frac{2E_0}{hn^3}$

Substitute E_0: $f_{Bohr} = \frac{2E_0}{hn^3} = \frac{2}{hn^3}\left(\frac{e^2}{8\pi\varepsilon_0 a_0}\right) = \frac{m_e e^4}{4\varepsilon_0^2 h^3}\frac{1}{n^3} = f_{Classical}$

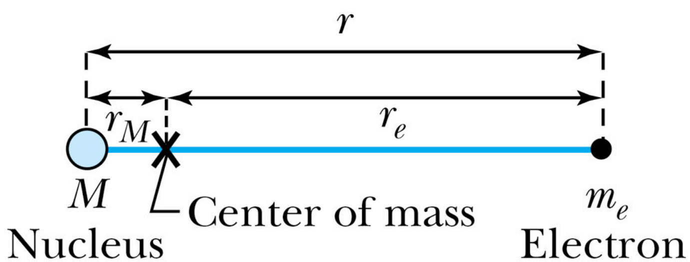
So the frequency of the radiated E between classical theory and Bohr model agrees in large n case!!

The Importance of Bohr's Model

- Demonstrated the need for Plank's constant in understanding the atomic structure
- Assumption of quantized angular momentum which led to quantization of other quantities, r, v and E as follows
- Orbital Radius: $$r_n = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2} n^2 = a_0 n^2$$
- Orbital Speed: $$v = \frac{n\hbar}{mr_n} = \frac{\hbar}{ma_0}\frac{1}{n}$$
- Energy levels: $$E_n = \frac{e^2}{8\pi\varepsilon_0 a_0 n^2} = \frac{E_0}{n^2}$$

Successes and Failures of the Bohr Model

- The electron and hydrogen nucleus actually revolve about their mutual center of mass ➔ reduced mass correction!!



- All we need is to replace m_e with atom's **reduced mass**.

$$\mu_e = \frac{m_e M}{m_e + M} = \frac{m_e}{1 + m_e / M}$$

- The Rydberg constant for infinite nuclear mass, R_∞ is replaced by *R*.

$$R = \frac{\mu_e}{m_e} R_\infty = \frac{1}{1 + m_e / M} R_\infty = \frac{\mu_e e^4}{4\pi c\hbar^3 (4\pi\varepsilon_0)^2}$$

For H: $R_H = 1.096776 \times 10^7 \, m^{-1}$

Limitations of the Bohr Model

The Bohr model was a great step of the new quantum theory, but it had its limitations.

1) Works only to single-electron atoms (H, He+, Li++..)
   - Works even for ions ➔ What would change?
   - The charge of the nucleus $$\frac{1}{\lambda} = Z^2 R\left(\frac{1}{n_l^2} - \frac{1}{n_u^2}\right)$$
2) Could not account for the intensities or the fine structure of the spectral lines
   - Fine structure is caused by the electron spin
   - Under a magnetic field, the spectrum splits by the spin
3) Could not explain the binding of atoms into molecules

Characteristic X-Ray Spectra and Atomic Number

- Shells have letter names:

  K shell for $n = 1$

  L shell for $n = 2$

  ⋮

- The atom is most stable in its ground state.

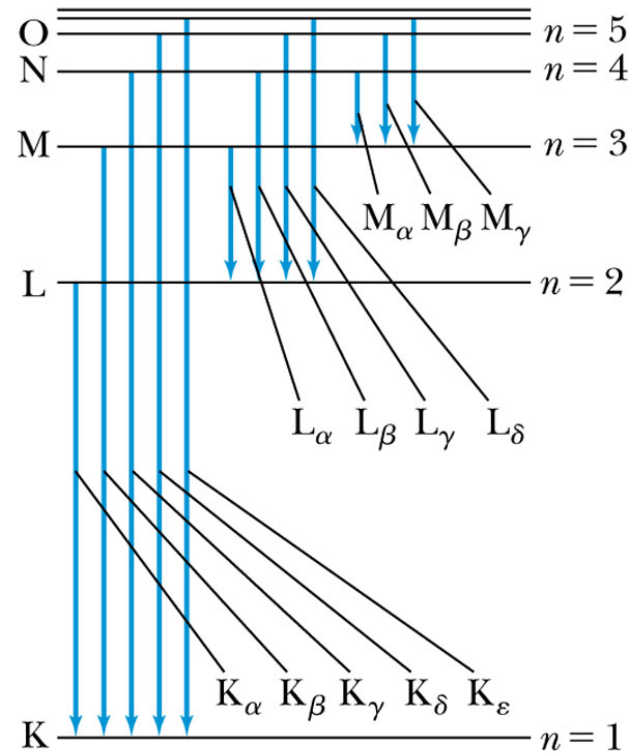
→ An electron from higher shells will fill the inner-shell vacancy at lower energy.

- When a transition occurs in a heavy atom, the radiation emitted is an **x ray**.
- It has the energy E (x ray) $= E_u - E_\ell$.

Atomic Number

L shell to K shell → K_α x ray

M shell to K shell → K_β x ray



- *Atomic number Z = number of protons in the nucleus*
- Moseley found a relationship between the frequencies of the characteristic x ray and Z.

  This holds for the K_α x ray

$$f_{K_\alpha} = \frac{3cR}{4}(Z-1)^2$$

Moseley's Empirical Results

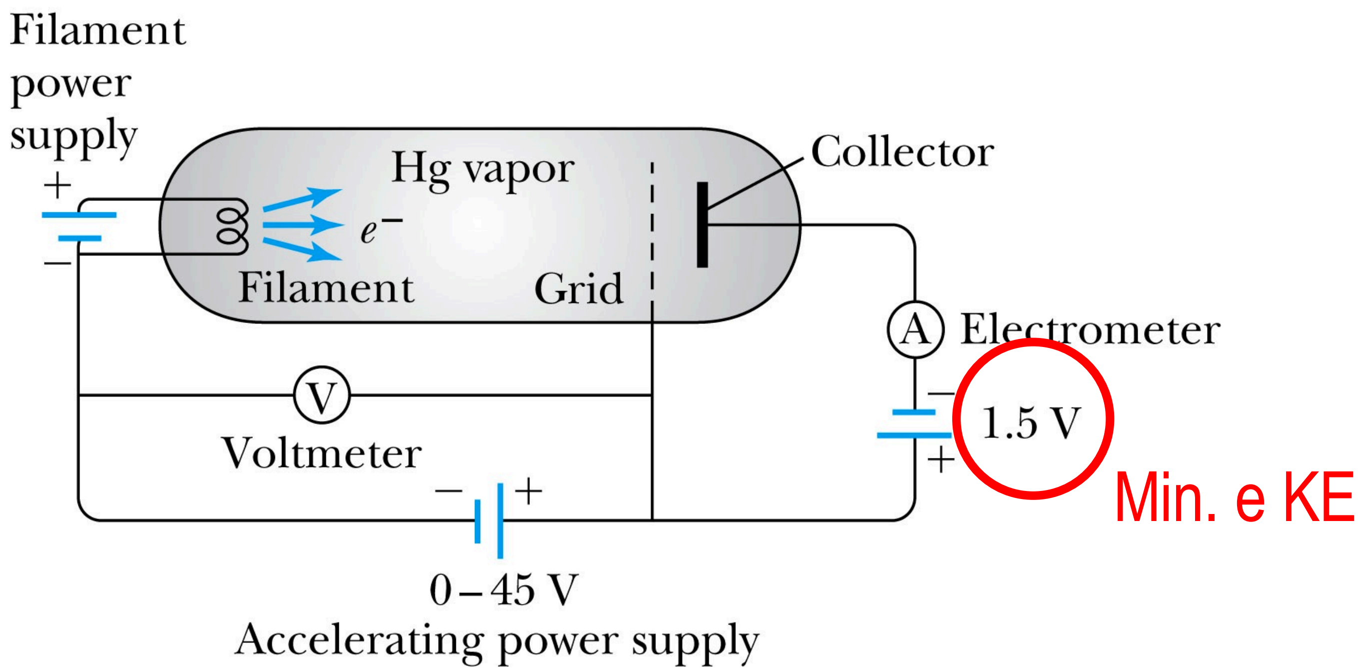
- The x ray is produced from n = 2 to n = 1 transition.
- In general, the K series of x ray wavelengths are

$$\frac{1}{\lambda_K} = R(Z-1)^2\left(\frac{1}{1^2}-\frac{1}{n^2}\right) = R(Z-1)^2\left(1-\frac{1}{n^2}\right)$$

- Moseley's research clarified the importance of the electron shells for all the elements, not just for hydrogen
  - Concluded correctly that atomic number Z, rather than the atomic weight, is the determining factor in ordering of the periodic table

Atomic Excitation by Electrons

- Franck and Hertz studied the phenomenon of ionization KE transfer from electrons to atoms.



When the accelerating voltage is below 5 V

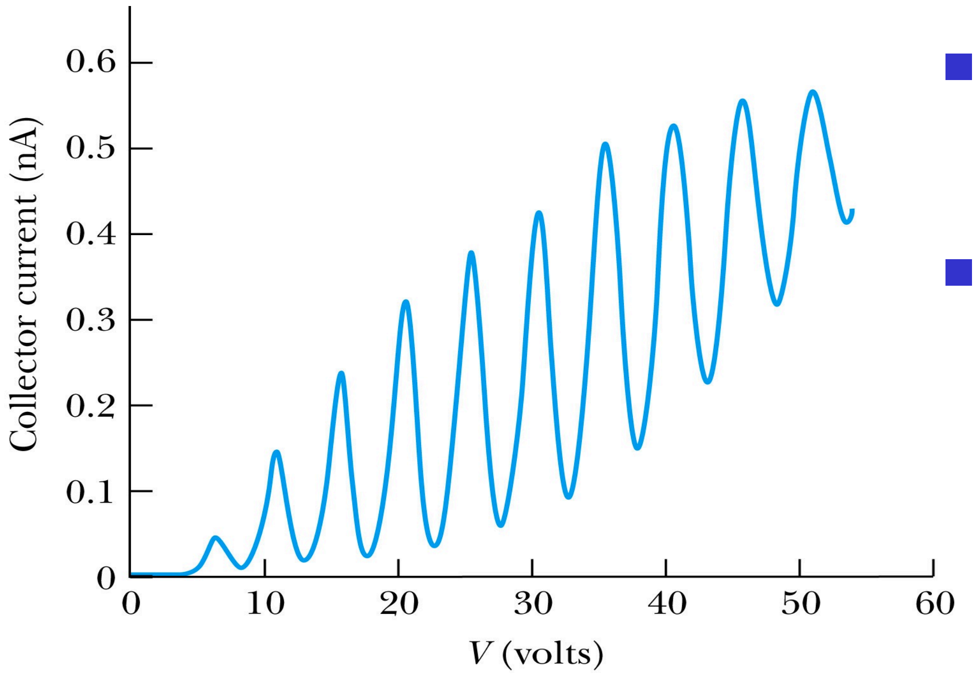
→ electrons did not lose energy going through the mercury vapor

When the accelerating voltage is above 5 V, 10V, etc..

→ sudden drop in the current

Atomic Excitation by Electrons

- Ground state has E_0 which can be considered as 0.
  First excited state has E_1.
  The energy difference $E_1 - 0 = E_1$ is the **excitation energy**.

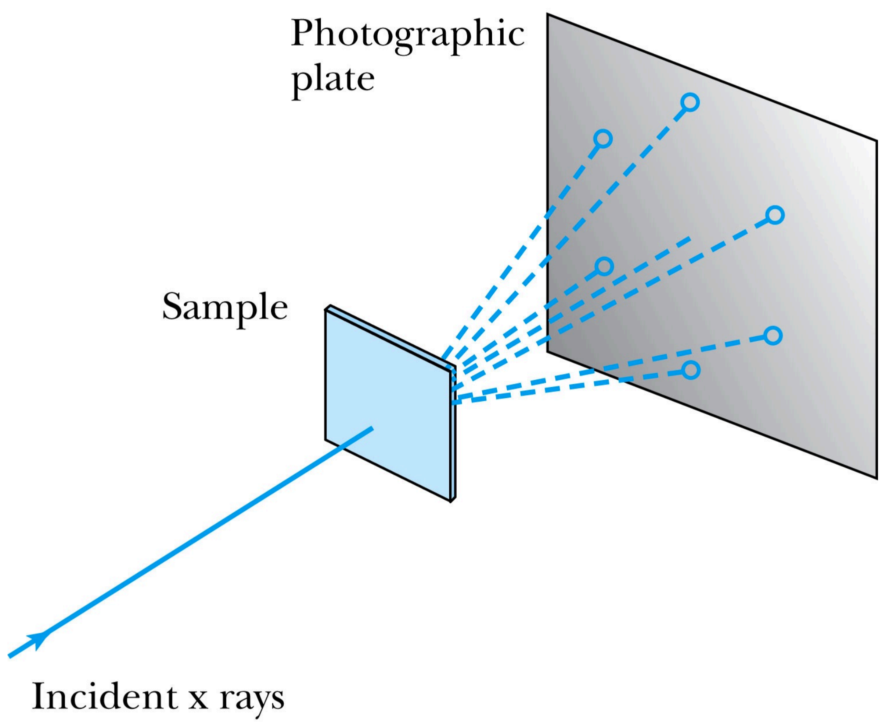


- Hg (mercury) has an excitation energy of 4.88 eV in the first excited state
- No energy can be transferred to Hg below 4.88 eV because not enough energy is available to excite an electron to the next energy level

- Above 4.88 eV, the current drops because scattered electrons no longer reach the collector until the accelerating voltage reaches 9.76 eV and so on.

X-Ray Scattering

- Max von Laue suggested that if X rays were a form of electromagnetic radiation, interference effects should be observed. (Wave property!!)
- Crystals act as three-dimensional gratings, scattering the waves and producing observable interference effects.



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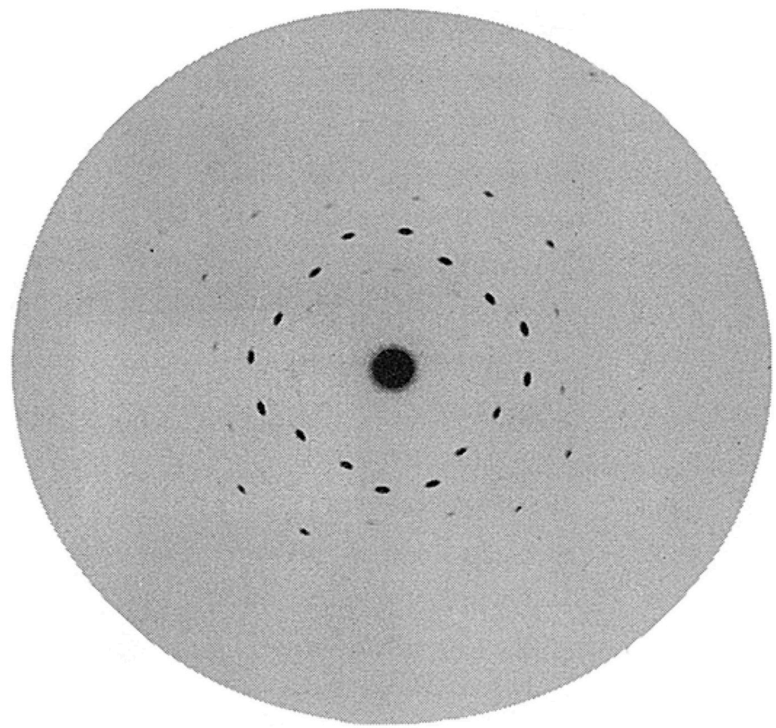

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