PHYS 3313 – Section 001
Lecture #14

Monday, Mar. 3, 2014
Dr. Jaehoon Yu

- Bohr's Hydrogen Model and Its Limitations
- Characteristic X-ray Spectra
- Hydrogen Spectrum Series
- X-ray Scattering
- Bragg's Law

Announcements

- Mid-term exam
  - In class on this Wednesday, Mar. 5
  - Covers CH1.1 – what we finish today (CH4.6)+ 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 or solutions of any problems allowed!
  - No additional formulae or values of constants will be provided!
- Reminder Homework #3
  - End of chapter problems on CH4: 5, 14, 17, 21, 23 and 45
  - Due: Monday, March 17
- Colloquium this Wednesday at 4pm in SH101
  - Dr. Xun Jia of UTSW Medical Center

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Radiation Oncology Physics Research: Challenges and Opportunities

Dr. Xun Jia

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Division of Medical Physics and Engineering
Department of Radiation Oncology
Dallas Texas

4:00 pm Wednesday March 5, 2014 in room 010 UH

Abstract:

Radiation oncology physics is a field about physics applications in cancer treatment using radiation as a tool. Its success requires combined efforts from researchers with different expertise, such as physicians, physicists, engineers, and mathematicians. With advanced technologies introduced into routine clinical practice, physicists play an increasingly important role. The complicated treatment modalities and the physics behind it call for extensive physics research to ensure the safety, efficacy, and efficiency. Challenges and opportunities co-exist. This talk will give an introduction to the medical physics field. It will then cover a few research topics currently conducted at our group, including cone beam CT reconstruction and Monte Carlo simulations for radiation transport. High-performance computing on computer graphics processing unit (GPUs) and its applications in radiotherapy will also be discussed.

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

The Correspondence Principle

Classical electrodynamics + Bohr’s atomic model

Determine the properties of radiation

Need a principle to relate the new modern results with 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.

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

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

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

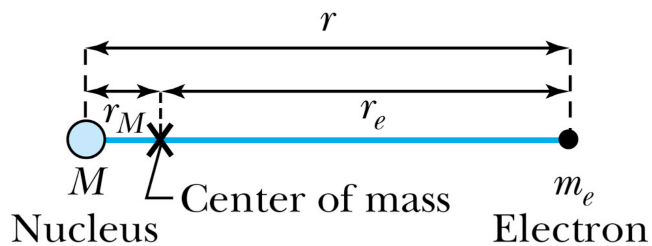
So the frequency of the radiated E between classical theory and Bohr model agrees in large n case!!

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*.

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

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
   – 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.

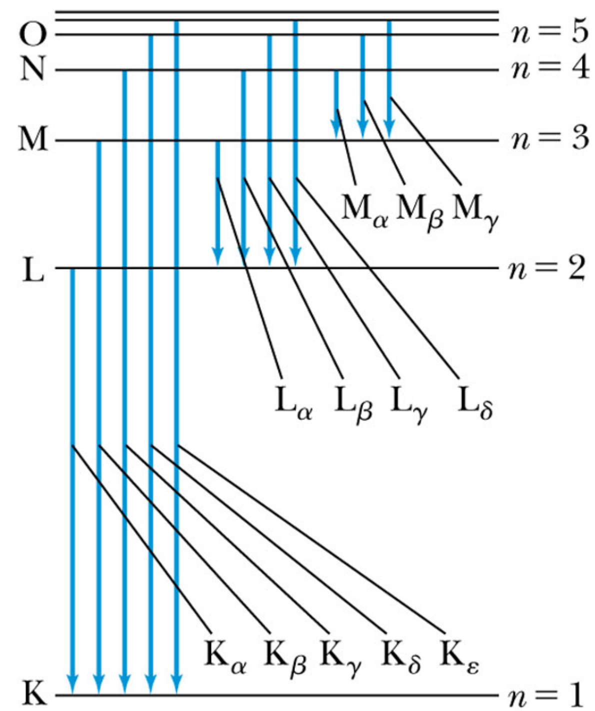
→ An electron from higher shells will fill the inner-shell vacancy at lower energy.

- 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