PHYS 3313 – Section 001
Lecture #15

Monday, March 20, 2017
Dr. Jaehoon Yu

- Bohr's Hydrogen Model and Its Limitations
- Characteristic X-ray Spectra
- X-ray Scattering

Announcements

- Mid-term grade discussions
  - Today at the bottom of the class in CPB342
    - Last names: A – D
  - Wednesday, March 22
    - 12:45 – 1:20 pm: Last names start with D – J
    - 1: 20 – 2:00 pm : Last names start with K – P
    - 2:00 – 2:30 pm. : Last names start with P – Z
- Mid-term exam results
  - Class average: 52.7/96
    - Equivalent to 54.9/100
  - Top score: 93/96

Evaluation Policy

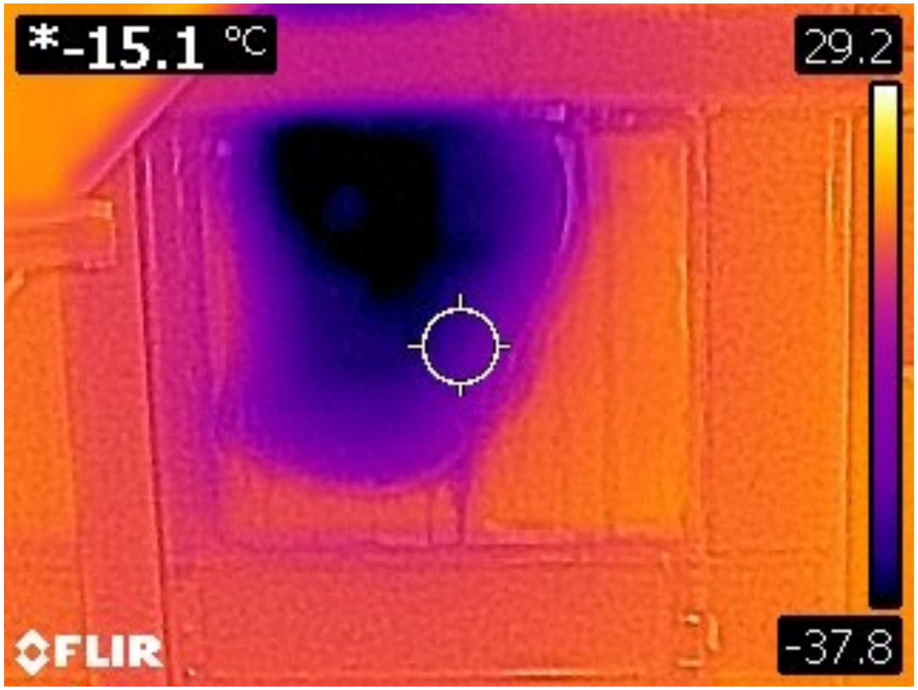
- Homework: 30%
- Exams
  - Mid-term Exam (Wed., Mar. 8): 20%
  - Final Comprehensive Exam (11 – 1:30pm, Wed, May. 3): 25%
  - Missing an exam is not permissible unless pre-approved
    - No makeup test
    - You will get an F if you miss any of the exams without a prior approval
- Group Research Project: 15%
- Pop-quizzes: 10%

100%

- Extra credits: 10% of the total
- Grading will be done on a sliding scale
- 55% of the grade is in your hand!!

What did I do at CERN?

- Figured out the size of the leak!

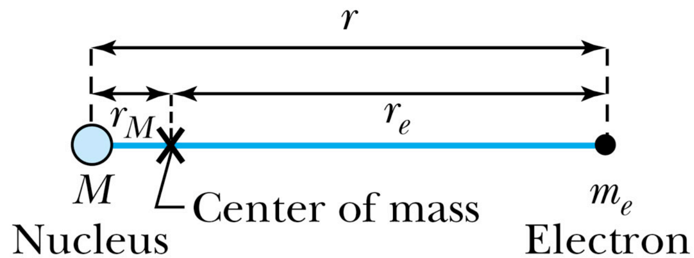


The Importance of Bohr's Model

- 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
   - 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 $n = 2$

  ⋮

- An atom is most stable in its ground state.

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

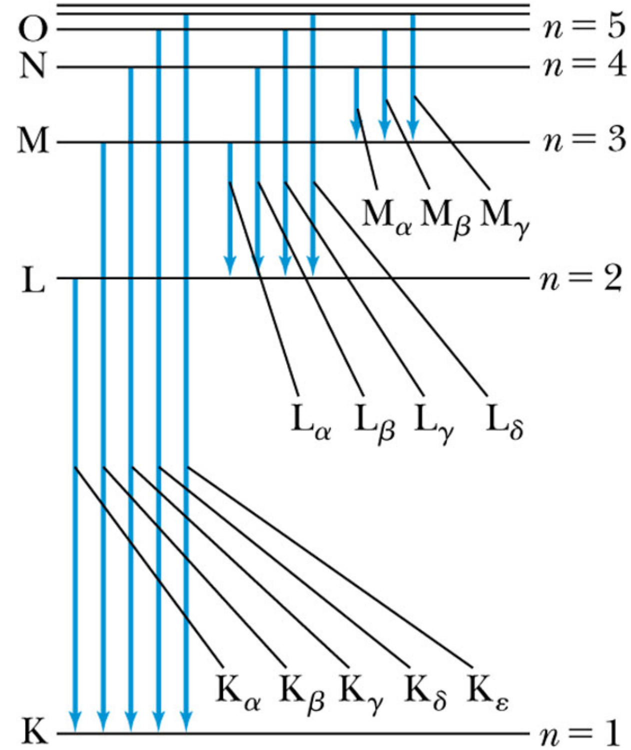
- When a transition occurs in a heavy atom, the radiation emitted is an **X ray**.
- It has the energy E (x ray) $= E_u - E_\ell$.

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

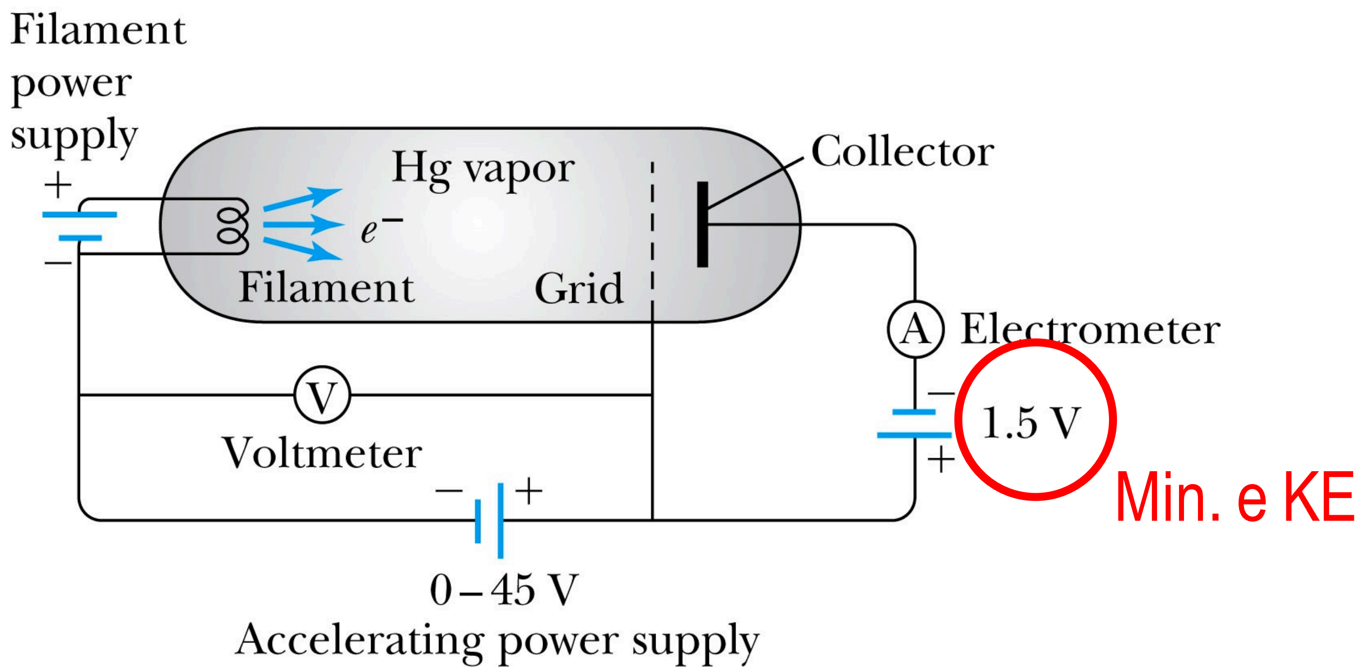
- The X ray is produced from $n = 2$ to $n = 1$ transition.
- In general, the K series of X ray wavelengths are

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

- 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 kinetic energy transfer from electrons to atoms.



When the accelerating voltage is below 5 V

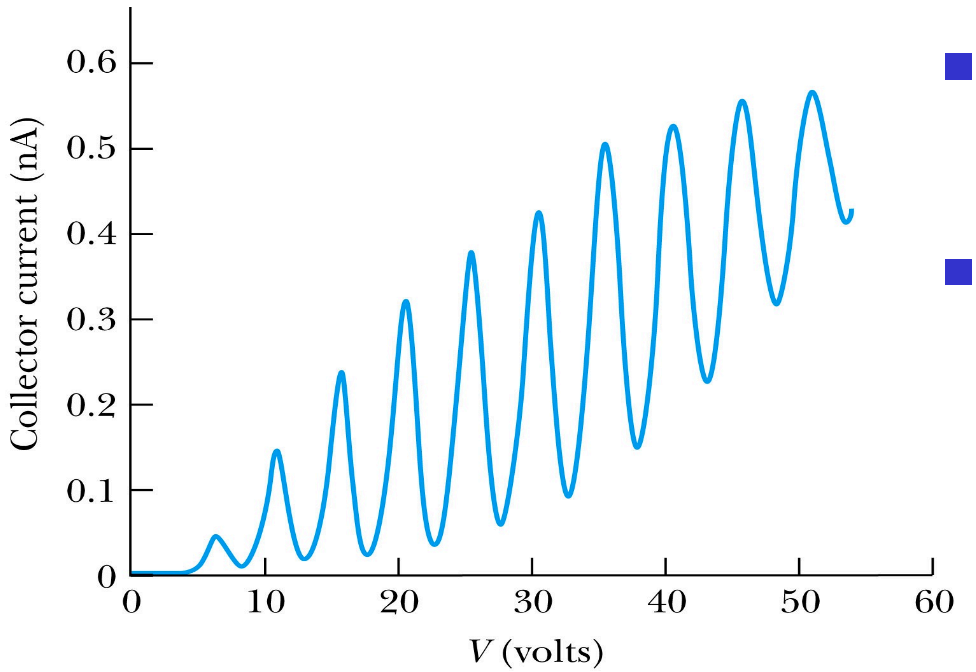
→ electrons did not lose energy going through the mercury vapor

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 the scattered electrons no longer reach the collector until the accelerating voltage reaches 9.76 eV and so on.