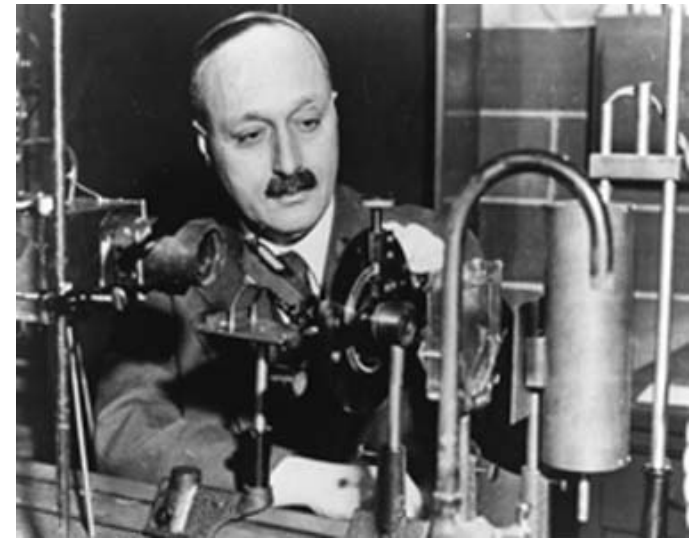


Bohr model and Franck-Hertz experiment

Announcements:

- Homework solutions will be up this afternoon.
- Next weeks homework will be available by noon tomorrow.
- On Friday, I would like to take a vote on when we should have the other midterm exam. Either 3/31 or 4/7. Check your schedules.
- Today we will be analyzing the Bohr model with clicker questions.

Gustav Hertz:
1887-1985

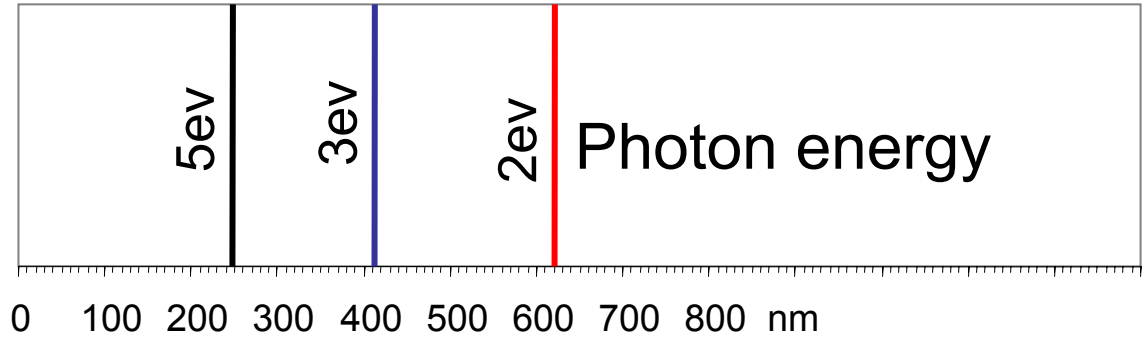


James Franck: 1882-1964

Clicker question 1

Set frequency to DA

What energy levels for electrons are consistent with this spectrum?



Electron Energy levels:

A

----- 0 eV
—— -2 eV
—— -3 eV
—— -5 eV

B

----- 0 eV
—— -5 eV
—— -7 eV
—— -8 eV
—— -10 eV

C

----- 0 eV
—— -5 eV
—— -7 eV
—— -10 eV

D

—— 10 eV
—— 7 eV
—— 5 eV
----- 0 eV

E

—— 5 eV
—— 3 eV
—— 2 eV
----- 0 eV

Why are only certain energy levels allowed?

Bohr postulated that angular momentum was quantized so:

$$L = m_e v r = n \hbar$$

where

$$\hbar = h / 2\pi$$

Quantizing angular momentum leads to a quantization of radius:

$$r_n = n^2 a_B$$

where

$$a_B = \frac{\hbar^2}{m_e k e^2} = 0.053 \text{ nm}$$

is the Bohr radius

Quantizing radius leads to a quantization of energy:

$$E_n = -\frac{k e^2}{2 a_B} \frac{1}{n^2} = -\frac{E_R}{n^2} = -\frac{13.6 \text{ eV}}{n^2}$$

where E_R is the Rydberg energy:

$$E_R = hcR = \frac{k e^2}{2 a_B} = \frac{m (k e^2)^2}{2 \hbar^2} = 13.6 \text{ eV}$$

Which of the following principles of classical physics is violated in deriving the Bohr model of the atom?

- A. Opposite charges attract with a force inversely proportional to the square of the distance between them.
- B. The force on an object is equal to its mass times its acceleration.
- C. Accelerating charges radiate energy.
- D. Particles have a well-defined position and momentum.
- E. All of the above.

Note that A & B were used in the derivation of the Bohr model.

Bohr's calculation of hydrogen energy levels

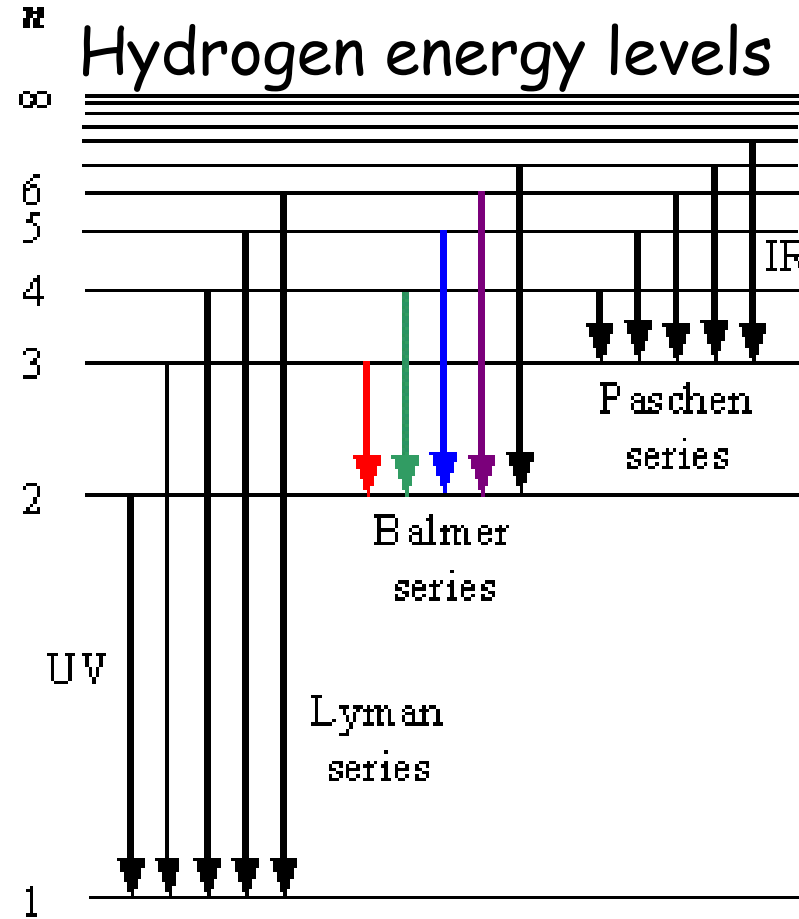
Using the formula for energy

$$E_n = -\frac{ke^2}{2a_B} \frac{1}{n^2} = -\frac{E_R}{n^2} = -\frac{13.6 \text{ eV}}{n^2}$$

Bohr could calculate the various transitions and they agreed with the generalized Balmer formula.

Photon energy is given by:

$$E_\gamma = E_n - E_{n'} = -E_R \left(\frac{1}{n'^2} - \frac{1}{n^2} \right) = -13.6 \text{ eV} \left(\frac{1}{n'^2} - \frac{1}{n^2} \right)$$



Clicker question 3

Set frequency to DA

An atom with the energy levels shown is initially in the ground state. A free electron with an energy of 16.0 eV hits the atom. What possible states could the atom be in after the interaction?

n=5	_____	-1 eV
n=4	_____	-2 eV
n=3	_____	-5 eV
n=2	_____	-10 eV
n=1	_____	-20 eV

A. n=1

B. n=1, n=2, or n=3

C. n=3

D. n=2 or n=3

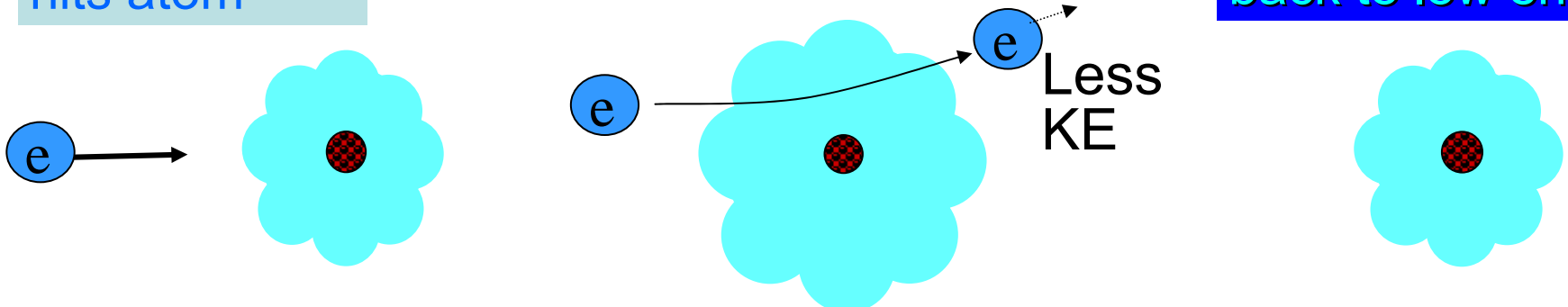
E. Any of the states

If the atom goes to n=1, 2, or 3, the free electron will lose 0 eV, 10 eV, or 15 eV of kinetic energy.

Free electron hits atom

Atomic electron excited to higher energy and free electron loses same amount of energy.

Electron jumps back to low energy



Clicker question 4

Set frequency to DA

An atom with the energy levels shown is initially in the ground state. A photon with an energy of 16.0 eV hits the atom. What possible states could the atom be in after the interaction?

n=5	_____	-1 eV
n=4	_____	-2 eV
n=3	_____	-5 eV
n=2	_____	-10 eV
n=1	_____	-20 eV

A. n=1

B. n=1, n=2, or n=3

C. n=3

D. n=2 or n=3

E. Any of the states

For the free electron, whatever energy is absorbed by the atom is deducted from the free electron's kinetic energy.

For photons, the photon is absorbed and so it must transfer **all** of its energy to the atom. Otherwise energy would not be conserved. Therefore, atoms can only absorb photons with an energy that will exactly move the atom to another energy level.

Clicker question 5

Set frequency to DA

An atom with the energy levels shown is initially in the ground state. Which of the following is the most complete list of photon energies that can be absorbed by the atom?

n=5	_____	-1 eV
n=4	_____	-2 eV
n=3	_____	-5 eV
n=2	_____	-10 eV
n=1	_____	-20 eV

- A. 1 eV
- B. 1 eV, 2 eV, 5 eV, 10 eV
- C. 10 eV
- D. 10 eV, 15 eV, 18 eV
- E. 10 eV, 15 eV, 18 eV, 25 eV

Photons with energy of 10 eV, 15 eV, 18 eV, 19 eV will cause the electron to jump to the n=2, n=3, n=4, n=5 energy level.

Any photon with an energy ≥ 20 eV will *ionize* the atom. The electron will escape. Since a free electron can have any energy, any photon with energy ≥ 20 eV can be absorbed by the atom.

20 eV will go into ejecting the electron and the rest will go into the free electron's kinetic energy. Similar to the photoelectric effect.

Hydrogen like ions

Atoms which have only one electron can be analyzed much like the hydrogen atom.

An atom with atomic number Z with $Z-1$ electrons removed is a hydrogen like ion

The (Coulomb) force on the electron is
$$F_C = \frac{kq_1q_2}{r^2} = \frac{kZe^2}{r^2}$$

The increase in the force results in tighter orbits and a deeper potential well, reducing the energy (more negative).

$$r_n = \frac{n^2 a_B}{Z}$$

$$E_n = -Z^2 \frac{E_R}{n^2} = -Z^2 \frac{13.6 \text{ eV}}{n^2}$$

Clicker question 6

Set frequency to DA

A single electron is in the $n=2$ energy level around a helium nucleus (He^+). What is the minimum energy photon that can remove this electron?

A. 3.4 eV

B. 13.6 eV

C. 27.2 eV

D. 54.4 eV

E. None of the above

$$r_n = \frac{n^2 a_B}{Z}$$

$$E_n = -Z^2 \frac{E_R}{n^2} = -Z^2 \frac{13.6 \text{ eV}}{n^2}$$

The atomic number of helium is $Z=2$ and the electron is in the $n=2$ energy level. So the energy of the state is

$$E_n = -Z^2 \frac{13.6 \text{ eV}}{n^2} = -2^2 \frac{13.6 \text{ eV}}{2^2} = -13.6 \text{ eV}$$

The value $|E_n|$ is also referred to as the *binding energy* since it is a measure of how bound the electron is. It takes that amount of energy to free the electron (break its bond to the proton).