3. Early atom models

3.1 Brief history

Word "atom" goes back to Greek philosophers and means literally indivisible. It was used later by John Dalton, who claimed that all matter consists of atoms, that are the smallest parts of matter and cannot be further divided.

This is not true as we know today. The first evidence was given by the experiment by J.J. Thomson who discovered that electrons as being part of atoms.

Thomson studied the so-called cathode rays which were emitted by strong heating of a cathode. He showed that these rays can be deflected using an electric field

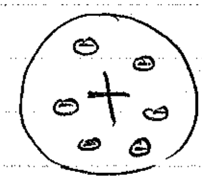
=> rays must consist of (negatively) charged particles

By using crossed $\vec{E}$- and $\vec{B}$-fields he could determine the charge-to-mass ratio of the particles and moreover showed that this ratio was always the same, independent of material of cathode

=> rays consist of a fundamental (new) particle which is part of any material

Thomson called this particle "electron" and claimed that it is part of any atom.

Since atoms are neutral particles, Thomson further concluded that an atom consists of negative (the electrons) and positive parts. Thomson's model was the so-called plum-pudding model



where the electrons are in a positively charged soup.

Scientists then started to study the structure of atom, i.e. the distribution of the charges inside the atom. This can be done using charged particles or light.

Ernest Rutherford (1911) did an experiment in which the scattered α-particles (nowadays we know these are He-nuclei consisting of two <u>protons</u> and two neutrons) on atoms. His observation were:

- most particles past through the atom undeflected
- some were deflected and
- few were scattered backwards

Since α-particles are positively charged particles, the positively charged part in the atom must be concentrated in a small region at the center of the atom, while the rest of the atom is mainly empty (except for the electrons). He could even measure that the nucleus must be about 10000 times smaller than the whole atom.

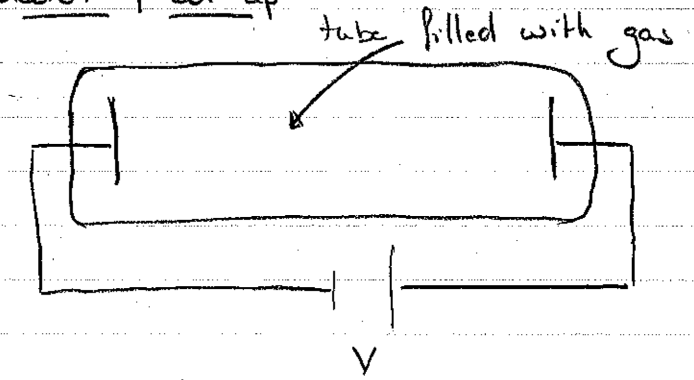
Rutherford then introduced a planetary model of the atom. He proposed that the electrons orbit the nucleus.

There are severe problems with this model, as we will discuss a bit later. But, before let's add another observation to this picture → namely which energies can the electrons have inside the atom?

3.2 Discharge lamps and discrete energy levels

Discharge lamps have been used earlier by Faraday already and have still today many applications.

Sketch of set-up



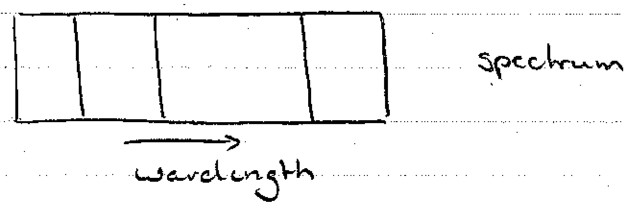
By applying a high voltage some atoms of the gas can set free an electron (can be ionized).

These free electrons will be accelerated in the potential difference between the plates and hit other atoms.

Faraday observed that

- the tube 'started to glow', that is there was light emitted from the atoms.

- further experiments with diffraction gratings showed that the emitted light consisted of a few discrete lines at specific wave-lengths



and further this spectrum was different for each gas (atom)

Using Einstein's interpretation ($E = hf = h\frac{c}{\lambda}$) of light as energy quanta, we can conclude about the energies of electrons in an atom:

- Only way for atoms to give off energy is by emitting light.

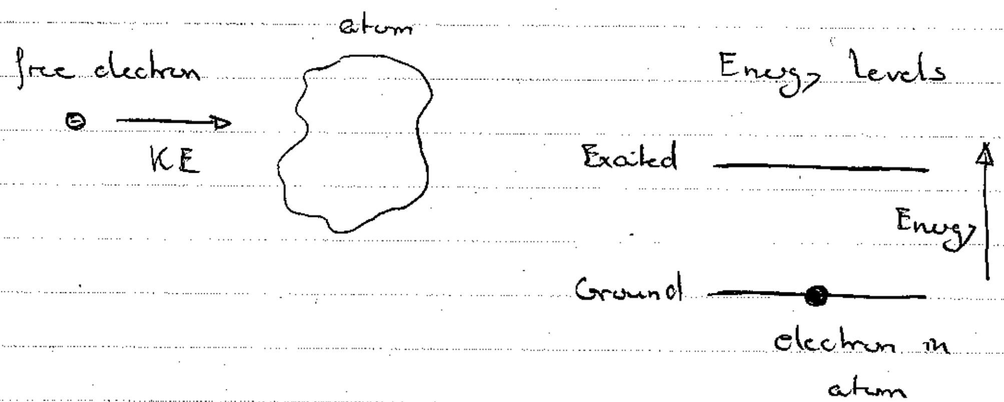
- Each time an atom emits light (energy quantum = photon of specific wavelength), an electron must change energy in atom by the amount of $E = hf$

- Since the lines in the spectra are discrete, that is light of very specific energy is emitted only => electron in atom can change between specific energy levels only.

With this concept of specific discrete energy levels inside the atom, we can understand the observations in the experiments with discharge lamps as follows.

__Step 1__: Free electron gains KE in the tube due to the potential difference and hits the atom in which there is an electron in the lowest energy state (also called ground state)

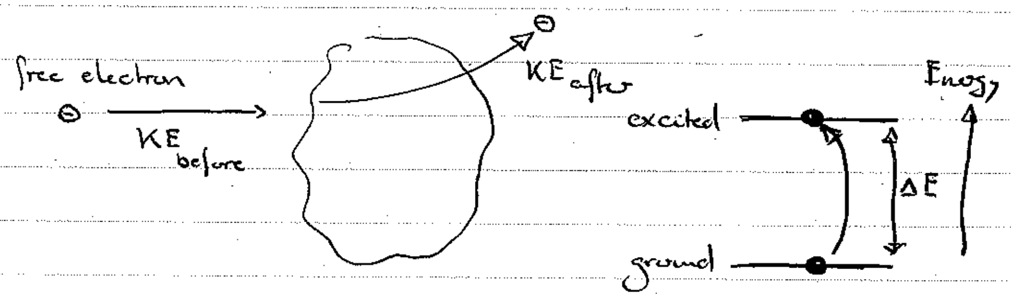
state = level



__Step 2__: If the kinetic energy of the free electron is __greater__ or __equal__ to the energy difference between the energy levels in the atom, the free electron __can__ transfer (part of) its energy to the electron in the atom

⇒ free electron looses kinetic energy, which is exactly the amount of energy equal to the energy difference between the levels in the atom.

⇒ Electron in atom jump to the higher energy level



$$\underbrace{KE_{before} - KE_{after}}_{\text{change in KE of free electron}} = \Delta E$$

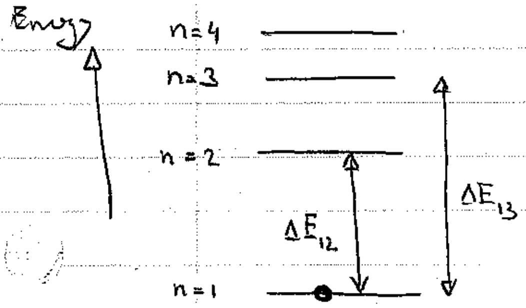
(ΔE: energy difference between levels)

Notes:

- The free electron cannot transfer any arbitrary amount of energy. It can only transfer energy exactly equal to the energy difference between energy levels in the atom

- If the free electron does have less KE than the smallest energy difference between energy levels in an atom, then there cannot be an energy transfer. So, the free electron will just pass by.

- (More strangely) Even if the electron has *more* energy than the energy difference, it actually *may* or *may not* transfer part of its energy. Or in other words, there is a certain probability that it transfers energy and with a certain probability it does not transfer energy.



- Suppose the atom has more than two energy levels (see right for example) and the electron is in the ground ($n=1$) state.
If the KE of the free electron

→ is larger than ΔE_{12} but smaller than ΔE_{13} then free electron *can* transfer ΔE_{12} and electron in atom will jump to $n=2$ level. (or it can pass by)

→ is larger than ΔE_{13} but smaller than ΔE_{14} then
free electron *can* *either* transfer
ΔE_{12} → electron in atom goes to $n = 2$
or it can transfer
ΔE_{13} → electron in atom goes to $n = 3$
or it can pass by without energy transfer
→ electron in atom remains in $n = 1$

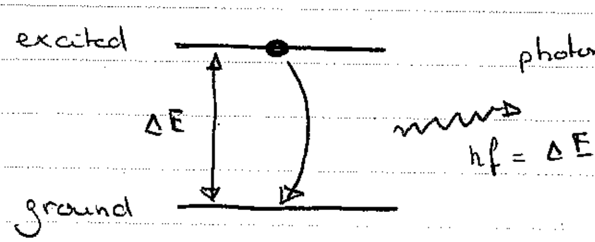
All this does not look like the physics of an ordinary classical collision between particles.
Yep, that's right. We will need to change our thinking about the nature of an electron as well, as we did already for light.

But, let's wait and first finish our analysis of the experiments with discharge lamps.

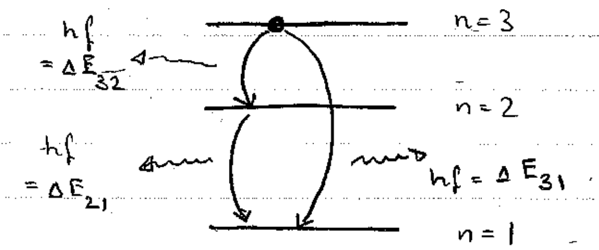
Free electron can transfer discrete amounts of energy to the electron in atom and thus goes to a higher energy level.

What happens next?

Step 3: An atom in an excited state (is lazy and) wants to go back to its ground state. Thus, the electron in a higher energy level will jump down to a lower energy level. The electron looses energy and the atom therefore emits a photon with energy exactly equal to the energy difference between the two energy levels in the atom.



If there is more than one level and the electron is in one of the highest levels then it can either jump directly to the ground state or it can jump step by step.



Correspondingly, we would observe photons of three different energies, three different frequencies, three different wavelengths.