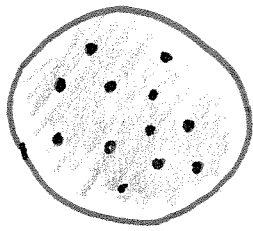


11 BOHR ATOM + DUALITY

Between 1910 and 1925 a huge upheaval took place in the understanding of the atom. Today we will talk about the first part of this revolution - the BOHR MODEL OF THE ATOM.

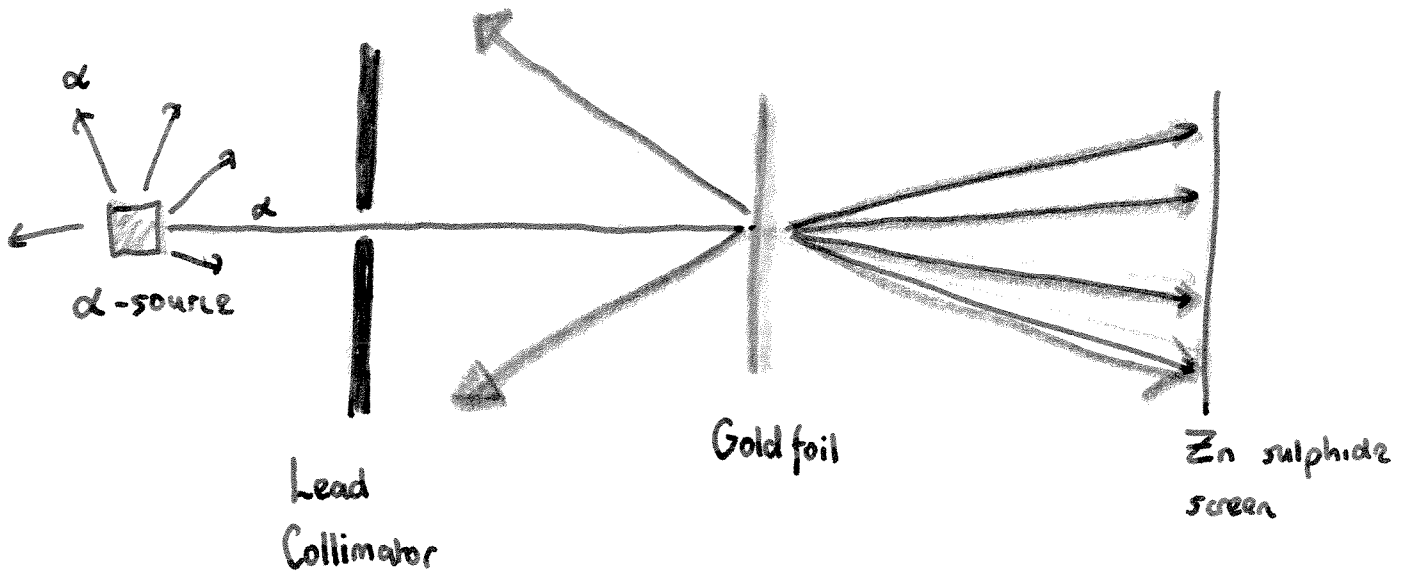
At the outset of this period, the leading model of the atom was one proposed by the discoverer of the electron - J.J. Thompson. J.J. proposed the "plum pudding" model according to which the atom contained electrons embedded in a positive background, like a "plum pudding". In this model, positive charge was spread over a region of about an angstrom ($1\text{\AA} = 10^{-10}\text{m}$).



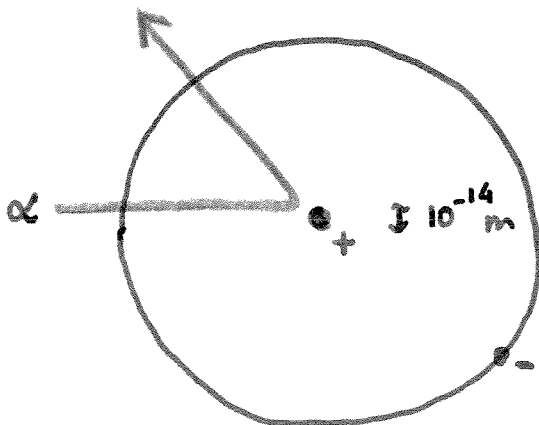
THOMPSONS PLUM PUDDING MODEL OF THE ATOM

In 1911, Rutherford, Geiger + Marston put this model to the test. They fired high velocity " α -particles" — (Helium atoms which have lost their electrons and carry charge $+2e$) at a gold foil. The experimenters expected to see a gentle deflection of the incoming particles. To their surprise, an α -particle occasionally bounced right back off the gold atoms. It was as if you had fired a machine gun at a haystack, & found one in a hundred

of the bullets bounced right back!



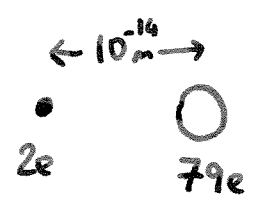
To explain this required a radical redesign of the model of the atom — to account for the large angle scattering the positive charge needed to be concentrated in a tiny region of order 10^{-14} m; the atomic nucleus.



Rutherford's
Nuclear Atom.
(Largely empty space)

e.g. An alpha particle, with charge $q = +2e$ approaches to within 10^{-14} m of a gold nucleus.

($q = Ze = 79e$) What is its kinetic energy?



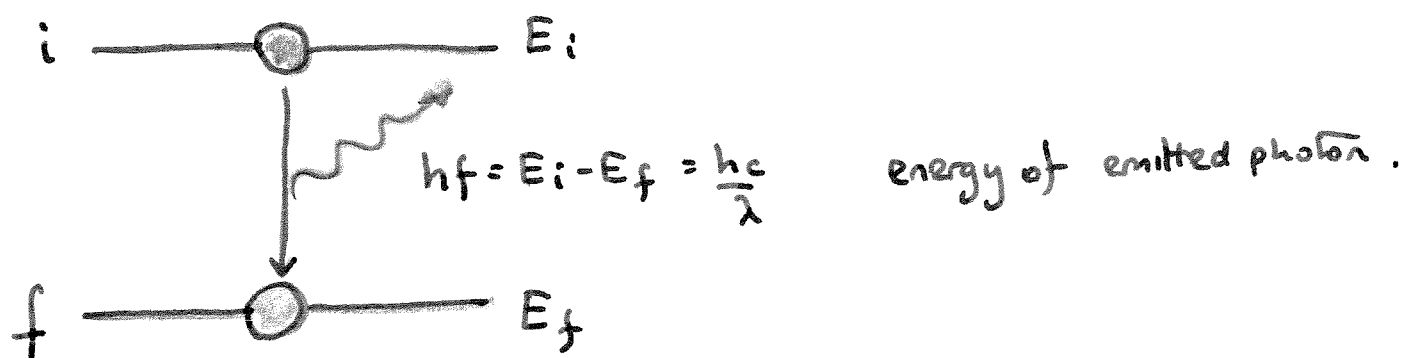
$$U = \frac{q_1 q_2}{4\pi\epsilon_0 r} = \text{K.E.}$$

$$\text{K.E.} = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2 \times 9 \times 10^9}{(10^{-14} \text{ m})} = 3.64 \times 10^{-12} \text{ J}$$

$$= \frac{3.64 \times 10^{-12}}{1.6 \times 10^{-19}} \text{ eV} = 2.28 \times 10^7 \text{ eV} = \underline{\underline{22.8 \text{ MeV}}}$$

38.3 ATOMIC LINE SPECTRA + ENERGY LEVELS

11.5



The origin of the line spectra derives

from the EMISSION OF A PHOTON

(BOHR, 1913).

in making a transition between two energy levels.

e.g Orange light emitted by krypton. $\lambda = 606 \text{ nm}$

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{606 \times 10^{-9} \text{ m}} = 3.28 \times 10^{-19} \text{ J}$$

or

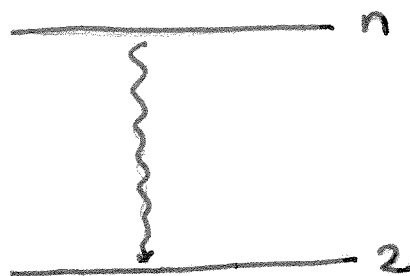
$$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \text{ eVs} \times 3 \times 10^8}{606 \times 10^{-9} \text{ m}} = 2.05 \text{ eV} \quad \left(= \frac{3.28 \times 10^{-19}}{1.6 \times 10^{-19}} \right)$$

HYDROGEN SPECTRUM

BALMER SERIES (VISIBLE)

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

$$R = 1.097 \times 10^7 \text{ m}^{-1}$$



e.g. $n = 3$

$$\frac{1}{\lambda} = 1.097 \times 10^7 \left(\frac{1}{4} - \frac{1}{9} \right) = 1.52 \times 10^6 \text{ m}^{-1}$$

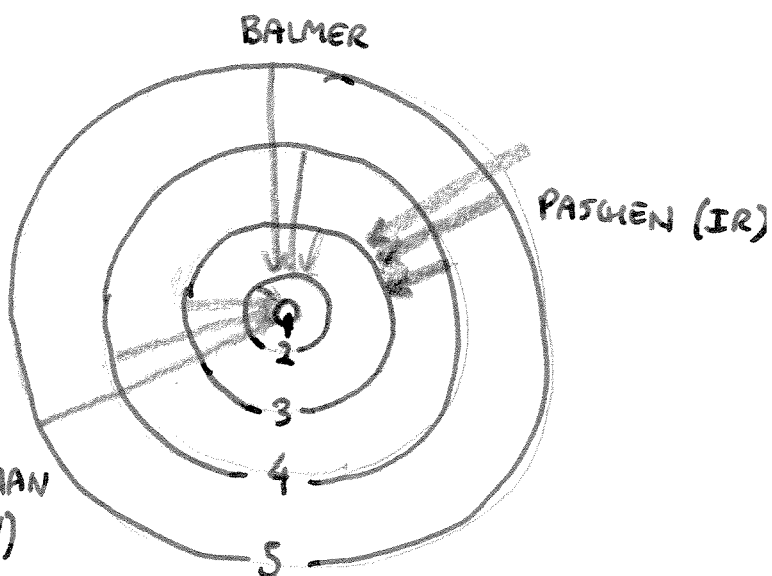
$$\lambda = 656 \text{ nm}$$

$$E = \frac{hc}{\lambda} = \frac{hcR}{2^2} - \frac{hcR}{n^2}$$

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

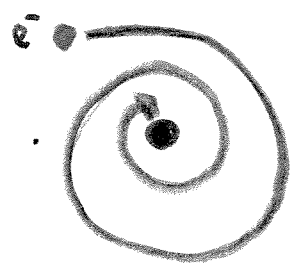
BOHR HYPOTHESIS.

LYMAN (UV)



$$\frac{hc}{\lambda} = hcR \left[\frac{1}{n_f^2} - \frac{1}{n_i^2} \right]$$

38.5 THE BOHR MODEL



11.7

RADIATION
COLLAPSE

$\Delta t \sim 10^{-16} \text{ s}$

The main difficulty with the Rutherford model, is that the electrons orbiting the nucleus are expected to radiate electromagnetic waves. An estimate of the lifetime of an atom gives about 10^{-16} s !

To account for the stability of atoms, Bohr proposed that in the H-atom, angular momentum is quantized in units of $h/2\pi$

$$l_n = m v_n r_n = n \left(\frac{h}{2\pi} \right)$$

QUANTIZATION
OF ANGULAR
MOMENTUM.

Force on electron in orbit = $m \times \text{accel.}$

$$\frac{1}{4\pi\epsilon_0} \frac{e^2}{r_n^2} = m \frac{(v_n)^2}{r_n}$$

$$\Rightarrow \underbrace{(m v_n r_n)^2}_{n^2 (h/2\pi)^2} = \left(\frac{e^2}{4\pi\epsilon_0} \right) m r_n$$

\Rightarrow

$$r_n = n^2 a_0$$

where

$$a_0 = \left(\frac{h}{2\pi} \right)^2 \times \frac{4\pi\epsilon_0}{e^2 m} = \epsilon_0 \left(\frac{h^2}{\pi m e^2} \right)$$

$$a_0 = 8.85 \times 10^{-12} \times \frac{(6.62 \times 10^{-34})^2}{\pi \times (9.1 \times 10^{-31}) \times (1.6 \times 10^{-19})^2} \approx \underline{5.29 \times 10^{-11} \text{ m}}$$

$$\approx \underline{\underline{0.5 \text{ \AA}}}$$

Energy Levels

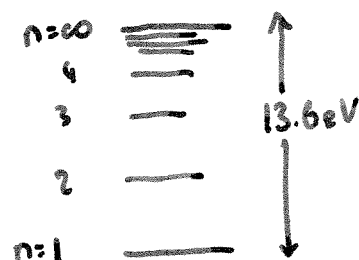
$$K_n = \frac{1}{2} m v_n^2 = \frac{1}{2} \times \frac{1}{4\pi\epsilon_0} \frac{e^2}{r_n} = \frac{1}{n^2} \left(\frac{m e^4}{8 h^2 \epsilon_0^2} \right)$$

$$U_n = -\frac{1}{4\pi\epsilon_0} \frac{e^2}{r_n} = -\frac{1}{n^2} \left(\frac{m e^4}{4 h^2 \epsilon_0^2} \right)$$

$$E_n = K_n + U_n = -\frac{1}{n^2} \times \left(\frac{m e^4}{8 h^2 \epsilon_0^2} \right)$$

But according to Bohr's earlier hypothesis

$$E_n = -\frac{hcR}{n^2}$$



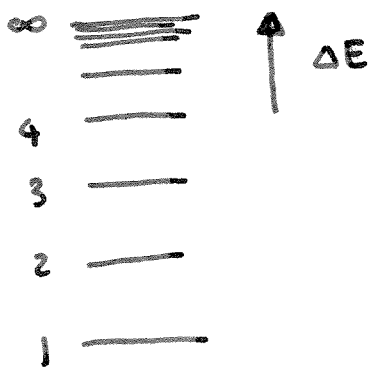
$$\text{so } R = \frac{m e^4}{8 \epsilon_0^2 h^2 c} = 1.097 \times 10^7 \text{ m}^{-1}$$

$$|E_1| = \frac{m e^4}{8 \epsilon_0^2 h^2} = 13.606 \text{ eV}$$

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

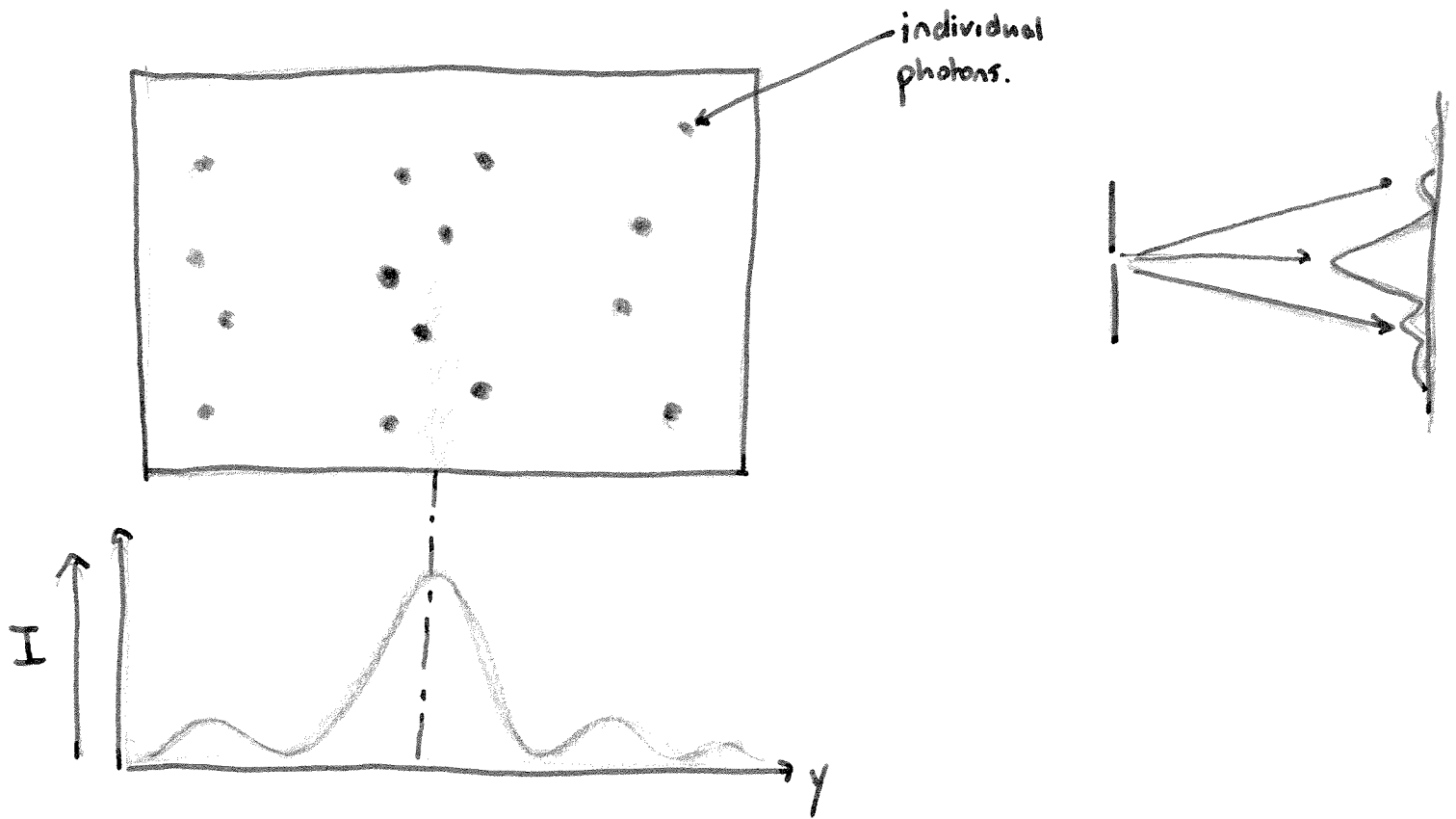
e.g. What is the energy required to ionize an Hydrogen atom in its 4th excited state?

$$\Delta E = E_{\infty} - E_4 = \frac{13.6}{(4)^2} = \underline{0.85 \text{ eV}}$$



But Bohr's model raised many questions. It mixes classical + quantum arguments. It does not account for the quantization of angular momentum.

38.9/39.1

Wave-Particle Duality

$I \propto$ probability of arrival of photon.

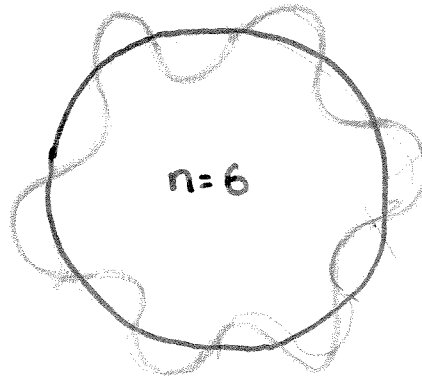
even when the intensity is low enough that only one photon passes at a time — interference pattern still observed.

$$p_{\text{photon}} = mc = \left(\frac{E}{mc^2} \right) c = \frac{hf}{c} = \frac{h}{\lambda_{\text{photon}}}$$

Louis de Broglie: wave-particle duality holds for non-relativistic particles too.

$$\lambda = h/p$$

de Broglie
wavelength



$$n \lambda = 2\pi r$$

$$\Rightarrow p r = \left(\frac{h}{\lambda}\right) r = n \left(\frac{h}{2\pi}\right)$$

- Predicts electron diffraction: confirmed by Davisson + Germer.