Phys106, II-Semester 2019/20, Tutorial 8, Fri 6.3.

Work in teams of three. Do "Stages" in the order below. When all teams finished a stage, make sure all students at your table understand the solution and agree on one by using the board.

Stage 1 On your table discuss the difference between the Thompson, Rutherford, Bohr- and current state of the art model of the atom. Make a drawing on the board for each of those models.

Stage 2 The electric field strength of a point charge Ze at the origin, where Z is the nuclear charge number (an integer) and e the electron charge, is given by

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{Ze}{r^2}. \tag{1}$$

Here r is the radial distance from the origin.

Instead of this, if we have a spatially extended homogeneous charge distribution of total charge $Q = Ze$ within a sphere of radius R, the electric field strength is

$$E(r) = \begin{cases} \frac{1}{4\pi\epsilon_0}\frac{Zer}{R^3} & r \leq R, \\ \frac{1}{4\pi\epsilon_0}\frac{Ze}{r^2} & r > R. \end{cases} \tag{2}$$

(i) This corresponds roughly to the nuclear charge distribution in the case of the Thompson or Rutherford atom models. Make drawings of $E(r)$.

(ii) The force magnitude experienced by a scattering α-particle now is $|F(r)| = E(r)Z_\alpha e$, where $Z_\alpha e$ is the charge of the alpha particle. With this in mind and your drawing, discuss the following: Why would the scattering of α-particles from nucleii be very different between the Thompson and Rutherford atom models?

Stage 3 We know now that nucleii are made of protons p and neutrons n, approximately in equal number. The two (p, n) are also roughly the same size, assume spheres with a radius of $r_p \approx 1$ femto-meter (fm). The following tables gives you the numbers of protons N_p and neutrons N_n in a couple of nucleii of selected elements and the radius of those nuclei r_{nuc}. How does nuclear volume relate to the added volume of constituents. From this, discuss the typical distance between protons and neutrons.

element	N_p	N_n	$r_{nuc}(fm)$
Gold ^{197}Au	79	118	7.3
Carbon ^{12}C	6	6	2.7
Uranium ^{238}U	146	92	7.4

Stage 4 The power radiated away by a non-relativistic charge q accelerated with acceleration a is $P = \frac{q^2 a^2}{6\pi\epsilon_0 c^3}$. Consider an electron on a classical circular orbit around a proton with speed $v = 2.188 \times 10^6 \frac{\sqrt{Z}}{n}$m/s at a distance $r = a_0$ (the Bohr radius).

Assuming it stays on that orbit, estimate the time for it to loose all the energy it would have for $n = 1$ according to Bohr theory, which is $E_1 = -13.6Z^2 eV$. Compare this with typical life-times of electronic excited states, which are $\tau \sim 1$ ns. How could the calculation above be improved?
Bonus: More precisely, electro-magnetic theory states, that if the spatial current and charge distribution is changing in time, radiation will be emitted. How does the modern atom model thus solve the problem of atomic stability?