Teacher notes
Topic E

Nuclei are not made of protons and electrons

In a lecture to the Royal Society of London in 1920, Rutherford proposed that nuclei consist of protons and neutral particles (later called neutrons). The neutron was not discovered until 1931 by James Chadwick. Rutherford did not consider the “neutron” to be a new particle. He assumed the neutron to be a combination of a proton and an electron and so not a new particle at all. The idea of electrons inside nuclei was not unreasonable since it was known that in beta decay electrons were emitted from nuclei. So for Rutherford the nucleus consisted of protons and neutrons but neutrons were a combination of protons and electrons so for practical purposes *the nucleus consisted of protons and electrons*. This would explain the fact that the atomic weights of elements are almost an integer times the mass of a proton: the electron has a negligible mass compared to a proton and thus the weight of an atom would be essentially the mass of a proton times the number of protons in the nucleus.

However, for many reasons electrons cannot exist within nuclei. One objection is that the proton-electron system has energy levels whose energies are much more negative than those of the hydrogen atom. Therefore there would be no reason why an electron in the hydrogen atom would not make the transition to one of these lower energy states emitting the difference in energy as a photon. The hydrogen atom would be unstable, which it is not.

A later objection would come from the Heisenberg uncertainty principle: an electron within the nucleus (of typical size 10^{-15} m) would have such an enormous energy as a result of being confined to such a small region that the nucleus would break apart. The principle says that the uncertainty in position and the uncertainty in momentum are related by $\Delta x \Delta p \ge \frac{h}{4\pi}$. For $\Delta x \approx 10^{-15}$ m we find $\Delta p \approx \frac{1.24\times 10^{-6}\,\text{eV m c}^{-1}}{4\pi \times 10^{-15}\,\text{m}} \approx 10^{8}\ \text{eV c}^{-1} = 100\ \text{MeV c}^{-1}$. The total relativistic energy of the electron would then be of order $E = \sqrt{(mc^2)^2 + p^2c^2} = \sqrt{0.5^2 + 100^2} \approx 100\ \text{MeV}$ which is of the order of the binding energy of many nuclei. The nucleus would break apart trying to confine the jittering electron inside it.

Alternatively, this energy is much greater than the electric potential energy of the electron. The electron would then escape the nucleus and would not be found within it.

The proton-electron theory of nuclei was soon abandoned.