5.61 Lecture #2 Supplement: Geiger–Marsden Revisited

Tomohiro Soejima asked me a question after my September 6, 2013 lecture that made me realize that my discussion of the Geiger-Marsden experiment was too glib. There is an excellent discussion of the experiment in Karplus and Porter, *Atoms and Molecules*, Benjamin (1970), pages 18–20. But several key questions remain:

1. Why were α^+–particles rather than electrons used?
2. How is this experiment different from the Davisson-Germer experiment in which diffraction rings were observed? How can the back-scattering observed by Geiger and Marsden be distinguished from diffraction of the α^+–particle by the crystal lattice structure of the metal foil used?

<u>Answers</u>

α^+–particles are much heavier (almost by a factor of 10^4) than electrons. They are also a product of radioactive decay. They are formed with higher kinetic energy than was experimentally achievable for electrons in 1911, as Robert van de Graff did not build his high voltage source (at MIT) until the early 1930s. Thus α^+–particles are easily available in the laboratory with

$$\lambda = \frac{h}{[2m_{\alpha^+}\mathrm{KE}]^{1/2}} < 10^{-2}\text{Å}$$

and, in 1911

$$\lambda_{\alpha^+} \ll \lambda_{e^-}.$$

The diffraction equation, where $d \approx 1$Å,

$$n\lambda = 2d\sin\theta$$
$$\frac{n\lambda}{2d} = \sin\theta \ll 0.01 \qquad \text{for } \alpha^+$$

implies that the diffraction rings associated with the metal crystal lattice would be of ignorably small diameter. This would at worst result in a tiny spreading of the $\theta = 0$ spot on the detector screen in the forward direction.

The wave character of the α^+-particle is therefore not relevant to the Geiger–Marsden experiment. The α^+–particle acts as a positively charged (2^+) bullet-like particle. The angular distribution of the α^+-particles scattered by heavy metal atoms in the target foil is consistent with nearly all of the atomic mass (known at the time) being located within a positively charged (a charge equal to the atomic number) sphere with radius $\sim 10^{-4}$Å. The scattering is a result of Coulomb repulsion.