

## TAP 522- 3: Rutherford scattering: directions of forces

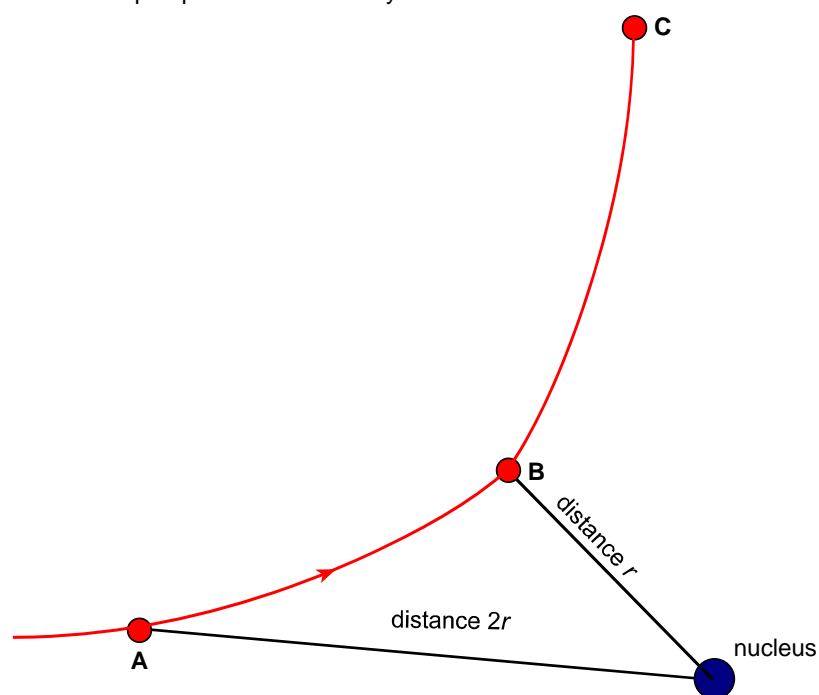
### Scattering of alpha particles

Rutherford did not have a particle accelerator. Instead he used alpha particles, typically of energy 5 MeV, from radioactive decay. These questions are about the force of the nucleus on the alpha particle.

An alpha particle has charge  $+2e$ , where  $e$  is the elementary unit of charge. A nucleus has charge  $+Ze$ , where  $Z$  is the number of protons in the nucleus (and the number of electrons in the atom).

### Directions of forces

Path of alpha particle scattered by nucleus



The diagram shows an alpha particle approaching a massive nucleus from A. Assume that the nucleus recoils negligibly as the alpha particle is scattered.

1. Add to the diagram an arrow showing the direction of the force on the alpha particle when it is at point A, approaching the nucleus. Label the arrow  $F_A$ .
2. Add to the diagram an arrow showing the direction of the force on the alpha particle when it is at point B, at its closest to the nucleus. Label the arrow  $F_B$ .
3. What is the ratio of the magnitudes of the two forces,  $F_A / F_B$  given the distances shown in the diagram?
4. Add to the diagram an arrow showing the direction of the force on the nucleus when the alpha particle is at point B. Label the arrow  $F_N$ . How does this force compare with the force  $F_A$  on the alpha particle at the same instant?

5. At which point, A, B or C, is the alpha particle travelling slowest?
6. At which point, A, B or C, is the alpha particle travelling fastest?
7. The nucleus does in fact recoil a little. Add an arrow labelled 'recoil' to show the direction of recoil you expect as a result of the passage of an alpha particle along the whole path shown.

### **Uphill–downhill**

The electrical potential gradient around the nucleus can be thought of as like the slope of a hill. Imagine that you are riding on the alpha particle as it goes by the nucleus. Are you riding uphill, downhill or momentarily along a contour of the hill:

8. At A?
9. At B?
10. At C?
11. Is the electric potential at B larger or smaller than the electric potential at A? By what factor?

## Practical advice

These are intended as simple 'start-up' questions for the discussion of alpha scattering. They are mainly qualitative, asking students to think about the direction of forces, and the nature of changes of kinetic and potential energy. The 'hill' metaphor for potential is exploited.

## Alternative approaches

Alpha particle orbits generated by a computer simulation could be studied is:

A Useful web site that includes a simulation of alpha particle scattering

[http://www-outreach.phy.cam.ac.uk/camphy/nucleus/nucleus\\_index.htm](http://www-outreach.phy.cam.ac.uk/camphy/nucleus/nucleus_index.htm)

The following sections are relevant to this topic

Plum pudding atoms,  $\alpha$  scattering, Geiger & Marsden, Shells off tissue paper, Nucleus

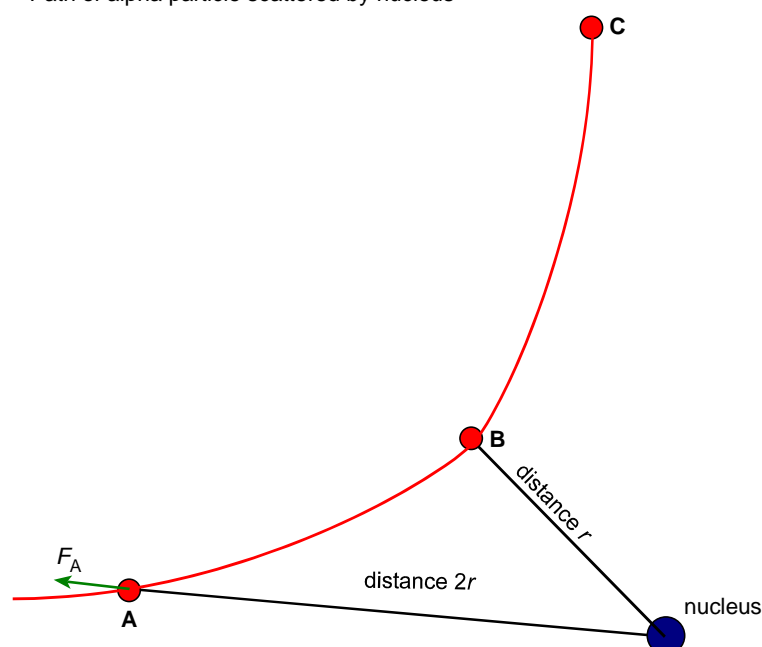
## Social and human context

The mathematical tools developed by the French mathematicians in the 1700s to deal with planetary orbits in the solar system were just as useful for alpha particle orbits under a repulsive force.

## Answers and worked solutions

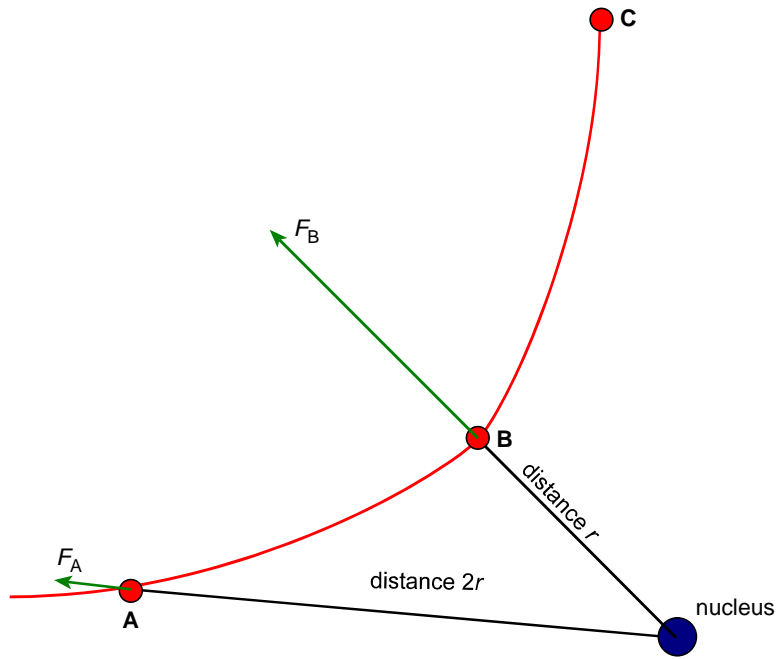
1. The repulsive force is along the line joining the alpha particle and the nucleus.

Path of alpha particle scattered by nucleus



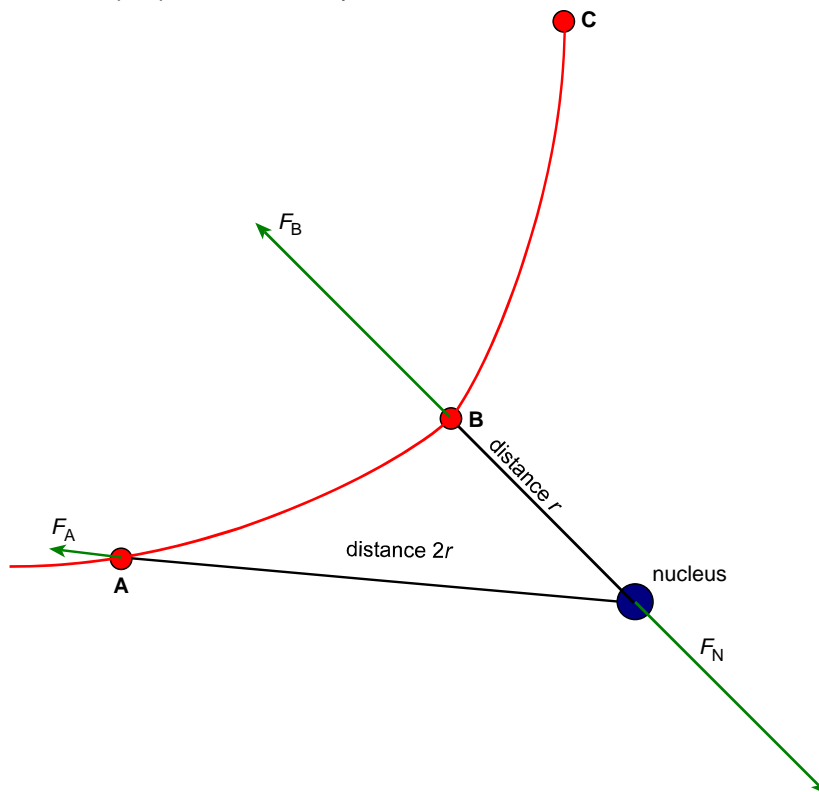
2. The repulsive force is along the line joining the alpha particle and the nucleus.

Path of alpha particle scattered by nucleus



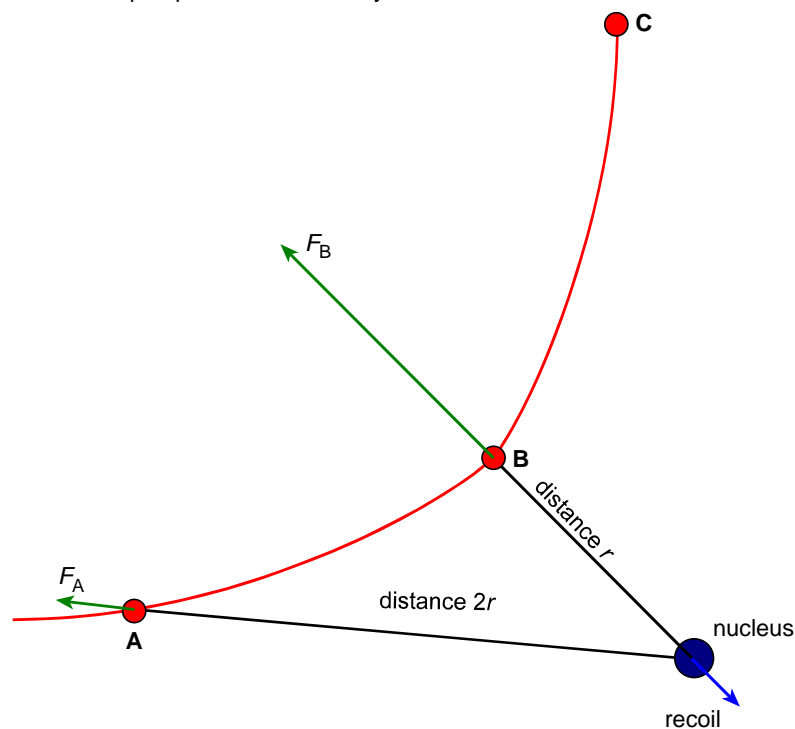
3. The force at B is four times as large as the force at A, because the distance is halved and the force varies as  $1/r^2$ .
4. The force on the nucleus is equal and opposite to the force on the alpha particle. But because the nucleus is much more massive, it recoils only slightly.

Path of alpha particle scattered by nucleus



5. Particle moves slowest at B, because this is the distance of closest approach, the particle has been decelerating due to repulsive force. After B it accelerates away.
6. Here the particle is furthest from the nucleus, the alpha particle has been accelerated between B and C and is therefore going fastest at C.
7. The alpha particle path is symmetrical about the line from the nucleus to B. So the net change of momentum of the nucleus is along this direction.

Path of alpha particle scattered by nucleus



8. Uphill, because the particle is approaching the nucleus but being pushed away from it.
9. Along contour, because the particle is travelling at right angles to the direction of the force on it.
10. Downhill, because the particle is travelling away from the nucleus and is being pushed away from it.
11. Potential at B larger than potential at A by a factor of 2, because the distance is halved and the potential varies as  $1/r$ .

### External reference

This activity is taken from Advancing Physics chapter 17, 80S