Coulomb's Law

Why?
There are only four forces in the universe – electromagnetic, gravitational, strong nuclear and weak nuclear. The last two are involved only in the nucleus. Gravity is too small of a force to matter in chemical reactions. Only the electromagnetic force plays a role in chemistry. This force, created by charges and magnets, is responsible for all chemical phenomena. We will explore to most basic properties of the electromagnetic force in this activity.

Model I: Magnets

Obtain two magnets. Separate them from each other starting with the magnets

- Touching
- With the surfaces 2 mm apart
- With the surfaces 4 mm apart and
- With the surfaces 8 mm apart.

The ruler below is in 2 mm increments:

Questions

1. From which distance was it hardest to separate the magnets?

2. Was there much difference in the force you had to use between touching and 2 mm?

3. Was there much difference in the force you had to use between 2 mm and 4 mm?

4. Does the force decrease evenly each time you double the distance? Explain briefly.

Information

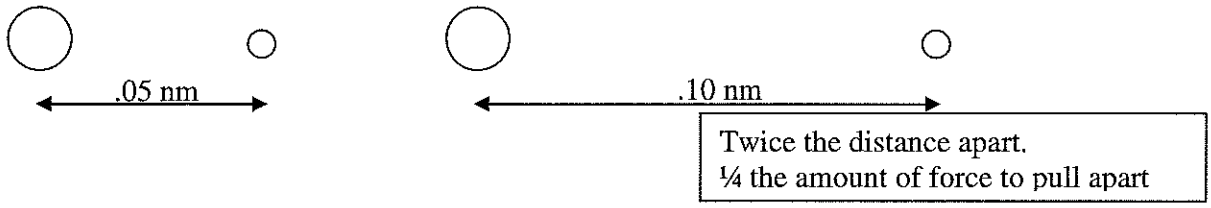
The force between two magnets is NOT linear with distance. Instead the force required to pull two magnets apart decreases much faster than that. The force is inversely proportional not to the *square* of the distance between them. If we use F for force and r for distance,

$$F \propto \frac{1}{r^2}$$

This means that it that if the magnets are twice as far apart it requires ¼ the force to separate them.

The force between a positive and a negative charge work the same way. Recall first that positively charged particles and negatively charged particles attract one another ("opposites attract"). This relationship for charged particles is the first half of a relationship called **Coulomb's Law.**

For an electron that is twice as far from a proton, only ¼ the force is needed to pull them apart.



Questions

5. What is the relationship between the force needed to separate two magnets and the distance between them?

6. Why is it so very much easier to separate magnets that are 4 mm apart than it is to separate magnets that are 2 mm apart?

7. If two magnets were held at 2 mm apart, then 4 mm apart, by what factor is the force between them reduced?

8. If two magnets were held at 2 mm apart, then 20 mm apart, by what factor is the force between them reduced?

9. In chemistry, we really are not all that interested in magnets, we are interested in charge. Why does *charge* matter

   (a) inside the atom?

   (b) Inside ionic compounds?

10. In a hydrogen atom, the 1s electron is, on average, about 5.3×10^{-11} m from the nucleus. A 2s electron is, on average, about 10.6×10^{-11}m from the nucleus[1].

    (a) Which is easier to remove completely from an atom, a 1s electron or a 2s electron?

    (b) How much easier is it to remove a 2s electron?

Model II: Magnitude of charge

The other part of Coulomb's law deals with the magnitude of the charges. In all our examples above, the charges were +1 and −1. But what if we have a +2 object and −2 object, such as Ca^{2+} and O^{2-}?

In our previous discussion of magnets, if we had replaced one of the magnets with one that was twice as powerful, it would have taken twice as much force to pull them apart. If we had two magnets twice as powerful as the original ones, it would have taken *four* times as much force to pull them apart. In other words, the force required to separate them is proportional to the *product* of their strengths.

The same is true for charged particles. A +2 charged object and −2 object have 4 times the attraction as a +1 and a −1 object at the same distance apart. The force required to separate them is proportional to the *product* of the two charges.

[1] This is not the gospel truth. I can't find the number and, as it is 11 pm at night, I am too tired to dig out my quantum mechanics textbooks and calculate it. Please excuse the approximation.

Questions

11. Which takes more energy to separate, a +1 charged and −1 charged object or a +2 and a −2 object? How much more force is required?

12. Which takes more energy to separate, a +1 charged and −1 charged object or a +3 and a −1 object? How much more force is required?

13. Mathematically, how do you determine how much more force is required to separate each of the two different sets of objects in the previous two questions?

14. Consider a 1s electron in hydrogen and a 1s electron in helium.
    (a) What is the charge of a hydrogen nucleus?

    (b) What is the charge of a helium nucleus?

    (c) What I the charge of an electron?

    (d) Which electron requires more energy tò remove, the 1s electron in hydrogen or the 1s electron in helium? Justify your answer.

15. Which of the following would require more energy to remove, a 1s electron from a Li atom or a 1s electron from a Na atom? Briefly explain.

16. (a) Which set of ions is harder to separate from one another at the same distance, Na^+ from F^- or Mg^{2+} from O^{2-}? Justify your answer.

    (b) Which compound do you think has the higher melting point, NaF or MgO? Justify your answer.

Extension

Information

Coulomb's law is used to calculate the force between two charged objects. The formula is:

$$F = (k)\frac{q_1 q_2}{r^2}$$

where
F = force (in Newtons)
k = a constant (8.988×10^9 N·m^2/C^2)
q_1 = the charge on the first object (in C)
q_2 = the amount of charge on the second object (in C)
r = distance between charges (in meters)

If the calculated force is positive, the force is repulsive so the two charges push each other away. If the calculated force is negative, the force is attractive so the two charge pull each other together.

Imagine two sets of metal balls that have been charged, pictured below. The first set are both positively charged. The force between them is repulsive. The second set have one positively charged and one negatively charged ball. The force between them is attractive.

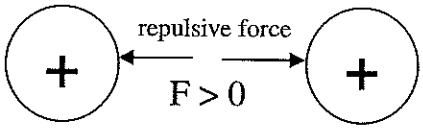


Figure 1.

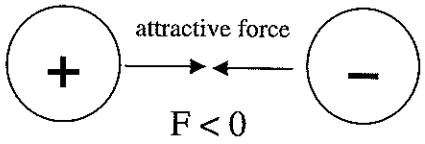


Figure 2.

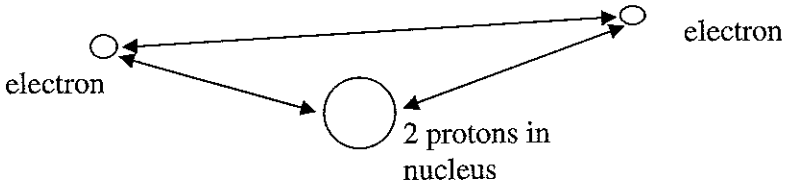
Questions and Activities

17. In a hydrogen atom there is one proton (positively charged) and one electron (negatively charged). The proton and electron have opposite charges of equal magnitude (1.60×10^{-19} C). The electron is typically 5.3×10^{-11} m away from the proton.

(a) Draw a diagram of this simplified view of the atom. Label the proton and electron and include their charges. Draw arrows to show the direction of the force. Also mark the distance between the particles

(b) Using Coulomb's law, calculate the force between two particles?

18. In the helium atom (He) there are 2 protons in the nucleus and two electrons elsewhere outside the nucleus. For the purposes of this problem, imagine the electrons frozen in the position shown. The electrons are each 5.3×10^{-11} m away from the protons, and the two electrons are 1.0×10^{-10} m away from each other.



Using Coulomb's law, calculate the total force on each particle (both attractive and repulsive). (Recall from physics that forces simply add. You need only calculate one force, then the other then add them together. However, remember your signs!)

19. Which atom, hydrogen or helium, requires more force (and hence more energy) to remove a single electron from the atom? Justify your answer in terms of your answers to Questions 4 and