Scientists have understood for centuries that a planet's fixed path around the sun results from a balance of opposing forces; the gravitational attraction which draws the two bodies together is counterbalanced by the centrifugal force associated with the planet's orbital motion which tends to throw the planet into outer space. In the case of the hydrogen atom, there is an **electrostatic attraction** between the proton and the electron which is counterbalanced by the centrifugal force associated with the electron's orbital motion. The electrostatic attraction is also called a **Coulombic attraction**.

---

**Coulomb's Law**

Organic chemistry is the embodiment of Coulomb's law. The trick for students is to learn to recognize the manifestations of this law: **Opposite charges attract**. This statement is so fundamental to the understanding of organic chemistry that we need to consider it in detail before we proceed. Figure 1 illustrates a torsion balance like Coulomb used to determine the relationship of the distance between charged objects and the force of their interaction.

---

**Figure 1: Using a Torsion Balance to Determine Coulomb's Law**

Coulomb measured the interaction between electrostatically charged pith balls. As the animation indicates, the oppositely charged pith balls are attracted to each other. As the balls suspended from the thin fiber rotate toward the one attached to a glass rod, Coulomb was able to measure the torsion on the fiber with the scale near the top of the device and the distance between the balls on the scale that circumscribed the jar. He was able to derive a mathematical equation that described the relationship between these two variables.

It is instructive to compare the form of the mathematical expressions of Newton's law for the gravitational attraction between two planetary bodies and Coulomb's law for the electrostatic attraction between two charged particles. Figure 2 presents these expressions side-by-side.

Newton's Law of Gravity:
\[ F_g \propto \frac{m_1m_2}{r^2}\]

Coulomb's Law:

\[ F_c \propto \frac{q_1q_2}{r^2}\]

**Exercise 1** Given the mathematical formulation of Newton's law in Figure 2,

a. Is the gravitational force, \( F_g \), between two bodies \( \bigcirc \) directly or \( \bigcirc \) inversely proportional to the mass of each body?

b. Is there a \( \bigcirc \) direct or an \( \bigcirc \) inverse relationship between the distance between two bodies and the gravitational force between them?

According to Coulomb's law the electrostatic force, \( F_c \), between two charged particles is directly proportional to the magnitude of the charge on each particle. While this is obviously similar to the situation described by Newton's law, there is an important difference. Since \( m_1 \) and \( m_2 \) are both positive numbers, the value of \( F_g \) must always be positive. In contrast, \( q_1 \) and \( q_2 \) may be either positive or negative. If \( q_1 \) and \( q_2 \) are both positive, or if they are both negative, the value of the product \( q_1q_2 \) will be positive. In either case the value of \( F_c \) must be positive. However, if \( q_1 \) is positive while \( q_2 \) is negative (or vice versa) then the product \( q_1q_2 \) will be negative and the value of \( F_c \) will also be negative.

We now need to expand our initial statement of Coulomb's law: **Opposite charges attract, and the attraction leads to a more stable system.** The converse of this statement is **Like charges repel, and the repulsion leads to a more stable system.** This is a critical point. We are now relating Coulomb's law to stability, i.e. energy. Specifically we are going to establish correlations between Coulomb's law and the potential energy of electrons in atoms and molecules.

**Exercise 2** Imagine you have two protons very far apart (\( r = \infty \)). According to Coulomb's law, what is the value of \( F_c \) when \( r = \infty \)?

**Exercise 3** Now start to bring these two particles closer and closer together until their electric fields begin to interact.

a. Will the energy of this system \( \bigcirc \) increase or \( \bigcirc \) decrease?

b. Will this system become more stable or less stable? \( \bigcirc \) more stable \( \bigcirc \) less stable

**Exercise 4** You continue to bring the two protons together until they are superimposed. What will the value of \( F_c \) be when the two protons are superimposed?

**Exercise 5** Now imagine the same scenario except that your system contains a proton and an electron.

a. As you bring these two particles closer together, will the energy of this system \( \bigcirc \) increase or \( \bigcirc \) decrease?

b. Will this system become \( \bigcirc \) more stable or \( \bigcirc \) less stable?

Figure 3 illustrates the energy changes that occur in these two scenarios.
Figure 3: Energy Changes and Coulomb's Law

Figure 3 suggests that the second system is most stable when the distance between the proton and the electron is zero, i.e., when they are superimposed. This is clearly not consistent with reality. In a hydrogen atom, the electron exists at a finite distance from the proton. What we’re forgetting here is the counterbalancing force due to the electron’s motion around the nucleus. We’ll consider how that counterbalancing force changes the shape of the lower curve in Figure 3 when we discuss chemical bonding.

Because Coulomb’s law is so central to the mastery of organic chemistry, we will invoke it repeatedly in this course. Specifically, we will consider Coulomb’s law as it applies to

- trends in the periodic table
- relative stabilities of atoms and molecules
- ionic versus covalent molecules
- polarity
- intermolecular interactions
- physical properties of molecules
- chemical reactivity

In the meantime your goal should be to make certain you understand the relationships between Coulomb’s law, potential energy, and stability. You should also be aware of the assumption that allows us to focus on the electron when we talk about the energy of an atom.

Contributors

- Otis Rothenberger (Illinois State University) and Thomas Newton (University of Southern Maine)