April 1: Electric Charge

Objectives

- Determine electric force using Coulomb's Law.
- Explain forces in terms of electric fields.
- Determine energies from electric potential and charge.

What's the point?

- Electric charge is fundamental to most forces we encounter.

Electric charge

Electric **charge**, like mass, is a fundamental property of matter. Unlike mass, the charge of an object can be positive, zero, or negative. The SI unit of charge is the **coulomb** (C), which is the charge of 6.24146×10^{18} protons. The **electrical force** between two objects is given by **Coulomb's law**:

$$F = \frac{kq_1q_2}{d^2}$$

where q_1 and q_2 are the electric charges of the two objects, d is the distance between them, and $k = 8.992 \times 10^9\ \mathrm{Nm^2/C^2}$ is **Coulomb's constant**. If F is positive, the objects repel each other electrically; if F is negative, the objects attract each other electrically. In other words, *like charges repel and opposite charges attract.*

The form of Coulomb's law is very similar to Newton's law of universal gravitation. The force is inversely proportional to the distance between the interacting objects, and proportional to some property of the two objects: in Coulomb's law, the objects' charges, and in Newton's law of gravitation, their masses.

Charge polarization

Objects with zero net electric charge are nonetheless attracted to charges. This is because ordinary matter is composed of particles with negative and positive charges. These particles move in response to the charge, with the repelled particles moving away from and the attracted particles moving toward the charge. The closer attracted particles experience a stronger force, so the overall force is attractive.

Electric fields

It is often convenient to describe the electric force on an object at a particular position in terms of the electric field at that position. The **electric field** is a vector describing the magnitude and direction of the electrical force that would be exerted upon an object with a charge of +1 C at some position. The force exerted on an object of charge q at a location where the electric field is E is given by $F = qE$. If the charge q is *positive*, the force is in the *same* direction as the electric field; if the charge q is *negative*, the force is in the *opposite* direction. The SI **unit** of electric field is the **N/C**.

Field lines

Electric fields are often depicted as continuous curves labeled with arrows. The arrows show the direction of the electric field vectors, and *magnitude* of the electric field at any position is qualitatively indicated by the *spacing* between field lines: if the field lines are close together, the magnitude of the electric field is large; if the field lines are widely-spaced, the magnitude of the electric field is near zero.

Electric potential

Just as a mass in a gravitational field has gravitational potential energy, an electric charge in an electric field has electric potential energy. To bring a charge to some position in an electric field from infinitely far away requires work. The charge's electric potential energy at that position is precisely equal to that amount of work.

The **electric potential** at some position tells the electric potential energy of a given amount of charge at that position. More precisely, the electric potential energy of an object with electric charge q at a location where the electric potential is ε is given by $PE = q\varepsilon$. The SI **unit** of electric potential is the **J/C**, also known as the **volt**, abbreviated V.