OpenStax College Physics (Ch. 18) — Coulomb's Law & Electric Field

Accessibility Modality Note: This Tagged PDF/UA-1 file provides high-resolution vector equations paired with step-by-step spoken Alt descriptions for print and LMS archival use. For interactive symbol-by-symbol screen-reader navigation (NVDA + MathCAT, JAWS, VoiceOver), open the companion deliverable_accessible.html or deliverable_accessible.epub file included in this package.

Source Lecture Page 1

Chapter 18.3 — Comparing Electrostatic & Gravitational Forces (OpenStax College Physics)

$$= \left(8.99 \times 10^{9}\ \mathrm{N \cdot m^2/C^2}\right) \times \frac{(1.60 \times 10^{-19}\ \mathrm{C})(1.60 \times 10^{-19}\ \mathrm{C})}{(0.530 \times 10^{-10}\ \mathrm{m})^2}$$

[Page 1 · Eq #1] equals open paren 8.99 times 10 to the ninth power newton meters squared per coulomb squared close paren times the quantity 1.60 times 10 to the negative 19 power coulombs, end quantity times the quantity 1.60 times 10 to the negative 19 power coulombs, end quantity over the quantity 0.530 times 10 to the negative 10 power meters, end quantity squared

Thus the Coulomb force is:

$$F = 8.19 \times 10^{-8}\ \mathrm{N}$$

[Page 1 · Eq #2] F equals 8.19 times 10 to the negative 8 power newtons

The charges are opposite in sign, so this is an attractive force. This is a very large force for an electron—it would cause an acceleration of $8.99 \times 10^{22}\ \mathrm{m/s^2}$ (verification is left as an end-of-section problem). The gravitational force is given by Newton's law of gravitation as:

$$F_G = G\frac{mM}{r^2}$$

[Page 1 · Eq #3] F sub G equals G times m M, over r squared

where $G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$. Here m and M represent the electron and proton masses, which can be found in the appendices. Entering values for the knowns yields:

$$F_G = \left(6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}\right) \times \frac{(9.11 \times 10^{-31}\ \mathrm{kg})(1.67 \times 10^{-27}\ \mathrm{kg})}{(0.530 \times 10^{-10}\ \mathrm{m})^2} = 3.61 \times 10^{-47}\ \mathrm{N}$$

[Page 1 · Eq #4] 3-step mathematical derivation. Step 1: F sub G. Step 2: equals open paren 6.67 times 10 to the negative 11 power newton meters squared per kilogram squared close paren times the quantity 9.11 times 10 to the negative 31 power kilograms, end quantity times the quantity 1.67 times 10 to the negative 27 power kilograms, end quantity over the quantity 0.530 times 10 to the negative 10 power meters, end quantity squared. Step 3: equals 3.61 times 10 to the negative 47 power newtons.

This is also an attractive force, although it is traditionally shown as positive since gravitational force is always attractive. The ratio of the magnitude of the electrostatic force to gravitational force in this case is, thus:

$$\frac{F}{F_G} = 2.27 \times 10^{39}$$

[Page 1 · Eq #5] F over F sub G equals 2.27 times 10 to the 39th power

Discussion: This is a remarkably large ratio! Note that this will be the ratio of electrostatic force to gravitational force for an electron and a proton at any distance (taking the ratio before entering numerical values shows that the distance cancels). This ratio gives some indication of just how much larger the Coulomb force is than the gravitational force between two of the most common particles in nature.

18.4 Electric Field: Concept of a Field Revisited

Contact forces, such as between a baseball and a bat, are explained on the small scale by the interaction of the charges in atoms and molecules in close proximity. They interact through forces that include the Coulomb force. Action at a distance is a force between objects that are not close enough for their atoms to "touch." That is, they are separated by more than a few atomic diameters.

Concept of a Field: A field is a way of conceptualizing and mapping the force that surrounds any object and acts on another object at a distance without apparent physical connection. Using Coulomb's law, $F = k|q_1 q_2|/r^2$, its magnitude is given by the equation $F = k|qQ|/r^2$, for a point charge (a particle having a charge Q) acting on a test charge q at a distance r (see Figure 18.20).

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Electric Field Definition & Point-Charge Magnitude (Page 2)

[Page 2 · Spatial Figure] Figure 18.20 (Page 2): Coulomb Force Field of Positive Charge Q on Two Test Charges: Two horizontal force diagrams separated by distance r from positive source charge Q on the left: (a) Positive test charge q1 on the right experiences a repulsive force arrow F1 pointing away to the

right; (b) Larger negative test charge q2 on the right experiences a longer attractive force arrow F2 pointing left toward Q.

To simplify things, we would prefer to have a field that depends only on Q and not on the test charge q. The electric field is defined in such a manner that it represents only the charge creating it and is unique at every point in space. Specifically, the electric field E is defined to be the ratio of the Coulomb force to the test charge:

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

[Page 2 · Eq #6] vector E equals vector F over q

where $\mathbf{F}$ is the electrostatic force (or Coulomb force) exerted on a positive test charge q. The units of electric field are newtons per coulomb (N/C). If the electric field is known, then the electrostatic force on any charge q is $\mathbf{F} = q\mathbf{E}$. Thus the magnitude of the electric field, E, for a point charge is:

$$E = \left|\frac{F}{q}\right| = k\left|\frac{qQ}{qr^2}\right| = k\frac{|Q|}{r^2}$$

[Page 2 · Eq #7] E, equals the absolute value of F over q, equals k times the absolute value of q Q over q r squared, equals k times the absolute value of Q, over r squared

Since the test charge cancels, we see that:

$$E = k\frac{|Q|}{r^2}$$

[Page 2 · Eq #8] E equals k times the absolute value of Q, over r squared

Example 18.2 — Calculating the Electric Field of a Point Charge: Calculate the strength and direction of the electric field E due to a point charge of 2.00 nC (nano-Coulombs) at a distance of 5.00 mm from the charge. Here $Q = 2.00 \times 10^{-9}\ \mathrm{C}$ and $r = 5.00 \times 10^{-3}\ \mathrm{m}$.

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