University Physics with Modern Physics
Electromagnetism Problems

Chris Doble

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Contents

21 Electric Charge and Electric Field

21.3 Coulomb's Law

21.3.1 Example 21.1

The magnitude of electric repulsion between two α particles is given by

$$F_e = \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}$$

and the magnitude of gravitational attraction is given by

$$F_g = \frac{Gm^2}{r^2}$$

. The ratio of the two values is

$$\begin{aligned}
\frac{F_e}{F_g} &= \frac{1}{4\pi\epsilon_0}\frac{q^2}{r^2}\frac{r^2}{Gm^2} \\
&= \frac{1}{4\pi\epsilon_0}\frac{q^2}{Gm^2} \\
&= 3.1 \times 10^{35}
\end{aligned}$$

showing that the electric repulsion is significantly stronger than the gravitational attraction.

21.3.2 Example 21.2

a) The magnitude of the force that q_1 exerts on q_2 is

$$
\begin{aligned}
F &= \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} \\
&= (9.0\times 10^9)\frac{|(25\times 10^{-9})(-75\times 10^{-9})|}{0.030^2} \\
&= 1.9\times 10^{-2}\,\mathrm{N}.
\end{aligned}
$$

Since q_1 and q_2 have opposite charge, the force is attractive (from q_2 to q_1).

b) The magnitude of the force that q_2 exerts on q_1 is the same as in part a, but the direction is reversed (from q_1 to q_2).

21.3.3 Example 21.3

By the principle of superposition of forces, the net force exerted on q_3 is equal to the vector sum of the forces exerted on it by q_1 and q_2 separately.

Both q_1 and q_3 have positive charge so they repel each other. q_1 is to the right of q_3 so q_3 experiences a force to the left of magnitude

$$
\begin{aligned}
F_{1\text{ on }3} &= \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_3|}{r^2} \\
&= (9.0\times 10^9)\frac{|(1.0\times 10^{-9})(5.0\times 10^{-9})|}{0.020^2} \\
&= 1.1\times 10^{-4}\,\mathrm{N}.
\end{aligned}
$$

However q_2 has a negative charge so it attracts q_3. It is also to the right of q_3 so q_3 experiences a force to the right of magnitude

$$
\begin{aligned}
F_{2\text{ on }3} &= \frac{1}{4\pi\epsilon_0}\frac{|q_2 q_3|}{r^2} \\
&= (9.0\times 10^9)\frac{|(-3.0\times 10^{-9})(5.0\times 10^{-9})}{0.040^2} \\
&= 8.4\times 10^{-5}\,\mathrm{N}.
\end{aligned}
$$

The net force experienced by q_3 is therefore

$$
\begin{aligned}
F &= -F_{1\text{ on }3} + F_{2\text{ on }3} \\
&= -1.1\times 10^{-4} + 8.4\times 10^{-5} \\
&= -2.6\times 10^{-5}\,\mathrm{N}.
\end{aligned}
$$

21.3.4 Example 21.4

Since q_1 and q_2 are of equal charge and are symmetric about the x axis on which Q lies, the vertical components of their forces cancel leaving only the horizontal.

The horizontal component of q_1's force on Q is given by

$$\begin{aligned}
F_{1 \text{ on Q, x}} &= \frac{1}{4\pi\epsilon_0}\frac{q_1 Q}{r_{1,\mathrm{Q}}^2}\cos\alpha \\
&= (9.0\times10^9)\frac{(2.0\times10^{-6})(4.0\times10^{-6})}{\sqrt{0.30^2+0.40^2}^2}\frac{0.40}{0.50} \\
&= 0.23\,\mathrm{N}.
\end{aligned}$$

Again, since q_1 and q_2 are of equal charge and symmetric about the x axis, $F_{1 \text{ on Q, x}} = F_{2 \text{ on Q, x}}$ and the total force experienced by Q is in the positive x direction of magnitude

$$F = 2F_{1 \text{ on Q, x}} = 0.46\,\mathrm{N}.$$

21.4 Example 21.5

The magnitude of the electric field vector is given by

$$\begin{aligned}
E &= \frac{1}{4\pi\epsilon_0}\frac{|q|}{r^2} \\
&= (9.0\times10^9)\frac{|4.0\times10^{-9}|}{2.0^2} \\
&= 9.0\,\mathrm{N/C}.
\end{aligned}$$

21.5 Example 21.6

The magnitude of the electric field vector is given by

$$\begin{aligned}
E &= \frac{1}{4\pi\epsilon_0}\frac{|q|}{r^2} \\
&= (9.0\times10^9)\frac{|-8.0\times10^{-9}|}{1.2^2+1.6^2} \\
&= 18\,\mathrm{N/C}
\end{aligned}$$

and it is directed towards the origin. If θ is the angle between the positive x axis and $\hat{\mathbf{r}}$ then the component form of $\mathbf{E}$ is

$$
\begin{aligned}
E &= -E\left(\cos\theta\hat{\mathbf{i}} + \sin\theta\hat{\mathbf{j}}\right) \\
&= -E\left(\frac{x}{r}\hat{\mathbf{i}} + \frac{-y}{r}\hat{\mathbf{j}}\right) \\
&= \frac{-18}{\sqrt{1.2^2 + 1.6^2}}\left(1.2\hat{\mathbf{i}} + 1.6\hat{\mathbf{j}}\right) \\
&= (-11\,\mathrm{N/C})\hat{\mathbf{i}} - (14\,\mathrm{N/C})\hat{\mathbf{j}}.
\end{aligned}
$$

21.6 Example 21.7

a) Electrons have a negative charge and the electric field is directed upwards, so the electron will move downwards. The magnitude of its acceleration is

$$
\begin{aligned}
a &= \frac{F}{m} \\
&= \frac{eE}{m} \\
&= \frac{(1.60 \times 10^{-19})(1.00 \times 10^4)}{9.11 \times 10^{-31}} \\
&= 1.76 \times 10^{15}\,\mathrm{m/s^2}.
\end{aligned}
$$

b) Its acceleration is constant between the plates, so its final speed is

$$
\begin{aligned}
v^2 &= v_0^2 + 2a(x - x_0) \\
&= 2ax \\
v &= \sqrt{2ax} \\
&= \sqrt{2(1.76 \times 10^{15})(0.01)} \\
&= 5.9 \times 10^6\,\mathrm{m/s^2}
\end{aligned}
$$

and thus its final kinetic energy is

$$
\begin{aligned}
K &= \frac{1}{2}mv^2 \\
&= \frac{1}{2}(9.11 \times 10^{-31})(5.9 \times 10^6)^2 \\
&= 1.6 \times 10^{-17}\,\mathrm{J}.
\end{aligned}
$$

c) We can find the time it takes for the electron to travel this distance by rearranging the kinematic equation

$$
v = v_0 + at
$$

to

$$
\begin{aligned}
t &= \frac{v - v_0}{a} \\
&= \frac{5.9 \times 10^6}{1.76 \times 10^{15}} \\
&= 3.4 \times 10^{-9}\,\mathrm{s}.
\end{aligned}
$$