Answers: Electric Charges

Quick checks

1 c $n = \dfrac{Q}{e} = \dfrac{4.8 \times 10^{-9}}{1.6 \times 10^{-19}} = 3.0 \times 10^{10}$ electrons: thirty billion, and still only a tiny charge.

2 b Only electrons move. The glass loses electrons to the silk, so it is left with more protons than electrons: positive. The silk, with extra electrons, is negative by the same amount.

3 c The positive rod attracts free electrons towards it. While the finger touches the sphere, more electrons flow up from the Earth through the body, attracted by the rod. Once the finger is removed they can't leave again, so when the rod is taken away the sphere is left with extra electrons, spread over its surface: **negative**, the opposite of the rod.

4 d $F \propto 1/r^2$: three times the distance gives $1/3^2 = 1/9$ of the force.

5 ? Adding +Q to each charge: −2Q becomes −Q, and +Q becomes +2Q. The product of the charges is still $-2Q^2$, the same size and the same sign as before, so the force is still **attractive**. The distance is doubled, so the force is $1/2^2$ of what it was: **F/4**.

2. **Where can the field be zero?** Between the charges, both fields point towards Q_1 (towards the negative, away from the positive), so they add and can't cancel. Outside the charges they point in opposite directions, and they can cancel only on the side of the **smaller** charge, Q_1, where its being nearer makes up for its being smaller. So P is beyond Q_1, as in the figure.

Let P be x from Q_1 and $x + 0.12$ m from Q_2. The fields are equal in size:

$$\frac{k \times 32 \times 10^{-6}}{x^2} = \frac{k \times 45 \times 10^{-6}}{(x+0.12)^2} \quad \Rightarrow \quad \left(\frac{x+0.12}{x}\right)^2 = \frac{45}{32} = 1.406$$

$$\frac{x+0.12}{x} = \sqrt{1.406} = 1.186 \quad \Rightarrow \quad 0.12 = 0.186\,x \quad \Rightarrow \quad x = 0.646$$

P is **65 cm from** Q_1 (77 cm from Q_2), on the side away from Q_2.

3. The point is **between** the charges. There, the two fields point in opposite directions only if the charges have the **same sign** (both push away from themselves, or both pull towards themselves). Let the distance between the charges be ℓ: the point is $\ell/3$ from Q_1 and $2\ell/3$ from Q_2.

$$\frac{kQ_1}{(\ell/3)^2} = \frac{kQ_2}{(2\ell/3)^2} \quad \Rightarrow \quad \frac{Q_1}{Q_2} = \frac{(\ell/3)^2}{(2\ell/3)^2} = \frac{1}{4}$$

$Q_1/Q_2 = \mathbf{1/4}$ (positive: the charges have the same sign). The zero is nearer the smaller charge, as it must be.

4.

a. $F = \dfrac{kQ_1Q_2}{r^2} = \dfrac{9.0\times10^{9}\times30\times10^{-9}\times30\times10^{-9}}{(0.25)^2} = \dfrac{8.1\times10^{-6}}{0.0625} = \mathbf{1.3\times10^{-4}\ N}$, attractive.

b. Each charge is $r = 0.125$ m from the midpoint. The field of the + charge points away from it, towards the − charge; the field of the − charge points towards it, the same way. So they add:

$$E = 2\times\frac{kQ}{r^2} = 2\times\frac{9.0\times10^{9}\times30\times10^{-9}}{(0.125)^2} = 2\times\frac{270}{0.015625} = 2\times1.73\times10^{4} = 3.5\times10^{4}$$

3.5×10^{4} N/C, pointing from the + charge towards the − charge.

c. The lines start on the + charge and end on the − charge, curving out between them; they are closest together (the field strongest) near the charges and between them.

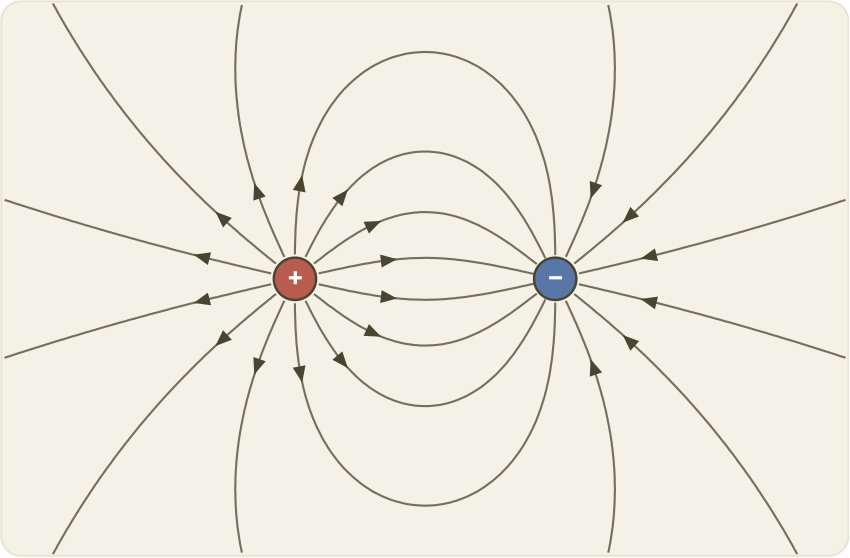


Figure 19.13 *The field of a dipole, traced from Coulomb's law: every line leaves the + charge and ends on the − charge.*

5. The angle of each thread with the vertical: $\sin\theta = \dfrac{3.0}{15} = 0.20$, so $\theta = 11.5^\circ$ and $\tan\theta = 0.204$.

Each sphere is in equilibrium:

- vertically, $T\cos\theta = mg$;
- horizontally, $T\sin\theta = F$.

Dividing, $F = mg\tan\theta$.

$$m = 0.08\ = 8.0\times10^{-5}\,, \quad mg = 8.0\times10^{-5}\times 9.8 = 7.84\times10^{-4}$$

$$F = 7.84\times10^{-4}\times 0.204 = 1.60\times10^{-4}$$

The spheres' centers are $r = 2\times 3.0 = 6.0$ cm $= 0.060$ m apart. By Coulomb's law, with equal charges Q:

$$F = \frac{kQ^2}{r^2} \quad\Rightarrow\quad Q = r\sqrt{\frac{F}{k}} = 0.060\times\sqrt{\frac{1.60\times10^{-4}}{9.0\times10^{9}}} = 0.060\times 1.33\times10^{-7} = 8.0\times10^{-9}$$

Each sphere carries about $\mathbf{8.0\times10^{-9}\ C}$ (8.0 nC).