Solution Key

Coulomb's Law

1. What will happen to the magnitude of the force between two charges Q_1 and Q_2 separated by a distance R if:

(a) one of the charges is doubled?
(b) both charges are doubled?
(c) separation distance is doubled?
(d) separation distance is tripled?
(e) both charges are doubled and separation distance is doubled?
(f) both charges are doubled and separation distance is halved?

$$F_1 = \frac{k Q_1 Q_2}{r_1^2}$$

a) $$2F_1 = \frac{k(2Q_1)Q_2}{r_1^2}$$ Force is doubled

b) $$4F_1 = \frac{k(2Q_1)(2Q_2)}{r_1^2}$$ Force is quadrupled (x4)

c) $$\frac{F_1}{4} = \frac{k Q_1 Q_2}{(2r_1)^2}$$ Force is quartered

d) $$\frac{F_1}{9} = \frac{k Q_1 Q_2}{(3r_1)^2}$$ Force is divided by 9

e) $$F_1 = \frac{k(2Q_1)(2Q_2)}{(2r_1)^2}$$ Force is unchanged

f) $$16F_1 = \frac{k(2Q_1)(2Q_2)}{\left(\frac{r_1}{2}\right)^2}$$ # Force is increased 16-fold

2. What force would be exerted on a 1.00 μC positive charge by a 1.00 μC negative charge 1.00m from it?

$$F_c = \frac{KQ_1Q_2}{r^2} = \frac{9.0\times10^9 \frac{Nm^2}{C^2} \times 1.00\times10^{-6}C \times (-1.00\times10^{-6}C)}{(1\,m)^2}$$

$$= 0.00900\,N$$

$$= 9.00\times10^{-3}\,N$$

Towards the negative charge

3. What is the force of attraction between a proton and an electron in a hydrogen atom, if they are separated by 5.00 x 10^{-11}m?

$$F_e = \frac{kQ_1Q_2}{r^2} = \frac{9.0\times10^9 \frac{Nm^2}{C^2} \times 1.6\times10^{-19}C \times (-1.6\times10^{-19}C)}{(5.00\times10^{-11}m)^2}$$

$$= 9.2\times10^{-8}\,N$$

4. Calculate the gravitational force between the electron and the proton in the hydrogen atom. How does this force compare to the electric force?

Compare to question 3

~~$F_g = kQ_1$~~

$$F_g = \frac{GM_+m_e}{r^2} = \frac{6.67\times10^{-11}\frac{Nm^2}{kg^2} \times \underset{\text{electron}}{9.11\times10^{-31}kg} \times \underset{\text{proton}}{1.67\times10^{-27}kg}}{(5.00\times10^{-11}m)^2}$$

$$= 4.1\times10^{-47}\,N$$

Electric force is 2×10^{39} times greater than gravitational force

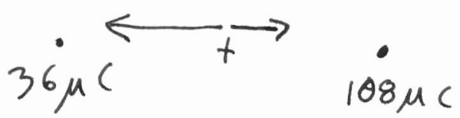
Electric Fields

5. An electron carries a charge of -1.6×10^{-19} C. If a force of 3.2×10^{-17} N causes it to move upwards, what is the magnitude and direction of the electric field strength?

$$E = \frac{F}{Q} = \frac{3.2 \times 10^{-17} N}{-1.6 \times 10^{-19} C} = 200 \frac{N}{C}$$

$$= 2.0 \times 10^{2} \frac{N}{C} [\downarrow]$$

6. A 36 μC charge is 0.80 m away form a + 108μC charge. What is the direction of the electric field a point midway between the two charges?



ans: ←

7. A proton has a mass of 1.67×10^{-27} kg. At what rate will it accelerate in an electric field strength of 1.0×10^{3} N/C?

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

$$a = \frac{Eq}{m} = \frac{1000 \frac{N}{C} \times 1.6 \times 10^{-19} C}{1.67 \times 10^{-27} kg} = 9.6 \times 10^{10} \frac{m}{s^2}$$

8. A nichrome wire 30.0 cm long is connected to the terminals of a 1.5 V dry cell. What is the magnitude and direction (relative to the terminals) of the electric field inside the wire?

$$E = \frac{\Delta V}{d} = \frac{1.5 V}{0.3 m} = 5 \frac{V}{m}$$

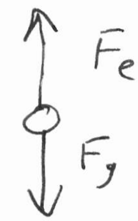
- direction from positive to negative terminal

9. A tiny sphere of mass 1.0 x 10^{-15} kg if held suspended between two charged plates by balancing the downward gravitational force with an upward electrical force of equal magnitude.

(a) What is the magnitude of the electrical force acting on the sphere?
(b) If the voltage applied to the plates is 30.0 V and the plates are 1.47 mm apart, what is the charge on the sphere?
(c) If the top of the plate is positively charged, is the sphere positively or negatively charged?
(d) What type of elementary charged particles are on the sphere, and how many of these excess elementary charged particles are there on the sphere?

a) $F_e = F_g = mg = 1.0 \times 10^{-15}\,\text{kg} \times 9.8\,\frac{N}{kg}$

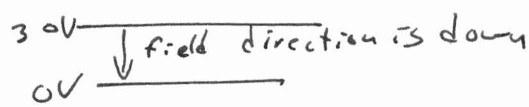
$= 9.8 \times 10^{-15}\ N$



b) $E = \frac{F}{Q} = \frac{\Delta V}{d}$

$Q = \frac{Fd}{\Delta V} = \frac{9.8 \times 10^{-15}\,N \times 0.00147\,m}{30\,V} = 4.8 \times 10^{-19}\ C$

(d) that's 3 elementary charges.



c) negative charge

d) 3 electrons

Electric Potential

Just bold because spelling mistake on original

1. Calculate the electric potential a distance of 0.40 m from a **spherical** point charge of + 6.4 x 10^{-6} C. (Take $V = 0$, at infinity.) [1.4 x 10^{5} J/C]

Note that the value for the potential created by a positive charge has a positive value, characteristic of a system where the force acting on the test charge is a repulsion. If the spherical point charge in the above example had been a negative charge, then substituting a negative value for q would have yielded a negative value for V, which is consistent with a system in which the force acting is an attraction.

$$V = \frac{KQ}{r} = \frac{9.0\times10^{9}\frac{Nm^2}{C^2} \times 6.4\times10^{-6}C}{0.4m} = 144000\frac{J}{C}$$

$$\overset{SF}{=} 1.4\times10^{5}V$$

2. How much work must be done to increase the potential of a charge of 3.0 x 10^{-7} C By 120 V? [3.6 x 10^{-5} J]

$$\Delta V = \frac{\Delta E_p}{Q}$$

$$W = \Delta E_p = Q\Delta V = 3.0\times10^{-7}C \times 120V = 3.6\times10^{-5}J$$

3. In a uniform electric field, the potential difference between two points 0.10 m apart is 80 V. Calculate the magnitude of the electric field intensity. [8.0 x 10^{2} N/C]

$$E = \frac{\Delta V}{d} = \frac{80V}{0.1m} = 800\frac{V}{m} = 800\frac{N}{C}$$

4. The electric field intensity in the region between two parallel plates is 400 N/C. If the plates are connected to a battery with a potential difference of 90 V, what is the separation of the plates? [0.23 m]

$$E = \frac{\Delta V}{d} \Rightarrow d = \frac{\Delta V}{E} = \frac{90V}{400\frac{N}{C}} = ~~0.02~~\ 0.225m$$

$$\overset{SF}{=} 0.23m$$

Practice

1. The potential at a distance of 25 cm from a point charge is –6.4 x 10^4 V. What is the sign and magnitude of the point charge? [-1.8 x 10^{-6} C]

$$V = \frac{kQ}{r}$$

$$Q = \frac{Vr}{k} = \frac{-6.4\times10^{4}\,V \times 0.25\,m}{9\times10^{9}\,\frac{Nm^2}{C^2}} = -1.77\times10^{-6}\,C$$

$$\overset{SF}{=} -1.8\times10^{-6}\,C$$

2. It takes 4.2 x 10^{-3} J of work to move 1.2 x 10^{-6} C of charge from point X to point Y in an electric field. What is the potential difference between X and Y? [3.5 x 10^3 V]

$$\Delta V = \frac{\Delta E_p}{Q} = \frac{4.2\times10^{-3}\,J}{1.2\times10^{-6}\,C} = 3500\,V$$

3. Calculate the magnitude of the electric field in a parallel plate apparatus whose plates are 5.0mm apart and have a potential difference of 300 V between them. [6.0 x 10^4 N/C]

$$E = \frac{\Delta V}{d} = \frac{300\,V}{0.005\,m} = 60\,000\,V$$

$$= 6.0\times10^{4}\,\frac{N}{C}$$

4. What potential difference would have to be maintained across the plates of a parallel plate apparatus, if they are 1.2 cm apart, to create an electric field of intensity 1.5 x 10^4 N/C? [1.8 x 10^2 V]

$$E = \frac{\Delta V}{d}$$

$$\Delta V = Ed = 1.5\times10^{4}\,\frac{V}{m} \times 0.012\,m = 180\,V$$

Practice

1. How many electrons must be removed from a neutral, isolated conducting sphere to give it a positive charge of 8.0×10^{-8} C? [5.0×10^{11} electrons]

$$\frac{1.6\times10^{-19}\ C}{\text{electron}}$$

$$8.0\times10^{-8}\ C \times \frac{1}{1.6\times10^{-19}}\ \frac{\text{electrons}}{\text{coulom}}$$

$$= 5.0\times10^{11}\ \text{electrons}$$

2. What will be the force of electric repulsion between two small spheres placed 1.0 m apart, if each has a deficit of 10^8 electrons? [2.3×10^{-12} N]

$$F = \frac{k Q_1 Q_2}{r^2} = \frac{9\times10^9\ \frac{Nm^2}{C^2} \times \left(10^8\ \text{electrons} \times 1.6\times10^{-19}\ \frac{C}{e^-}\right)^2}{(1\ m)^2}$$

$$= 2.3\times10^{-12}\ N$$

3. A small object has an excess of 5.00×10^9 electrons. Calculate the magnitude of the electric field intensity and the electric potential at a distance of 0.500 m from the object. [-28.8 N/C, -14.4 V]

symbol for electron: e^-

$$Q = 5.0\times10^9\ e^- \times \left(-1.6\times10^{-19}\ \frac{C}{e^-}\right) = -8\times10^{-10}\ C$$

$$V = \frac{kQ}{r} = \frac{9\times10^9\ \frac{Nm^2}{C^2} \times (-8\times10^{-10}\ C)}{0.50\ m} = -14.4\ V$$

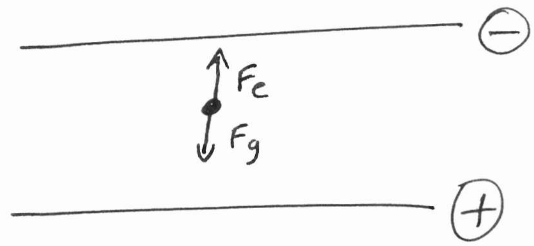
$$E = \frac{kQ}{r^2} = \frac{V}{r} = -28.8\ \frac{N}{C}$$

4. Two large, horizontal metal plates are separated by 0.050 m. A small plastic sphere is suspended halfway between them, and experiences an electric force of 4.5×10^{-15} N that just balances the force of gravity on it.

(e) What is the potential difference between the plates, if the charge on the plastic sphere in 6.4×10^{-19} C?

(f) Calculate the mass of the plastic sphere. (3.5×10^{2} V, 4.6×10^{-16} kg)

$F_e = EQ$



e) $E = \frac{F_e}{Q} = \frac{4.5 \times 10^{-15}\,N}{6.4 \times 10^{-19}\,C} = 7030\,\frac{N}{C}$

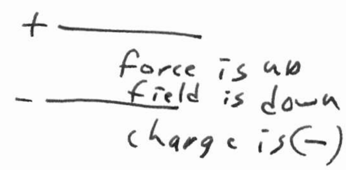
$E = \frac{\Delta V}{d} \Rightarrow \Delta V = Ed = 7030\,\frac{N}{C} \times 0.05\,m = 350\,V$

f) $F_e = F_g = mg$

$m = \frac{F_e}{g} = \frac{4.5 \times 10^{-15}\,N}{9.8\,\frac{N}{kg}} = 4.6 \times 10^{-16}\,kg$

5. An oil drop, whose mass is found to be 4.95×10^{-15} kg, is balanced between two large, horizontal parallel plates 1.0 cm apart, by a potential difference of 510 V, with the upper plate positive. What is the charge on the drop, both in coulombs and in elementary charges, and is it an excess or deficit of electrons? (9.5×10^{-19} C, 6 e, excess)

$F_e = F_g = EQ = \frac{\Delta V}{d} Q = mg$



$Q = \frac{F_e d}{\Delta V} = \frac{mgd}{\Delta V} = \frac{4.95 \times 10^{-15}\,kg \times 9.8\,\frac{N}{kg} \times 0.01\,m}{510\,V}$

$= 9.5 \times 10^{-19}\,C$

$9.5 \times 10^{-19} \div 1.6 \times 10^{-19} \approx 6 \Rightarrow 6$ electrons

6. Delicate measurements indicate that the Earth has an electric field surrounding it, similar to that around a positively charged sphere. Its magnitude at the surface of the Earth is about 100 N/C. What charge would an oil drop of mass 2.0×10^{-15} kg have to have, in order remain suspended by the Earth's electric field? Give your answer in both coulombs and elementary charges. (1.96×10^{-16} C, 1.2×10^{3} e)

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$$E = \frac{F}{Q} = \frac{mg}{Q}$$

~~$$Q = \frac{E}{mg} = \frac{100\ \frac{N}{C}}{2.0 \times 10^{-15}\ kg \cdot 9.8\ \frac{N}{kg}}$$~~

$$Q = \frac{mg}{E} = \frac{2.0 \times 10^{-15}\ kg \times 9.8\ \frac{N}{kg}}{100\ \frac{N}{C}}$$

$$= 1.96 \times 10^{-16}\ C$$

$$\frac{1.96 \times 10^{-16}\ C}{1.6 \times 10^{-19}\ \frac{e^-}{C}} = 1225 \text{ electrons}$$