

## Chapter 5.1

Q1 The charge is positive. A positive charge brought near the electroscope will attract electrons towards the ball of the electroscope making the leaves even more positive and hence the leaves will diverge further. If the unknown charge is negative, then electrons will be pushed towards the leaves, neutralizing some of the positive charge there making the leaves diverge less. However, if the body that is brought nearby is neutral, then charge separation will take place in the body with the result that more positive charge must now exist on the ball of the electroscope. This means that negative charge has left the ball for the leaves, neutralizing positive charge there and the leaves will diverge less. So if the leaves diverge less, we cannot be sure if the body was charged or neutral.

Q2 The flame ionized air molecules creating electrons and positive ions. The electrons or the ions would be attracted to the charged electroscope neutralizing its charge.

Q3 The net charge available is  $-6\text{ C}$  and this would be shared equally by the three identical spheres. Hence each would get  $-2\text{ C}$ .

Q4 (a)  $F = \frac{kQ_1Q_2}{r^2} = \frac{8.99 \times 10^9 \times 2.0 \times 10^{-6} \times 4.0 \times 10^{-6}}{(5.0 \times 10^{-2})^2} = 28.8 \approx 29\text{ N}$ . (b) The force would be becomes 4 times as small.

Q5 The middle charge is attracted to the left by the charge on the left with a force of

$$F_1 = \frac{kqQ_2}{r^2} = \frac{8.99 \times 10^9 \times 2.0 \times 10^{-6} \times 4.0 \times 10^{-6}}{(4.0 \times 10^{-2})^2} = 45\text{ N}$$
. It is attracted to the right by the

charge on the right with a force of  $F_2 = \frac{kqQ_2}{r^2} = \frac{8.99 \times 10^9 \times 2.0 \times 10^{-6} \times 3.0 \times 10^{-6}}{(2.0 \times 10^{-2})^2} = 135\text{ N}$ .

The net force is thus  $135 - 45 = 90\text{ N}$  directed towards the right.

Q6 (a) Suppose we call the distance (in cm) from the left charge  $x$ . Then we need

$$\frac{8.99 \times 10^9 \times 2.0 \times 10^{-6} \times 4.0 \times 10^{-6}}{x^2} = \frac{8.99 \times 10^9 \times 2.0 \times 10^{-6} \times 3.0 \times 10^{-6}}{(6-x)^2}$$

$$\frac{4.0}{x^2} = \frac{3.0}{(6-x)^2}$$

This means that

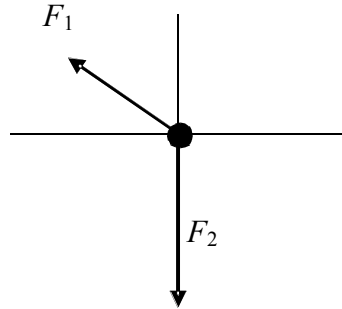
$$4.0(6-x)^2 = 3.0x^2$$

$$4(36 - 12x + x^2) = 3x^2$$

$$x^2 - 48x + 144 = 0$$

The solution is  $x = 3.22 \text{ cm}$ . (b) If we displace the middle charge a bit to the left of the equilibrium position the force from the left charge will be bigger and so the charge will move towards the left i.e. away from the equilibrium position. The same is true if it is displaced a bit to the right of the equilibrium position. Hence the position is unstable.

Q7 The forces are as shown. The distance between the charge  $Q$  and the charge  $2Q$  is  $5.0 \text{ cm}$ .



The magnitudes are  $F_1 = \frac{kQ(2Q)}{d^2} = \frac{8.99 \times 10^9 \times 3.0 \times 10^{-6} \times 6.0 \times 10^{-6}}{(5.0 \times 10^{-2})^2} = 64.7 \text{ N}$  and

$F_2 = \frac{kQQ}{d^2} = \frac{8.99 \times 10^9 \times (3.0 \times 10^{-6})^2}{(3.0 \times 10^{-2})^2} = 89.9 \text{ N}$ . We need to find the components of  $F_1$ :

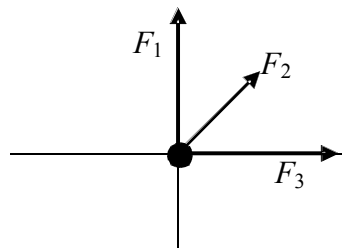
$F_{1x} = 64.7 \cos \theta = 64.7 \times \frac{4}{5} = 51.76 \text{ N}$  and  $F_{1y} = 64.7 \sin \theta = 64.7 \times \frac{3}{5} = 38.82 \text{ N}$ . The

components of the net force are:  $F_x = -51.76 \text{ N}$  and  $F_y = 38.82 - 89.9 = -51.08 \text{ N}$ . The

net force has magnitude  $F = \sqrt{51.76^2 + 51.08^2} = 72.7 \approx 73 \text{ N}$  and direction

$180^\circ + \arctan \frac{51.08}{51.76} = 224.6^\circ \approx 225^\circ$ .

Q8 The directions of the forces are as shown.

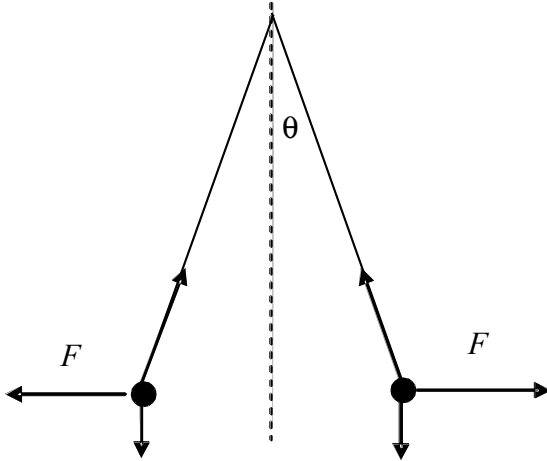


The magnitudes are  $F_1 = F_3 = \frac{kQ^2}{d^2} = \frac{8.99 \times 10^9 \times (5.0 \times 10^{-6})^2}{(12 \times 10^{-2})^2} = 15.60 \text{ N}$  and

$F_2 = \frac{kQ^2}{(d\sqrt{2})^2} = \frac{8.99 \times 10^9 \times (5.0 \times 10^{-6})^2}{2 \times (12 \times 10^{-2})^2} = 7.80 \text{ N}$ . The direction of the force is clearly

along the direction of  $F_2$  and has magnitude  $7.80 + \sqrt{15.60^2 + 15.60^2} = 29.9 \text{ N}$ .

Q9 (a) A diagram is the following in which the angle  $\theta$  of each string to the vertical is given by  $\sin \theta = \frac{5}{85} \Rightarrow \theta = 3.37^\circ$ .



We have that

$T \cos \theta = mg$  and  $T \sin \theta = F = \frac{kQ^2}{d^2}$  so that dividing side by side gives

$$\tan \theta = \frac{kQ^2}{mgd^2} \Rightarrow Q = \sqrt{\frac{mgd^2 \tan \theta}{k}} = \sqrt{\frac{100 \times 10^{-6} \times 9.8 \times 0.1^2 \times \tan 3.37^\circ}{8.99 \times 10^9}} = 8.0 \times 10^{-9} \text{ C. (b)}$$

This corresponds to  $\frac{8.0 \times 10^{-9}}{1.6 \times 10^{-19}} = 5.0 \times 10^{10}$  electronic charges.

Q10 Assume for the sake of discussion that the charge on the sphere of the van de Graaf generator is negative. This charge causes a small separation of the charge inside the plastic sphere: electrons are made to move slightly away leaving positive charge to face the negative charge on the generator. As the charge on the generator increases the force of attraction increases as well bringing the small plastic sphere closer and closer to the generator. Once it touches, the plastic sphere will become negatively charged and so will be immediately repelled by the negative charge on the generator.

Q11 (a) Since the molar mass of water is 18 g per mole, a mass of 60 kg corresponds to  $\frac{60 \times 10^3}{18} = 3333$  moles i.e.  $3333 \times 6.02 \times 10^{23} = 2 \times 10^{27}$  molecules of water. A molecule of water contains 10 electrons (2 from hydrogen and 8 from oxygen) and so we have  $2 \times 10^{28}$  electrons in each person. (b) The electric force is therefore

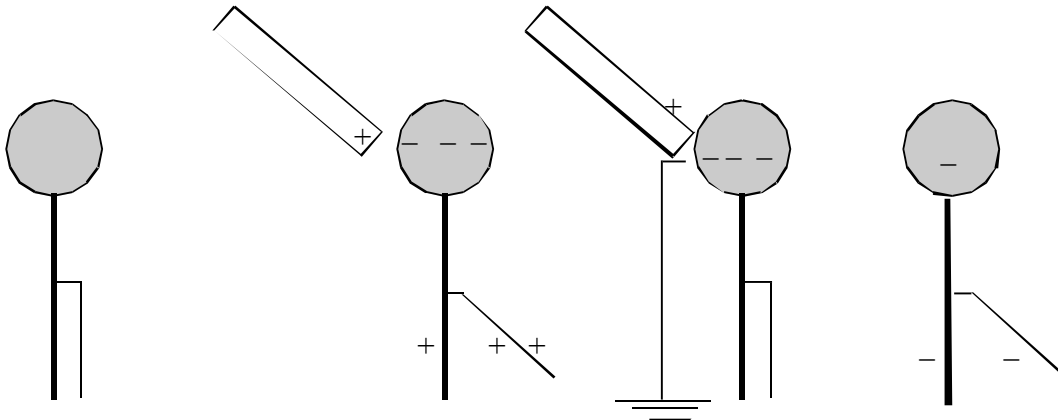
$$F_1 = \frac{kQ_1Q_2}{r^2} = \frac{9 \times 10^9 \times (2.0 \times 10^{28} \times 1.6 \times 10^{-19})^2}{(10)^2} = 9 \times 10^{26} \approx 10^{27} \text{ N, an enormous force. (c)}$$

Assumptions include the use of Coulomb's law for objects that are not point charges,

assuming the same distance between charges etc. (d) We have neglected the existence of protons which gives each person a zero electric charge and hence zero electric force.

Q12 The electroscope will become negatively charged everywhere and the leaves will diverge.

Q13



The diagram assumes that the earth has been removed before the rod was also removed. If the rod is removed before the earth is, the electroscope will be left neutral.

Q14 This question is removed.

Q15 As the negatively charged sphere is lowered in the container, positive charge will be induced in the inside surface of the container and an equal amount of negative charge on the outside surface. The amount of positive charge on the inside is equal to the negative charge on the sphere. When the sphere touches, its charge will be neutralized, leaving the sphere with zero net charge. The law of conservation of charge holds since the negative charge on the sphere now finds itself on the outside surface of the container.