CHAPTER 21
ELECTRIC CHARGE AND ELECTRIC FIELD

Discussion Questions

Q21.1 When a strip of tape is quickly peeled off the roll, electrons are transferred between the strip and the rest of the roll. Therefore, the two strips have the same sign of net charge and repel. When they are stuck together and then ripped apart, they transfer electrons and end up with net charge of opposite sign and attract each other.

Q21.2 Since they attract, they cannot have net charges of the same sign. Either one is neutral and the other has net positive or negative charge, or one has positive charge and the other has negative charge. After they touch the negative and positive charges neutralize. Any residual net charges spread over the two spheres so they now have charges of the same sign and repel. If there is no residual net charge they don't repel, but in any case they no longer attract.

Q21.3 The charged comb would still pull charges of opposite sign toward it and thereby polarize the charges in the insulator. But the neutral insulator would not be attracted to the comb. The attraction depends on the electric force increasing with decreasing distance.

Q21.4 The tumbling motion in the dryer produces static charges on the clothes and these charges tend not to leak away in the dry air inside the dryer. There will be less clinging if all the clothing is made of the same material; charge is transferred most readily between dissimilar materials. The tumbling of dissimilar materials transfers charge from one material to the other.

Q21.5 The sphere is attracted because its charges become polarized. Negative charge is drawn toward the rod and since the electrical force increases with decreasing distance this causes a net attraction. When the neutral sphere touches the charged rod some of the positive charge of the rod is transferred to the sphere. Now both objects have positive charge and they repel.

Q21.6 Assume that your mass is 70 kg. The mass of an electron is much less than the mass of a proton or neutron. Assume that you have about equal numbers of protons and neutrons, so the total mass of the protons in your body is about 35 kg. The mass of one proton is $1.67\times10^{-27}\ \text{kg}$, so the number of protons in your body is about $\dfrac{35\ \text{kg}}{1.67\times10^{-27}\ \text{kg/proton}} = 2\times10^{28}$. You have neutral charge (or close to neutral) so the number of electrons is 2×10^{28}, equal to the number of protons. The total charge of these electrons is about $(2\times10^{28}\ \text{electrons})(-1.6\times10^{-19}\ \text{C/electron}) = -3\times10^{9}\ \text{C}$.

Q21.7 (a) Electric field points away from positive charge and toward negative charge. So, the top and bottom charges are positive and the middle charge is negative. (b) The electric field is the smallest on the horizontal line through the middle charge, at the two positions on either side where the field lines are least dense. Here the *y*-components of the electric fields of the two positive charges are equal in magnitude and are in opposite directions and the electric field of the negative charge has no *y*-component. Therefore, along this line the *y*-component of the net field is zero. On this line to the right of the charges the *x*-components of the fields of the positive charges are to the right and the *x*-component of the field due to the negative charge is to the left and the *x*-components tend to cancel. On this line to the left of the charges the *y*-component of the net field is again zero and the *x*-components of the positive charges are in opposite directions and tend to cancel.

Q21.8 Both kinds of conduction are due to the free electrons in the conductor.

Q21.9 In Fig.21.28a the field lines are straight lines so the force is always in a straight line and the velocity and acceleration are always in the same direction. The particle moves in a straight line alone a field line, with increasing speed. In fig.21.28b the field lines are curved and the force continually changes direction. As the particle moves, its velocity and acceleration are not in the same direction and the trajectory does not follow a field line.

Q21.10 Place the two objects in contact. Bring a positively charged rod close to one object, on its side opposite the second object. This will pull electrons into the object closest to the rod. With the rod held nearby separate the objects. This will leave one with negative charge and the other with positive charge. The two objects were originally neutral, so the magnitude of the negative charge on one equals the magnitude of the positive charge on the other.

Q21.11 The mass of the book is about 2 kg. Protons and neutrons have about equal masses and their mass is about 2000 times greater than the mass of an electron. There are approximately equal numbers of neutrons and protons so about half the mass of the book (1 kg) is due to protons. The number of protons therefore is about $\frac{1\text{ kg}}{1.67\times 10^{-27}\text{ kg/proton}} = 6\times 10^{26}\text{ protons}$. Assuming equal numbers of electrons and protons there are 6×10^{26} electrons. The net charge if the magnitude of the charge of an electron is $1.00\times 10^{-3}\%$ less than that of a proton is $\Delta q = (1.00\times 10^{-5})(1.6\times 10^{-19}\text{ C})(6\times 10^{26}) = 960\text{ C}$. The textbook would have a charge of about 1000 C. The repulsive force between two textbooks placed 5 m apart would be about $(9\times 10^{9}\text{ N}\bullet\text{m}^2/\text{C}^2)(1000\text{ C})^2/(5\text{ m})^2 = 4\times 10^{14}\text{ N}$. This is an immense force. Even the slightest difference in the proton charge and the magnitude of the electron charge would result in explosive repulsion.

Q21.12 It is easier for charge to build up on you when the air is dry. Humid air conducts the charge from your body. There is more space for net charge on a large object, so a large object can accept more charge.

Q21.13 Charging by touching transfers charge of the same sign to another object. Using a charged object to charge another object by induction places charge of the opposite sign on the second object.

Q21.14 The acceleration of the charge depends on the electric force exerted on it by the other charge. This force is given by $F = k\frac{q^2}{r^2}$. The force at the instant the charge is released depends only on the distance between the two charges and is the same whether the other charge is free to move or is held fixed in place.

Q21.15 The force on each charge has magnitude $F = k\frac{Q(2Q)}{r^2}$. The same magnitude of force acts on each charge and the charges have the same mass. Therefore, the charges will have initial accelerations of the same magnitude.

Q21.16 The two particles have charges of the same magnitude and opposite sign. The electric field exerts forces of the same magnitude and opposite direction on the two particles. They have different masses, so the accelerations are of different magnitude, with the electron's acceleration being larger. The acceleration of the proton is in the direction of the electric field and the acceleration of the electron is opposite to the direction of the electric field.

Q21.17 The earth contains an immense number of electrons and protons, but in equal numbers so it is electrically neutral and exerts no electrical force on other objects. The mass of the earth is very large so the gravitational force it exerts is large.

Q21.18 They both occur between pairs of objects. They both are inversely proportional to the square of the distance between the objects. All objects have mass and exert a gravitational force on each other. Only objects with net charge exert an electrical force. The gravitational force is always attractive but the electrical force can be either attractive or repulsive depending on whether the two objects have charges of the opposite or of the same sign.

Q21.19 (a) Electric field points away from positive charge and toward negative charge so object *B* has positive charge and object *A* has negative charge. (b) The electric field lines are closer together near object *A* so the field is stronger near object *A*.

Q21.20 If the only forces were the electrical and gravitational forces, the gravitational force wouldn't be strong enough to overcome the electrical repulsion of the protons and the nucleus would be unstable. The protons and neutrons are all bound together by a nuclear force.

Q21.21 The electric field exerts a force on the electrons, according to Eq.(21.3). If the force from the external electric field is stronger than the forces that bind the electron to the atom, the force from the field can pull electrons from the atom.

Q21.22 No. Field lines for the resultant field due to the set of charges never cross. But $\vec{E}_1$ and $\vec{E}_2$ are the electric fields of individual charges and it is their vector sum that determines the direction of the field line at point *P*.

Q21.23 Air velocity is a vector field because velocity is a vector. Temperature is not a vector field because temperature is a scalar, not a vector.