22 Electrostatics

The Part Five opening photo is my granddaughter Megan Abrams, daughter of Leslie and Bob Abrams.

Photo openers for the chapter begin with physicist Jim Stith operating a Wimhurst generator that the rest of us would love to have for our electrostatic demos. Photos 3 and 4 are classroom shots at a laboratory school on the outskirts of Istanbul, Turkey. Teacher Z. Tugba Kahyaoglu is a friend of mine and my wife Lillian.

If Benjamin Frankin weren't born, the United States as we know it, wouldn't be. So it is pleasing to open this chapter with a profile of this great man.

The study of electricity begins with electrostatics. The material in this chapter should be supported with lecture demonstrations, such as the electrophorus (a metal plate charged by induction that rests on a sheet of Plexiglas which has been charged with cat's fur, or equivalently, a pizza pan that rests on a charged phonograph record), the Wimshurst generator (nice if as impressive as the one Jim Stith plays with), and the Van de Graaff generator (that Tugba playfully uses in her class).

Electric shielding and the zero E field inside metals is briefly treated in the chapter, but not explained. Instead, reference is made to the similar case of the zero *G* field inside a hollow spherical shell back on page 172, Figure 9.25. You may want to expand this idea in lecture.

You may note also, as Paul Doherty pointed out to me, that different colored balloons acquire different amounts of charge, likely due to the different effects of dyes in the rubber.

Bill Blunk gives a bit of good advice for charging hair with the Van de Graaff generator. Charge yourself and then hold a metal object with sharp points near the head of the person whose hair is to stand on end. You charge the person's head, and when she takes your place at the generator, the charge she already has makes for a more pronounced display of standing hair.

Web info tells us that meteorologists estimate that, at any given moment, some 1,800 thunderstorms are in progress over Earth's surface, with some 18 million a year around the world. Approximately 100,000 to 125,000 thunderstorms occur in the United States each year. Of that total anywhere from 10 to 20 percent may be severe.

Arbor Scientific supplies van de Graaff generators, a spiffy one (P6-3300), and a hand-cranked economy one (P6-3400). There's a small one that produces up to 200 kV (P6-3200).

Beware: The danger from car batteries is not so much electrocution, as it is explosion. If you touch both terminals with a metal wrench, for instance, you can create a spark that can ignite hydrogen gas in the battery and send pieces of battery and acid flying. It is also good practice to electrically discharge yourself before pumping gasoline at a service station.

Superconducting wire is expected to play a major role in wind turbines, particularly those at sea where maintenance is expensive.

This chapter is prerequisite to the following chapters in Part 5.

Practicing Physics Book:
- Static Charge
- Electric Potential

Problem Solving Book:
Good electrostatic problems

Laboratory Manual:
- A Force to be Reckoned *Introduction to Electrostatic Force* (Activity)
- Electroscopia *Conduction, Induction, Conductors, and Insulators* (Experiment)
- Charging Ahead *The Van de Graaff Generator* (Demonstration)
- Electric Field Hockey *Field Manipulation Challenge Simulation* (Tech Lab)
- Greased Lightning *Carpet Shock Puzzle Simulation* (Tech Lab)

Next-Time Questions:
• Alpha Particle and Electron •Battery and Balloon • Polarized Water Stream • Electron Gravity
• Van de Graaff Generator •Shocking Tale

Hewitt-Drew-It Screencasts: •*Electricity* •*Coulomb's Law* •*Electric Fields* •*Electric Potential*

The order of topics in the lecture sequence below departs somewhat from the order of topics in the chapter. The ideas of each demo flow nicely to the next. Have your lecture table set up with rods, pith ball, and charging demos at one end of the table, then an electrophorus, then a Wimshurst or whatever electrostatic generating machine, and finally the Van de Graaff generator. Then your lecture begins at one end of the table and proceeds in order to the opposite end.

SUGGESTED LECTURE PRESENTATION

Electrical forces: Begin by comparing the strength of the electric force to gravitational force—billions of billions of times stronger. Acknowledge the fundamental rule of electricity: that *like charges repel and unlike charges attract*. Why? Nobody knows. Hence we say it is fundamental.

Electric Charges: Electrical effects have to do with electric charges, minus for the electron and plus for the proton. Discuss the near balance that exists in common materials, and the slight imbalance when electrons transfer from one material to another. Different materials have different affinities for electrons, which explains why charge transfers from fur to rubber when rubbed. It also explains why it's painful for people with silver fillings in their teeth to chew aluminum spitballs. Silver has more affinity for acquiring electrons than aluminum. The mildly acidic saliva in your mouth facilitates a flow of electrons, which when transmitted to the nerves of your teeth produce that familiar unpleasant sensation. Discuss **charging**.

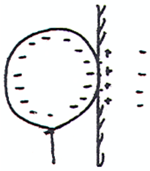
> DEMONSTRATION: Bring out the cat's fur, rubber and glass rods, and suspended pith balls. An alternative to the pith ball is a copper-painted Ping-Pong ball. Explain the transfer of electrons

when you rub fur against rubber rod (and silk against glass). Explain what it means to say an object is electrically charged, and discuss the **conservation of charge**.

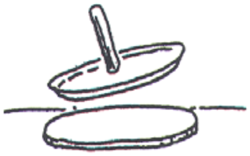
Rubbing a rubber rod on cat's fur or a glass rod on silk illustrates charging by friction, but charge separation can occur without friction, by the simple contact between dissimilar insulating materials. In this case charge simply peels from one material to another, like dust is peeled from a surface when a piece of sticky tape is peeled from it.

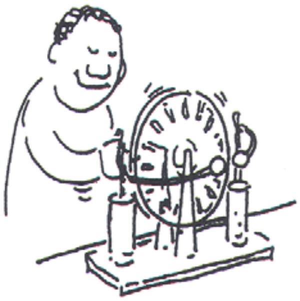
DEMONSTRATION: Show the effects of electrical force and **charge by induction** by holding a charged rod near the ends of a more-than-a-meter-long wooden 2 × 4, that balances and easily rotates sideways at its midpoint on a protrusion such as the bottom of a metal spoon. You can easily set the massive piece of wood in motion. This is quite impressive!

DEMONSTRATION: Rub a balloon on your hair and show how it sticks to the wall. Draw a sketch on the board (Figure 22.14) and show by induction how the attracting charges are slightly closer than the repelling charges. Closeness wins and it sticks!



DEMONSTRATION: Charge the electrophorus, place the insulated metal disk on top of it, and show that the disk is not charged when removed and brought near a charged pith ball. Why should it be, for the insulating surface of the electrophorus has more grab on the electrons than the metal plate. But rest the plate on the electrophorus again and touch the top of the plate. You're grounding it (producing a conducting path to ground for the repelling electrons). Bring the plate near the pith ball and show that it is charged. Then show this by the flash of light produced when the charged metal plate is touched to the end of a gas discharge tube—or a fluorescent lamp. Engage neighbor discussion of the process demonstrated. Only after this is generally understood, proceed to the next demo.

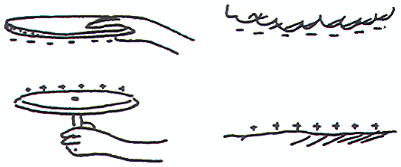




DEMONSTRATION: Move up the lecture table to the Wimshurst generator, explaining its similarity to the electrophorus (actually a rotating electrophorus). You'll be lucky if you have access to a fine one as shown by Jim Stith in the photograph that opens this chapter. Show sparks jumping between the spheres of the machine and so forth, and discuss the sizes (radii of curvature) of the spheres in terms of their capacity for storing charge. [The amount of charge that can be stored before discharge into the air is directly proportional to the radius of the sphere.] Fasten a metal point, which has a tiny radius of curvature and hence a tiny charge storing capacity, to one of the Wimshurst spheres and demonstrate the leakage of charge.

If you wish to expand upon charge leakage from a point, you might simplify it this way: On the surface of an electrically charged flat metal plate, every charge is mutually repelled by every other charge. If the surface is curved, charges on one part of the plate will not interact with charges on some distant part of the plate because of the **shielding** effect of the metal—they are "out of the line of sight" of each other. Hence for the same amount of work or potential, a greater number of charges may be placed on a curved surface than on a flat surface. The more pronounced the curvature, the more shielding and the more charge may be stored there. To carry this idea further, consider a charged needle. Under mutual repulsion, charges gather to the region of greatest curvature, the point. Although all parts of the needle are charged to the same electric potential, the charge density is greatest at the point. The **electric field** intensity about the needle, on the other hand, is greatest about the point, usually great enough to ionize the surrounding air and provide a conducting path from the charge concentration. Hence charge readily gathers at points and readily leaks from points. DEMONSTRATE this leakage and the reaction force (ion propulsion) with a set of metal points arranged to rotate when charged. This is the "ion propulsion" that science fiction buffs talk about in space travel. Interestingly enough, this leaking of charge from points causes static with radio antennas; hence the small metal ball atop automobile antennas.

Discuss **lightning rods** and show how the bottoms of negatively charged clouds and the resulting induced positive charge on the surface of the Earth below are similar to the electrophorus held upside down; where the charged Plexiglas plate is analogous to the clouds and the metal plate is analogous to the Earth. After sketching the charged clouds and Earth on the chalkboard, be sure to hold the inverted electrophorus pieces against your drawing on the board in their respective places. Discuss the lightning rod as a preventer of lightning while showing the similar function of the metal point attached to the Wimshurst generator. [Notice that one idea is related to the next in this sequence—very important, as the ideas of electricity are usually difficult to grasp the first time through. So be sure to take care in moving through this sequence of demonstrations and their explanations.]



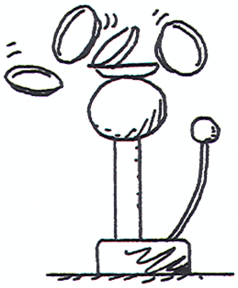
Benjamin Franklin's kite, by the way, was not struck by lightning. If it had, he would likely have not been around to report his experience. Franklin showed that the kite collected charges from the air during a thunderstorm. Hairs on the kite string stood apart, implying that lightning was a huge electric spark.

Storage of electric charge is accomplished with a **capacitor**. My dear Egyptian friend Mona El Tawil Nassar (my adopted sister) sets parallel plates in Figure 22.27.

> DEMONSTRATION: Show one of the most impressive capacitors, the Leyden Jar, and a sparking demonstration.

After establishing the idea that charge capacity depends on the size and curvature of the conductor being charged, advance to what your students have been waiting for: The Van de Graaff generator (invented by the way, by Robert Generator—this quip was with his permission! In previous editions my editors allowed this humor in the text itself, with a qualifying footnote)☺.

> DEMONSTRATION: When showing the long sparks that jump from the dome of the generator to the smaller grounded sphere, do as Bruce Bernard suggests and hold a lightning rod (any sharp pointed conductor) in the vicinity of the dome and the sparking will stop. Bring the lightning rod farther away and the frequency of sparking will resume.



> DEMONSTRATION: Set a cup of puffed rice or puffed wheat on top of the Van de Graaff generator. Your students will like the fountain that follows when you charge it. Or do as Marshall Ellenstein does and place a stack of aluminum pie plates on the dome and watch them one by one levitate and fly away. Or as Tugba does with aluminum foil as shown in the photo openers to this chapter. Then snuff out a match by holding it near the charged dome. Introduce (or reintroduce) the idea of the **electric field** at this time, the aura of energy that surrounds all charged things. Compare electric and gravitational fields.

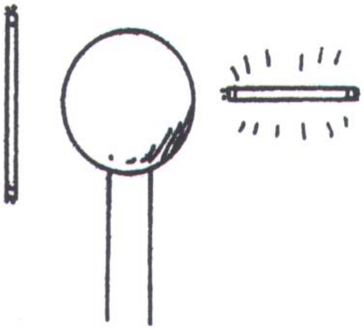
Fields are called "force fields" because forces are exerted on bodies in their vicinity, but a better term would be "energy field," because energy is stored in a field. In the case of an electric field, any charges in the vicinity are energized. We speak about the potential energy that electrically charged bodies have in a field—or more often, the potential energy compared to the amount of charge—**electric potential**. Explain that the field energy, and correspondingly the electric potential, is greatest nearest the charged dome and weaker with increased distance (**inverse-square law**).

> DEMONSTRATION: Hold a fluorescent lamp tube in the field to show that it lights up when one end of the tube is closer to the dome than the other end. Relate this to potential difference, and show that when both ends of the fluorescent tube are equidistant from the charged dome, light emission ceases. (This can be affected when your hand is a bit closer to the dome than the far end of the tube, so current does not flow through the tube when the dome discharges through you to the ground. There is no potential difference across the tube and therefore no illuminating current, which sets the groundwork for your next lecture on electric current.)

My wife Lil grew her hair long for the photo of Figure 22.29. After the shot was deemed successful, she then had her hair cut to her preferred shorter length. Hey, she, like me, wraps her life around physics!

The Van de Graaff generator nicely illustrates the difference between **electric potential energy** and **electric potential**: Although it is normally charged to thousands of volts, the amount of charge is relatively small so the electric potential energy is relatively small. That's why you're normally not harmed when it discharges through your body. Very little energy flows through you. In contrast, you wouldn't intentionally become the short-circuit for household 110 volts because although the voltage is much lower, the transfer of energy is appreciable. Less energy per charge, but many many more charges!

> NEXT-TIME QUESTION: Why does current flow when one end of the fluorescent tube is held closer to the charged Van de Graaff generator, but not when both ends are equidistant? [The simplified answer you're looking for at this point is that the close end is in a stronger part of the field than the far end. More energy per charge means more voltage at the near end. With a voltage difference across the tube, you get a current. When both ends are equidistant, there is no voltage difference across the tube, and no current. This leads into the next chapter. Strictly speaking, the current path is more than simply between the ends of the tube; it goes through you also and the ground where it returns to the generator.]



Answers and Solutions for Chapter 22

Reading Check Questions

1. Electrostatics is the term for electricity at rest.
2. Electrical forces cancel out, leaving weaker gravity predominant.
3. The nucleus and its protons are positively charged; electrons are negatively charged.
4. The charge of one electron is identical to the charge on all electrons, and is equal and opposite for protons.
5. The normal net charge is zero.
6. A positive ion is an atom with one or more fewer electrons than protons. A negative ion is an atom with one or more extra electrons.
7. Conservation of charge means charge cannot be created or destroyed, but merely transferred.
8. Quantized means that there is a smallest possible amount of charge of which all other amounts of charge are multiples.
9. One quantum unit of charge is that of an electron (or proton).
10. A coulomb is much larger than the charge of an electron; one coulomb is the charge of 6.25×10^{19} electrons!
11. Both laws are inverse-square laws. How they differ is mainly that gravitation is only attractive, whereas electrical forces can repel.
12. Atoms of metals are good conductors because of their free outer electrons
13. Atoms of insulators are poor conductors because of their strong hold on their electrons.
14. A semiconductor can be made to conduct or insulate.
15. A transistor is composed of thin layers of semiconducting materials. Functions include controlling the flow of electrons, amplifying signals, and acting as switches.
16. Flow in a superconductor is without electrical resistance.
17. Electrons are transferred from one place to another.
18. Sliding across plastic seating is charging by contact and by friction.
19. Charging by induction occurs during thunderstorms.
20. The primary purpose of the lightning rod is to prevent a lightning stroke.
21. A polarized object may have no net charge, whereas a charged object does.
22. An electric dipole is an object electrically polarized in its normal state.
23. An electric dipole is H_2O.
24. Gravitational and electric. (Magnetic fields also, that we'll learn about in Chapter 24.)
25. The direction of an electric field is the direction of force on a positive charge.
26. At the center of a charged spherical conductor all field components cancel out.
27. The electric field inside a conductor cancels to zero.
28. Each coulomb is given 1.5 joules of energy.
29. No. Several thousand volts is different than the *ratio* several thousand volts per coulomb. Voltage is measured in volts; voltage/coulomb is energy and measured in joules. Several thousand joules per coulomb isn't much energy if you have a tiny fraction of a coulomb.
30. The energy in a capacitor is stored in its electric field.

Think and Do

31. In dry climates this is a common nuisance!

32. Tell Grandpa that when inside any metal surface the electric field remains zero.

33. The stream is indeed deflected, due to the polarity of water molecules.

Plug and Chug

34. $$F = k\frac{q_1 q_2}{d^2} = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\ \frac{(0.1\ \text{C})(0.1\ \text{C})}{(0.1\ \text{m})^2} = 9 \times 10^9\ \text{N}.$$

35. $$F = k\frac{q_1 q_2}{d^2} = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\ \frac{(0.1\ \text{C})(0.1\ \text{C})}{(0.2\ \text{m})^2} = 2.25 \times 10^9\ \text{N}.$$

Think and Solve

36. By the inverse-square law, twice as far is 1/4 the force; **5 N**.
    The solution involves relative distance only, so the magnitude of charges is irrelevant.

37. From Coulomb's law, the force is given by $F = \frac{kq^2}{d^2}$, so the square of the charge is

$q^2 = \frac{Fd^2}{k} = \frac{(20\text{ N})(0.06\text{ m})^2}{9 \times 10^9\text{ N m}^2/\text{C}^2} = 8.0 \times 10^{-12}\text{ C}^2$. Taking the square root of this gives $q = 2.8 \times 10^{-6}$ C, or 2.8 microcoulombs.

38. From Coulomb's law, $F = k\frac{q_1q_2}{d^2} = (9 \times 10^9)\frac{(1.0 \times 10^{-6})^2}{(0.03)^2} = 10$ N. This is the same as the weight of a 1-kg mass.

39. $F_{\text{grav}} = mg = (9.1 \times 10^{-31}\text{kg})(9.8\text{ m/s}^2) = 8.9 \times 10^{-30}$ N. $F_{\text{elec}} = qE = (1.6 \times 10^{-19}\text{ C})(10{,}000\text{ V/m}) = 1.6 \times 10^{-15}$ N, more than 10^{14} times larger than the gravitational force!

40. $F_{\text{grav}} = Gm_1m_2/d^2 = (6.67 \times 10^{-11})\frac{(9.1 \times 10^{-31})(1.67 \times 10^{-27})}{(1.0 \times 10^{-10})^2} = 1.0 \times 10^{-47}$ N.

$F_{\text{elec}} = kq_1q_2/d^2 = (9 \times 10^9)\frac{(1.6 \times 10^{-19})^2}{(1.0 \times 10^{-10})^2} = 2.3 \times 10^{-8}$ N.

The electrical force between an electron and a proton is more than 1,000,000,000,000,000,000,000,000,000,000,000,000,000 times greater than the gravitational force between them! (Note that this ratio of forces is the same for any separation of the particles.)

41. Electric field is force divided by charge: $E = \frac{F}{q} = \frac{3.2 \times 10^{-4}\text{N}}{1.6 \times 10^{-10}\text{C}} = 2 \times 10^6$ N/C. (The unit N/C is the same as the unit V/m, so the field can be expressed as 2 million volts per meter.)

42. Energy is charge × potential: PE = qV = (2 C)(100 × 10^6 V) = 2 × 10^8 J.

43. Potential is defined as energy per unit charge, so V = PE/q = (0.1 J)/(1.0 × 10^{-6} C) = 1 × 10^5 V or 100,000 V.

44. (a) $\Delta V = \frac{\text{energy}}{\text{charge}} = \frac{12\text{ J}}{0.0001\text{ C}}$ = 120,000 volts.

(b) ΔV for twice the charge is $\frac{24\text{ J}}{0.0002}$ = same 120 kV.

45.(a) From $E = \frac{F}{q}$ we see that $q = \frac{F}{E} = \frac{mg}{E} = \frac{(1.1 \times 10^{-14})(9.8)}{1.68 \times 10^5} =$ 6.4×10^{-19} C.

(b) Number of electrons = $\frac{6.4 \times 10^{-19}\text{C}}{1.6 \times 10^{-19}\text{C/electron}}$ = 4 electrons.

Think and Rank

46. A, C, B

47. C, B, A

Think and Explain

48. Something is electrically charged when it has an excess or deficiency of electrons, compared with the number of protons in the atomic nuclei of the material.

49. Electrons are loosely bound on the outside of atoms, whereas protons are very tightly bound within the atomic nuclei.

50. The objects aren't charged because of their equal number of protons.

51. Clothes become charged when electrons from a garment of one material are rubbed onto another material. If the materials were good conductors, discharge between materials would soon occur. But

the clothes are nonconducting and the charge remains long enough for oppositely charged garments to be electrically attracted and stick to one another.

52. When wiped the DVD becomes charged, which polarizes and attracts dust particles.

53. Excess electrons rubbed from your hair leave it with a positive charge; excess electrons on the comb give it a negative charge.

54. The wires at toll-collecting stations are used to discharge the cars so that paying the toll is not a shocking experience for the driver or the collector.

55. In the previous century, before truck tires were made electrically conducting, chains or wires were commonly dragged along the road surface from the bodies of trucks. Their purpose was to discharge any charge that would otherwise build up because of friction with the air and the road. Today's electrically-conducting tires prevent the buildup of static charge that could produce a spark—especially dangerous for trucks carrying flammable cargoes.

56. The leaves, like the rest of the electroscope, acquire charge from the charged object and repel each other because they both have the same sign of charge. The weight of the conducting metal foil is so small that even tiny forces are clearly evident.

57. Cosmic rays produce ions in air, which offer a conducting path for the discharge of charged objects. Cosmic-ray particles streaming downward through the atmosphere are attenuated by radioactive decay and by absorption, so the radiation and the ionization are stronger at high altitude than at low altitude. Charged objects more quickly lose their charge at higher altitudes.

58. The charged body need not touch the ball of an electroscope. If a negative charge is simply brought near, some electrons in the ball are repelled and driven to the gold leaves, leaving the ball positively charged. Or if a positive charge is brought near the ball, some electrons will be attracted and move up to the ball to make it negative and leave the leaves positively charged. This is charge separation due to *induction*. (If by small chance you are attempting an answer to this question without having witnessed this, pity, pity, pity! Better that your time is spent studying the physics of familiar things.)

59. The crystal as a whole has a zero net charge, so any negative charge in one part is countered with as much positive charge in another part. So the net charge of the negative electrons has the same magnitude as the net charge of the ions. (This balancing of positive and negative charges within the crystal is almost, but not precisely, perfect because the crystal can gain or lose a few extra electrons.)

60. By induction: Bring the positively charged object near the object to be charged and the far side of the uncharged object will become positively charged. If you then touch the far side, you will in effect remove this charge because electrons will flow from your body to the positive charge. Remove your finger and the object then has a negative charge. (Interestingly enough, touching any side will produce the same result.)

61. Electrons are easily dislodged from the outer regions of atoms, but protons are held tightly within the nucleus.

62. It says that force decreases with the square of increasing distance, or increases as the square of decreasing distance.

63. The electrons don't fly out of the penny because they are attracted to the fifty thousand billion billion positively charged protons in the atomic nuclei of atoms in the penny.

64. By the inverse-square law, the force increases. It will be four times as great when at half the distance, and nine times as great when at one-third the distance.

65. The inverse-square law is at play here. At half the distance the electric force field is four times as strong; at 1/4 the distance, 16 times stronger. At four times the distance, one-sixteenth as strong.

66. Doubling the distance reduces the force to 1/4, whatever the sign of charge. This is in accord with Coulomb's law.

67. Doubling one charge doubles the force. The magnitude of the force does not depend on the sign of charge.

68. Doubling both charges quadruples the force. The magnitude of the force does not depend on the sign of charge.

69. The huge value of the constant *k* for electrical force indicates a relatively huge force between charges, compared with the small gravitational force between masses and the small value of the gravitational constant *G*.

70. Where lines are closer, the field is stronger.

71. By convention, the direction goes from positive to negative as the arrows indicate.

72. At twice the distance the field strength will be 1/4, in accord with the inverse-square law.

73. Electrical resistance disappears.

74. Planet Earth is negatively charged. If it were positive, the field would point outward.

75. They're taller to be closer to the clouds, closer to lightning.

76. The metal spikes penetrating into the ground reduce electrical resistance between the golfer and the ground, providing an effective electrical path from cloud to ground. Not a good idea!

77. A neutral atom in an electric field is electrically distorted (see Figure 22.11). If the field is strong enough, the distortion results in ionization, where the charges are torn from each other. The ions then provide a conducting path for an electric current.

78. The mechanism of sticking is charge induction. If it's a metal door, the charged balloon will induce an opposite charge on the door. It will accomplish this by attracting opposite charges to it and repelling like charges to parts of the door farther away. The balloon and the oppositely-charged part of the door are attracted and the balloon sticks. If the door is an insulator, the balloon induces polarization of the molecules in the door material. Oppositely-charged sides of the molecules in the surface of the door face the balloon and attraction results. So whether you consider the door to be an insulator or a conductor, the balloon sticks by induction.

79. The paint particles in the mist are polarized and are therefore attracted to the charged chassis.

80. An ion polarizes a nearby neutral atom, so that the part of the atom nearer to the ion acquires a charge opposite to the charge of the ion, and the part of the atom farther from the ion acquires a charge of the same sign as the ion. The side of the atom closer to the ion is then attracted more strongly to the ion than the farther side is repelled, making for a net attraction. (By Newton's third law, the ion, in turn, is attracted to the atom.)

81. The forces on the electron and proton will be equal in magnitude, but opposite in direction.

82. Because of the greater mass of the proton, its acceleration will be less than that of the electron, and be in the direction of the electric field. How much less? Since the mass of the proton is nearly 2000 times that of the electron, its acceleration will be about 1/2000 that of the electron. The greater acceleration of the electron will be in the direction opposite to the electric field.

83. The electron and proton accelerate in opposite directions.

84. The field is zero because the forces midway between the two test charges cancel to zero.

85. The electron will have the greater speed on impact. The force on both will be the same, the distance is the same, so work done by the field is the same and KE of the particles is the same. But for the same KE, the particle with the smaller mass, the electron, has the greater speed.

86. By convention only, the direction of an electric field at any point is the direction of the force acting on a positive test charge placed at that point. A positive charge placed in the vicinity of a proton is pushed away from the proton, hence, the direction of the electric field vector is away from the proton.

87. The bits of thread become polarized in the electric field, one end positive and the other negative, and become the electric counterparts of the north and south poles of the magnetic compass. Opposite forces on the end of the fibers (or compass needle) produce torques that orient the fibers along the field direction (look ahead to Figure 24.3 in the next chapter).

88. Charge will be more concentrated on the corners. (See Figure 22.21.)

89. Its change is 10 volts (10 joules per coulomb is 10 volts).

90. When released, its 10 joules of potential energy will become 10 joules of kinetic energy as it passes its starting position.

91. Voltage = (0.5 J)/0.0001 C = 5000 V.

92. In a thunder storm the metal affords a field-free region (called a Faraday cage). Charges on the surface of the metal arrange themselves such that the field in the interior cancels to zero.

93. The charges are of equal magnitude because the charge taken from one plate is given to the other. That’s why the net charge of a capacitor is always zero.

94. Increase the area of the plates and you’ll increase energy storage. (You can also increase energy storage by bringing the plates closer together, but not touching. Or you can insert a nonconducting material, called a *dielectric*, between the plates.)

95. It is dangerous because the capacitor may be still be charged.

96. 1 Mev is 1 million ev (10^6 eV); 1 Gev is 1 billion eV (10^9 eV), so a GeV is 1000 times larger than a MeV.

97. Zero, whether or not charge is on the outside.

98. No, nor inside any statically charged conducting body. Mutually repelling charges on the surface cancel the electric field inside the body to zero—true for solids as well as hollow conductors. (If the electric field were not zero, then conduction electrons would move in response to the field until electrical equilibrium was established—which is a zero electric field.)

99. Agree with your friend. The hairs act like leaves in an electroscope. If your arms were as light, they’d stand out too.

Think and Discuss

100. When the wool and plastic rub against each other, electrons are rubbed from the plastic onto the wool. The deficiency of electrons on the plastic bag results in its positive charge.

101. The charged wrap nicely polarizes nonconducting plastic rather than metal, resulting in better sticking on plastic than on metal.

102. When an object acquires a positive charge, it loses electrons and its mass decreases. How much? By an amount equal to the mass of the electrons that have left. When an object acquires a negative charge, it gains electrons, and the mass of the electrons as well. (The masses involved are incredibly tiny compared to the masses of the objects. For a balloon rubbed against your hair, for example, the extra electrons on the balloon comprise less than a billionth of a billionth of a billionth the mass of the balloon.)

103. The penny will be slightly more massive with a negative charge, for it will have more electrons than when neutral. If it were positively charged, it would be slightly lighter because of missing electrons.

104. For the outer electrons, the attractive force of the nucleus is largely canceled by the repulsive force of the inner electrons, leaving a force on the outer electrons little different from the force on the single electron in a hydrogen atom. For the inner electrons, on the other hand, all of the electrons farther from the nucleus exert no net force (it is similar to the situation within the Earth, where only the Earth below, not the Earth above, exerts a gravitational force on a deeply buried piece of matter). So the inner

electrons feel the full force of the nucleus, and a large amount of energy is required to remove them. Stripping all of the electrons from a heavy atom is especially difficult. Only in recent years have researchers at the University of California, Berkeley succeeded in removing all of the electrons from the atoms of heavy elements like uranium.

105. The law would be written no differently.

106. The tree is likely to be hit because it provides a path of less resistance between the cloud overhead and the ground. The tree and the ground near it are then raised to a high potential relative to the ground farther away. If you stand with your legs far apart, one leg on a higher-potential part of the ground than the other, or if you lie down with a significant potential difference between your head and your feet, you may find yourself a conducting path. That, you want to avoid!

107. The half ring has the greater electric field at its center because the electric field at the center of the whole ring cancels to zero. The electric field at the center of the half ring is due to a multitude of electric vectors, vertical components canceling, with horizontal components adding to produce a resultant field acting horizontally to the right.

108. Yes, in both cases we have a ratio of energy per something. In the case of temperature, the ratio is energy/molecule. In the case of voltage it is energy/charge. Even with a small numerator, the ratio can be large if the denominator is small enough. Such is the case with the small energies involved to produce high-temperature sparklers and high-voltage metal balls.