SUMMARY OF TERMS

Coulomb's law The relationship among electrical force, charge, and distance: If the charges are alike in sign, the force is repelling; if the charges are unlike, the force is attractive.

Coulomb The SI unit of electrical charge. One coulomb (symbol C) is equal in magnitude to the total charge of 6.25×10^{18} electrons.

Electrically polarized Term applied to an atom or molecule in which the charges are aligned so that one side has a slight excess of positive charge and the other side a slight excess of negative charge.

Electric field Defined as force per unit charge, it can be considered to be an energetic "aura" surrounding charged objects. About a charged point, the field decreases with distance according to the inverse-square law, like a gravitational field. Between oppositely charged parallel plates, the electric field is uniform.

Electric potential energy The energy a charge possesses by virtue of its location in an electric field.

Conductor Any material having free charged particles that easily flow through it when an electric force acts on them.

Electric potential The electric potential energy per amount of charge, measured in volts, and often called voltage.

Potential difference The difference in potential between two points, measured in volts, and often called voltage difference.

Electric current The flow of electric charge that transports energy from one place to another.

Ampere The unit of electric current; the rate of flow of 1 coulomb of charge per second.

Direct current (dc) An electric current flowing in one direction only.

Alternating current (ac) Electric current that repeatedly reverses its direction; the electric charges vibrate about relatively fixed points. In the United States, the vibrational rate is 60 Hz.

Electrical resistance The property of a material that resists the flow of an electric current through it. It is measured in ohms (Ω).

Superconductor Any material with zero electrical resistance, wherein electrons flow without losing energy and without generating heat.

Ohm's law The statement that the current in a circuit varies in direct proportion to the potential difference or voltage and inversely with the resistance:

$$\text{Current} = \frac{\text{voltage}}{\text{resistance}}$$

A current of 1 A is produced by a potential difference of 1 V across a resistance of 1 Ω.

Series circuit An electric circuit with devices connected in such a way that the same electric current flows through each of them.

Parallel circuit An electric circuit with two or more devices connected in such a way that the same voltage acts across each one, and any single one completes the circuit independently of all the others.

Electric power The rate of energy transfer, or the rate of doing work; the amount of energy per unit time, which can be measured by the product of current and voltage:

$$\text{Power} = \text{current} \times \text{voltage}$$

It is measured in watts (or kilowatts), where

$$1\text{ A} \times 1\text{ V} = 1\text{ W}.$$

REVIEW QUESTIONS

10.1 Electric Force and Charge

1. Which part of an atom is positively charged, and which part is negatively charged?
2. How does the charge of one electron compare with that of another electron?
3. How do the masses of electrons compare with the masses of protons?
4. How does the number of protons in the atomic nucleus normally compare with the number of electrons that orbit the nucleus?
5. What kind of charge does an object acquire when electrons are stripped from it?
6. What is meant by saying that charge is conserved?

10.2 Coulomb's Law

7. How is Coulomb's law similar to Newton's law of gravitation? How is it different?
8. How does a coulomb of charge compare with the charge of a single electron?
9. How does the magnitude of electrical force between a pair of charged particles change when the particles are moved twice as far apart? Three times as far apart?
10. How does an electrically polarized object differ from an electrically charged object?

10.3 Electric Field

11. Give two examples of common force fields.
12. How is the direction of an electric field defined?

10.4 Electric Potential

13. In terms of the units that measure them, distinguish between electric potential energy and electric potential.
14. A balloon may easily be charged to several thousand volts. Does that mean it has several thousand joules of energy? Explain.

10.5 Voltage Sources

15. What condition is necessary for heat energy to flow from one end of a metal bar to the other? For electric charge to flow?
16. What condition is necessary for a sustained flow of electric charge through a conducting medium?
17. How much energy is given to each coulomb of charge passing through a 6-V battery?

10.6 Electric Current

18. Why do electrons, rather than protons, make up the flow of charge in a metal wire?
19. Does electric charge flow *across* a circuit or *through* a circuit? Does voltage flow *across* a circuit or is it *impressed across* a circuit? Explain.
20. Distinguish between dc and ac.
21. Does a battery produce dc or ac? Does the generator at a power station produce dc or ac?

10.7 Electric Resistance

22. Which has the greater resistance, a thick wire or a thin wire of the same length?
23. What is the unit of electrical resistance?

10.8 Ohm's Law

24. What is the effect on current through a circuit of steady resistance when the voltage is doubled? What if both voltage and resistance are doubled?
25. How much current flows through a radio speaker that has a resistance of 8 V when 12 V is impressed across the speaker?
26. Which has the greater electrical resistance, wet skin or dry skin?
27. High voltage by itself does not produce electric shock. What does?
28. What is the function of the third prong on the plug of an electric appliance?
29. What is the source of electrons that makes a shock when you touch a charged conductor?

10.9 Electric Circuits

30. What is an electric circuit, and what is the effect of a gap in such a circuit?
31. In a circuit consisting of two lamps connected in series, if the current in one lamp is 1 A, what is the current in the other lamp?
32. If 6 V were impressed across the circuit in question 31, and the voltage across the first lamp were 2 V, what would be the voltage across the second lamp?
33. In a circuit consisting of two lamps connected in parallel, if there is 6 V across one lamp, what is the voltage across the other lamp?
34. If the current through each of the two branches of a parallel circuit is the same, what does this tell you about the resistance of the two branches?
35. How does the total current through the branches of a parallel circuit compare with the current through the voltage source?
36. As more lines are opened at a fast-food restaurant, the resistance to the motion of people trying to get served is reduced. How is this similar to what happens when more branches are added to a parallel circuit?
37. Are household circuits normally wired in series or in parallel?
38. Why will too many electrical devices operating at one time often blow a fuse?

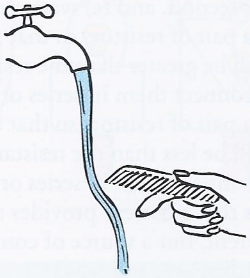
10.10 Electric Power

39. What is the relationship among electric power, current, and voltage?
40. Which draws more current, a 40-W bulb or a 100-W bulb?

ACTIVE EXPLORATIONS

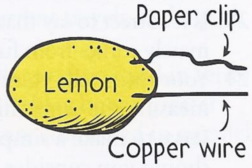
1. Write a letter to your favorite uncle and bring him up to speed on your progress with physics. Relate the greater number of terms in this chapter, and how learning to distinguish among them contributes to your understanding. Select four of the terms and discuss them. Relate the terms to practical examples.
2. Demonstrate charging by friction and discharging from points with a friend who stands at the far end of a carpeted room. With leather shoes, scuff your way across the rug until your noses are close together. This can be a delightfully tingling experience, depending on how dry the air is and how pointed your noses are.

3. Briskly rub a comb against your hair or a woolen garment and bring it near a small but smooth stream of running water. Is the stream of water charged? (Before you say yes, note the behavior of the stream when an opposite charge is brought nearby.)



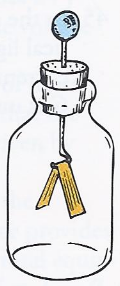
4. An electric cell is made by placing two plates of different materials that have different affinities for electrons in a conducting solution. You can make a simple 1.5-V cell by placing a strip of copper and a strip of zinc in a tumbler of saltwater. The voltage of a cell depends on the materials used and the solution they are placed in, not the size of the plates. A battery is actually a series of cells.

An easy cell to construct is the citrus cell. Stick a paper clip and a piece of copper wire into a lemon. Hold the ends of the wire close together, but not touching, and place the ends on your tongue. The slight tingle you feel and the metallic taste you experience result from a slight current of electricity pushed by the citrus cell through the wires when your moist tongue closes the circuit.



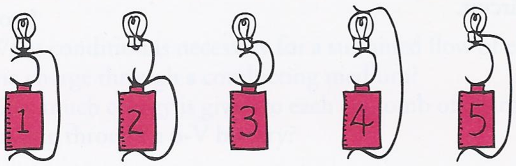
EXERCISES

1. We do not feel the gravitational forces between ourselves and the objects around us because these forces are extremely small. Electrical forces, in comparison, are extremely huge. Since we and the objects around us are composed of charged particles, why don't we usually feel electrical forces?
2. With respect to forces, how are electric charge and mass alike? How are they different?
3. When combing your hair, you scuff electrons from your hair onto the comb. Is your hair then positively or negatively charged? How about the comb?
4. An electroscope is a simple device consisting of a metal ball that is attached by a conductor to two thin leaves of metal foil protected from air disturbances in a jar, as shown. When the ball is touched by a charged body, the leaves that normally hang straight down spread apart. Why? (Electroscopes are useful not only as charge detectors but also for measuring the quantity of charge: the greater the charge transferred to the ball, the more the leaves diverge.)

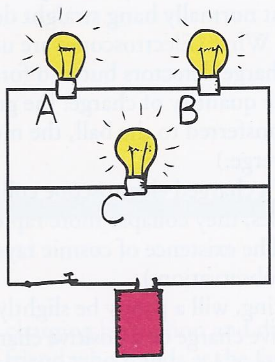


5. The leaves of a charged electroscope collapse in time. At higher altitudes, they collapse more rapidly. Why is this true? (Hint: The existence of cosmic rays was first indicated by this observation.)
6. Strictly speaking, will a penny be slightly more massive if it has a negative charge or a positive charge? Explain.
7. When one material is rubbed against another, electrons jump readily from one to the other, but protons do not. Why is this? (Think in atomic terms.)
8. If electrons were positive and protons were negative, would Coulomb's law be written the same or differently?
9. The five thousand billion billion freely moving electrons in a penny repel one another. Why don't they fly out of the penny?
10. Two equal charges exert equal forces on each other. What if one charge has twice the magnitude of the other? How do the forces they exert on each other compare?
11. How does the magnitude of electric force compare with the charge between a pair of charged particles when they are brought to half their original distance of separation? To one-quarter their original distance? To four times their original distance? (What law guides your answers?)
12. Suppose that the strength of the electric field about an isolated point charge has a certain value at a distance of 1 m. How will the electric field strength compare at a distance of 2 m from the point charge? What law guides your answer?
13. Why is a good conductor of electricity also a good conductor of heat?
14. When a car is moved into a painting chamber, a mist of paint is sprayed around it. When the body of the car is given a sudden electric charge and the mist of paint is attracted to it, presto—the car is quickly and uniformly painted. What does the phenomenon of polarization have to do with this?
15. If you place a free electron and a free proton in the same electric field, how will the forces acting on them compare? How will their accelerations compare? Their directions of travel?
16. If you put in 10 joules of work to push 1 coulomb of charge against an electric field, what will be its voltage with respect to its starting position? When released, what will be its kinetic energy if it flies past its starting position?
17. What is the voltage at the location of a 0.0001 C charge that has an electric potential energy of 0.5 J (both voltage and potential relative to the same reference point)?

18. What happens to the brightness of light emitted by a lightbulb when the current in it increases?
19. One example of a water system is a garden hose that waters a garden. Another is the cooling system of an automobile. Which of these exhibits behavior more analogous to that of an electric circuit? Why?
20. Is it correct to say that the energy from a car battery ultimately comes from fuel in the gas tank? Defend your answer.
21. Your tutor tells you that an ampere and a volt really measure the same thing, and the different terms only serve to make a simple concept seem confusing. Why should you consider getting a different tutor?
22. In which of the circuits below does a current exist to light the bulb?

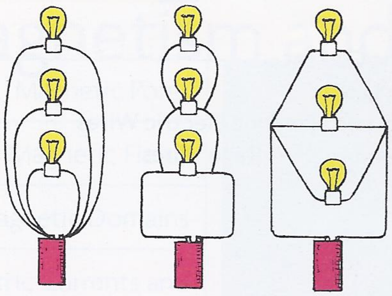


23. Does more current flow out of a battery than into it? Does more current flow into a lightbulb than out of it? Explain.
24. Sometimes you hear someone say that a particular appliance "uses up" electricity. What is it that the appliance actually consumes, and what becomes of it?
25. A simple lie detector consists of an electric circuit, one part of which is part of your body, such as having wires connected to two of your fingers so that your hand is part of the circuit. A sensitive meter shows the current that flows when a small voltage is applied. How does this technique indicate that a person is lying? (And when does this technique not indicate when someone is lying?)
26. Only a small percentage of the electric energy fed into a common lightbulb is transformed into light. What happens to the rest?
27. Will a lamp with a thick filament draw more current or less current than a lamp with a thin filament?
28. A 1-mile-long copper wire has a resistance of 10 ohms. What will be its new resistance when it is shortened by (a) cutting it in half or by (b) doubling it over and using it as if it were one wire of half the length but twice the cross-sectional area?
29. Will the current in a lightbulb connected to a 220-V source be greater or less than that in the same bulb when it is connected to a 110-V source?
30. Which will do less damage—plugging a 110-V appliance into a 220-V circuit or plugging a 220-V appliance into a 110-V circuit? Explain.
31. If a current of one- or two-tenths of an ampere were to flow into one of your hands and out the other, you would probably be electrocuted. But, if the same current were to flow into your hand and out the elbow above the same hand, you could survive, even though the current might be large enough to burn your flesh. Explain.
32. Would you expect to find dc or ac in the filament of a lightbulb in your home? How about in the headlight of an automobile?
33. Are automobile headlights wired in parallel or in series? What is your evidence?
34. A car's headlights dissipate 40 W on low beam and 50 W on high beam. Is there more or less resistance in the high-beam filament?
35. What unit is represented by (a) joule per coulomb, (b) coulomb per second, and (c) watt-second?
36. To connect a pair of resistors so that their equivalent resistance will be greater than the resistance of either one, should you connect them in series or in parallel?
37. To connect a pair of resistors so that their equivalent resistance will be less than the resistance of either one, should you connect them in series or in parallel?
38. A friend says that a battery provides not a source of constant current, but a source of constant voltage. Do you agree or disagree, and why?
39. A friend says that adding bulbs in series to a circuit provides more obstacles to the flow of charge, so there is less current with more bulbs. However, she also says that adding bulbs in parallel provides more paths so more current can flow. Do you agree or disagree, and why?
40. Why might the wingspans of birds be a consideration in determining the spacing between parallel wires on power poles?
41. Estimate the number of electrons that a power company delivers annually to the homes of a typical city of 50,000 people.
42. If electrons flow very slowly through a circuit, why doesn't it take a noticeably long time for a lamp to glow when you turn on a distant switch?
43. Consider a pair of flashlight bulbs connected to a battery. Will they glow brighter if they are connected in series or in parallel? Will the battery run down faster if they are connected in series or in parallel?
44. If several bulbs are connected in series to a battery, they may feel warm to the touch even though they are not visibly glowing. What is your explanation?
45. In the circuit shown, how do the brightnesses of the identical lightbulbs compare? Which lightbulb draws the most current? What will happen if bulb A is unscrewed? If bulb C is unscrewed?



46. As more and more bulbs are connected in series to a flashlight battery, what happens to the brightness of each bulb? Assuming that the heating inside the battery is negligible, what happens to the brightness of each bulb when more and more bulbs are connected in parallel?

47. Are these circuits equivalent to one another? Why or why not?



48. A battery has internal resistance, so, if the current it supplies goes up, the voltage it supplies goes down. If too many bulbs are connected in parallel across a battery, will their brightness diminish? Explain.
49. Your friend says that electric current takes the path of least resistance. Why is it more accurate in the case of a parallel circuit to say that *most* current travels in the path of least resistance?
50. If a 60-W bulb and a 100-W bulb are connected in series in a circuit, across which bulb will there be the greater voltage drop? How about if they are connected in parallel?

PROBLEMS

● **BEGINNER** ■ **INTERMEDIATE** ◆ **EXPERT**

1. ● Two pellets, each with a charge of 1 microcoulomb (10^{-6} C), are located 3 cm (0.03 m) apart. Show that the electric force between them is 10 N.
2. ● Two point charges are separated by 6 cm. The attractive force between them is 20 N. Show that when they are separated by 12 cm the force between them is 5 N. (Why can you solve this problem without knowing the magnitudes of the charges?)
3. ● If the charges attracting each other in the preceding problem have equal magnitudes, show that the magnitude of each charge is 2.8 microcoulombs.
4. ● A droplet of ink in an industrial ink-jet printer carries a charge of 1.6×10^{-10} C and is deflected onto paper by a force of 3.2×10^{-4} N. Show that the strength of the electric field required to produce this force is 2×10^{-6} N/C.
5. ● When an electric field does 12 J of work on a charge of 0.0001 C, (a) show that the change in voltage is 120,000 V. (b) When the same electric field does 24 J of work on a charge of 0.0002 C, show that the voltage change is the same.
6. ■ The current driven by voltage V in a circuit of resistance R is given by Ohm's law, $I = V/R$. Show that the resistance of a circuit carrying current I and driven by voltage V is given by the equation $R = V/I$.
7. ■ The same voltage V is impressed on each of the branches of a parallel circuit. The voltage source provides a total current I_{total} to the circuit, and "sees" a total equivalent resistance of R_{eq} in the circuit. That is, $V = I_{\text{total}} R_{\text{eq}}$ The total current is equal to the sum of the currents through each branch of the parallel circuit. In a circuit with n branches, $I_{\text{total}} = I_1 + I_2 + I_3 \ldots I_n$. Use Ohm's law ($I = V/R$) and show that the equivalent resistance of a parallel circuit with n branches is given by

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots + \frac{1}{R_n}$$

8. ● The wattage marked on a light bulb is not an inherent property of the bulb; rather, it depends on the voltage to which it is connected, usually 110 or 120 V. Show that the current in a 60-W bulb connected in a 120-V circuit is 0.5 A.
9. ● Rearrange the equation current = voltage/resistance to express *resistance* in terms of current and voltage. Then consider the following: a certain device in a 120-V circuit has a current rating of 20 A. Show that the resistance of the device is 6 Ω.
10. ● Using the formula Power = current × voltage, show that the current drawn by a 1200-W hair dryer connected to 120 V is 10 A. Then using your same method for the solution to the previous problem, show that the resistance of the hair dryer is 12 Ω.
11. ■ The power in an electric circuit is given by the equation $P = IV$. Use Ohm's law to express V and show that power can be expressed by the equation $P = I^2R$.
12. ■ The total charge that an automobile battery can supply without being recharged is given in terms of ampere-hours. A typical 12-V battery has a rating of 60 ampere-hours (60 A for 1 h, 30 A for 2 h, and so on). Suppose that you forget to turn off the headlights in your parked automobile. If each of the two headlights draws 3 A, show that your battery will be dead in about 10 hours.
13. ■ Suppose you operate a 100-W lamp continuously for 1 week when the power utility rate is 20¢/kWh. Show that this will cost you $3.36.
14. ■ An electric iron connected to a 110-V source draws 9 A of current. Show that the amount of heat generated in 1 minute is almost 60 kJ.
15. ■ For the electric iron of the previous problem, show that the number of coulombs that flow through it in 1 minute is 540 C.
16. ◆ A certain lightbulb with a resistance of 95 ohms is labeled "150 W." Was this bulb designed for use in a 120-V circuit or a 220-V circuit?
17. ◆ In periods of peak demand, power companies lower their voltage. This saves them power (and saves you money)! To see the effect, consider a 1200-W toaster that draws 10 A when connected to 120 V. Suppose the voltage is lowered by 10 percent to 108 V. By how much does the current decrease? By how much does the power decrease? (Caution: The 1200-W label is valid only when 120 V is applied. When the voltage is lowered, it is the resistance of the toaster, not its power, that remains constant.)