***University Physics Volume II***

**Unit 2: Electricity and Magnetism**

**Chapter 9: Current and Resistance**

**Conceptual Questions**

1. Can a wire carry a current and still be neutral—that is, have a total charge of zero? Explain.

Solution

If a wire is carrying a current, charges enter the wire from the voltage source’s positive terminal and leave at the negative terminal, so the total charge remains zero while the current flows through it.

1. Car batteries are rated in ampere-hours (). To what physical quantity do ampere-hours correspond (voltage, current, charge, energy, power,…)?

Solution

() is a measure of charge.

1. When working with high-power electric circuits, it is advised that whenever possible, you work “one-handed” or “keep one hand in your pocket.” Why is this a sensible suggestion?

Solution

Using one hand will reduce the possibility of “completing the circuit” and having current run through your body, especially current running through your heart.

1. Incandescent light bulbs are being replaced with more efficient LED and CFL light bulbs. Is there any obvious evidence that incandescent light bulbs might not be that energy efficient? Is energy converted into anything but visible light?

Solution

An incandescent light bulb gives off both light and heat. Since the purpose of the light bulb is to supply light, the fact that heat is also produced means that all the energy is not being used to produce light and the bulb may not be very efficient at producing light.

1. It was stated that the motion of an electron appears nearly random when an electrical field is applied to the conductor. What makes the motion nearly random and differentiates it from the random motion of molecules in a gas?

Solution

Even though the electrons collide with atoms and other electrons in the wire, they travel from the negative terminal to the positive terminal, so they drift in one direction. Gas molecules travel in completely random directions.

1. Electric circuits are sometimes explained using a conceptual model of water flowing through a pipe. In this conceptual model, the voltage source is represented as a pump that pumps water through pipes and the pipes connect components in the circuit. Is a conceptual model of water flowing through a pipe an adequate representation of the circuit? How are electrons and wires similar to water molecules and pipes? How are they different?

Solution

Water is pumped into the pipe, much like electrons are “pumped” into a circuit by a battery or another voltage source. Unlike water in a pipe, the flow of charges require a complete circuit. If the end of the pipe filled with water, the water spills out, but if the wire is not connected to anything, the charges do not spill out.

1. An incandescent light bulb is partially evacuated. Why do you suppose that is?

Solution

In the early years of light bulbs, the bulbs are partially evacuated to reduce the amount of heat conducted through the air to the glass envelope. Dissipating the heat would cool the filament, increasing the amount of energy needed to produce light from the filament. It also protects the glass from the heat produced from the hot filament. If the glass heats, it expands, and as it cools, it contacts. This expansion and contraction could cause the glass to become brittle and crack, reducing the life of the bulbs. Many bulbs are now partially filled with an inert gas. It is also useful to remove the oxygen to reduce the possibility of the filament actually burning. When the original filaments were replaced with more efficient tungsten filaments, atoms from the tungsten would evaporate off the filament at such high temperatures. The atoms collide with the atoms of the inert gas and land back on the filament.

1. The *IR* drop across a resistor means that there is a change in potential or voltage across the resistor. Is there any change in current as it passes through a resistor? Explain.

Solution

If the change in voltage is constant, then the current is constant and is equal to .

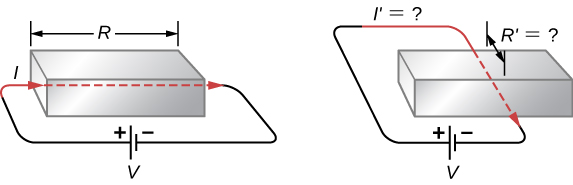
1. Do impurities in semiconducting materials listed in the table below supply free charges? (*Hint*: Examine the range of resistivity for each and determine whether the pure semiconductor has the higher or lower conductivity.)

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Conductivity, | Resistivity, | Temperature  Coefficient, |
| *Conductors* |  |  |  |
| Silver |  |  | 0.0038 |
| Copper |  |  | 0.0039 |
| Gold |  |  | 0.0034 |
| Aluminum |  |  | 0.0039 |
| Tungsten |  |  | 0.0045 |
| Iron |  |  | 0.0065 |
| Platinum |  |  | 0.0039 |
| Steel |  |  |  |
| Lead |  |  |  |
| Manganin (Cu, Mn, Ni alloy) |  |  | 0.000002 |
| Constantan (Cu, Ni alloy) |  |  | 0.00003 |
| Mercury |  |  | 0.0009 |
| Nichrome (Ni, Fe, Cr alloy) |  |  | 0.0004 |
| *Semiconductors*[1] |  |  |  |
| Carbon (pure) |  |  | –0.0005 |
| Carbon |  |  | –0.0005 |
| Germanium (pure) |  |  | –0.048 |
| Germanium |  |  | –0.050 |
| Silicon (pure) |  | 2300 | –0.075 |
| Silicon |  | 0.1 – 2300 | –0.07 |
| *Insulators* |  |  |  |
| Amber |  |  |  |
| Glass |  |  |  |
| Lucite |  |  |  |
| Mica |  |  |  |
| Quartz (fused) |  |  |  |
| Rubber (hard) |  |  |  |
| Sulfur |  |  |  |
| TeflonTM |  |  |  |
| Wood |  |  |  |

Solution

In carbon, resistivity increases with the amount of impurities, meaning fewer free charges. In silicon and germanium, impurities decrease resistivity, meaning more free electrons.

1. Does the resistance of an object depend on the path current takes through it? Consider, for example, a rectangular bar—is its resistance the same along its length as across its width?



Solution

Resistance is equal to , so if the increase in *L* is larger than the increase in *A*, the resistance will increase.

1. If aluminum and copper wires of the same length have the same resistance, which has the larger diameter? Why?

Solution

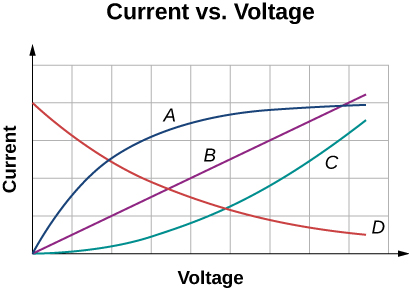
Copper has a lower resistivity than aluminum, so if length is the same, copper must have the smaller diameter.

1. In Determining Field from Potential, resistance was defined as  In this section, we presented Ohm’s law, which is commonly expressed as  The equations look exactly alike. What is the difference between Ohm’s law and the definition of resistance?

Solution

Ohm’s law expresses the relationship between voltage and current for an ohmic device. The resistance of a device can be defined even if the device is nonohmic.

1. Shown below are the results of an experiment where four devices were connected across a variable voltage source. The voltage is increased and the current is measured. Which device, if any, is an ohmic device?



Solution

Device *B* shows a linear relationship and the device is ohmic.

1. The current *I* is measured through a sample of an ohmic material as a voltage *V* is applied. (a) What is the current when the voltage is doubled to 2*V* (assume the change in temperature of the material is negligible)? (b) What is the voltage applied is the current measured is 0.2*I* (assume the change in temperature of the material is negligible)? What will happen to the current if the material if the voltage remains constant, but the temperature of the material increases significantly?

Solution

a. The current is 2*I*. b. The voltage is 0.2*V*. It depends on the material. If the material has a negative temperature coefficient, the current will increase because the resistance will decrease. If the material has a positive temperature coefficient, the current will decrease because the resistance will increase.

1. Common household appliances are rated at 110 V, but power companies deliver voltage in the kilovolt range and then step the voltage down using transformers to 110 V to be used in homes. You will learn in later chapters that transformers consist of many turns of wire, which warm up as current flows through them, wasting some of the energy that is given off as heat. This sounds inefficient. Why do the power companies transport electric power using this method?

Solution

Although the conductors have a low resistance, the lines from the power company can be kilometers long. Using a high voltage reduces the current that is required to supply the power demand and that reduces line losses.

1. Your electric bill gives your consumption in units of kilowatt-hour (kWh). Does this unit represent the amount of charge, current, voltage, power, or energy you buy?

Solution

The unit is a unit of energy, power times time.

1. Resistors are commonly rated at , ,, 1 W and 2 W for use in electrical circuits. If a current of  is accidentally passed through a  resistor rated at 1 W, what would be the most probable outcome? Is there anything that can be done to prevent such an accident?

Solution

The resistor would overheat, possibly to the point of causing the resistor to burn. Fuses are commonly added to circuits to prevent such accidents.

1. An immersion heater is a small appliance used to heat a cup of water for tea by passing current through a resistor. If the voltage applied to the appliance is doubled, will the time required to heat the water change? By how much? Is this a good idea?

Solution

The heat supplied to the water equals  , so the time required is  If the voltage is doubled, the time required will be quartered. Probably not a good idea, since the device is rated for a specific power and could possibly burn up.

1. What requirement for superconductivity makes current superconducting devices expensive to operate?

Solution

Very low temperatures necessitate refrigeration. Some materials require liquid nitrogen to cool them below their critical temperatures. Other materials may need liquid helium, which is even more costly.

1. Name two applications for superconductivity listed in this section and explain how superconductivity is used in the application. Can you think of a use for superconductivity that is not listed?

Solution

Superconducting magnets are used that are up to 10 times stronger than regular electromagnets. Another is a SQUID, used in the detection of very weak magnetic fields. Maglev trains in Japan have used Type II superconducting material for rails to levitate trains with permanent magnets. A use could also be found by using a loop of superconducting material as a replacement for a battery. This would have the advantage of not degrading in capacity over time or leaking charge away.

**Problems**

1. A Van de Graaff generator is one of the original particle accelerators and can be used to accelerate charged particles like protons or electrons. You may have seen it used to make human hair stand on end or produce large sparks. One application of the Van de Graaff generator is to create X-rays by bombarding a hard metal target with the beam. Consider a beam of protons at 1.00 keV and a current of 5.00 mA produced by the generator. (a) What is the speed of the protons? (b) How many protons are produced each second?

Solution

a.

b.

1. A cathode ray tube (CRT) is a device that produces a focused beam of electrons in a vacuum. The electrons strike a phosphor-coated glass screen at the end of the tube, which produces a bright spot of light. The position of the bright spot of light on the screen can be adjusted by deflecting the electrons with electrical fields, magnetic fields, or both. Although the CRT tube was once commonly found in televisions, computer displays, and oscilloscopes, newer appliances use a liquid crystal display (LCD) or plasma screen. You still may come across a CRT in your study of science. Consider a CRT with an electron beam average current of  How many electrons strike the screen every minute?

Solution



1. How many electrons flow through a point in a wire in 3.00 s if there is a constant current of

Solution





1. A conductor carries a current that is decreasing exponentially with time. The current is modeled as  where  is the current at time  and  is the time constant. How much charge flows through the conductor between  and ?

Solution



1. The quantity of charge through a conductor is modeled as 

What is the current at time 

Solution



1. The current through a conductor is modeled as . Write an equation for the charge as a function of time.

Solution



1. The charge on a capacitor in a circuit is modeled as . What is the current through the circuit as a function of time?

Solution



1. An aluminum wire 1.628 mm in diameter (14-gauge) carries a current of 3.00 amps. (a) What is the absolute value of the charge density in the wire? (b) What is the drift velocity of the electrons? (c) What would be the drift velocity if the same gauge copper were used instead of aluminum? The density of copper is  and the density of aluminum is  The molar mass of aluminum is 26.98 g/mol and the molar mass of copper is 63.5 g/mol. Assume each atom of metal contributes one free electron.

Solution

a.

b.

c. 



1. The current of an electron beam has a measured current of  with a radius of . What is the magnitude of the current density of the beam?

Solution



1. A high-energy proton accelerator produces a proton beam with a radius of  The beam current is  and is constant. The charge density of the beam is  protons per cubic meter. (a) What is the current density of the beam? (b) What is the drift velocity of the beam? (c) How much time does it take for  protons to be emitted by the accelerator?

Solution

a. , ;

b. 

c. 

1. Consider a wire of a circular cross-section with a radius of  The magnitude of the current density is modeled as  What is the current through the inner section of the wire from the center to 

Solution



1. A cylindrical wire has a current density from the center of the wire’s cross section as where *r* is in meters, *J* is in amps per square meter and . This current density continues to the end of the wire at a radius of 1.0 mm. Calculate the current just outside of this wire.

Solution

1.6 nA

1. The current supplied to an air conditioner unit is 4.00 amps. The air conditioner is wired using a 10-gauge (diameter 2.588 mm) wire. The charge density is  Find the magnitude of (a) current density and (b) the drift velocity.

Solution

a. ; b. 

1. What current flows through the bulb of a 3.00-V flashlight when its hot resistance is ?

Solution



1. Calculate the effective resistance of a pocket calculator that has a 1.35-V battery and through which 0.200 mA flows.

Solution



1. How many volts are supplied to operate an indicator light on a DVD player that has a resistance of , given that 25.0 mA passes through it?

Solution



1. What is the resistance of a 20.0-m-long piece of 12-gauge copper wire having a 2.053-mm diameter?

Solution



1. The diameter of 0-gauge copper wire is 8.252 mm. Find the resistance of a 1.00-km length of such wire used for power transmission.

Solution



1. If the 0.100-mm-diameter tungsten filament in a light bulb is to have a resistance of  at , how long should it be?

Solution



1. A lead rod has a length of 30.00 cm and a resistance of What is the radius of the rod?

Solution



1. Find the ratio of the diameter of aluminum to copper wire, if they have the same resistance per unit length (as they might in household wiring).

Solution



1. What current flows through a 2.54-cm-diameter rod of pure silicon that is 20.0 cm long, when  is applied to it? (Such a rod may be used to make nuclear-particle detectors, for example.)

Solution



1. (a) To what temperature must you raise a copper wire, originally at , to double its resistance, neglecting any changes in dimensions? (b) Does this happen in household wiring under ordinary circumstances?

Solution

a. ;

b. Under normal conditions, no it should not occur.

1. A resistor made of nichrome wire is used in an application where its resistance cannot change more than 1.00% from its value at . Over what temperature range can it be used?

Solution



1. Of what material is a resistor made if its resistance is 40.0% greater at  than at ?

Solution

, iron

1. An electronic device designed to operate at any temperature in the range from  to  contains pure carbon resistors. By what factor does their resistance increase over this range?

Solution



1. (a) Of what material is a wire made, if it is 25.0 m long with a diameter of 0.100 mm and has a resistance of  at ? (b) What is its resistance at ?

Solution

a. , gold;



1. Assuming a constant temperature coefficient of resistivity, what is the maximum percent decrease in the resistance of a constantan wire starting at ?

Solution

, max percent decrease 1%

1. A copper wire has a resistance of  at , and an iron wire has a resistance of  at the same temperature. At what temperature are their resistances equal?

Solution



1. A  resistor is connected across a D cell battery (1.5 V). What is the current through the resistor?

Solution



1. A resistor rated at  is connected across two D cell batteries (each 1.50 V) in series, with a total voltage of 3.00 V. The manufacturer advertises that their resistors are within 5% of the rated value. What are the possible minimum current and maximum current through the resistor?

Solution

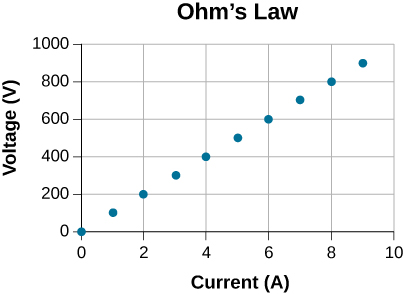


1. A resistor is connected in series with a power supply of 20.00 V. The current measure is 0.50 A. What is the resistance of the resistor?

Solution



1. A resistor is placed in a circuit with an adjustable voltage source. The voltage across and the current through the resistor and the measurements are shown below. Estimate the resistance of the resistor.



Solution



1. The following table show the measurements of a current through and the voltage across a sample of material. Plot the data, and assuming the object is an ohmic device, estimate the resistance.

|  |  |
| --- | --- |
| *I*(A) | *V*(V) |
| 0 | 3 |
| 2 | 23 |
| 4 | 39 |
| 6 | 58 |
| 8 | 77 |
| 10 | 100 |
| 12 | 119 |
| 14 | 142 |
| 16 | 162 |

Solution



1. A  battery is used to supply current to a  resistor. Assume the voltage drop across any wires used for connections is negligible. (a) What is the current through the resistor? (b) What is the power dissipated by the resistor? (c) What is the power input from the battery, assuming all the electrical power is dissipated by the resistor? (d) What happens to the energy dissipated by the resistor?

Solution

a. ;

b. ;

c. ; d. It is converted into heat.

1. What is the maximum voltage that can be applied to a  resistor rated at 

Solution



1. A heater is being designed that uses a coil of 14-gauge nichrome wire to generate 300 W using a voltage of  How long should the engineer make the wire?

Solution

 , 

1. An alternative to CFL bulbs and incandescent bulbs are light-emitting diode (LED) bulbs. A 100-W incandescent bulb can be replaced by a 16-W LED bulb. Both produce 1600 lumens of light. Assuming the cost of electricity is $0.10 per kilowatt-hour, how much does it cost to run the bulb for one year if it runs for four hours a day?

Solution



1. The power dissipated by a resistor with a resistance of  is  What are the current through and the voltage drop across the resistor?

Solution



1. Running late to catch a plane, a driver accidentally leaves the headlights on after parking the car in the airport parking lot. During takeoff, the driver realizes the mistake. Having just replaced the battery, the driver knows that the battery is a 12-V automobile battery, rated at 100  The driver, knowing there is nothing that can be done, estimates how long the lights will shine, assuming there are two 12-V headlights, each rated at 40 W. What did the driver conclude?

Solution



1. A physics student has a single-occupancy dorm room. The student has a small refrigerator that runs with a current of 3.00 A and a voltage of 110 V, a lamp that contains a 100-W bulb, an overhead light with a 60-W bulb, and various other small devices adding up to 3.00 W. (a) Assuming the power plant that supplies 110 V electricity to the dorm is 10 km away and the two aluminum transmission cables use 0-gauge wire with a diameter of 8.252 mm, estimate the percentage of the total power supplied by the power company that is lost in the transmission. (b) What would be the result is the power company delivered the electric power at 110 kV?

Solution

a. ,

b. 

1. A 0.50-W,  resistor carries the maximum current possible without damaging the resistor. If the current were reduced to half the value, what would be the power consumed?

Solution



1. Consider a power plant is located 60 km away from a residential area uses 0-gauge  wire of copper to transmit power at a current of  How much more power is dissipated in the copper wires than it would be in superconducting wires?

Solution



1. A wire is drawn through a die, stretching it to four times its original length. By what factor does its resistance increase?

Solution



1. Digital medical thermometers determine temperature by measuring the resistance of a semiconductor device called a thermistor (which has ) when it is at the same temperature as the patient. What is a patient’s temperature if the thermistor’s resistance

at that temperature is 82.0% of its value at  (normal body temperature)?

Solution



1. Electrical power generators are sometimes “load tested” by passing current through a large vat of water. A similar method can be used to test the heat output of a resistor. A  resistor is connected to a 9.0-V battery and the resistor leads are waterproofed and the resistor is placed in 1.0 kg of room temperature water . Current runs through the resistor for 20 minutes. Assuming all the electrical energy dissipated by the resistor is converted to heat, what is the final temperature of the water?

Solution



1. A 12-guage gold wire has a length of 1 meter. (a) What would be the length of a silver 12-gauge wire with the same resistance? (b) What are their respective resistances at the temperature of boiling water?

Solution

a. ;

b. 

1. What is the change in temperature required to decrease the resistance for a carbon resistor by 10%?

Solution



**Additional Problems**

1. A coaxial cable consists of an inner conductor with radius  and an outer radius of  and has a length of 10 meters. Plastic, with a resistivity of separates the two conductors. What is the resistance of the cable?

Solution



1. A 10.00-meter long wire cable that is made of copper has a resistance of 0.051 ohms. (a) What is the weight if the wire was made of copper? (b) What is the weight of a 10.00-meter-long wire of the same gauge made of aluminum? (c)What is the resistance of the aluminum wire? The density of copper is  and the density of aluminum is 

Solution

a. ;

b. ; c. 

1. A nichrome rod that is 3.00 mm long with a cross-sectional area of  is used for a digital thermometer. (a) What is the resistance at room temperature? (b) What is the resistance at body temperature?

Solution

a. ;

b. 

1. The temperature in Philadelphia, PA can vary between  and  in one summer day. By what percentage will an aluminum wire’s resistance change during the day?

Solution

,



1. When 100.0 V is applied across a 5-gauge (diameter 4.621 mm) wire that is 10 m long, the magnitude of the current density is . What is the resistivity of the wire?

Solution



1. A wire with a resistance of  is drawn out through a die so that its new length is twice times its original length. Find the resistance of the longer wire. You may assume that the resistivity and density of the material are unchanged.

Solution



1. What is the resistivity of a wire of 5-gauge wire (), 5.00 m length, and  resistance?

Solution



1. Coils are often used in electrical and electronic circuits. Consider a coil which is formed by winding 1000 turns of insulated 20-gauge copper wire (area ) in a single layer on a cylindrical non-conducting core of radius 2.0 mm. What is the resistance of the coil? Neglect the thickness of the insulation.

Solution



1. Currents of approximately 0.06 A can be potentially fatal. Currents in that range can make the heart fibrillate (beat in an uncontrolled manner). The resistance of a dry human body can be approximately . (a) What voltage can cause 0.06 A through a dry human body? (b) When a human body is wet, the resistance can fall to . What voltage can cause harm to a wet body?

Solution

a. ; b. 

1. A 20.00-ohm, 5.00-watt resistor is placed in series with a power supply. (a) What is the maximum voltage that can be applied to the resistor without harming the resistor? (b) What would be the current through the resistor?

Solution



1. A battery with an emf of 24.00 V delivers a constant current of 2.00 mA to an appliance. How much work does the battery do in three minutes?

Solution



1. A 12.00-V battery has an internal resistance of a tenth of an ohm. (a) What is the current if the battery terminals are momentarily shorted together? (b) What is the terminal voltage if the battery delivers 0.25 amps to a circuit?

Solution

a. ; b. 

**Challenge Problems**

1. A 10-gauge copper wire has a cross-sectional area  and carries a current of  The density of copper is  One mole of copper atoms  has a mass of approximately 63.50 g. What is the magnitude of the drift velocity of the electrons, assuming that each copper atom contributes one free electron to the current?

Solution



1. The current through a 12-gauge wire is given as  What is the current density at time 15.00 ms?

Solution



1. A particle accelerator produces a beam with a radius of 1.25 mm with a current of 2.00 mA. Each proton has a kinetic energy of 10.00 MeV. (a) What is the velocity of the protons? (b) What is the number (*n*) of protons per unit volume? (b) How many electrons pass a cross sectional area each second?

Solution

a. ;

b. 

c. 

1. In this chapter, most examples and problems involved direct current (DC). DC circuits have the current flowing in one direction, from positive to negative. When the current was changing, it was changed linearly from  to  and the voltage changed linearly from  to , where . Suppose a voltage source is placed in series with a resistor of  that supplied a current that alternated as a sine wave, for example, . (a) What would a graph of the voltage drop across the resistor *V*(*t*)versus time look like? (b) What would a plot of *V*(*t*) versus *I*(*t*) for one period look like? (*Hint*: If you are not sure, try plotting *V*(*t*) versus *I*(*t*) using a spreadsheet.)

Solution

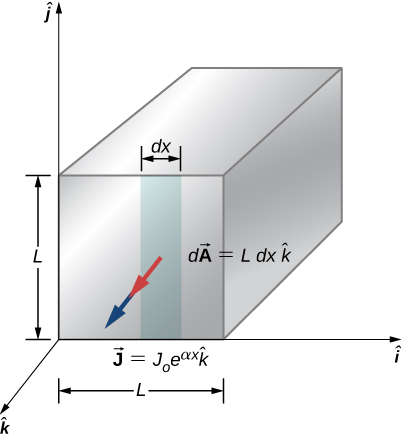
a. A plot of *V*(*t*) versus *t* would be a sine wave with a period of  with a maximum voltage of . b. A plot of *V*(*t*) versus *I*(*t*) would be a line that starts at  and ends at  with a slope of .

1. A current of  is drawn from a 100-V battery for 30 seconds. By how much is the chemical energy reduced?

Solution



1. Consider a square rod of material with sides of length  with a current density of  as shown below. Find the current that passes through the face of the rod.



Solution



1. A resistor of an unknown resistance is placed in an insulated container filled with 0.75 kg of water. A voltage source is connected in series with the resistor and a current of 1.2 amps flows through the resistor for 10 minutes. During this time, the temperature of the water is measured and the temperature change during this time is  (a) What is the resistance of the resistor? (b) What is the voltage supplied by the power supply?

Solution

a.  ; b. 

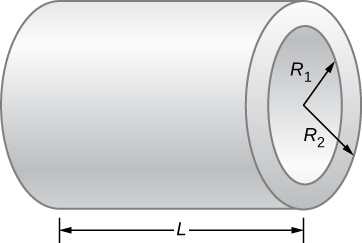
1. The charge that flows through a point in a wire as a function of time is modeled as  (a) What is the initial current through the wire at time *t* = 0.00 s? (b) Find the current at time  (c) At what time t will the current be reduced by one-half 

Solution

a. 2.00A; b. ;

c. 

1. Consider a resistor made from a hollow cylinder of carbon as shown below. The inner radius of the cylinder is  and the outer radius is . The length of the resistor is . The resistivity of the carbon is . (a) Prove that the resistance perpendicular from the axis is . (b) What is the resistance?



Solution

a. ; b. 

1. What is the current through a cylindrical wire of radius  if the current density is , where 

Solution



1. A student uses a 100.00-W, 115.00-V radiant heater to heat the student’s dorm room, during the hours between sunset and sunrise, 6:00 p.m. to 7:00 a.m. (a) What current does the heater operate at? (b) How many electrons move through the heater? (c) What is the resistance of the heater? (d) How much heat was added to the dorm room?

Solution

a.  b. 

c.  d. 

1. A 12-V car battery is used to power a 20.00-W, 12.00-V lamp during the physics club camping trip/star party. The cable to the lamp is 2.00 meters long, 14-gauge copper wire with a charge density of . (a) What is the current draw by the lamp? (b) How long would it take an electron to get from the battery to the lamp?

Solution

a. ; b. 

1. A physics student uses a 115.00-V immersion heater to heat 400.00 grams (almost two cups) of water for herbal tea. During the two minutes it takes the water to heat, the physics student becomes bored and decides to figure out the resistance of the heater. The student starts with the assumption that the water is initially at the temperature of the room  and reachesThe specific heat of the water is . What is the resistance of the heater?

Solution



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