Electrostatics

Example 1: Anthea rubs two latex balloons against her hair, causing the balloons to become charged negatively with 2.0×10^{-6} C. She holds them a distance of 0.70 m apart. a) What is the electric force between the two balloons? b) Is it one of attraction or repulsion?

Example 2: Two pieces of puffed rice become equally charged as they are poured out of the box and into Kirk's cereal bowl. If the force between the puffed rice pieces is 4×10^{-23} N when the pieces are 0.03 m apart, what is the charge on each of the pieces?

Example 3: Deepika pulls her wool sweater over her head, which charges her body as the sweater rubs against her cotton shirt. What is the electric field at a location where a 1.60×10^{-19} C-piece of lint experiences a force of 3.2×10^{-9} N as it floats near Deepika? b) What will happen if Deepika now touches a conductor such as a door knob?

Example 4: A fly accumulates 3.0×10^{-10} C of positive charge as it flies through the air. What is the magnitude and direction of the electric field at a location 2.0 cm away from the fly?

Example 5: An electron in Tammie's TV is accelerated toward the screen across a potential difference of 22 000 V. How much kinetic energy does the electron lose when it strikes the TV screen?

Example 6: Amir shuffles his feet across the living room rug, building up a charge on his body. A spark will jump when there is a potential difference of 9000 V between the door and the palm of Amir's hand. This happens when his hand is 0.3 cm from the door. At this point, what is the electric field between Amir's hand and the door?

Additional Exercises

A-1: A raindrop acquires a negative charge of 3.0×10^{-18} C as it falls. What is the force of attraction when the raindrop is 6.0 cm from the bulb on the end of a car antenna that holds a charge of 2.0×10^{-6} C?

A-2: In a grain elevator on Farmer Judd's farm, pieces of grain become electrically charged while falling through the elevator. If one piece of grain is charged with 5.0×10^{-16} C while another holds 2.0×10^{-16} C of charge, what is the electrostatic force between them when they are separated by 0.050 m?

A-3: Rocco, an auto body painter, applies paint to automobiles by electrically charging the car's outer surface and oppositely charging the paint particles that he sprays onto the car. This causes the paint to adhere tightly to the car's surface. If two paint particles of equal charge experience a force of 4.0×10^{-8} N between them at a separation of 0.020 cm, what is the charge on each?

A-4: After unpacking a shipment of laboratory glasswear, Mrs. Payne dumps the box of Styrofoam packing chips into a recycling bin. The chips rub together and two chips 0.015 m apart repel each other with a force of 6.0×10^{-3} N. What is the charge on each of the chips?

A-5: Wiz the cat is batting at two Ping-Pong balls hanging from insulating threads with their sides just barely touching. Each ball acquires a positive charge of 3.5×10^{-9} C from Wiz's fur and they swing apart. a) If a force of 6.0×10^{-5} N acts on one of the balls, how far apart are they from each other? b) Is the force between them one of attraction or repulsion?

A-6: A droplet of ink in an ink-jet printer carrying a charge of 8.0×10^{-13} C is deflected onto the paper by a force of 3.2×10^{-4} N. How strong is the field that causes this force?

A-7: In the human body, nerve cells work by pumping sodium ions out of a cell in order to maintain a potential difference across the cell wall. If a sodium ion carries a charge of 1.60×10^{-19} C as it is pumped with an electrical force of 2.0×10^{-12} N, what is the electric field between the inside and outside of the nerve cell?

A-8: Each of two Van de Graaff generators, whose centers are separated from one another by 0.50 m, becomes charged after they are switched on. One Van de Graaff generator holds $+3.0 \times 10^{-2}$ C while the other holds -2.0×10^{-2} C. What is the magnitude and direction of the electric field halfway between them?

A-9: Willa the witch dusts her crystal ball with her silk scarf, causing the ball to become charged with 5.0×10^{-9} C. Willa then stares into the crystal ball and the wart on the end of her nose experiences an electric field strength of 2200 N/C. How far is the tip of her nose from the center of the crystal ball?

A-10: The Millikan oil drop experiment of 1909 allowed Robert A. Millikan to determine the charge of an electron. In the experiment, an oil drop is suspended between two charged plates by an electric force that equals the gravitational force acting on the 1.1×10^{-14}-kg drop. a) What is the charge on the drop if it remains stationary in an electric field of 1.72×10^{5} N/C? b) How many extra electrons are there on this particular oil drop?

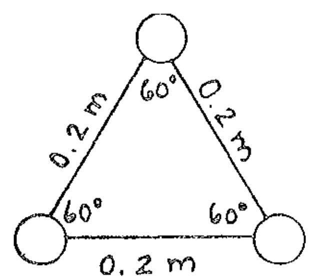
A-11: In eighteenth-century Europe, it was common practice to ring the church bells in an attempt to ward off lightning. However, during one 33-year period, nearly 400 church steeples were struck while the bells were being rung. If a bolt of lightning discharges 30.0 C of charge from a cloud to a steeple across a potential difference of 15 000 V, how much energy is lost by the cloud and gained by the steeple?

A-12: In Exercise A-7, how thick is the wall of the nerve cell if there is a potential difference of 0.089 between the inside and outside of the cell?

A-13: Ulrich stands next to the Van de Graaff generator and gets a shock as he holds his knuckle 0.2 m from the machine. In order for a spark to jump, the electric field strength must be 3×10^{6} V/m. At this distance, what is the potential difference between Ulrich and the generator?

Challenge Exercises for Further Study

B-1: Three glass Christmas balls become electrically charged when Noel removes them from the packaging material in their box. Noel hangs the balls on the tree as shown. If each ornament has acquired a charge of 2.0×10^{-10} C, what is the magnitude and direction of the force experienced by the ball at the top?



B-2: In a TV picture tube, electrons are accelerated from rest up to very high speeds through a potential difference of 22 000 V. At what speed will an electron be moving just as it strikes the TV screen? (In reality you would have to consider the effects of relativity in order to solve this exercise properly; however, ignore such relativistic effects here.)

B-3: A lightning bolt discharges into New Hampshire's Lake Winnipesaukee after passing through a potential difference of 9.00×10^{7} V. What is the minimum amount of charge the lightning bolt could be carrying, if it were to vaporize 1000. kg of water in the lake that was originally at a temperature of 20.0 °C?

Direct Current Circuits

Example 1: Household current in a circuit cannot generally exceed 15 A for safety reasons. What is the maximum amount of charge that could flow through this circuit in a house during the course of a 24.0-h day?

Solution: Because the unit ampere means coulombs per second, 24.0 h must be converted in 86 400 s.

Given: $I = 15\text{ A}$
$\Delta t = 86\,400\text{ s}$

Unknown: $\Delta q = ?$
Original equation: $I = \dfrac{\Delta q}{\Delta t}$

Solve: $\Delta q = I\Delta t = (15\text{ A})(86\,400\text{ s}) = \mathbf{1.3 \times 10^6\ C}$

Example 2: What is the resistance of the heating element in a car lock de-icer that contains a 1.5-V battery supplying a current of 0.5 A to the circuit?

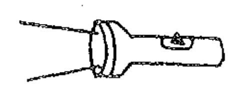
Given: $V = 1.5\text{ V}$
$I = 0.5\text{ A}$

Unknown: $R = ?$
Original equation: $V = IR$

Solve: $R = \dfrac{V}{I} = \dfrac{1.5\text{ V}}{0.5\text{ A}} = \mathbf{3\ \Omega}$

Practice Exercises

Exercise 1: Arthur is going trick-or-treating for Halloween so he puts new batteries in his flashlight before leaving the house. Until the batteries die, it draws 0.500 A of current, allowing a total of 5400. C of charge to flow through the circuit. How long will Arthur be able to use the flashlight before the batteries' energy is depleted?



Exercise 2: Fabian's car radio will run from the 12-V car battery that produces a current of 0.20 A even when the car is turned off. The car battery will no longer operate when it has lost 1.2×10^6 J of energy. If Fabian gets out of the car and leaves the radio on by mistake, how long will it take for the car battery to go completely dead (that is, lose all energy)?

Exercise 3: While cooking dinner, Dinah's oven uses a 220.-V line and draws 8.00 A of current when heated to its maximum temperature. What is the resistance of the oven when it is fully heated?

Exercise 4: Justine's hair dryer has a resistance of 9.00 Ω when first turned on. a) How much current does the hair dryer draw from the 110.-V line in Justine's house? b) What happens to the resistance of the hair dryer as it runs for a long time?

Exercise 5: Camille takes her pocket calculator out of her bookbag as she gets ready to do her physics homework. In the calculator, a 0.160-C charge encounters 19.0 Ω of resistance every 2.00 seconds. What is the potential difference of the battery?

Power

Vocabulary **Power:** The amount of work done in a given unit of time.

As seen in the previous chapter, electrical work is done when an amount of charge, Δq, is transferred across a potential difference, V, or $W = \Delta qV$. The faster this transfer of charge occurs, the more power is generated in the circuit.

$$\textbf{Power} = \frac{\textbf{work}}{\textbf{elapsed time}} \quad \text{or} \quad P = \frac{W}{\Delta t} = \frac{\Delta qV}{\Delta t} = IV$$

Therefore, as current is drawn in a circuit to power an appliance, a potential difference occurs across the appliance.

The SI unit for electrical power is the **watt (W)**, which equals one **joule per second (J/s).**

Solved Examples

Example 5: The lighter in Bryce's car has a resistance of 4.0 Ω. a) How much current does the lighter draw when it is run off the car's 12-V battery? b) How much power does the lighter use?

a. *Given:* $R = 4.0\ \Omega$, $V = 12\ \text{V}$

Unknown: $I = ?$
Original equation: $V = IR$

Solve: $I = \dfrac{V}{R} = \dfrac{12\ V}{4.0\ \Omega} = \mathbf{3.0\ A}$

b. *Given:* $I = 3.0\ \text{A}$, $V = 12\ \text{V}$

Unknown: $P = ?$
Original equation: $P = IV$

Solve: $P = IV = (3.0\ \text{A})(12\ \text{V}) = \mathbf{36\ W}$

Example 6: A 120.-V outlet in Carol's college dorm room is wired with a circuit breaker on a 5-A line so that students cannot overload the circuit. a) If Carol tries to iron a blouse for class with her 700-W iron, will she trip the circuit breaker? b) What is the resistance of the iron?

Solution: A circuit breaker is a switch that automatically turns a circuit off if the current is too high.

a. *Given:* $P = 700.\ \text{W}$, $V = 120.\ \text{V}$

Unknown: $I = ?$
Original equation: $P = IV$

Solve: $I = \dfrac{P}{V} = \dfrac{700.\ W}{120.\ V} = \mathbf{5.83\ A}$ Yes, she will!

It may be difficult to see how a watt/volt equals an amp until you begin to break down the units.

$$\frac{\text{watt}}{\text{volt}} = \frac{\text{joule/second}}{\text{joule/coulomb}} = \frac{\text{coulomb}}{\text{second}} = \text{amp}$$

b. Now find the resistance using $V = IR$.

Given: $V = 120.\ \text{V}$, $I = 5.83\ \text{A}$

Unknown: $R = ?$
Original equation: $V = IR$

Solve $R = \dfrac{V}{I} = \dfrac{120.\ V}{5.83A} = 20.5\ \Omega$

Exercise 10: How much power is used by a contact lens heating unit that draws 0.070 A of current from a 120-V line?

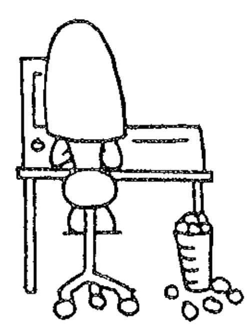
Exercise 11: Celeste's air conditioner uses 2160 W of power as a current of 9.0 A passes through it. a) What is the voltage drop when the air conditioner is running? b) How does this compare to the usual household voltage? c) What would happen if Celeste tried connecting her air conditioner to a usual 120-V line?

Exercise 12: Which has more resistance when plugged into a 120.-V line, a 1400.-W microwave oven or a 150.-W electric can opener?

Exercise 13: Valerie's 180-W electric rollers are plugged into a 120-V line in her bedroom. a) What current do the electric rollers draw? b) What is the resistance of the rollers when they are heated? c) Combining the equations just used, derive an equation that relates power to voltage and resistance.

Exercise 14: Mrs. Olsen leaves her 0.900-kW electric coffee maker on each day as she heads off to work at 6 A.M. because she likes to come home to a hot cup of coffee at 6 P.M. a) If the electric company charges Mrs. Olsen $0.100 per kWh, how much does running the coffee maker cost her each day? b) What is the yearly cost to run the coffee maker?

Exercise 15: While writing this book, the author spent about 1000 h working on her personal computer that has a power input of 60.0 W. Seventy additional hours were spent with the 60.0-W computer and the 240.-W printer running. How much did it cost for the energy use of these two devices, at a cost of $0.100 per kWh?

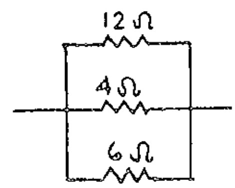


Series and Parallel Circuits

Example 8: Find the total resistance of the three resistors connected in series.

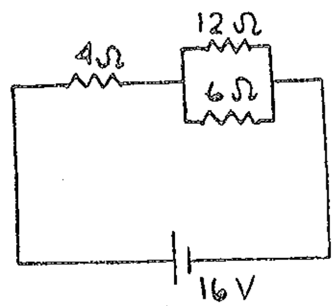
Solve: $R_T = R_1 + R_2 + R_3 = 12\ \Omega + 4\ \Omega + 6\ \Omega = \mathbf{22\ \Omega}$

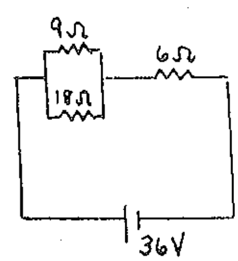
Example 9: Find the total resistance of the same three resistors now connected in parallel.



Example 10: Find the total current passing through the circuit.

This circuit contains resistors in parallel that are then combined with a resistor in series. Always begin solving such a resistor combination by working from the inside out. In other words, first determine the equivalent resistance of the two resistors in parallel before combining this total resistance with the one in series.

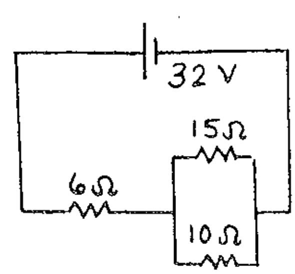




Example 11: Find the current in the 9-Ω resistor.

For the parallel branch

Exercise 18: Using the diagram, a) find the total resistance in the circuit. b) Find the total current through the circuit.



Exercise 19: Old-fashioned holiday lights were connected in series across a 120-V household line. a) If a string of these lights consists of 12 bulbs, what is the potential difference across each bulb? b) If the bulbs were connected in parallel, what would be the potential difference across each bulb?

Exercise 20: Before going to work each morning, Gene runs his 18-Ω toaster, 11-Ω electric frying pan, and 14-Ω electric coffee maker, all at the same time. The three are connected in parallel across a 120-V line. a) What is the current through each appliance? b) If a household circuit could carry a maximum current of 15 A, would Gene be able to run all of these appliances at the same time?

A-4: Herbert had just suffered a heart attack but he was revived in the hospital emergency room with a device called a defibrillator. (The paddles of a defibrillator supply a short pulse of high voltage to restart the heart.) The defibrillator contains a 20.-μF capacitor that releases 0.15 C of charge. a) What is the potential difference between the defribrillator paddles during the discharge? b) Why do you think doctors yell "Clear!" to the attendants before discharging the defibrillator?

A-5: Sherm is typing his term paper on a computer that contains a high-speed switch, controlled with a small 100×10^{-12} F speed-up capacitor. What is the current flow created by the capacitor if it discharges every 0.1 s across a potential difference of 5 V?

A-6: Every Sunday morning Stuart makes "breakfast in bed" for his wife. However, because the household wires can only carry a maximum current of 15 A from the 120.-V line, it is difficult to run all of the appliances simultaneously without blowing a fuse. What is the most power Stuart may use while cooking, before blowing a fuse?

A-7: In the previous exercise, a) how much current will Stuart draw if he tries to run the 700.-W toaster and 1000.-W coffee maker at the same time? b) Will this cause him to blow the fuse?

A-8: Xiaoyi's aquarium operates for 24.0 h a day and contains a 5.0-W heater, two 20.0-W lightbulbs, and a 35.0-W electric filter. If Xiaoyi pays $0.100 per kWh for her electricity bill, how much will it cost to maintain the aquarium for 30.0 days?

A-9: The average power plant, running at full capacity, puts out 500. MW of power. If the power company charges its customers $0.10 per kWh, what is the revenue brought in by the power plant each day?

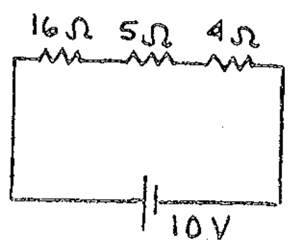
A-10: Horace has invented a unique pair of reading glasses that have two small light bulbs at the bottom wired in series, so that he can see the newspaper when he is reading at night. Each of the bulbs has a resistance of 2.00 Ω, and the system runs off a 3.20-V battery. How much current is drawn by Horace's reading glasses?

A-11: Jay has two 8-Ω stereo speakers wired in series in the front of his car connected to the 4.0-V output of the stereo. a) What is the current through each of the speakers? b) In his garage, Jay finds two more old speakers with resistances of 4 Ω and 16 Ω. He wires each in parallel with the 8-Ω combination. What is the new current through the 8-Ω speakers? c) If the loudness of each speaker is proportional to the amount of power used, how has the loudness of the two 8-Ω speakers changed?

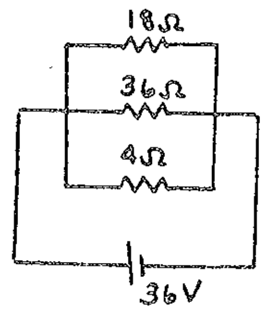
A-12: Find a) the total resistance in circuit A below. b) Find the total current through the circuit.

A-13: Find a) the total resistance in circuit B below. b) Find the total current through the circuit.

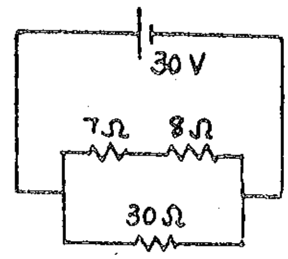
A-14: Find a) the total resistance in circuit C below. b) Find the total current through the circuit.



Circuit A



Circuit B

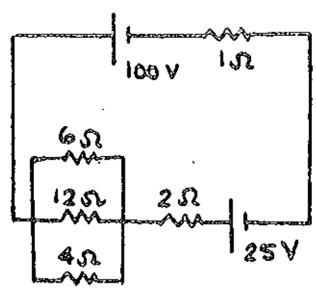


Circuit C

Challenge Exercises for Further Study

B-1: An 800.-W submersible electric heater is put into a 20.0 °C hottub until the 50.0-kg of tub water has warmed up to 70.0 °C. How long will it take for the heater to heat the tub water? (c_{water} = 4187 J/kg°C)

B-2: Find the total current in the circuit in the diagram.



B-3: In exercise A-10, the light bulbs are rated for 5 h of use before they burn out. If the battery can supply 5184 J to the circuit, which occurs first, energy depletion in the battery or failure of a bulb?

Magnetism

Example 1: A proton speeding through a synchrotron at 3.0×10^7 m/s experiences a magnetic field of 4.0 T that is produced by the steering magnets inside the synchrotron. What is the magnetic force pulling on the proton?

Solution: Remember, the charge of a proton or an electron is 1.60×10^{-19} C.

Given: $q = 1.60 \times 10^{-19}$ C
$v = 3.0 \times 10^7$ m/s
$B = 4.0$ T

Unknown: $F = ?$
Original equation: $F = qvB$

Solve: $F = qvB = (1.60 \times 10^{-19}\text{ C})(3.0 \times 10^7\text{ m/s})(4.0\text{ T}) = \mathbf{1.9 \times 10^{-11}}$ **N**

Example 2: A 10.0-m-long high-tension power line carries a current of 20.0 A perpendicular to Earth's magnetic field of 5.5×10^{-5} T. What is the magnetic force experienced by the power line?

Given: $I = 20.0$ A
$L = 10.0$ m
$B = 5.5 \times 10^{-5}$ T

Unknown: $F = ?$
Original equation: $F = ILB$

Solve: $F = ILB = (20.0\text{ A})(10.0\text{ m})(5.5 \times 10^{-5}\text{ T}) =$ **0.011 N**

Exercise 1: Dean is hunting in the Northwest Territories at a location where Earth's magnetic field is 7.0×10^{-5} T. He shoots by mistake at a duck decoy, and the rubber bullet he is using acquires a charge of 2.0×10^{-12} C as it leaves his gun at 300. m/s, perpendicular to Earth's magnetic field. What is the magnitude of the magnetic force acting on the bullet?

Exercise 2: A wasp accumulates 1.0×10^{-12} C of charge while flying perpendicular to Earth's magnetic field of 5.0×10^{-5} T. How fast is the wasp flying if the magnetic force acting on it is 6.0×10^{-16} N?

Exercise 3: Kron, the alien freedom fighter from the planet Krimbar, shoots his gun that fires protons at a speed of 3.0×10^6 m/s. a) What is Krimbar's magnetic field if it creates a force of 2.88×10^{-15} N on the protons? b) How does this compare to Earth's magnetic field?

Exercise 4: The magnetic field in Boston, Massachusetts has a horizontal component to the north of 0.18×10^{-4} T and a vertical component of 0.52×10^{-4} T straight downward. a) What is the magnitude and direction of Earth's magnetic field in Boston? b) If a 2.0-m-long household wire is carrying a current of 15 A in a direction perpendicular to the field, what is the magnitude of the magnetic force experienced by the wire?

Additional Exercises

A-1: In the giant CERN particle accelerator in Switzerland, protons are accelerated to speeds of 2.0×10^8 m/s through a magnetic field of 3.5 T and then collided with a fixed target. What is the magnitude of the magnetic force experienced by the protons as they are accelerated around the giant ring?

A-2: In Fred's color TV, electrons are shot toward the screen through a 1.0×10^{-3}-T magnetic field set up in the picture tube. a) If each electron experiences a magnetic force of 2.9×10^{-15} N, at what speed is it propelled through the picture tube? b) How does this speed compare to the speed of light?

A-3: A proton shot out of the sun at a speed of 6.0×10^6 m/s during a "sunspot maximum" travels through the strong magnetic field of the sun. What is the maximum magnetic force experienced by the proton at a point where the sun's magnetic field is 0.090 T?

A-4: A 0.90-m-long straight wire on board the *Voyager* spacecraft carries a current of 0.10 A perpendicular to Jupiter's strong magnetic field of 5.0×10^{-4} T. What is the magnitude of the magnetic force experienced by the wire?

A-5: While vacuuming the living room rug, Buster pulls the 4.0-m vacuum cleaner cord so that it is lying perpendicular to Earth's magnetic field of 5.3×10^{-5} T. a) If the cord is carrying a current of 6.0 A, how large a magnetic force is created on the cord by Earth's magnetic field? b) If Buster then pulls the cord so that it lies parallel to Earth's magnetic field, how large is the magnetic force now experienced by the cord?

A-6: At the equator, where Earth's 3.0×10^{-5}-T magnetic field is parallel to the surface of Earth, Donna is spinning her wedding ring (which has a diameter of 2.0 cm) on top of the table. Find the change in flux through the ring if Donna a) slides it horizontally across the table, b) rolls it across the table, c) spins it on its edge.

A-7: Amanda's little brother spins a bar magnet whose magnetic field is 3.0×10^{-2} T over the face of Amanda's electric watch, perpendicular to a circular loop of wire of radius 0.60 cm inside the watch. a) What is the induced voltage in the wire if the magnet is spun over the watch in 0.30 s? b) Why is it a bad idea to put an electric watch too close to a strong magnetic field?

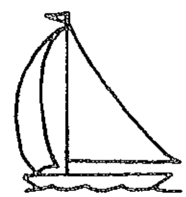
A-8: While Hiroshi sits in his living room, the newspaper carrier rings his doorbell. If a voltage of 120 V passes through the 200-turn primary coil of the transformer, how many turns are needed in the secondary coil to reduce the voltage to the 6.0 V needed to run the doorbell?

A-9: A bug zapper in the Snyders' back yard runs off a 120-V household line through a transformer whose primary coil contains 50. turns while the secondary coil contains 2000. turns. a) What is the output voltage of the transformer? b) Is this a step-up or a step-down transformer?

Challenge Exercises for Further Study

B-1: When Helen turns on the TV set, electrons are accelerated through a 20 000.-V potential difference and deflected by a 1.0×10^{-2}-T magnetic field. What is the average magnetic force experienced by an electron? ($m_e = 9.11 \times 10^{-31}$ kg)

B-2: Captain Kittredge is sailing due north, as indicated by his compass needle, in a location where Earth's magnetic field is 2.0×10^{-5} T. The captain inadvertently places his radio near the compass, allowing the wire from his radio to align in a north-south direction. The 0.80-m-long wire carries a current of 5.0 A and produces a magnetic force on the compass needle of 2.8×10^{-4} N. To what angle will the compass needle turn while the wire is over it?



B-3: A velocity selector is a device that measures the speed of a charged particle by shooting the particle through oppositely charged plates enclosed in a tube. Inside the tube is a constant magnetic field, B. If a particle is to travel, undeflected, down the center of the tube, the magnetic force must equal the electric force. If the magnetic field of 0.630 T is perpendicular to the electric field of 5.00×10^{4} N/C, find the speed of an electron sent through the velocity selector.

B-4: An alpha particle (He nucleus) is shot at 5.0×10^{6} m/s into a magnetic field of 0.20 T in a device known as a mass spectrometer. What is the radius of the path followed by the alpha particle? (Hint: He nuclei contain 2 protons and 2 neutrons, each with a mass of 1.67×10^{-27} kg.)