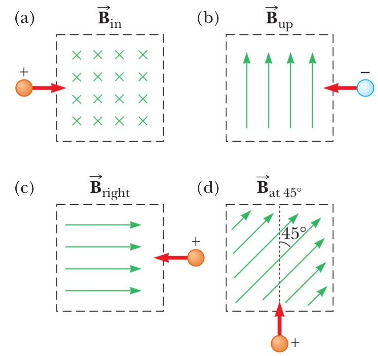
Homework 6 Magnetism

1. Determine the initial direction of the deflection of charged particles as they enter the magnetic fields as shown in the figure.



2. Consider an electron near the Earth's equator. In which direction does it tend to deflect if its velocity is directed (a) downward, (b) northward, (c) westward, or (d) south-eastward?

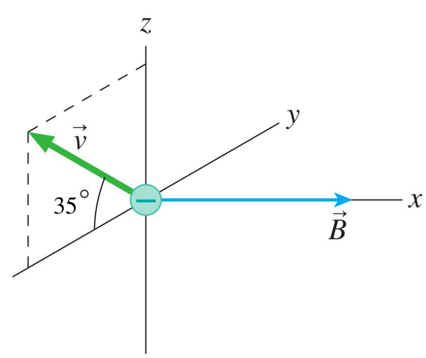
3. A proton travels with a speed of $3.00 \times 10^6\ m/s$ at an angle of 37.0° with the direction of a magnetic field of $0.300\ T$ in the $+y$ direction. What are (a) the magnitude of the magnetic force on the proton and (b) its acceleration?

4. An electron is accelerated through $2400\ V$ from rest and then enters a uniform $1.70 - T$ magnetic field. What are (a) the maximum and (b) the minimum values of the magnetic force this charge can experience?

5. At the equator, near the surface of the Earth, the magnetic field is approximately $50.0\ \mu T$ northward and the electric field is about $100\ N/C$ downward in fair weather. Find the gravitational, electric, and magnetic forces on an electron in this environment, assuming that the electron has an instantaneous velocity of $6.00 \times 10^6\ m/s$ directed to the east.

6. A proton moves with a velocity of $\vec{v} = (2\hat{\imath} - 4\hat{\jmath} + \hat{k})\ m/s$ in a region in which the magnetic field is $\vec{B} = (\hat{\imath} + 2\hat{\jmath} - 3\hat{k})\ T$. What is the magnitude of the magnetic force this charge experiences?

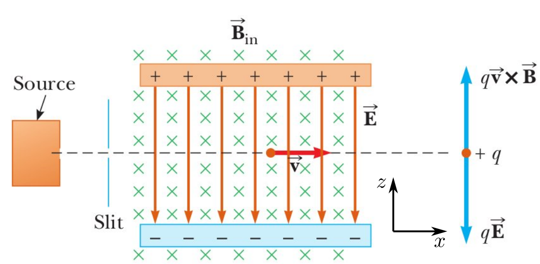
7. An electron moves in the magnetic field $\vec{B} = 0.7\hat{\imath}\ T$ with a speed $v = 5 \times 10^6\ m/s$ as shown in the figure to the right The y axis in the figure is going into the plane of the paper What is the magnetic force $\vec{F}_B$ on the electron? Give your answer in component form.



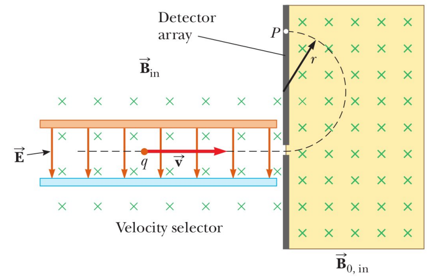
8. An electron moves in a circular path perpendicular to a constant magnetic field of magnitude 1.00 mT. The angular momentum of the electron about the center of the circle is $4.00 \times 10^{-25}\ J - s$. Determine (a) the radius of the circular path and (b) the speed of the electron.

9. A cosmic-ray proton in interstellar space has an energy of 10.0 MeV and executes a circular orbit having a radius equal to that of Mercury's orbit around the Sun ($5.80 \times 10^{10}\ m$). What is the magnetic field in that region of space?

10. A velocity selector consists of electric and magnetic fields described by the expressions $\vec{E} = -E\hat{k}$ and $\vec{B} = B\hat{\jmath}$, with $B = 15.0\ mT$. It is designed to only allow particles with a chosen speed to pass through the device without being deflected. The is done be requiring the magnetic and electric fields cancel one another. Find the value of E such that an electron of energy $E_e = 750\ eV$ is undeflected.

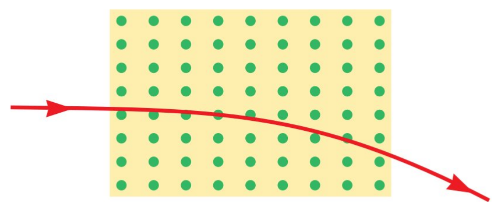


11. Consider the mass spectrometer shown schematically in the figure. The magnitude of the electric field between the plates of the velocity selector is 2500 V/m, and the magnetic field in both the velocity selector and the deflection chamber has a magnitude of 0.035 T. Calculate the radius of the path for a singly charged ion having a mass $m = 2.18 \times 10^{-26}\ kg$.



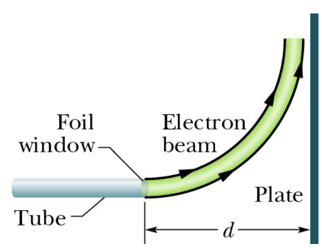
12. The picture tube in a television uses magnetic deflection coils rather than electric deflection plates. Suppose an electron beam is accelerated through a 50.0-kV potential difference and then moves through a region of uniform magnetic field 1.00 cm wide. The screen is located 10.0 cm from the center of the coils and is 50.0 cm wide. When the field is turned off, the electron beam hits the center of the screen. What field magnitude is necessary to deflect the beam to the side of the screen? Ignore relativistic corrections.

13. Protons having a kinetic energy of 5.00 MeV are moving in the positive x direction and enter a magnetic field $\vec{B} = 0.050\hat{k}\ T$ directed out of the plane of the page and extending from $x = 0$ to $x = 1.00\ m$ as shown in the figure. (a) Calculate the y component of the protons' momentum as they leave the magnetic field. (b) Find the angle α between the initial velocity vector of the proton beam and the velocity vector after the beam emerges from the field. Ignore relativistic effects and note that $1\ eV = 1.60 \times 10^{-19}\ J$.



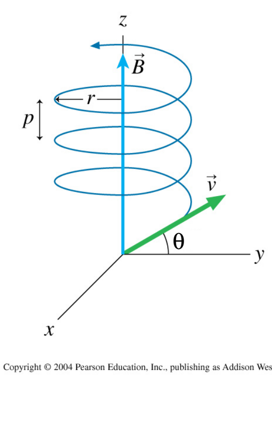
14. A proton (^{1}H, $m_p = 1\ u$, $q = e$), a deuteron (^{2}H, $m_d = 2\ u$, $q = e$), and a ^{4}He nucleus ($m_{He} = 4\ u$, $q = 2e$) with the same kinetic energies enter a region of uniform magnetic field $\vec{B}$ moving perpendicular to $\vec{B}$. What is the ratio of their radii in the magnetic field?

15. A beam of electrons with kinetic energy KE emerges from a thin-foil 'window' at the end of an accelerator tube. There is a metal plate a distance d from the window and perpendicular to the beam direction. See the figure below. What is the minimum magnetic field $\vec{B}$ needed to deflect the electron beam and prevent it from hitting the plate? How should $\vec{B}$ be oriented? Get your answer in terms of KE, d, and any other necessary constants.

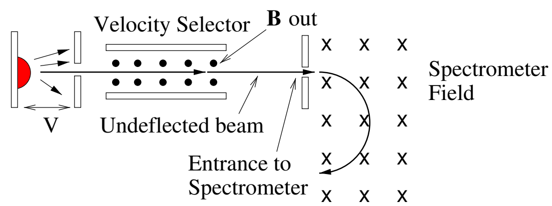


16. A singly-charged positive ion has a mass $m = 6.4 \times 10^{-26}\ kg$. After being accelerated from rest through an electric potential difference $V = 1000\ V$, the ion enter a magnetic field of $|\vec{B}| = 2.0\ T$ along a direction perpendicular to the direction of the field. Starting from Newton's Second Law ($\vec{F} = m\vec{a}$), what is the radius r of the path of the ion in the field?

17. The uniform magnetic field with $|\vec{B}| = 25 \times 10^{-3}\ T$ in the figure below points in the positive z-direction. An electron enters the region of uniform magnetic field with a speed $|\vec{v}| = 4 \times 10^6\ m/s$ and at an angle $\theta = 40°$. What is the radius r and the pitch p of the electron's spiral trajectory? See the figure for the definition of p.

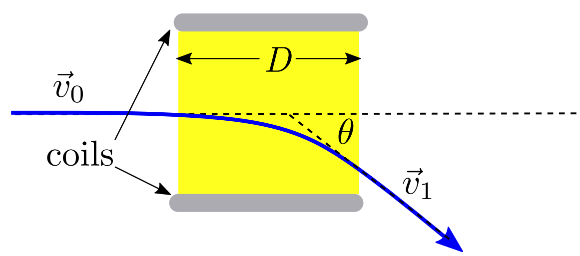


18. Many mass spectrometers have an additional device to insure the velocity of the particles entering the magnetic field of the spectrometer is the desired value. This 'velocity selector' consists of an electric field and a second magnetic field oriented perpendicular to the $\vec{E}$ field (see figure below). These two fields are set so that only particles with the desired velocity are undeflected as they move through the device. Negative ^{14}C ions with charge $q = -e$ are accelerated across the electric potential $V = 10^6\ V$ and enter the velocity selector. The magnetic field of the velocity selector is $0.5\ T$. To pick out the ^{14}C ions, what should be the value of the electric field in the velocity selector and how should it be oriented? What are the trajectories of negative ions that are going too fast or too slow?



19. An α particle ($q = 2e$, $m = 4\ u$) travels in circular path of radius $r = 0.10\ m$ in a magnetic field with $B = 1.0\ T$. The plane of the circle is perpendicular to the magnetic field. What is the α particle's speed, period of revolution, kinetic energy, and the size of the electric potential difference it fell through from rest to achieve this energy?

20. Old-style televisions operate by using a beam of electrons to strike 'pixels' on the TV screen that fluoresce and create the image that you see. This electron beam has to be steered to the correct pixel in order to create the appropriate image on the screen. Consider the steering device shown in the figure. It consists of a pair of coils that create a uniform magnetic field in the region between the coils (of length D) and perpendicular to the plane of the figure. The field bends the electron beam in a circular arc as shown. The maximum angle to reach all the pixels on the screen is $\theta = 25°$ and the length D of the coil is $0.06\ m$. The speed of the electron is $10^7\ m/s$. What is the field needed to reach the maximum angle? What is the direction of the field? Ignore the effects of gravity.



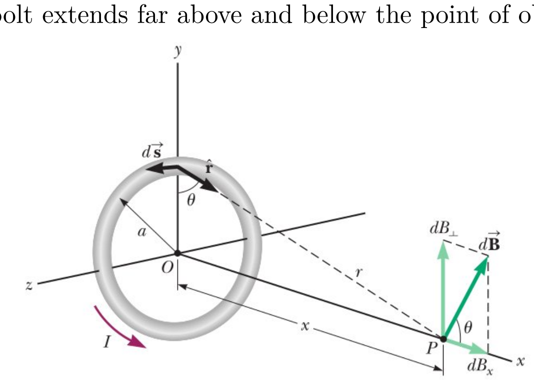
21. A mass spectrometer is used to separate ^{12}C and ^{14}C nuclei. The bare nuclei emerge from a velocity selector moving at a speed $v_0 = 1 \times 10^7\ m/s$ and enter a uniform magnetic field with $B = 2.0\ T$ and pointing perpendicular to the velocity $\vec{v}_0$. If the uncertainty in the position where the ions are detected is $\Delta x = 5 \times 10^{-4}\ m$, will the two types of nuclei be separated?

22. A long, straight wire carries a steady current I. What is the magnetic field a perpendicular distance y from the wire in terms of I, y and any other constants?

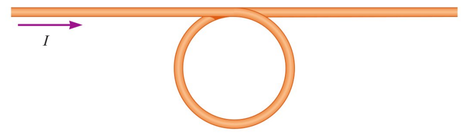
23. Calculate the magnitude of the magnetic field at a point 25.0 cm from a long, thin conductor carrying a current of 2.00 A.

24. A lightning bolt may carry a current of $1.00 \times 10^4\ A$ for a short time interval. What is the resulting magnetic field 100 m from the bolt? Assume the bolt extends far above and below the point of observation.

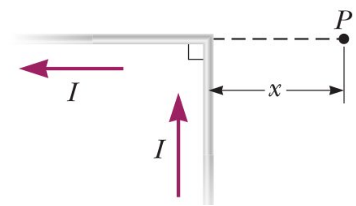
25. Consider a circular wire loop of radius a located in the yz plane and carrying a steady current I as in the figure. What is the magnetic field at an axial point P a distance x from the center of the loop?



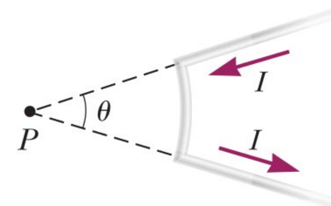
26. A conductor consists of a circular loop of radius R and two straight, long sections as shown in the figure. The wire lies in the plane of the paper and carries a current I. Find an expression for the vector magnetic field at the center of the loop.



27. An infinitely long wire carrying a current I is bent at a right angle as shown in the figure. Determine the magnetic field at point P, located a distance x from the corner of the wire.



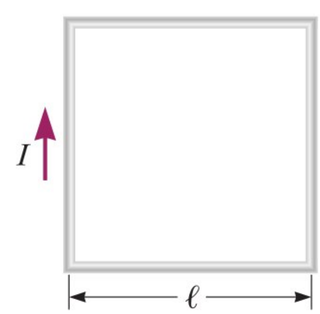
28. The electric current shown here creates a magnetic field at the point P at the center of the arc. If the arc subtends an angle of $\theta = 30°$ and the arc radius is $R = 0.60\ m$, what are the magnitude and direction of the field produced at P for a current $I = 3.0\ A$?



29. In Niels Bohr's 1913 model of the hydrogen atom, an electron circles the proton at a distance of $5.29 \times 10^{-11}\ m$ with a speed of $2.19 \times 10^6\ m/s$. Compute the magnitude of the magnetic field this motion produces at the location of the proton.

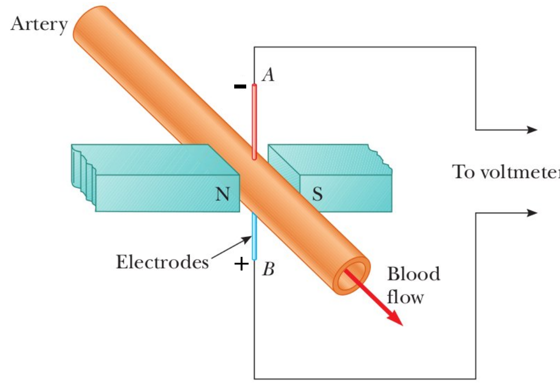
30. To see if migrating birds rely on the Earth's magnetic field to navigate, birds have been fitted with coils as 'caps' and 'collars' as shown in the figure. (a) If the identical coils have radii of 1.20 cm and are 2.20 cm apart, with 50 turns of wire apiece, what current should they both carry to produce a magnetic field of $4.50 \times 10^{-5}\ T$ halfway between them? The height of each coil is small compared to the distance between them. (b) If the resistance of each coil is 210 V, what voltage should the battery supplying each coil have? (c) What power is delivered to each coil?

31. A conducting loop in the shape of a square of edge length $\ell = 0.400\ m$ carries a current $I = 10.0\ A$ as shown in the figure. (a) Calculate the magnitude and direction of the magnetic field at the center of the square. (b) If this conductor is reshaped to form a circular loop and carries the same current, what is the value of the magnetic field at the center?

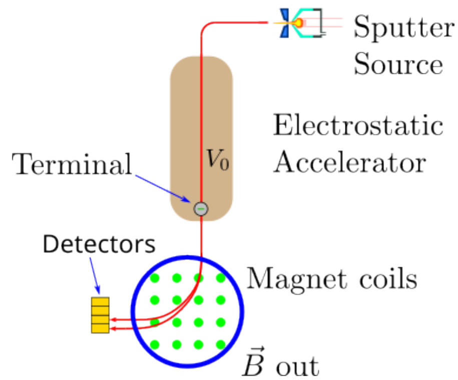


32. A long wire carries a current $I_1 = 30.0\ A$ to the left along the x axis. A second long wire carries current $I_2 = 50.0\ A$ to the right along the line ($y = 0.280\ m$, $z = 0$). (a) Where in the plane of the two wires is the total magnetic field equal to zero? (b) A particle with a charge of $-2.0\ \mu C$ is moving with a velocity of $150\hat{\imath}\ mm/s$ along the line ($y = 0.1\ m$, $z = 0$). What is the vector magnetic force acting on the particle? (c) A uniform electric field is applied to allow this particle to pass through this region undeflected. What is the required vector electric field.

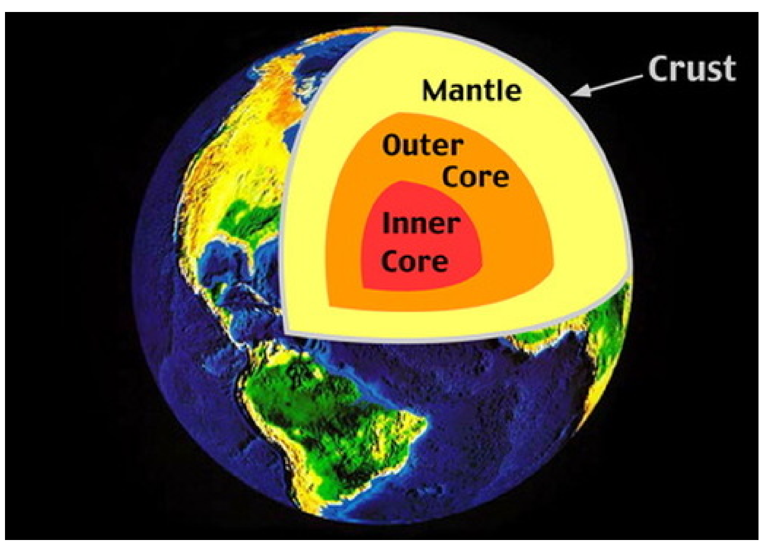
33. Surgeons use the following device to check on blood flow during an operation. Two electrodes A and B are in contact with the outer surface of an artery, which has an interior diameter $d = 3.0\ mm$. When a magnetic field of magnitude $B_0 = 0.04\ T$ is applied as shown, a voltage $V_0 = 1.60 \times 10^{-4}\ V$ is measured. Some of the blood constituents are positively charged and are deflected to one side of the vessel by the B field creating an electric field E_0 in the artery. Assume the electric field/force in the artery is constant and in equilibrium with the magnetic force. How are the voltage and the electric field related? What is the speed of the blood? Is electrode A negative as shown? Explain.



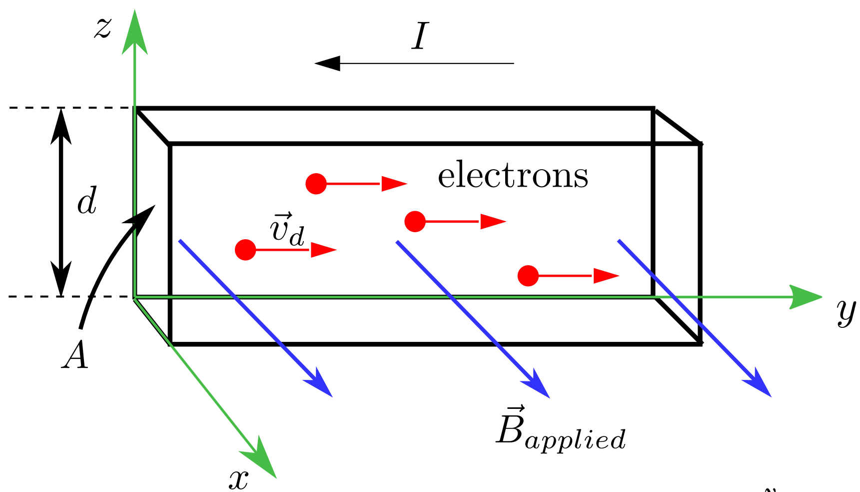
34. Isotopes of oxygen, ^{16}O and ^{18}O, are accelerated across a potential difference $V_0 = 5.0 \times 10^6\ V$. Each atom carries an extra electron initially, but that electron and three others are stripped off the oxygen in the accelerator by a thin foil at the terminal. The oxygen has a charge $+3e$ and is moving horizontally when it enters a uniform magnetic field pointing straight up with $B = 3.0\ T$. The positively-charged atoms follow a circular path through 90° before striking detectors that measure their position. The variation in the trajectory of each atom leads to an uncertainty in their final position of about $\pm 0.007\ m$. Will the spectrometer be able to separate the isotopes?



35. At the North Magnetic Pole the Earth's magnetic field is vertical and has a strength $|\vec{B}| = 6.2 \times 10^{-5}\ T$. Suppose this field is created by the flow of electrons in the equatorial region of the iron-rich core of the Earth. The radius of the Earth's iron core is $r_c = 3.6 \times 10^6\ m$. The radius of the Earth is $r_E = 6.37 \times 10^6\ m$. How large a current flowing around the equatorial region of the core would be needed to create a field of this strength at the North Magnetic Pole? In what direction does the current flow? Remember the north end of a compass points toward the Arctic.



36. Consider a wire with a square cross section of area $A = 5.5 \times 10^{-6}\ m^2$ and a number density $n = 8.46 \times 10^{28}\ electrons/m^3$. A current $i = 15\ A$ is flowing. A constant, uniform magnetic field transverse (*i.e.* perpendicular) to the motion of the electrons is suddenly turned on as shown in the figure below with $B_{applied} = 3.0\ T$. (a) What is the magnetic force on an individual electron due to the applied field and in what direction is the force? (b) The flow of electrons in the wire will be modified to balance the effect of the applied magnetic field by creating another electric field within the wire. What is the size and direction of the compensating electric field? (c) Sketch the distribution of electrons in the wire as a function of z after the transverse field is turned on. In 1985, Klaus von Klitzing received the Nobel Prize in physics for the use of this effect to understand conductivity and the behavior of charged particles in solids.



37. The figure below shows a configuration of two current loops known as a Helmholtz coil. This is the arrangement used in the lab 'Weighing an Electron' to bend the charged particles into circles. It consists of two, circular, coaxial coils, each of N turns and radius R separated by a distance R. The two coils carry equal currents i in the same direction. What is the magnetic field at the point P midway between the coils.