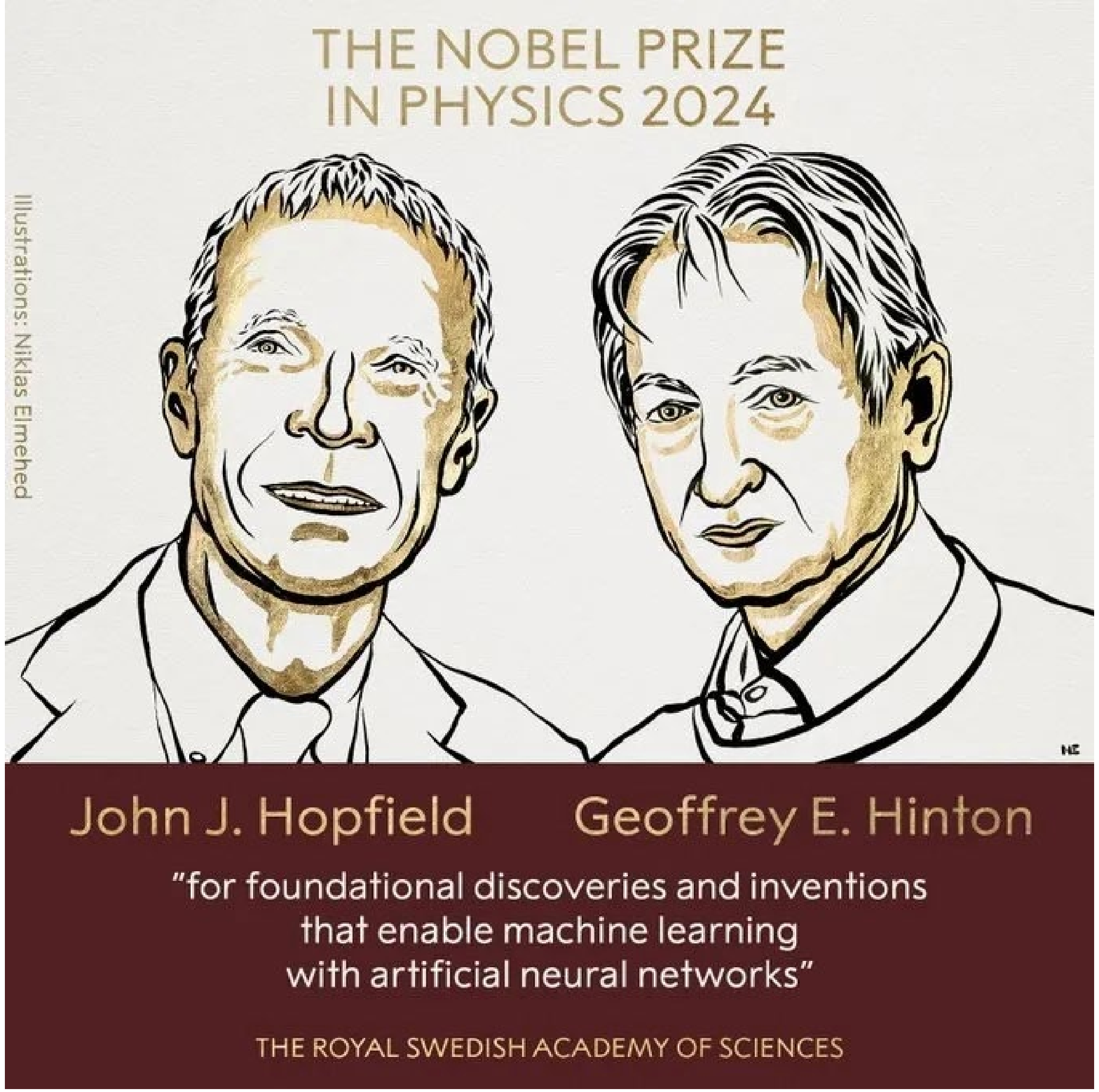
M1 Exam

This Friday, W1-101, 7 PM to 9 PM



The chair of the Nobel Physics Committee, Ellen Moons, stated at a press conference that the two laureates designed artificial neural networks using fundamental concepts from statistical physics, laying the foundation for machine learning. This technology has been used to advance research in multiple fields, including particle physics, materials science, and astrophysics, and it has also been applied in everyday life, such as in facial recognition and language translation. She warned that the rapid development of machine learning has raised concerns about the future, emphasizing that humanity has a responsibility to use this new technology in a safe and ethical manner.

诺贝尔物理学委员会主席埃伦·穆恩斯在当天的新闻发布会上表示，两名获奖者利用统计物理的基本概念设计了人工神经网络，构建了机器学习的基础。相关技术已被用于推动多个领域的研究，包括粒子物理、材料科学和天体物理等，也已用于日常生活中的人脸识别和语言翻译等。她同时警告说，机器学习的快速发展也引发了人们对未来的担忧，人类有责任以安全且道德的方式使用这项新技术

蓝鲸新闻10月9日讯（记者朱俊熹）OpenAI近日宣布已完成新一轮66亿美元的融资，推高公司投后估值达1570亿美元。 6天前

~1万亿 CNY

东方财富
https://finance.eastmoney.com › ...

OpenAI融资66亿美元终成千亿独角兽 - 财经

關於精選摘要 • 意見回饋

财富中文网
https://www.fortunechina.com › content_458047

OpenAI最新估值超千亿美元

2024年9月3日 — 此轮融资对该公司的估值据称达到惊人的1,030亿美元。据《华尔街日报》报道，OpenAI正在进行谈判，计划在新一轮融资中再融资数十亿美元。除了传统投资者（据 ...

新华网
http://www.news.cn › tech

OpenAI寻求新一轮融资

2024年9月13日 — 此次融资中OpenAI的新估值，比今年早些时候对该公司收购要约中的860亿美元估值高出74%。彭博社评论称，新的估值明显高于此前，"巩固了其作为全球最有 ...

排名	企业估值	企业信息
No. 1	¥ 37100 亿	台湾积体电路制造
No. 2	¥ 28500 亿	腾讯控股
No. 3	¥ 15700 亿	阿里巴巴
No. 4	¥ 14000 亿	字节跳动
No. 5	¥ 11000 亿	拼多多
No. 6	¥ 8110 亿	宁德时代
No. 7	¥ 7830 亿	友邦保险
No. 8	¥ 7370 亿	中国平安保险
No. 9	¥ 6850 亿	比亚迪
No. 10	¥ 6570 亿	美团
No. 11	¥ 5700 亿	华为

Week	Topic
1	Introduction, Coulomb's law (Ch21)
2	Electric field, Gauss's Law, (Ch22-23)
3	Electric potential, Capacitance, (Ch24-25)
4	Current and Resistance, Circuits (Ch26-27)
5	Module 1 exam
6	Magnetic Fields, Magnetic Field due to Currents (Ch28-29)
7	Magnetism and Electromagnetics, Induction and Inductance (Ch30-31)
8	Electromagnetic Oscillations, Maxwell's Equations I (Ch32)
9	Maxwell's Equations II, Electromagnetic Waves (Ch32-33)
10	Module 2 exam
11	Images, Interference, (Ch34-35)
12	Diffraction, Photons and Matters Waves (Ch36, 38)
13	Atoms, Conduction of Electricity in Solids (Ch40-41)
14	Review week
15	Module 3 exam

Chapter 28

Magnetic Fields

Summary (1 of 4)

The Magnetic Field $\vec{B}$

- Defined in terms of the force $\vec{F}_B$ acting on a test particle with charge q moving through the field with velocity $\vec{v}$

$$\vec{F}_B = q\vec{v} \times \vec{B}.$$ **Equation (28-2)**

A Charge Particle Circulating in a Magnetic Field

- Applying Newton's second law to the circular motion yields

$$|q|vB = \frac{mv^2}{r}$$ **Equation (28-15)**

- from which we find the radius r of the orbit circle to be

$$r = \frac{mv}{|q|B}.$$ **Equation (28-16)**

Summary (2 of 4)

Magnetic Force on a Current Carrying wire

- A straight wire carrying a current *i* in a uniform magnetic field experiences a sideways force

$$\vec{F}_B = i\vec{L} \times \vec{B}.$$ **Equation (28-26)**

- The force acting on a current element $id\vec{L}$ in a magnetic field is

$$d\vec{F}_B = id\vec{L} \times \vec{B}.$$ **Equation (28-28)**

Torque on a Current Carrying Coil

- A coil (of area *A* and *N* turns, carrying current *i*) in a uniform magnetic field $\vec{B}$ will experience a torque $\vec{\tau}$ given by

$$\vec{\tau} = \vec{\mu} \times \vec{B}.$$ **Equation (28-37)**

Summary (3 of 4)

The Hall Effect

- When a conducting strip carrying a current i is placed in a uniform magnetic field $\vec{B}$, some charge carriers (with charge e) build up on one side of the conductor, creating a potential difference V across the strip. The polarities of the sides indicate the sign of the charge carriers.

Summary (4 of 4)

Orientation Energy of a Magnetic Dipole

- The orientation energy of a magnetic dipole in a magnetic field is

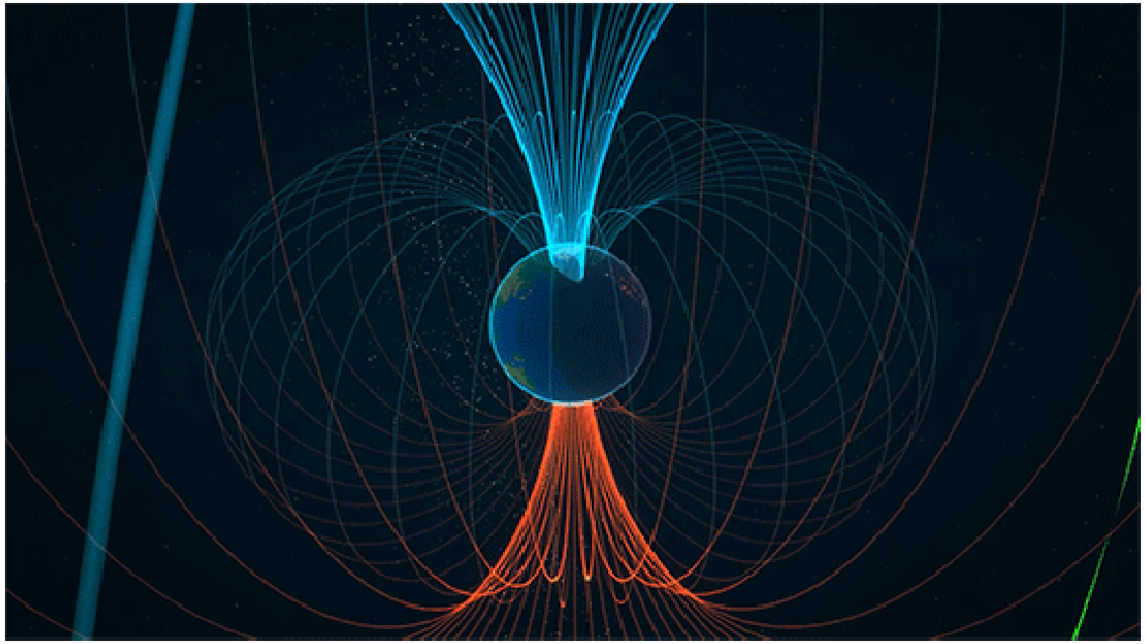
$$U(\theta) = -\vec{\mu} \cdot \vec{B}. \qquad \textbf{Equation (28-38)}$$

- If an external agent rotates a magnetic dipole from an initial orientation θ_i to some other orientation θ_f and the dipole is stationary both initially and finally, the work W_a done on the dipole by the agent is

$$W_a = \Delta U = U_f - U_i. \qquad \textbf{Equation (28-39)}$$

28-1 Magnetic Fields and the Definition of Vector B (5 of 14)

What Produces a Magnetic Field?



1. Moving electrically charged particles, such as a current in a wire, to make an **electromagnet. (Ch29)**

2. The other way to produce a magnetic field is by means of elementary particles who have an *intrinsic* magnetic field around them. (**permanent magnet)** (**Ch32**)

28-1 Magnetic Fields and the Definition of Vector B (5 of 14)

The Definition of *B*

The Field. We can define a magnetic field $\vec{B}$ to be a vector quantity that exists when it exerts a force $\vec{F}_B$ on a charge moving with velocity $\vec{v}$. We can next measure the magnitude of $\vec{F}_B$ when $\vec{v}$ is directed perpendicular to that force and then define the magnitude of $\vec{B}$ in terms of that force magnitude:

$$B = \frac{F_B}{|q|v},$$

The SI unit for B is **tesla** (T)

where q is the charge of the particle. We can summarize all these results with the following vector equation:

$$\vec{F}_B = q\vec{v} \times \vec{B};$$

28-1 Magnetic Fields and the Definition of Vector B (6 of 14)

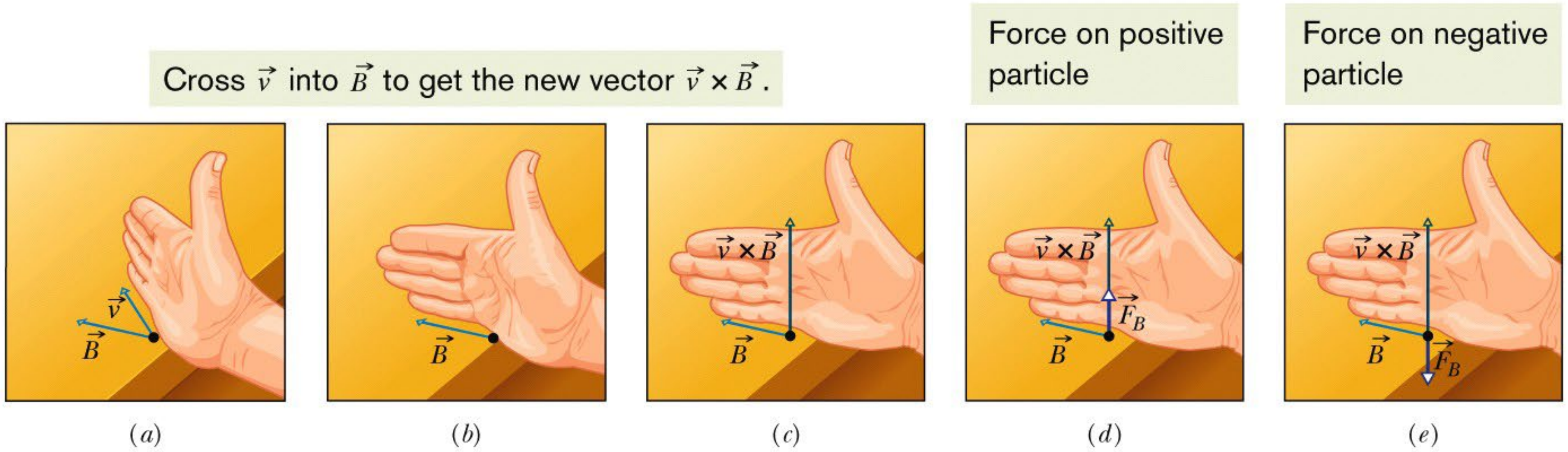
that is, the force $\vec{F}_B$ on the particle by the field $\vec{B}$ is equal to the charge q times the cross product of its velocity $\vec{v}$ and the field $\vec{B}$ (all measured in the same reference frame). We can write the magnitude of $\vec{F}_B$ as

$$F_B = |q| vB \sin\phi,$$

where ϕ is the angle between the directions of velocity $\vec{v}$ and magnetic field $\vec{B}$.

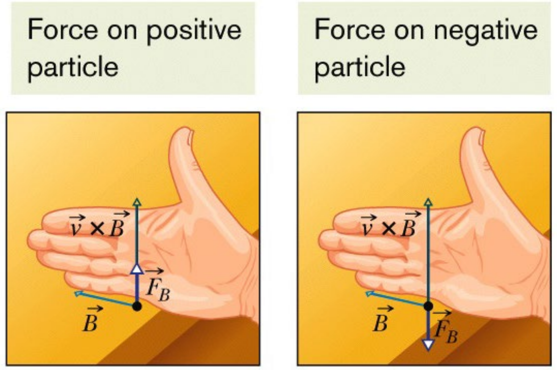
28-1 Magnetic Fields and the Definition of Vector B (7 of 14)

Finding the Magnetic Force on a Particle



$$\vec{F}_B = q\vec{v} \times \vec{B};$$

28-1 Magnetic Fields and the Definition of Vector B (8 of 14)



(d) (e)

$$\vec{F}_B = q\vec{v} \times \vec{B};$$

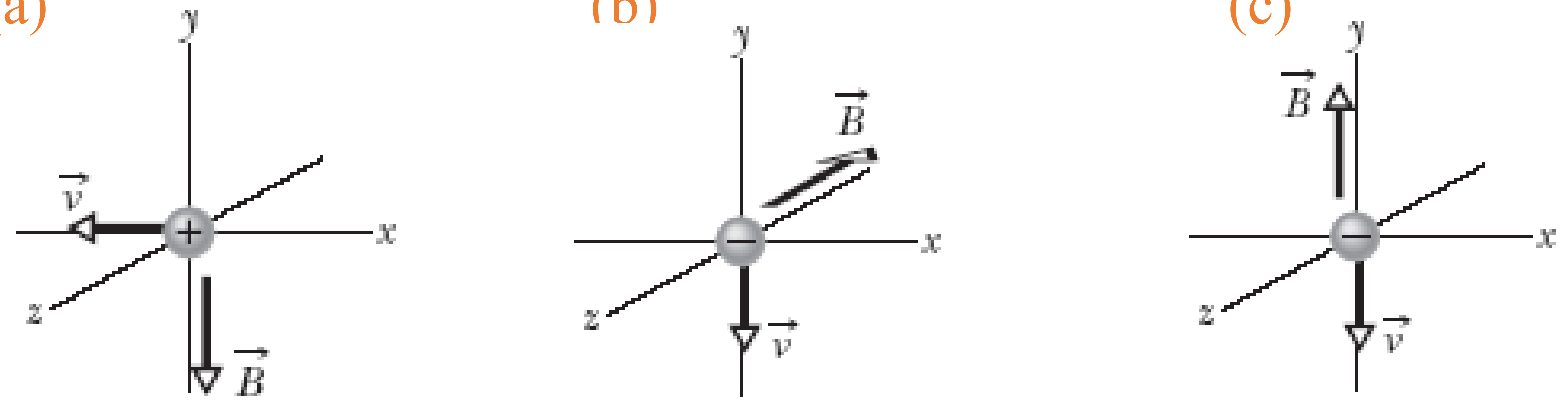
This equation tells us the direction of $\vec{F}$. We know the cross product of $\vec{v}$ and $\vec{B}$ is a vector that is perpendicular to these two vectors. The right-hand rule (Figures *a*-*c*) tells us that the thumb of the right hand points in the direction of $\vec{v} \times \vec{B}$ when the fingers sweep $\vec{v} \times \vec{B}$. If q is positive, then (by the above Equation) the force $\vec{F}_B$ has the same sign as $\vec{v} \times \vec{B}$ and thus must be in the same direction; that is, for positive q, $\vec{F}_B$ is directed along the thumb (Figure *d*). If q is negative, then the force $\vec{F}_B$ and cross product $\vec{v} \times \vec{B}$ have opposite signs and thus must be in opposite directions. For negative q, $\vec{F}$ is directed opposite the thumb (Figure *e*).

28-1 Magnetic Fields and the Definition of Vector B

Checkpoint 1

The figure shows three situations in which a charged particle travels through a uniform magnetic field $\vec{B}$. In each situation, what is the direction of the magnetic force $\vec{F}_B$ on the particle?

(a) (b) (c)



$$\vec{F}_B = q\vec{v}\times\vec{B};$$

Answer:

(a) towards the positive z-axis

(b) towards the negative x-axis

(c) none (cross product is zero)

28-1 Magnetic Fields and the Definition of Vector B (12 of 14)

Magnetic Field Lines

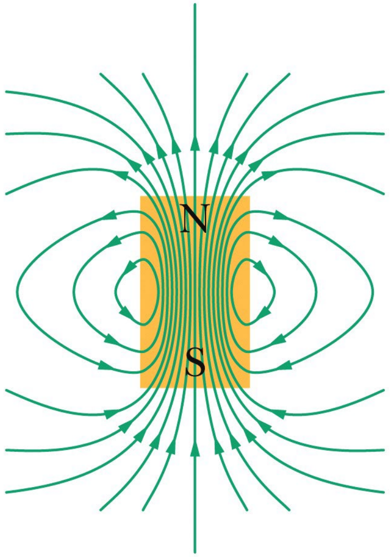
We can represent magnetic fields with field lines, as we did for electric fields. Similar rules apply:

(1) the direction of the tangent to a magnetic field line at any point gives the direction of $\vec{B}$ at that point

(2) the spacing of the lines represents the magnitude of $\vec{B}$ the magnetic field is stronger where the lines are closer together, and conversely.

28-1 Magnetic Fields and the Definition of Vector B (13 of 14)

Two Poles. The (closed) field lines enter one end of a magnet and exit the other end. The end of a magnet from which the field lines emerge is called the north pole of the magnet; the other end, where field lines enter the magnet, is called the south pole. Because a magnet has two poles, it is said to be a **magnetic dipole (磁偶极子)**.

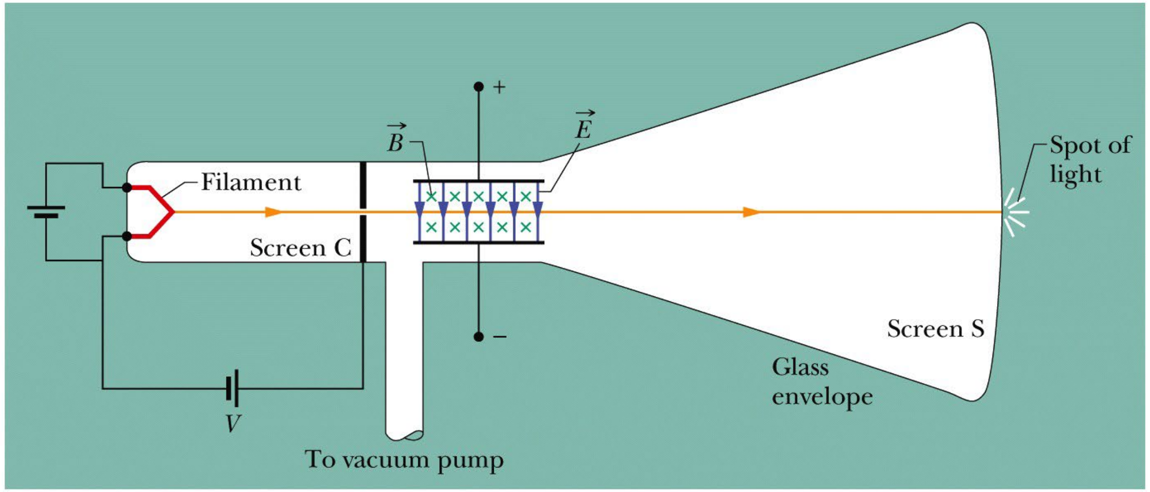


(*a*)

Opposite magnetic poles attract each other, and same magnetic poles repel each other.

28-2 Crossed Fields: Discovery of The Electron

A modern version of J.J. Thomson's apparatus for measuring the ratio of mass to charge for the electron ($m/|q|$). An electric field $\vec{E}$ is established by connecting a battery across the deflecting-plate terminals. The magnetic field $\vec{B}$ is set up by means of a current in a system of coils (not shown). The magnetic field shown is into the plane of the figure, as represented by the array of **X**s (which resemble the feathered ends of arrows).



1. Set $E = 0$ and $B = 0$ and note the position of the spot on screen S due to the undeflected beam.
2. Turn on $\vec{E}$ and measure the resulting beam deflection.
3. Maintaining $\vec{E}$, now turn on $\vec{B}$ and adjust its value until the beam returns to the undeflected position. (With the forces in opposition, they can be made to cancel.)

$$|q|E = |q|vB\sin(90°) = |q|vB$$

$$v = \frac{E}{B} \quad \text{(opposite forces canceling)}.$$

If a charged particle moves through a region containing both an electric field and a magnetic field, it can be affected by both an electric force and a magnetic force.

When the two fields are perpendicular to each other, they are said to be **crossed fields**.

If the forces are in opposite directions, one particular speed will result in no deflection of the particle.

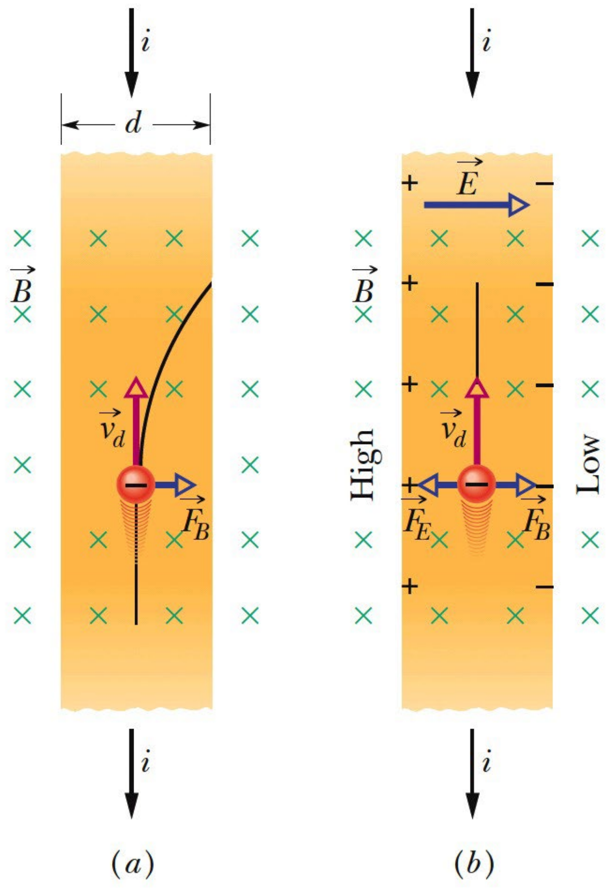
$$\frac{m}{|q|} = \frac{B^2L^2}{2yE}$$

28-3 Crossed Fields: The Hall Effect (3 of 6)

As we just discussed, a beam of electrons in a vacuum can be deflected by magnetic field. Can the drifting conduction electrons in a copper wire also be deflected by a magnetic field?

In 1879, Edwin H. Hall, then a 24-year-old graduate student at the Johns Hopkins University, showed that they can.

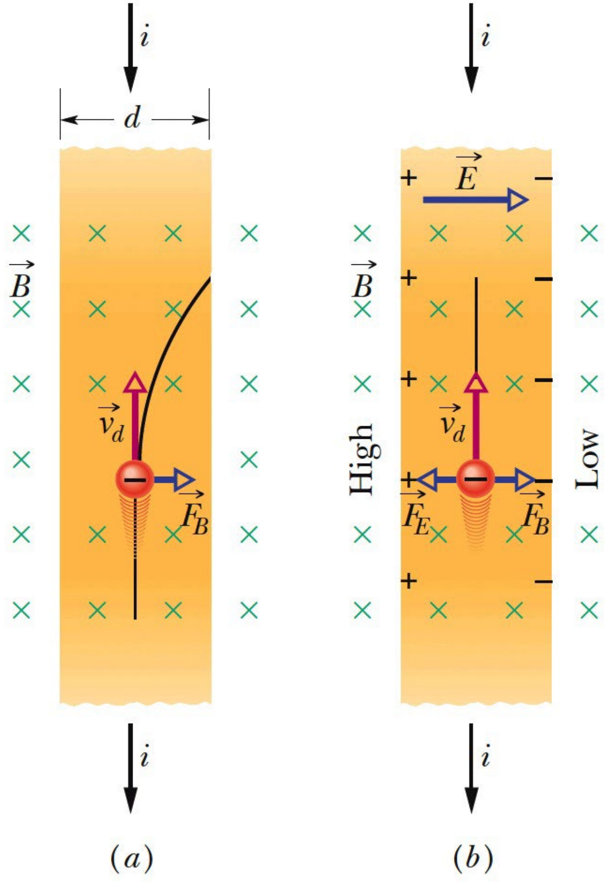
This **Hall effect (霍尔效应)** allows us to find out whether the charge carriers in a conductor are positively or negatively charged. Beyond that, we can measure the number of such carriers per unit volume of the conductor.



28-3 Crossed Fields: The Hall Effect (4 of 6)

Figure (*a*) shows a copper strip of width *d*, carrying a current *i* whose conventional direction is from the top to the bottom. The charge carriers are electrons and, as we know, they drift (with drift speed v_d) in the opposite direction, from bottom to top.

As time goes on, electrons move to the right, mostly piling up on the right edge of the strip, leaving uncompensated positive charges in fixed positions at the left edge as shown in figure (*b*).

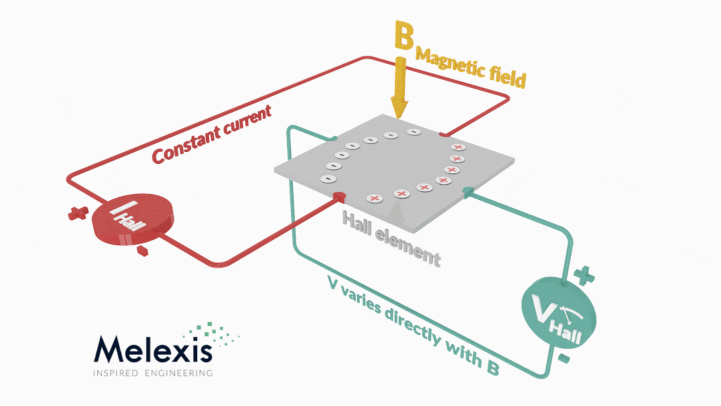


$$\vec{F}_B = q\vec{v} \times \vec{B};$$

This field exerts an electric force F on each electron, tending to push it to the left. Thus, this electric force on the electrons, which opposes the magnetic force on them, begins to build up.

Hall-effect potential difference *V* is set up across the strip

28-3 Crossed Fields: The Hall Effect (5 of 6)



When a uniform magnetic field B is applied to a conducting strip carrying current i, with the field perpendicular to the direction of the current, a Hall-effect potential difference V is set up across the strip.

$$V = Ed.$$

The electric force F_E on the charge carriers is then balanced by the the magnetic force F_B on them

$$eE = ev_d B$$

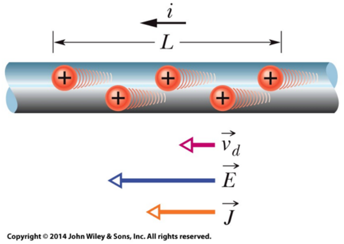
the drift speed v_d is $$v_d = \frac{J}{ne} = \frac{i}{neA}$$

The number density n of the charge carriers can then be determined from

$$\boxed{n = \frac{Bi}{Vle},}$$

in which $l\left(=\frac{A}{d}\right)$ is the thickness of the strip. With this equation we can find n from measurable quantities.

26-2 Current Density (7 of 7)



Current is said to be due to positive charges that are propelled by the electric field. In the figure, positive charge carriers drift at speed v_d in the direction of the applied electric field $\vec{E}$ which here is applied to the left. By convention, the direction of the current density $\vec{J}$ and the sense of the current arrow are drawn in that same direction, as is the drift speed v_d.

The drift velocity v_d is related to the current density (J) by

$$J = i/A \xrightarrow{i = \frac{q}{t} = \frac{nALe}{L/v_d} = nAev_d} \vec{J} = (ne)\vec{v}_d.$$

Here the product ne, whose SI unit is the coulomb per cubic meter $(\mathrm{C/m^3})$, is the **carrier charge density**.

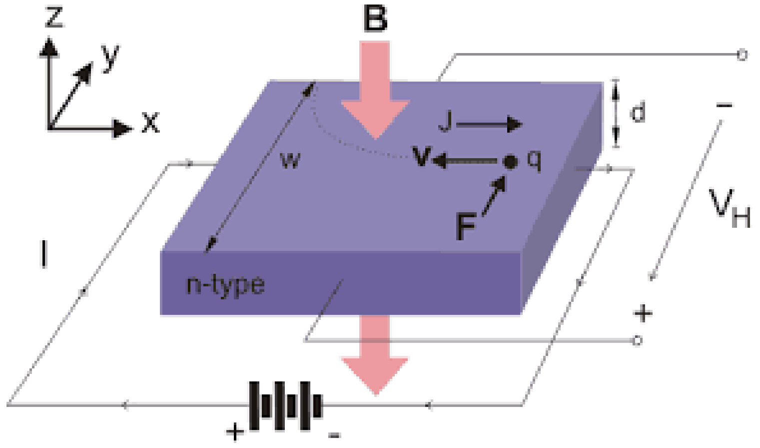
28-3 Crossed Fields: The Hall Effect (6 of 6)

The number density n of the charge carriers can then be determined from

$$\boxed{n = \frac{Bi}{Vle},}$$

in which $l\left(=\frac{A}{d}\right)$ is the thickness of the strip. With this equation we can find n from measurable quantities.

What do the l, d, A represent in this figure?



d= w
*l=d**
*A=w × d**

28-3 Crossed Fields: The Hall Effect (6 of 6)

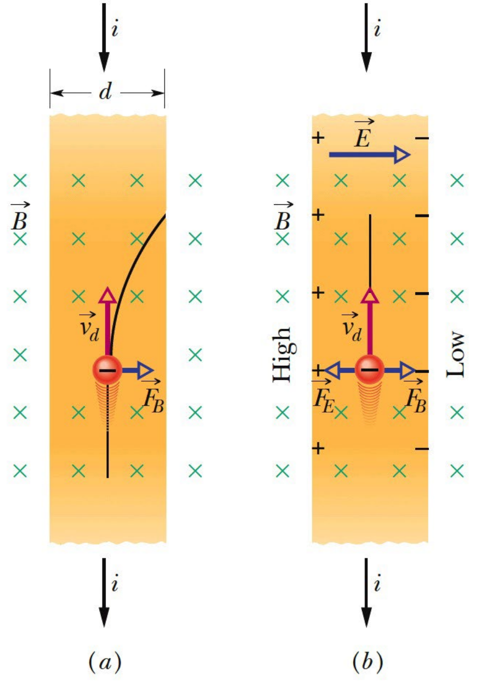
When a conductor moves through a uniform magnetic field $\vec{B}$ at speed v, the Hall-effect potential difference V across it is

$$V = vBd,$$

Where d is the width perpendicular to both velocity $\vec{v}$ and field $\vec{B}$.

Equilibrium of the electric and magnetic forces

$$eE = evB.$$
$$V = Ed.$$
$$\Rightarrow \quad V = vBd,$$

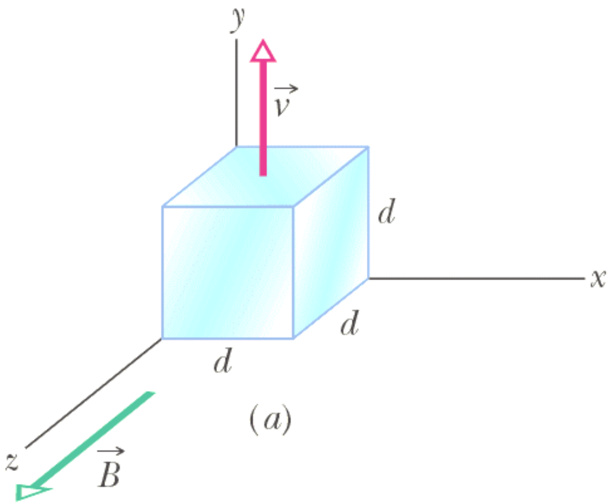


28-3 Crossed Fields: The Hall Effect (6 of 6)

Figure 28-9*a* shows a solid metal cube, of edge length $d = 1.5$ cm, moving in the positive y direction at a constant velocity $\vec{v}$ of magnitude 4.0 m/s. The cube moves through a uniform magnetic field $\vec{B}$ of magnitude 0.050 T in the positive z direction.

(a) Which cube face is at a lower electric potential and which is at a higher electric potential because of the motion through the field?

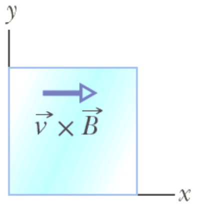
(b) What is the potential difference between the faces of higher and lower electric potential?



(*a*)

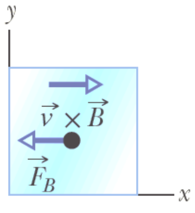
28-3 Crossed Fields: The Hall Effect (6 of 6)

This is the cross-product result.



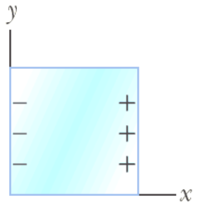
(b)

This is the magnetic force on an electron.



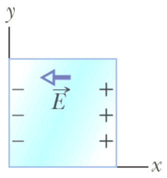
(c)

Electrons are forced to the left face, leaving the right face positive.



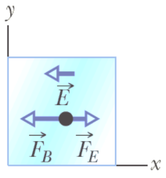
(d)

This is the resulting electric field.



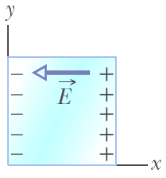
(e)

The weak electric field creates a weak electric force.



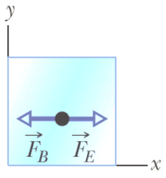
(f)

More migration creates a greater electric field.



(g)

The forces now balance. No more electrons move to the left face.



(h)

$$|q|E = |q|vB \sin 90° = |q|vB$$

$$E = vB$$

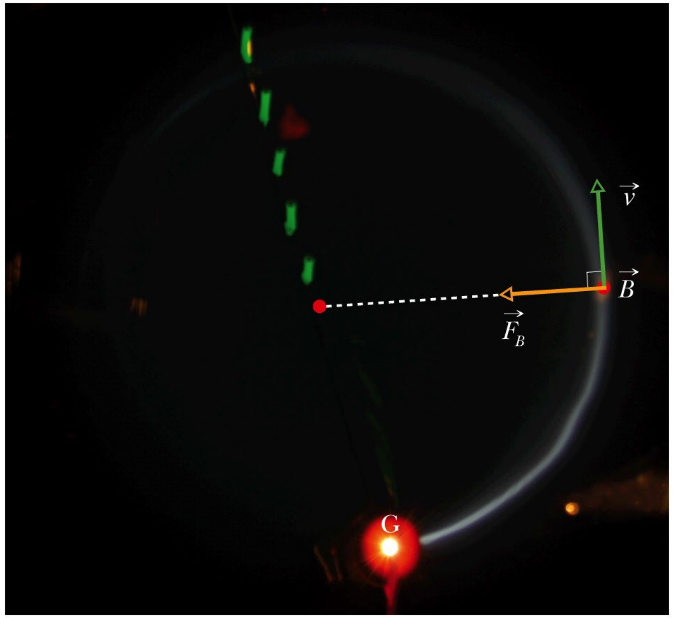
$$V = Ed$$

$$V = vBd.$$

$$V = (4.0 \text{ m/s})(0.050 \text{ T})(0.015 \text{ m})$$
$$= 0.0030 \text{ V} = 3.0 \text{ mV}.$$

28-4 A Circulating Charged Particle (3 of 4)

A beam of electrons is projected into a chamber by an electron gun G. The electrons enter in the plane of the page with speed v and then move in a region of uniform magnetic field $\vec{B}$ directed out of that plane. As a result, a magnetic force $\vec{F}_B = q(\vec{v} \times \vec{B})$ continuously deflects the electrons, and because $\vec{v}$ and $\vec{B}$ are always perpendicular to each other, this deflection causes the electrons to follow a circular path. The path is visible in the photo because atoms of gas in the chamber emit light when some of the circulating electrons collide with them.



uniform circular motion

28-4 A Circulating Charged Particle (4 of 4)

Applying Newton's second law to the circular motion yields

uniform circular motion $F = m\dfrac{v^2}{r}$

$$|q|vB = \frac{mv^2}{r}.$$

Therefore the radius r of the circle is

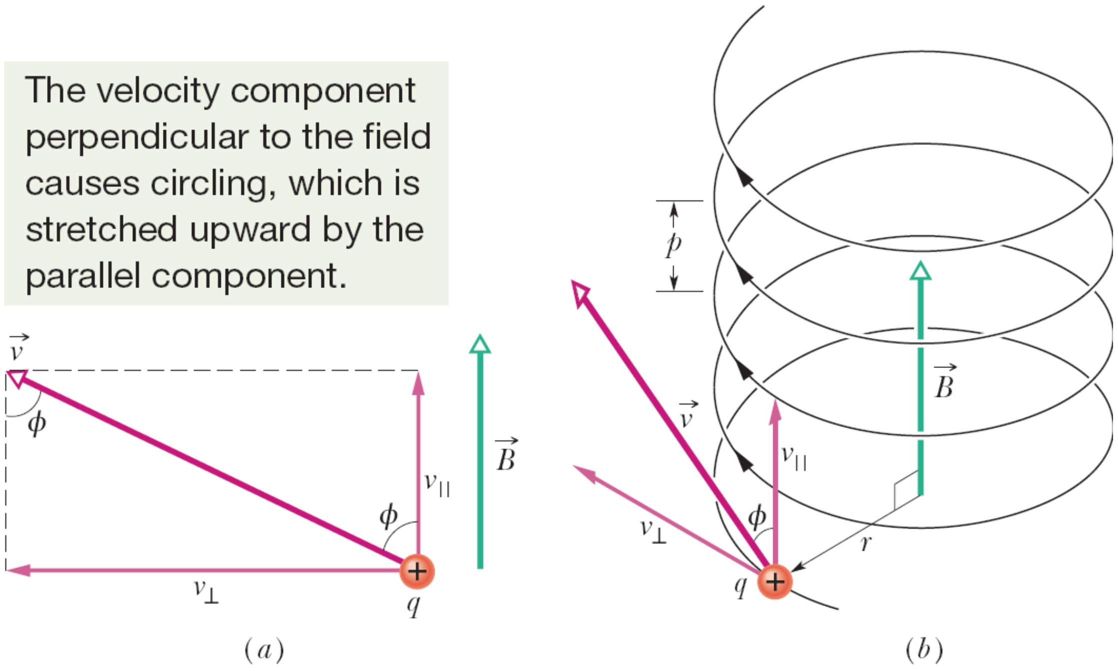
$$r = \frac{mv}{|q|B}.$$

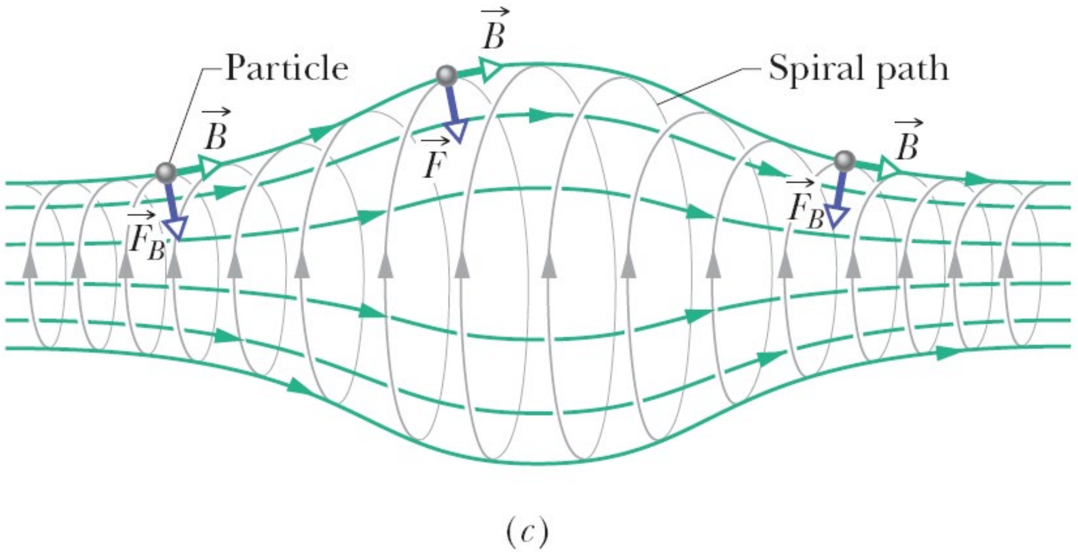
$$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\frac{mv}{|q|B} = \frac{2\pi m}{|q|B} \qquad f = \frac{1}{T} = \frac{|q|B}{2\pi m} \qquad \omega = 2\pi f = \frac{|q|B}{m}$$

28-4 A Circulating Charged Particle (4 of 4)

Helical Paths (螺旋路径)

The velocity component perpendicular to the field causes circling, which is stretched upward by the parallel component.





A charged particle spiraling ina nonuniform magnetic field

$$v_{\parallel} = v \cos \phi \quad \text{and} \quad v_{\perp} = v \sin \phi.$$

The particle follows a helical path of radius r and pitch p.

28-4 A Circulating Charged Particle (4 of 4)

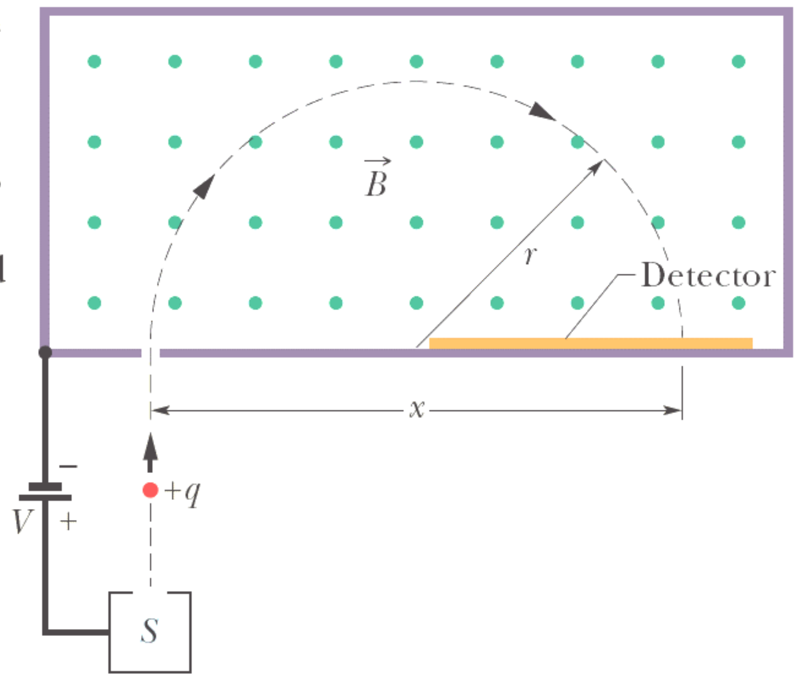
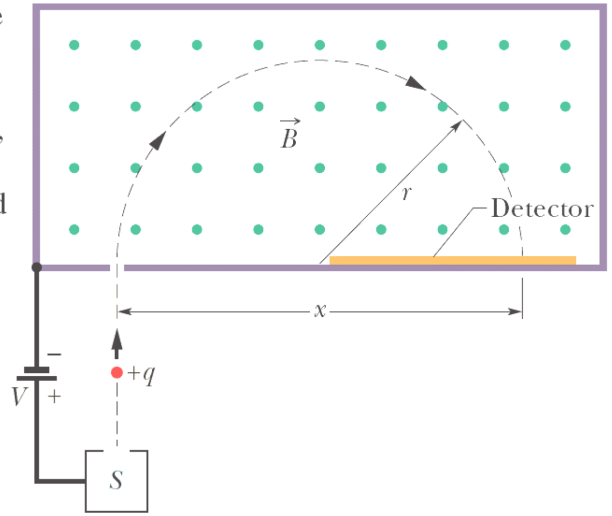


Figure 28-12 A positive ion is accelerated from its source S by a potential difference V, enters a chamber of uniform magnetic field $\vec{B}$, travels through a semicircle of radius r, and strikes a detector at a distance x.

Figure 28-12 shows the essentials of a *mass spectrometer (质谱仪)* which can be used to measure the mass of an ion; an ion of mass m (to be measured) and charge q is produced in source S. The initially stationary ion is accelerated by the electric field due to a potential difference V. The ion leaves S and enters a separator chamber in which a uniform magnetic field B is perpendicular to the path of the ion. A wide detector lines the bottom wall of the chamber, and the B causes the ion to move in a semicircle and thus strike the detector. Suppose that B = 80.000 mT, V = 1000.0 V, and ions of charge $q = +1.6022 \times 10^{-19}$ C strike the detector at a point that lies at x = 1.6254 m. What is the mass m of the individual ions, in atomic mass units (1 u = 1.6605×10^{-27} kg)?

28-4 A Circulating Charged Particle (4 of 4)

Figure 28-12 A positive ion is accelerated from its source S by a potential difference V, enters a chamber of uniform magnetic field $\vec{B}$, travels through a semicircle of radius r, and strikes a detector at a distance x.



conservation of mechanical energy $\Delta K + \Delta U = 0$,

$$\tfrac{1}{2}mv^2 - qV = 0 \text{ or } v = \sqrt{\frac{2qV}{m}}$$

uniform circular motion $|q|vB = \dfrac{mv^2}{r}$. ➡ $r = \dfrac{mv}{|q|B}$.

$$r = \frac{mv}{qB} = \frac{m}{qB}\sqrt{\frac{2qV}{m}} = \frac{1}{B}\sqrt{\frac{2mV}{q}}.$$

$$x = 2r = \frac{2}{B}\sqrt{\frac{2mV}{q}}$$

$$m = \frac{B^2qx^2}{8V}$$

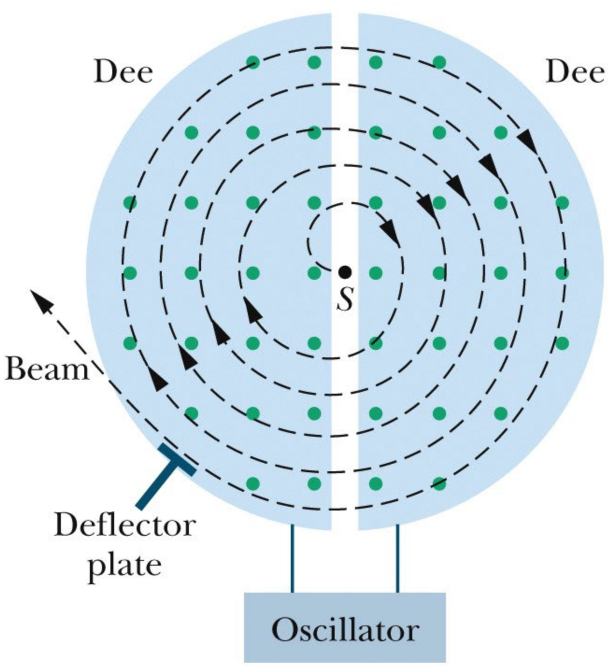
$$= \frac{(0.080000\ \mathrm{T})^2(1.6022 \times 10^{-19}\ \mathrm{C})(1.6254\ \mathrm{m})^2}{8(1000.0\ \mathrm{V})}$$

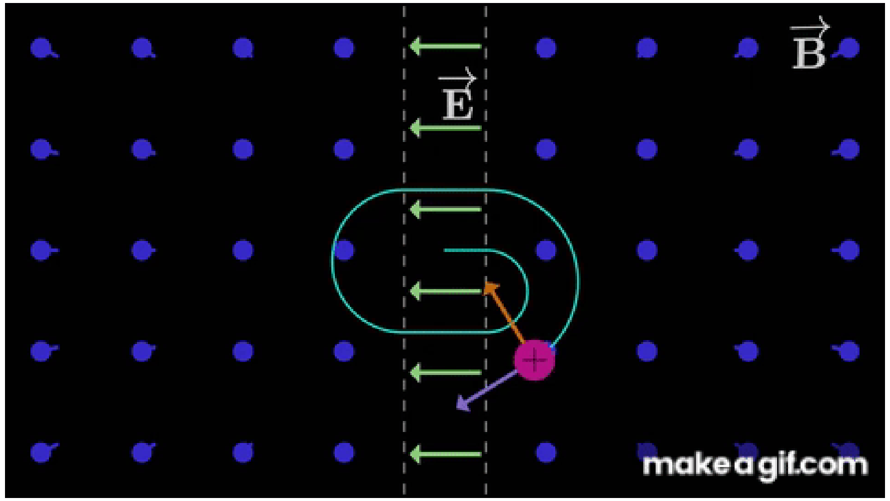
$$= 3.3863 \times 10^{-25}\ \mathrm{kg} = 203.93\ \mathrm{u}. \qquad \text{(Answer)}$$

28-5 Cyclotrons and Synchrotrons (回旋加速器和同步加速器)

The Cyclotron: The figure is a top view of the region of a cyclotron in which the particles (protons, say) circulate. The two hollow D-shaped objects (each open on its straight edge) are made of sheet copper. These dees, as they are called, are part of an electrical oscillator that alternates the electric potential difference across the gap between the dees. The electrical signs of the dees are alternated so that the electric field in the gap alternates in direction, first toward one dee and then toward the other dee, back and forth. The dees are immersed in a large magnetic field directed out of the plane of the page. The magnitude B of this field is set via a control on the electromagnet producing the field.

The protons spiral outward in a cyclotron, picking up energy in the gap.

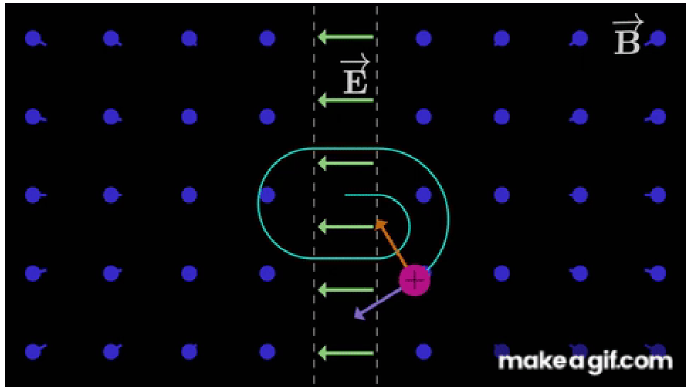




$$r = \frac{mv}{|q|B}.$$

v increase, B unchanged, r increase c

28-5 Cyclotrons and Synchrotrons (3 of 4)



The key to the operation of the cyclotron is that the frequency f at which the proton circulates in the magnetic field (and that does not depend on its speed) must be equal to the fixed frequency f_{osc} of the electrical oscillator, or

$$f = f_{\mathrm{osc}} \quad (\text{resonance condition}).$$

$$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\frac{mv}{|q|B} = \frac{2\pi m}{|q|B}$$

$$f = \frac{1}{T} = \frac{|q|B}{2\pi m}$$

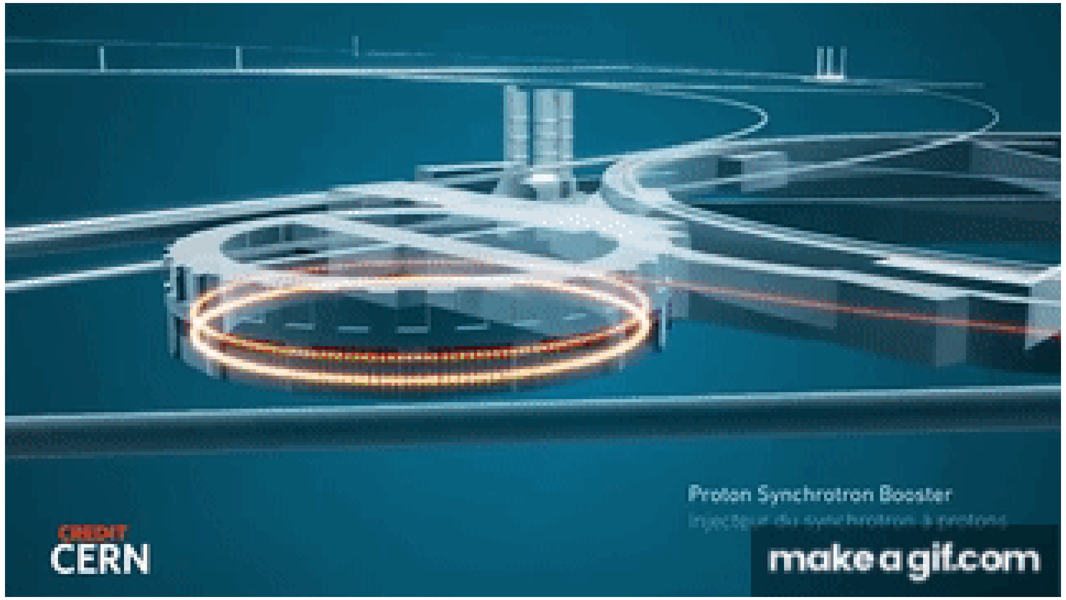
This resonance condition says that, if the energy of the circulating proton is to increase, energy must be fed to it at a frequency f_{osc} that is equal to the natural frequency f at which the proton circulates in the magnetic field.

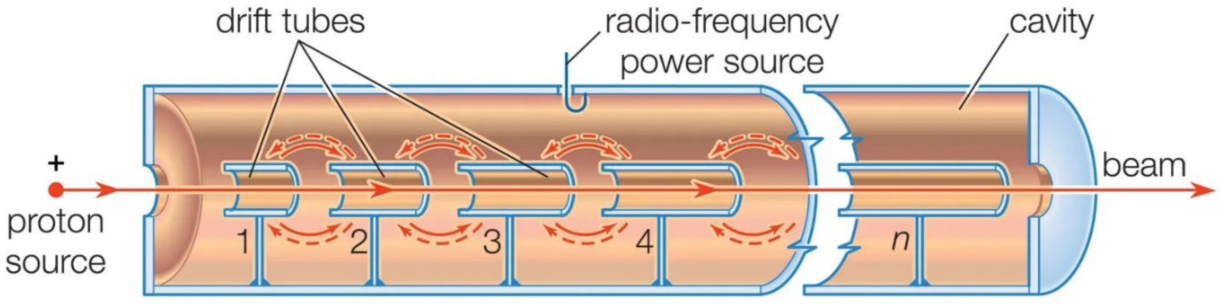
Frequency has nothing to do with speed, unchanged after start.

28-5 Cyclotrons and Synchrotrons (4 of 4)

Proton Synchrotron: The magnetic field B and the oscillator frequency f_{osc}, instead of having fixed values as in the conventional cyclotron, are made to vary with time during the accelerating cycle. When this is done properly, (1) the frequency of the circulating protons remains in step with the oscillator at all times, and (2) the protons follow a circular — not a spiral — path. Thus, the magnet need extend only along that circular path, not over some 4×10^6 m^2. The circular path, however, still must be large if high energies are to be achieved.

$$r = \frac{mv}{|q|B}.$$



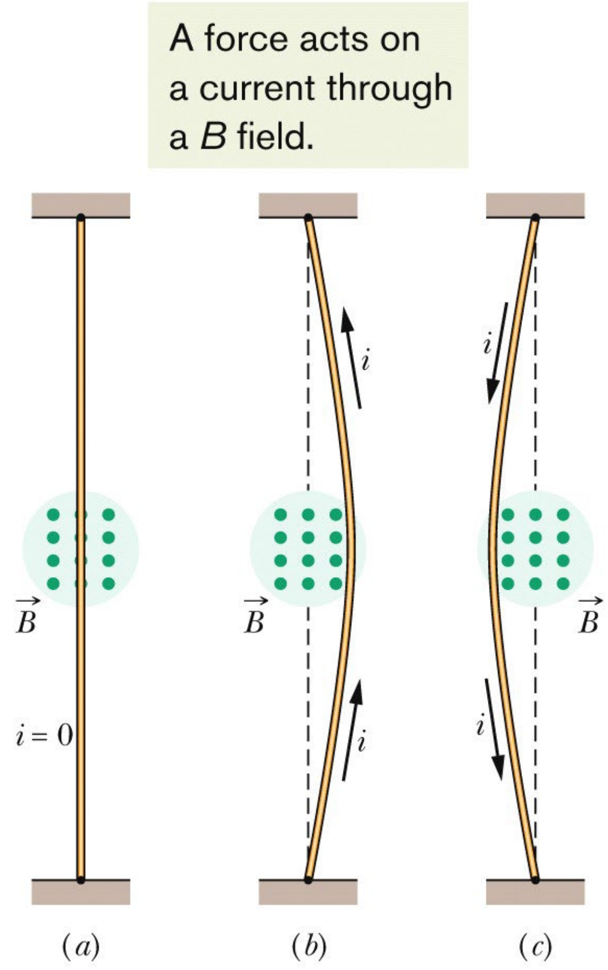


28-6 Magnetic Force on a Current-Carrying Wire (3 of 4)

A straight wire carrying a current i in a uniform magnetic field experiences a sideways force

$$\vec{F}_B = i\vec{L} \times \vec{B} \quad (\text{force on a current}).$$

Here $\vec{L}$ is a length vector that has magnitude L and is directed along the wire segment in the direction of the (conventional) current.



A flexible wire passes between the pole faces of a magnet (only the farther pole face is shown). (*a*) Without current in the wire, the wire is straight. (*b*) With upward current, the wire is deflected rightward. (*c*) With downward current, the deflection is leftward.

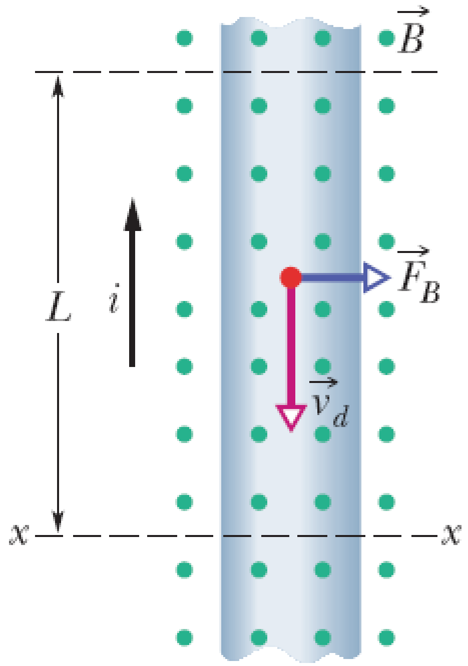
28-6 Magnetic Force on a Current-Carrying Wire (4 of 4)

All the conduction electrons in this section of wire will drift past plane *xx* in Fig. 28-15 in a time $t = L/v_d$

$$q = it = i\frac{L}{v_d}$$

$$\vec{F}_B = q\vec{v} \times \vec{B} = i\frac{L}{v}\vec{v} \times \vec{B}$$

$$\vec{F}_B = i\vec{L} \times \vec{B} \quad (\text{force on a current}).$$

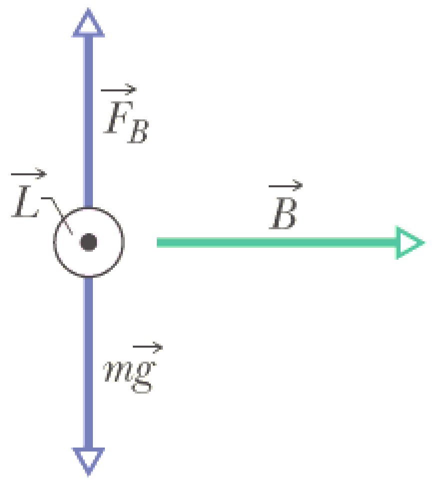


28-6 Magnetic Force on a Current-Carrying Wire (4 of 4)

A straight, horizontal length of copper wire has a current $i = 28$ A through it. What are the magnitude and direction of the minimum magnetic field $\vec{B}$ needed to suspend the wire — that is, to balance the gravitational force on it? The linear density (mass per unit length) of the wire is 46.6 g/m.

28-6 Magnetic Force on a Current-Carrying Wire (4 of 4)

A straight, horizontal length of copper wire has a current $i = 28$ A through it. What are the magnitude and direction of the minimum magnetic field $\vec{B}$ needed to suspend the wire — that is, to balance the gravitational force on it? The linear density (mass per unit length) of the wire is 46.6 g/m.



$$iLB \sin\phi = mg$$

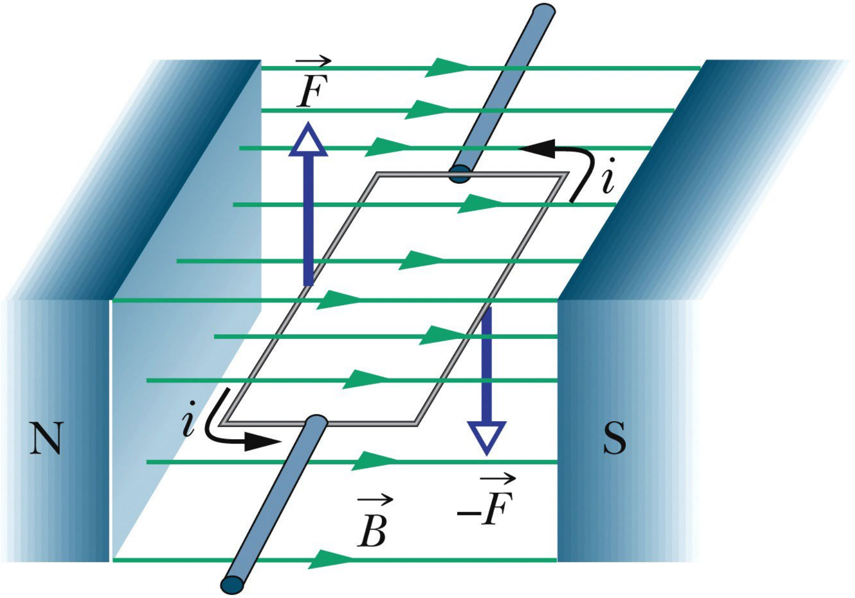
$$B = \frac{mg}{iL \sin\phi} = \frac{(m/L)g}{i}$$

$$B = \frac{(46.6 \times 10^{-3}\ \text{kg/m})(9.8\ \text{m/s}^2)}{28\ \text{A}}$$

$$= 1.6 \times 10^{-2}\ \text{T}.$$

28-7 Torque on a Current Loop (3 of 3)

The elements of an electric motor: A rectangular loop of wire, carrying a current and free to rotate about a fixed axis, is placed in a magnetic field. Magnetic forces on the wire produce a torque that rotates it. A commutator (换向器) (not shown) reverses the direction of the current every half-revolution so that the torque always acts in the same direction.



The elements of an electric motor

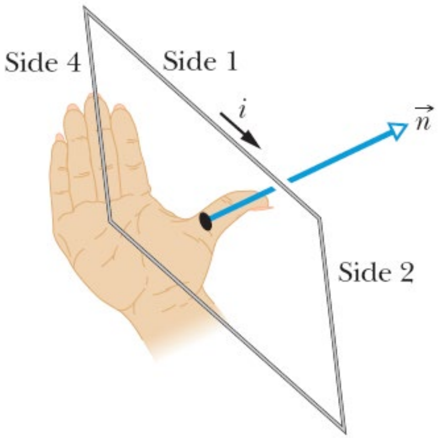
28-7 Torque on a Current Loop (2 of 3)

As shown in the figure the net force on the loop is the vector sum of the forces acting on its four sides and comes out to be zero. The net torque acting on the coil has a magnitude given by

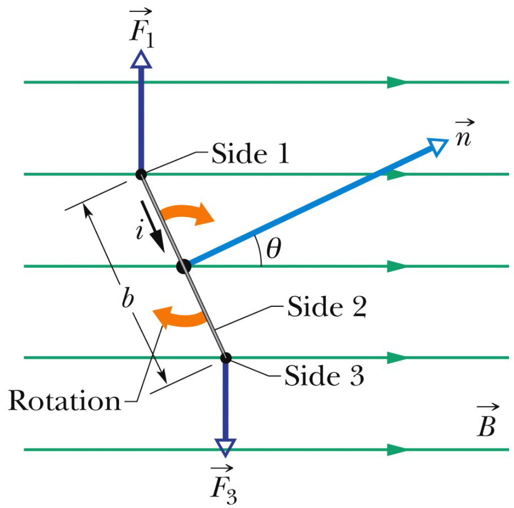
$$\tau = rF\sin\theta,$$

$$\tau' = \left(iaB\frac{b}{2}\sin\theta\right) + \left(iaB\frac{b}{2}\sin\theta\right) = iabB\sin\theta.$$

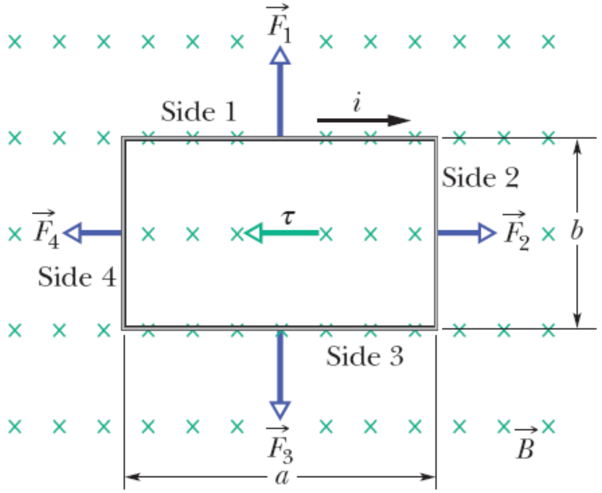
$$\tau = NiAB\sin\theta,$$



(b)



(c)



a)

where N is the number of turns in the coil (线圈匝数), A is the area of each turn, i is the current, B is the field magnitude, and θ is the angle between the magnetic field $\vec{B}$ and the normal vector to the coil $\vec{n}$.

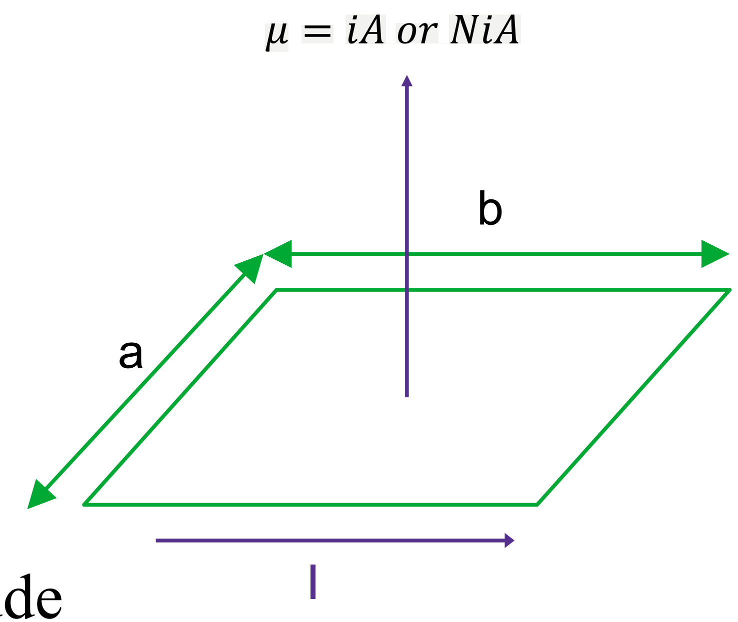
28-8 The Magnetic Dipole Moment 磁偶极矩

a current-carrying coil is said to be a *magnetic dipole*.

A coil (of area A and N turns, carrying current i) in a uniform magnetic field $\vec{B}$ will experience a torque $\vec{\tau}$ given by

$$\tau = NiAB\sin\theta, \quad \Rightarrow \quad \vec{\tau} = \vec{\mu} \times \vec{B},$$

where $\vec{\mu}$ is the **magnetic dipole moment** of the coil, with magnitude $\mu = NiA$ and direction given by the right- hand rule.



28-8 The Magnetic Dipole Moment (6 of 6)

Summary (5 of 5)

- The dipole has a potential energy U associated with its orientation in the field

$$U = -\vec{p} \cdot \vec{E}.$$ **Equation (22-38)**

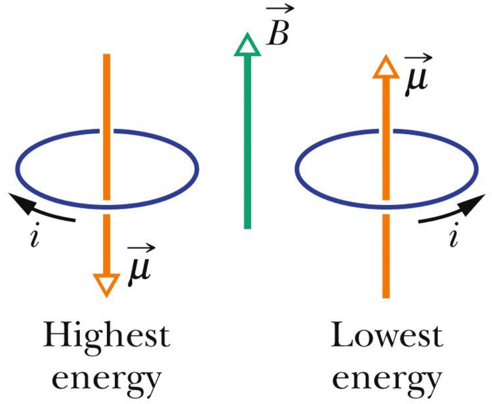
The orientation energy of a magnetic dipole in a magnetic field is

$$U(\theta) = -\vec{\mu} \cdot \vec{B}.$$

If an external agent rotates a magnetic dipole from an initial orientation θ_i to some other orientation θ_f and the dipole is stationary both initially and finally, the work W_a done on the dipole by the agent is

$$W_a = \Delta U = U_f - U_i.$$

The magnetic moment vector attempts to align with the magnetic field.



A magnetic dipole has its lowest energy (= $-\mu B \cos 0 = -\mu B$) when its dipole moment μ is lined up with the magnetic field, It has its highest energy (= $-\mu B \cos 180° = +\mu B$) when μ is directed opposite the field

Summary (1 of 4)

The Magnetic Field $\vec{B}$

- Defined in terms of the force $\vec{F}_B$ acting on a test particle with charge q moving through the field with velocity $\vec{v}$

$$\vec{F}_B = q\vec{v} \times \vec{B}.$$ **Equation (28-2)**

A Charge Particle Circulating in a Magnetic Field

- Applying Newton's second law to the circular motion yields

$$|q|vB = \frac{mv^2}{r}$$ **Equation (28-15)**

- from which we find the radius r of the orbit circle to be

$$r = \frac{mv}{|q|B}.$$ **Equation (28-16)**

Summary (2 of 4)

Magnetic Force on a Current Carrying wire

- A straight wire carrying a current i in a uniform magnetic field experiences a sideways force

$$\vec{F}_B = i\vec{L} \times \vec{B}.$$ **Equation (28-26)**

- The force acting on a current element $id\vec{L}$ in a magnetic field is

$$d\vec{F}_B = id\vec{L} \times \vec{B}.$$ **Equation (28-28)**

Torque on a Current Carrying Coil

- A coil (of area A and N turns, carrying current i) in a uniform magnetic field $\vec{B}$ will experience a torque $\vec{\tau}$ given by

$$\vec{\tau} = \vec{\mu} \times \vec{B}.$$ **Equation (28-37)**

Summary (3 of 4)

The Hall Effect

- When a conducting strip carrying a current i is placed in a uniform magnetic field $\vec{B}$, some charge carriers (with charge e) build up on one side of the conductor, creating a potential difference V across the strip. The polarities of the sides indicate the sign of the charge carriers.

Summary (4 of 4)

Orientation Energy of a Magnetic Dipole

- The orientation energy of a magnetic dipole in a magnetic field is

$$U(\theta) = -\vec{\mu} \cdot \vec{B}.$$

Equation (28-38)

- If an external agent rotates a magnetic dipole from an initial orientation θ_i to some other orientation θ_f and the dipole is stationary both initially and finally, the work W_a done on the dipole by the agent is

$$W_a = \Delta U = U_f - U_i.$$

Equation (28-39)

In-class quiz

•14 A metal strip 6.50 cm long, 0.850 cm wide, and 0.760 mm thick moves with constant velocity $\vec{v}$ through a uniform magnetic field $B = 1.20$ mT directed perpendicular to the strip, as shown in Fig. 28-34. A potential difference of 3.90 μV is measured between points x and y across the strip. Calculate the speed v.

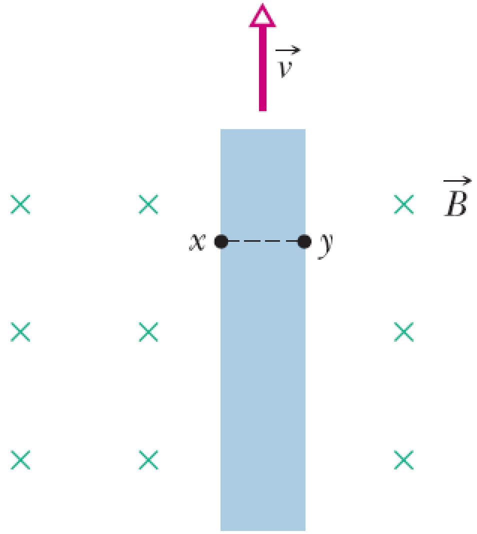


Figure 28-34 Problem 14.

In-class quiz

••33 SSM WWW A positron with kinetic energy 2.00 keV is projected into a uniform magnetic field $\vec{B}$ of magnitude 0.100 T, with its velocity vector making an angle of 89.0° with $\vec{B}$. Find (a) the period, (b) the pitch p, and (c) the radius r of its helical path.

In-class quiz

•42 The bent wire shown in Fig. 28-42 lies in a uniform magnetic field. Each straight section is 2.0 m long and makes an angle of $\theta = 60°$ with the x axis, and the wire carries a current of 2.0 A. What is the net magnetic force on the wire in unit-vector notation if the magnetic field is given by (a) $4.0\hat{k}$ T and (b) $4.0\hat{i}$ T?