

Storyline

Sources of the Magnetic Field



Physics for Scientists and Engineers, 10e
Raymond A. Serway
John W. Jewett, Jr.

 BROOKS/COLE
CENGAGE Learning™

Relationship between Magnetism and Electricity



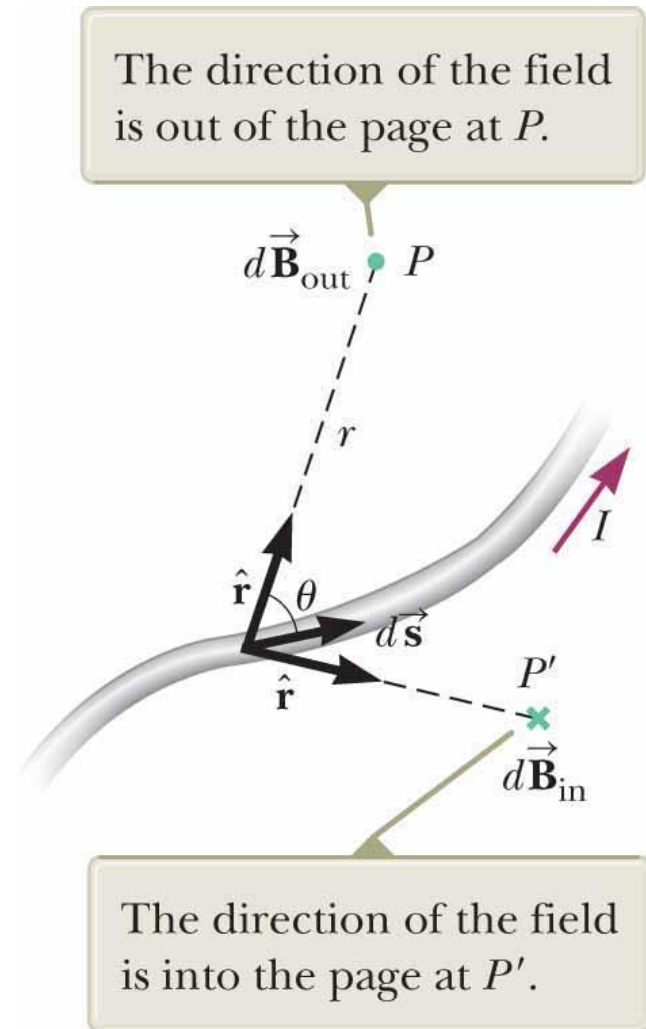
The Biot–Savart Law

$$d\vec{\mathbf{B}} = \frac{\mu_0}{4\pi} \frac{I d\vec{\mathbf{s}} \times \hat{\mathbf{r}}}{r^2}$$

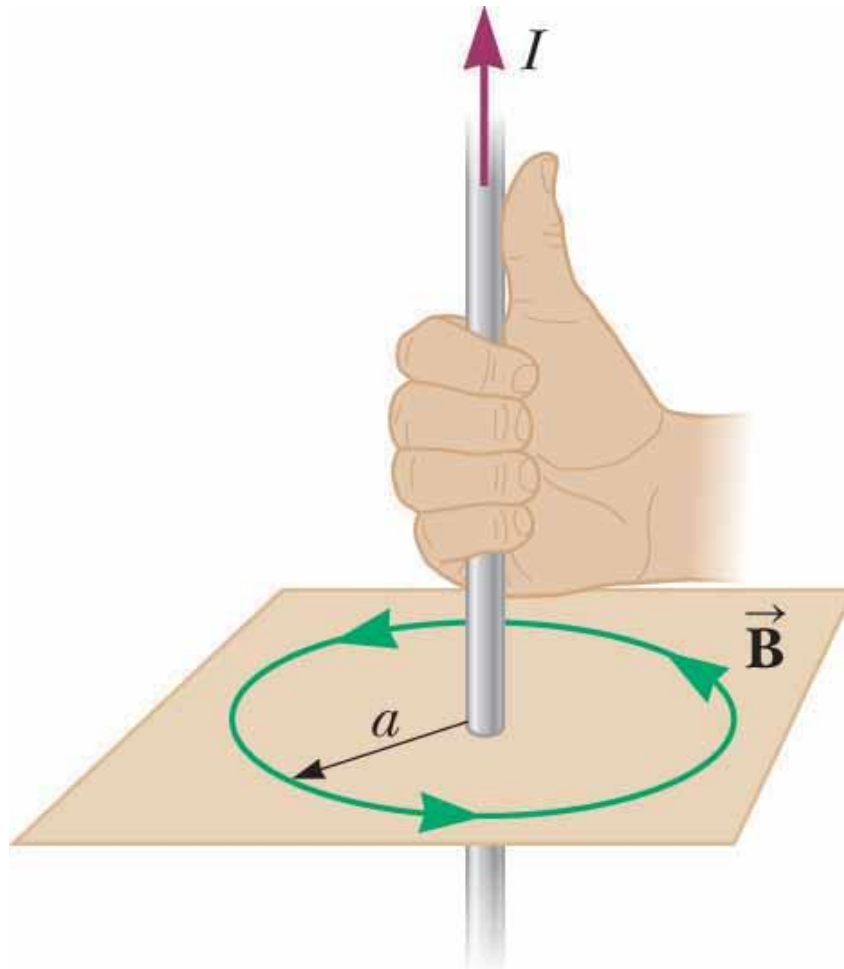
$$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$$

$$\vec{\mathbf{E}} = k_e \frac{q}{r^2} \hat{\mathbf{r}}$$

$$\vec{\mathbf{B}} = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{\mathbf{s}} \times \hat{\mathbf{r}}}{r^2}$$

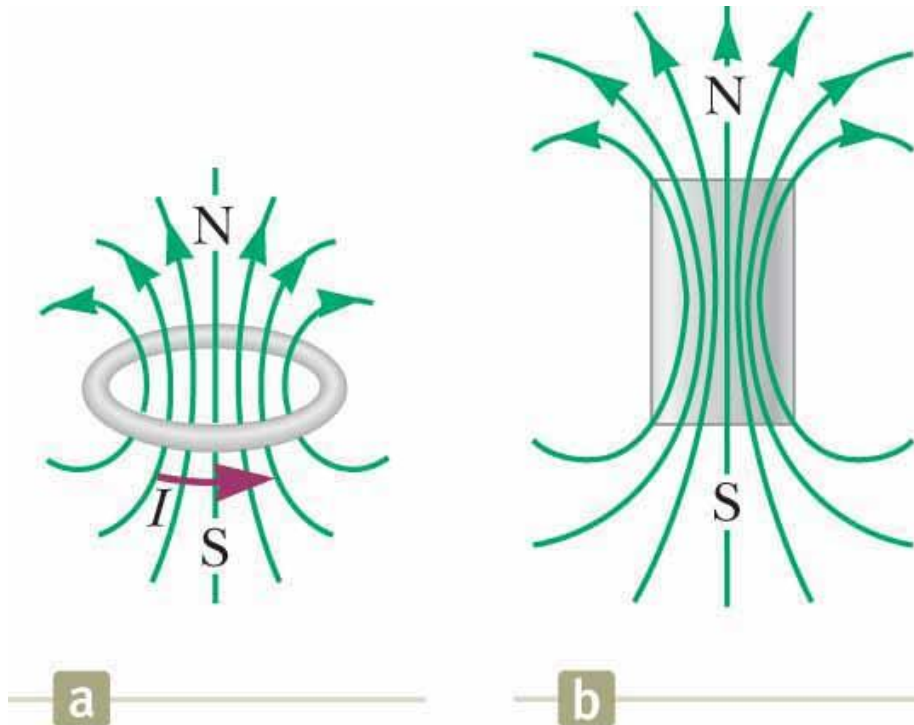


Magnetic Fields Due to Currents

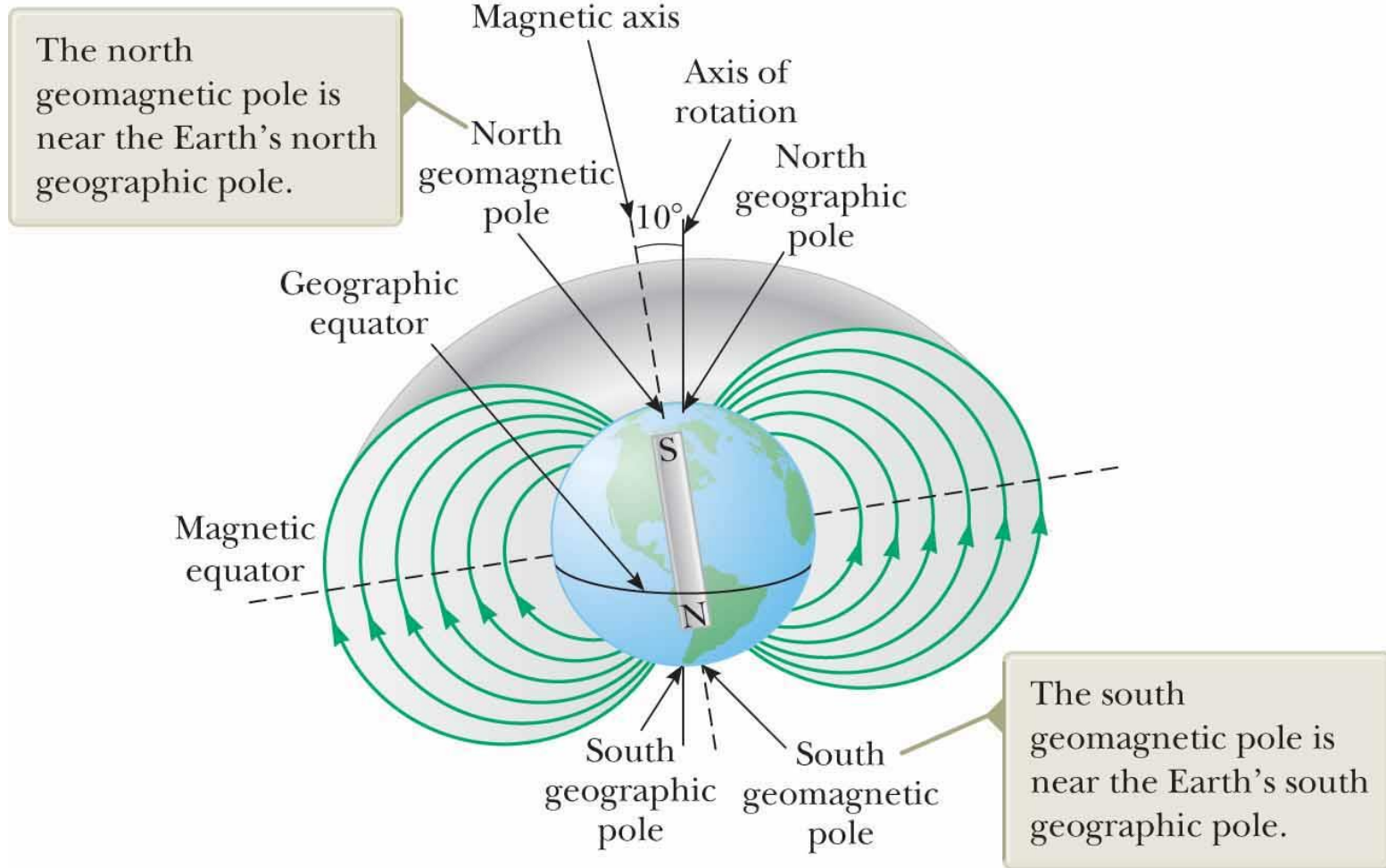


Example 29.3: Magnetic Field on the Axis of a Circular Current Loop

$$B = \frac{\mu_0 I}{2a} \quad (\text{at center of loop})$$



Source of Earth's Magnetic Field



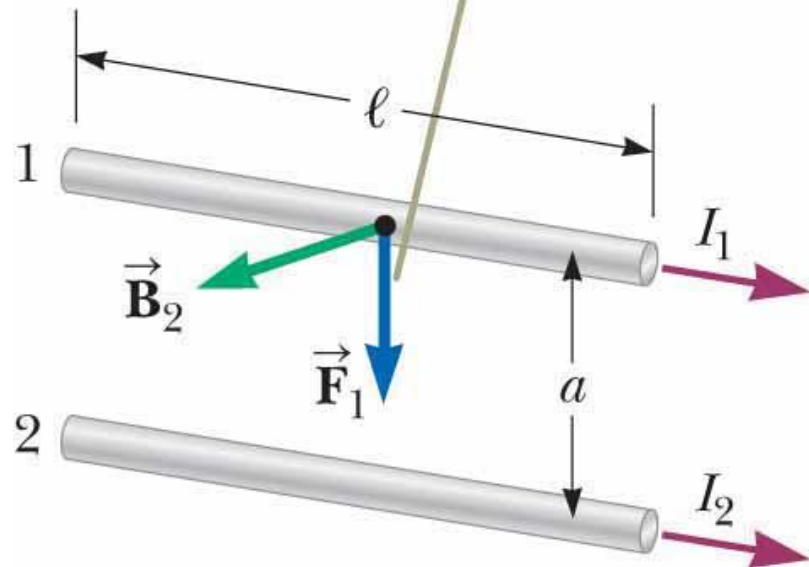
The Magnetic Force Between Two Parallel Conductors

$$\vec{\mathbf{F}}_1 = I_1 \vec{\ell} \times \vec{\mathbf{B}}_2 \quad F_1 = I_1 \ell B_2$$

$$\begin{aligned} F_1 &= I_1 \ell B_2 \\ &= I_1 \ell \left(\frac{\mu_0 I_2}{2\pi a} \right) \\ &= \frac{\mu_0 I_1 I_2}{2\pi a} \ell \end{aligned}$$

$$\frac{F_B}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi a}$$

The field $\vec{\mathbf{B}}_2$ due to the current in wire 2 exerts a magnetic force of magnitude $F_1 = I_1 \ell B_2$ on wire 1.



The Magnetic Force Between Two Parallel Conductors

When the magnitude of the force per unit length between two long, parallel wires that carry identical currents and are separated by 1 m is 2×10^{-7} N/m, the current in each wire is defined to be 1 A.

$$\frac{F_B}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi a} \qquad F_1 = \frac{\mu_0 I_1 I_2}{2\pi a} \ell$$

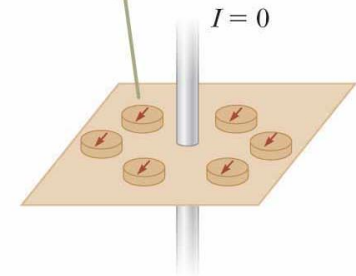
Ampère's Law

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = B \oint ds = \frac{\mu_0 I}{2\pi r} (2\pi r) = \mu_0 I$$

The line integral of $\vec{\mathbf{B}} \cdot d\vec{\mathbf{s}}$ around any closed path equals $\mu_0 I$, where I is the total steady current passing through any surface bounded by the closed path:

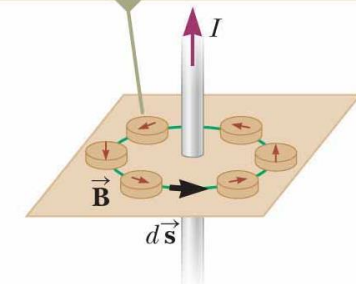
$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = \mu_0 I$$

When no current is present in the wire, all compass needles point in the same direction (toward the Earth's north pole).



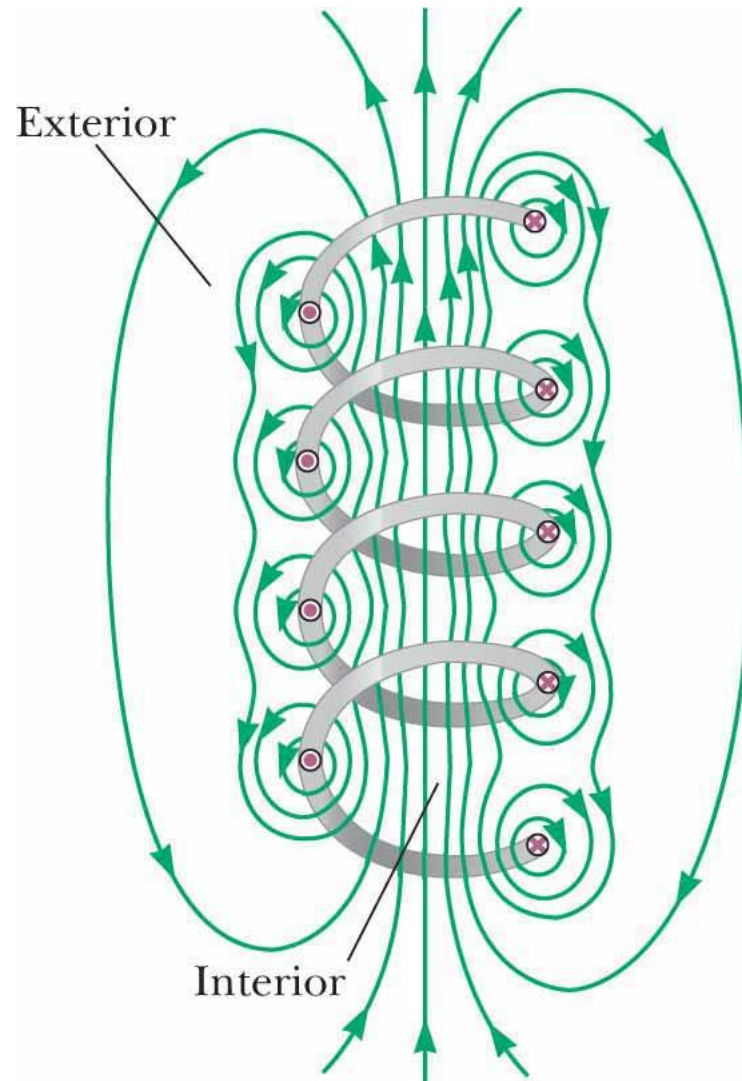
a

When the wire carries a strong current, the compass needles deflect in a direction tangent to the circle, which is the direction of the magnetic field created by the current.



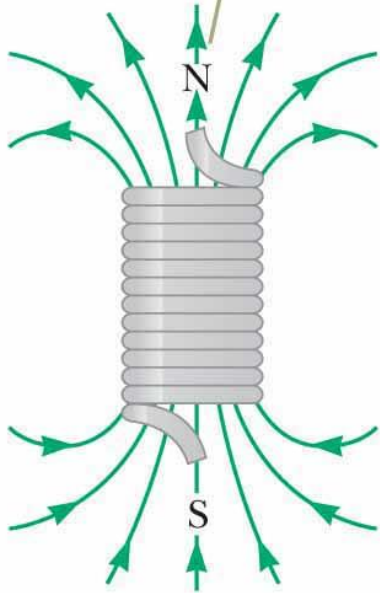
b

The Magnetic Field of a Solenoid

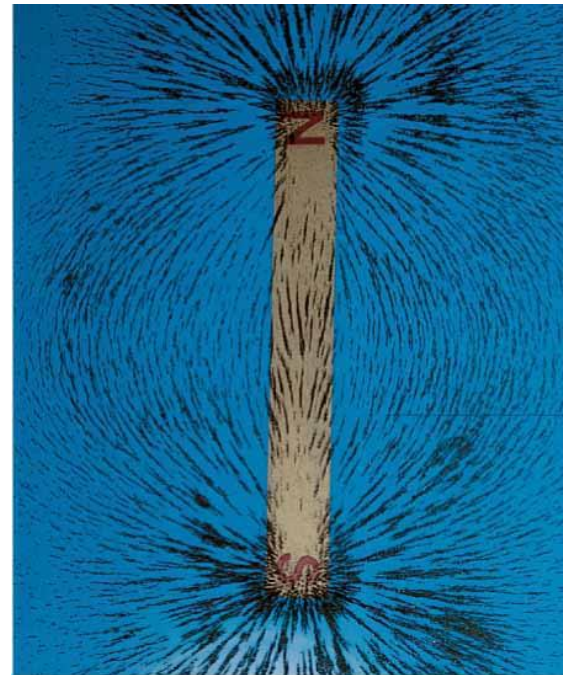


The Magnetic Field of a Solenoid

The magnetic field lines resemble those of a bar magnet, meaning that the solenoid effectively has north and south poles.



a



b

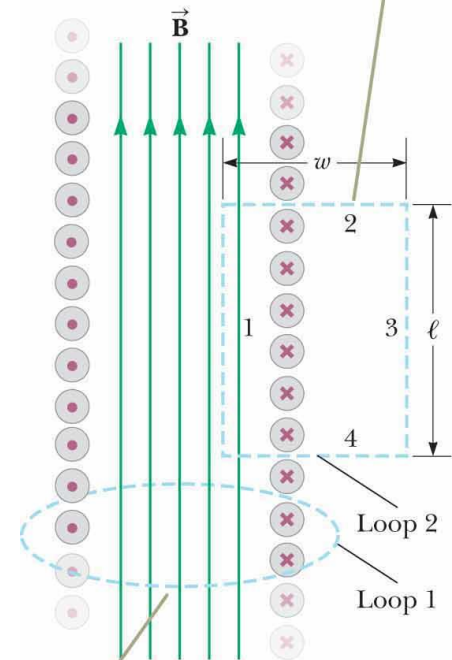
The Magnetic Field of a Solenoid

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = \underbrace{\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}}}_{\text{path 1}} + \underbrace{\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}}}_{\text{path 2}} = B\ell$$

$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = B\ell = \mu_0 NI$$

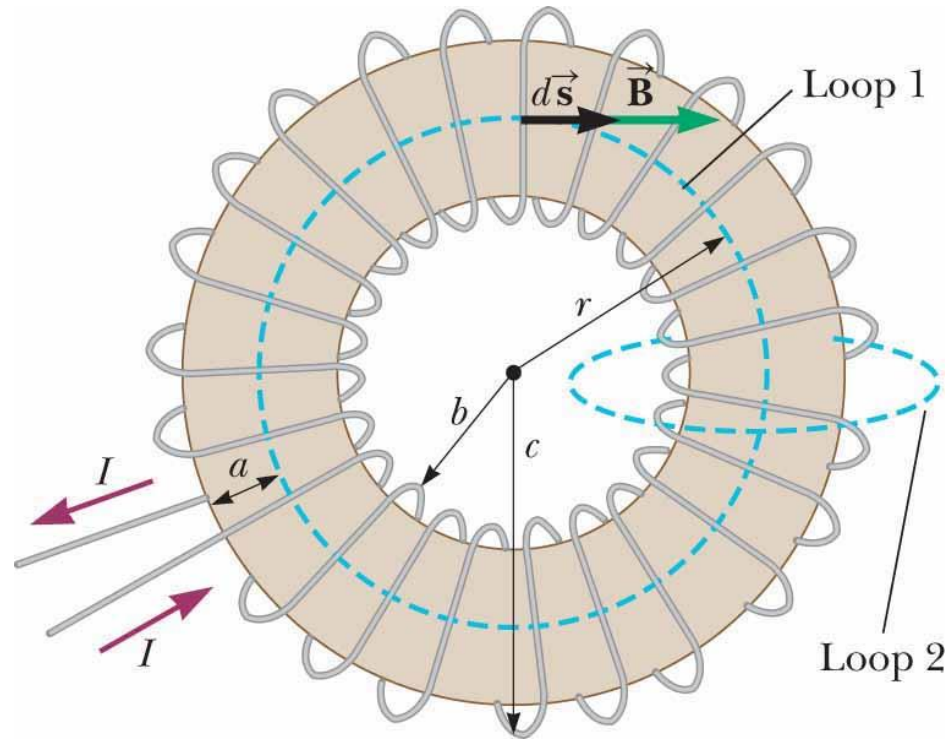
$$B = \mu_0 \frac{N}{\ell} I = \mu_0 nI$$

Ampère's law applied to the rectangular dashed path can be used to calculate the magnitude of the interior field.



Ampère's law applied to the circular path whose plane is perpendicular to the page can be used to show that there is a weak field outside the solenoid.

The Magnetic Field of a Solenoid

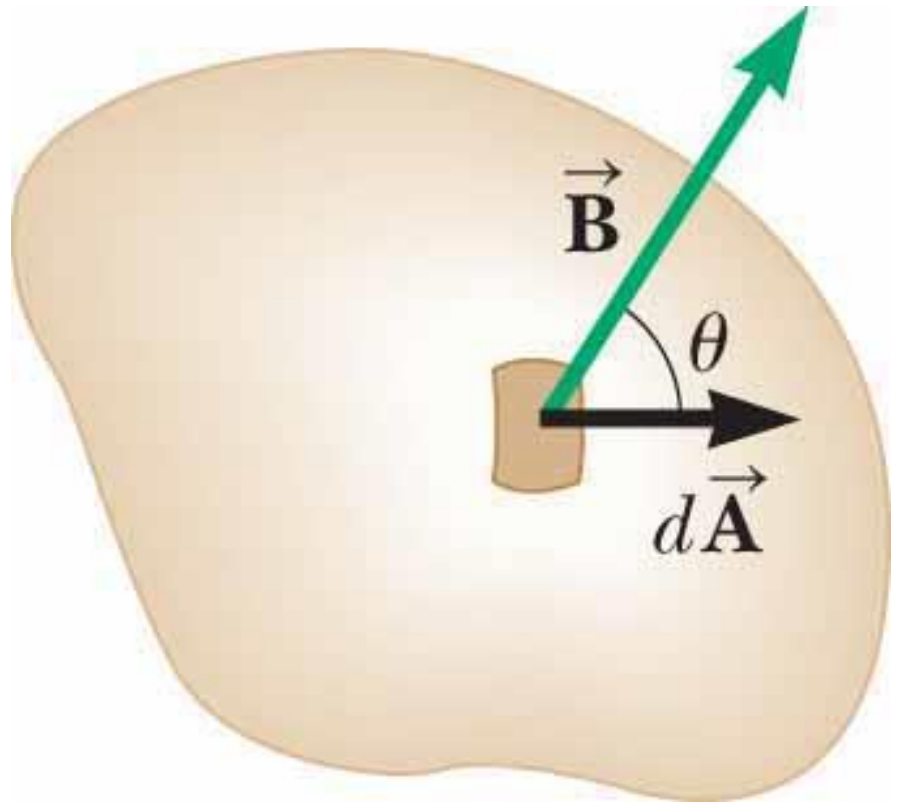


$$B_{\text{toroid}} = \frac{\mu_0 NI}{2\pi r} \quad B_{\text{solenoid}} = \mu_0 nI \Rightarrow n = \frac{N}{2\pi r}$$

Gauss's Law in Magnetism

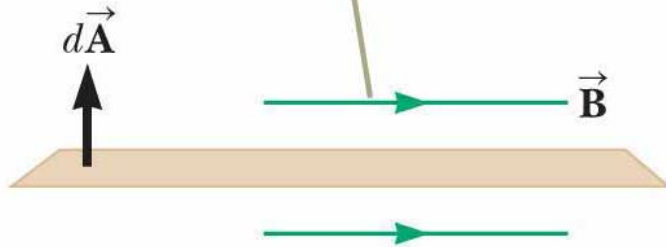
$$\Phi_B \equiv \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

$$\Phi_B = BA \cos \theta$$



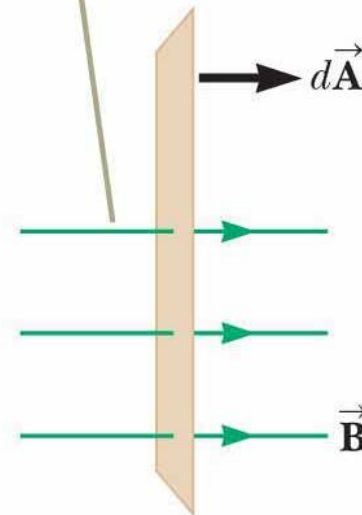
Gauss's Law in Magnetism

The flux through the plane is zero when the magnetic field is parallel to the plane surface.



a

The flux through the plane is a maximum when the magnetic field is perpendicular to the plane.



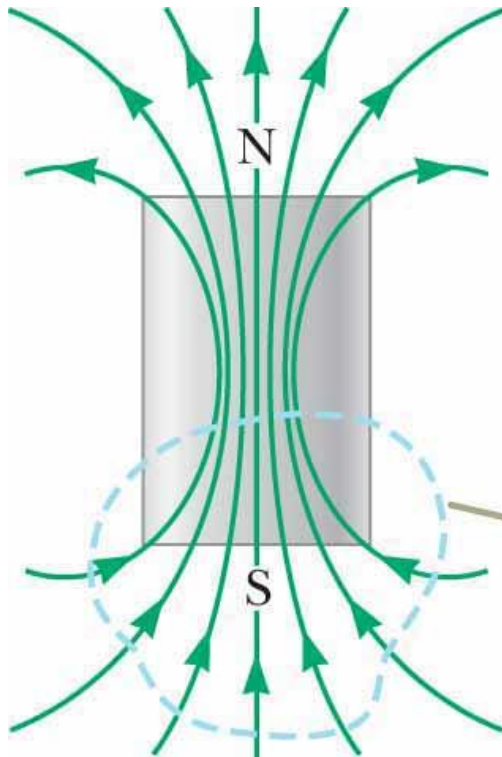
b

$$1 \text{ Wb} = 1 \text{ T} \cdot \text{m}^2$$

Gauss's Law in Magnetism

The net magnetic flux through any closed surface is always zero:

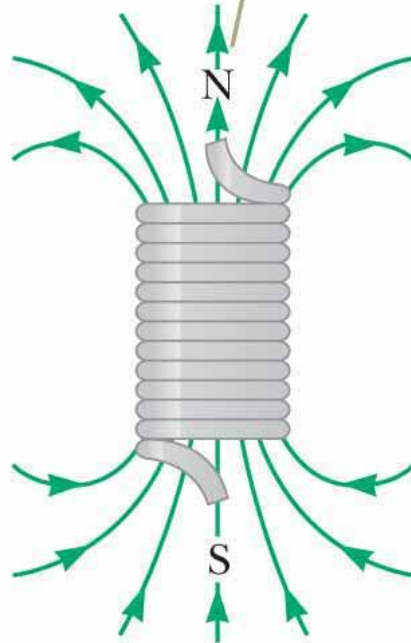
$$\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$$



The net magnetic flux through a closed surface surrounding one of the poles or any other closed surface is zero.

Magnetism in Matter

The magnetic field lines resemble those of a bar magnet, meaning that the solenoid effectively has north and south poles.



The Magnetic Moments of Atoms

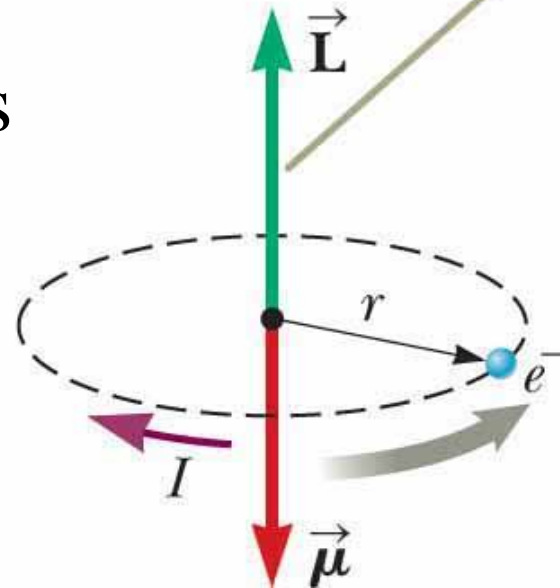
$$\mu = IA$$

$$L = m_e v r$$

$$\hbar = \frac{h}{2\pi} = 1.05 \times 10^{-34} \text{ J} \cdot \text{s}$$

$$\mu = \sqrt{2} \frac{e}{2m_e} \hbar$$

The electron has an angular momentum \vec{L} in one direction and a magnetic moment $\vec{\mu}$ in the opposite direction.

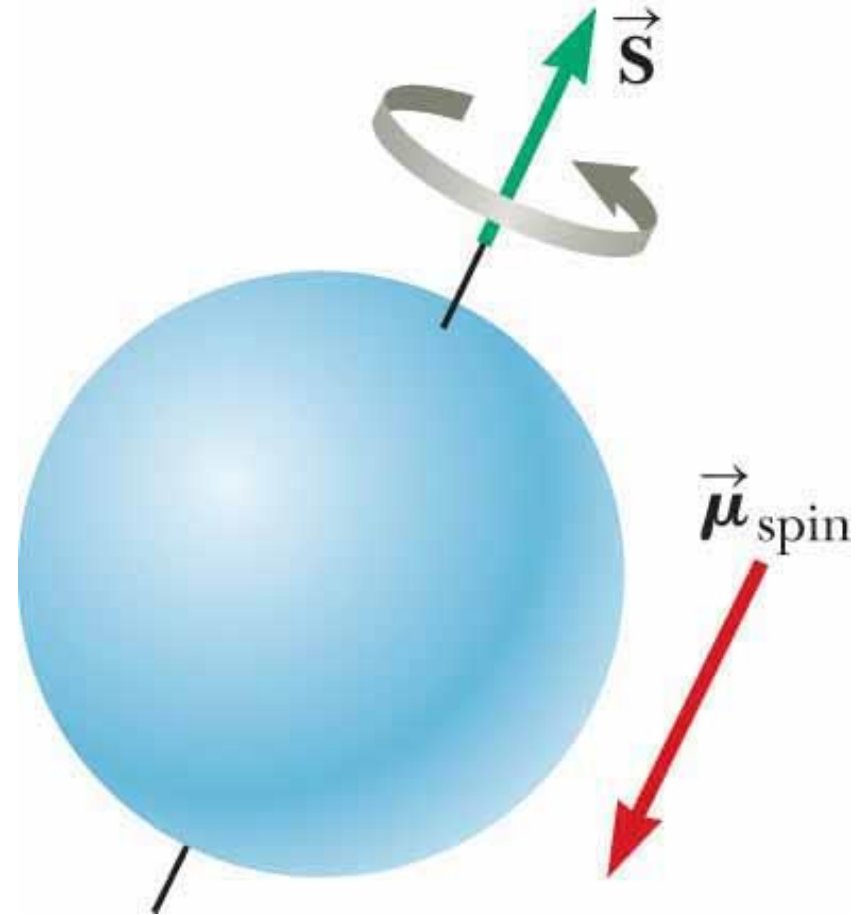


The Magnetic Moments of Atoms

$$S = \frac{\sqrt{3}}{2} \hbar$$

$$\mu_{\text{spin}} = \frac{e\hbar}{2m_e}$$

$$\mu_B = \frac{e\hbar}{2m_e} = 9.27 \times 10^{-24} \text{ J/T}$$



The Magnetic Moments of Atoms

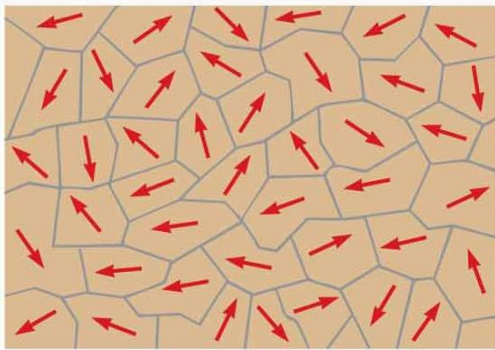
TABLE 29.1 Magnetic Moments of Some Atoms and Ions

Atom or Ion	Magnetic Moment (10^{-24} J/T)
H	9.27
He	0
Ne	0
Ce ³⁺	19.8
Yb ³⁺	37.1

$$\mu_B = \frac{e\hbar}{2m_e} = 9.27 \times 10^{-24} \text{ J/T}$$

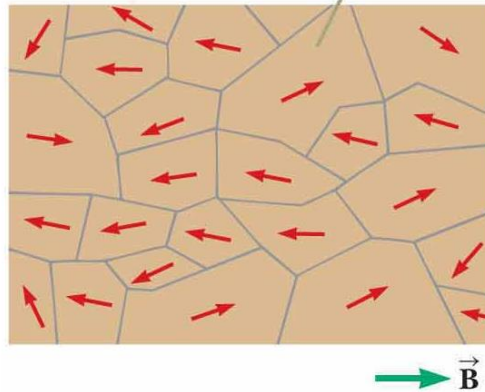
Ferromagnetism

In an unmagnetized substance, the atomic magnetic dipoles are randomly oriented.



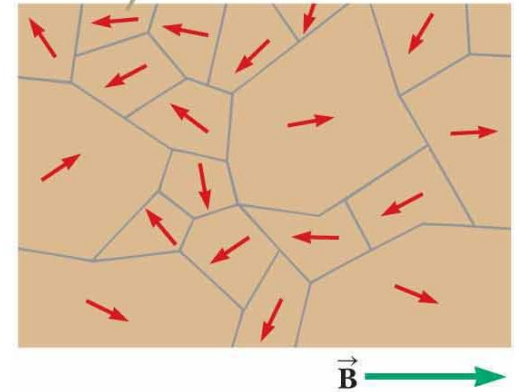
a

When an external field \vec{B} is applied, the domains with components of magnetic moment in the same direction as \vec{B} grow larger, giving the sample a net magnetization.



b

As the field is made even stronger, the domains with magnetic moment vectors not aligned with the external field become very small.



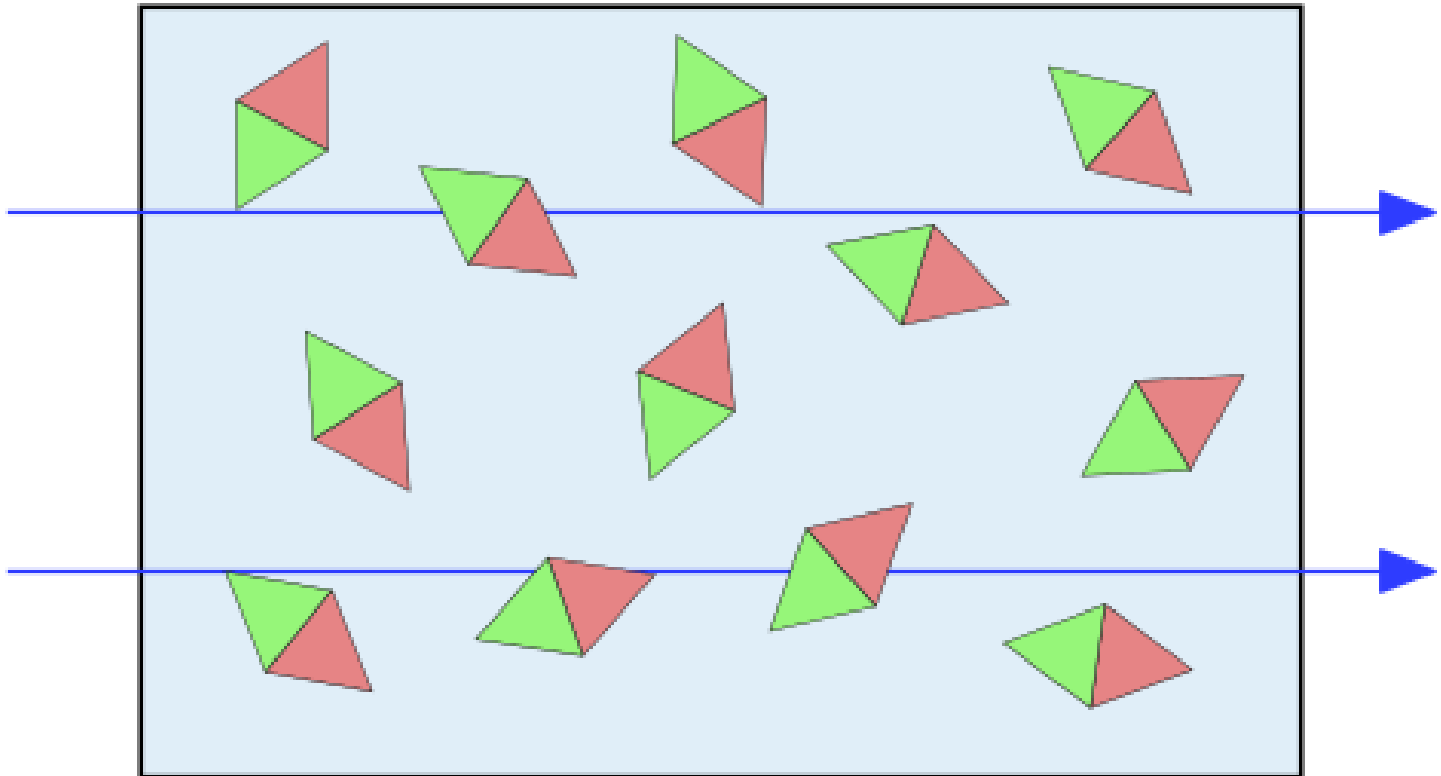
c

Ferromagnetism

TABLE 29.2 Curie Temperatures for Several Ferromagnetic Substances

Substance	T_{Curie} (K)
Iron	1 043
Cobalt	1 394
Nickel	631
Gadolinium	317
Fe_2O_3	893

Paramagnetism



Diamagnetism

In the Meissner effect, the small magnet at the top induces currents in the superconducting disk below, which is cooled to -321°F (77 K). The currents create a repulsive magnetic force on the magnet causing it to levitate above the superconducting disk.

