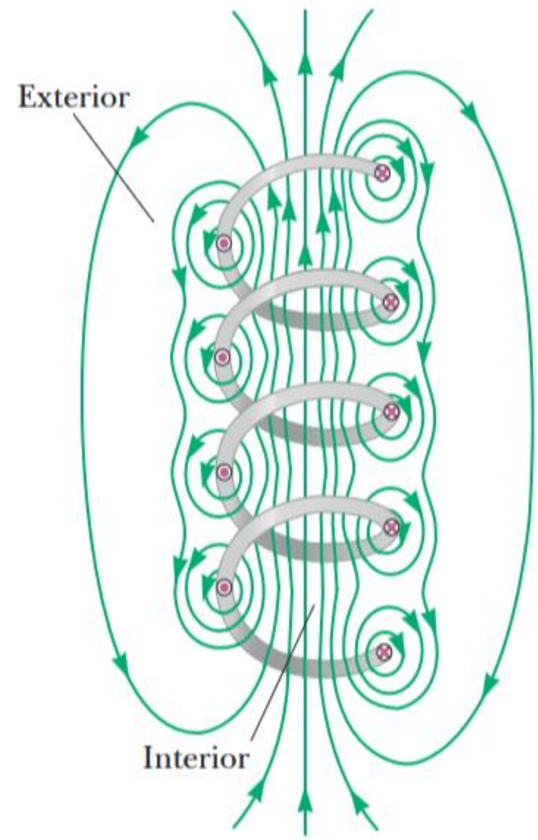
30.4 The magnetic field of a solenoid



A solenoid is a long wire wound in the form of a helix. With this configuration, a reasonably uniform magnetic field can be produced in the space surrounded by the turns of wire, which we shall call the interior of the solenoid, *when the solenoid* carries a current.

The **interior field** lines are nearly parallel, uniformly distributed, and close together, indicating that the field in this space is uniform and strong.

The field lines between current elements on two adjacent turns tend to cancel each other because the field vectors from the two aspects are in opposite directions.

The field at exterior points *is weak because* the field caused by current elements on the right-hand portion of a turn tends to cancel the field caused by current elements on the left-hand portion.

- ❖ **Magnetic field lines for a tightly wound solenoid of finite length, carrying a steady current**

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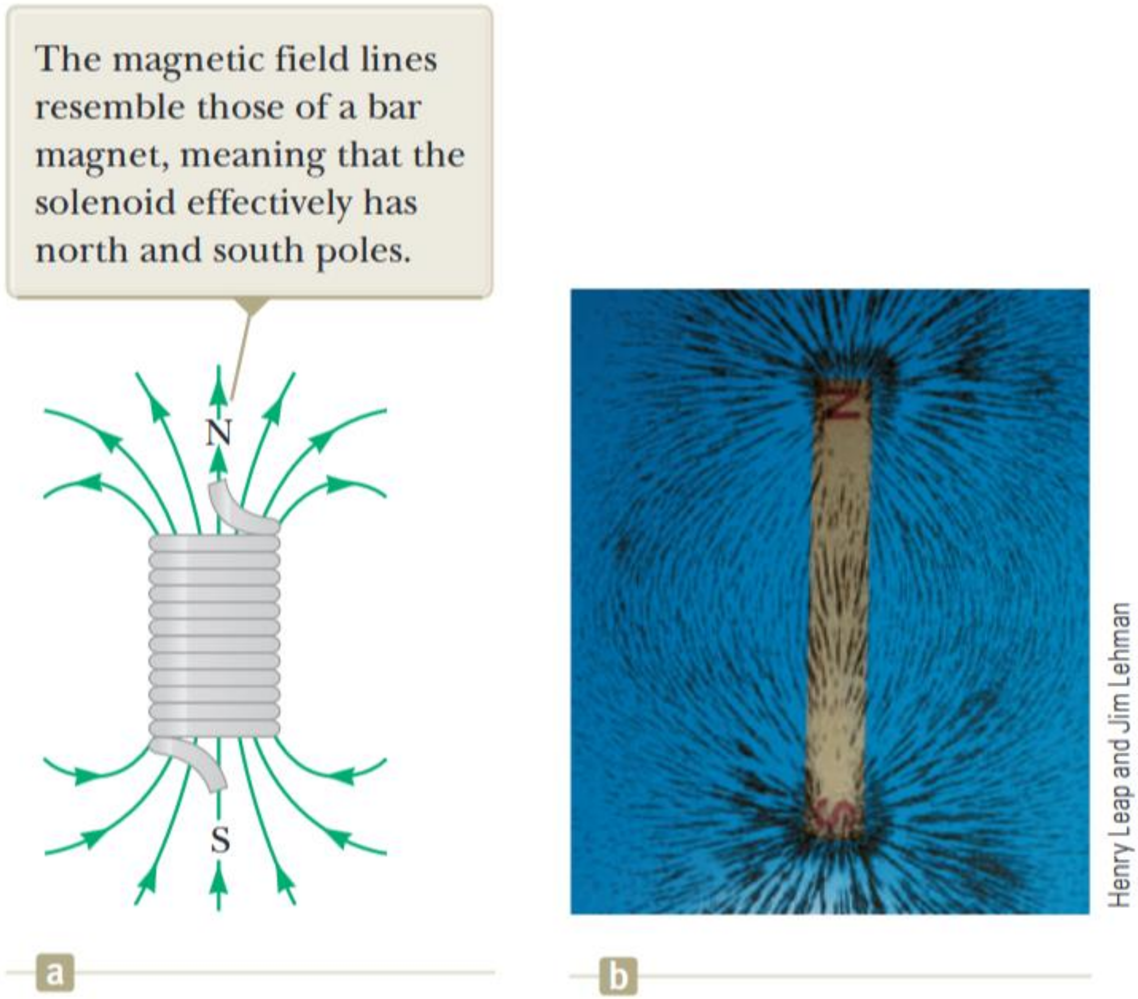
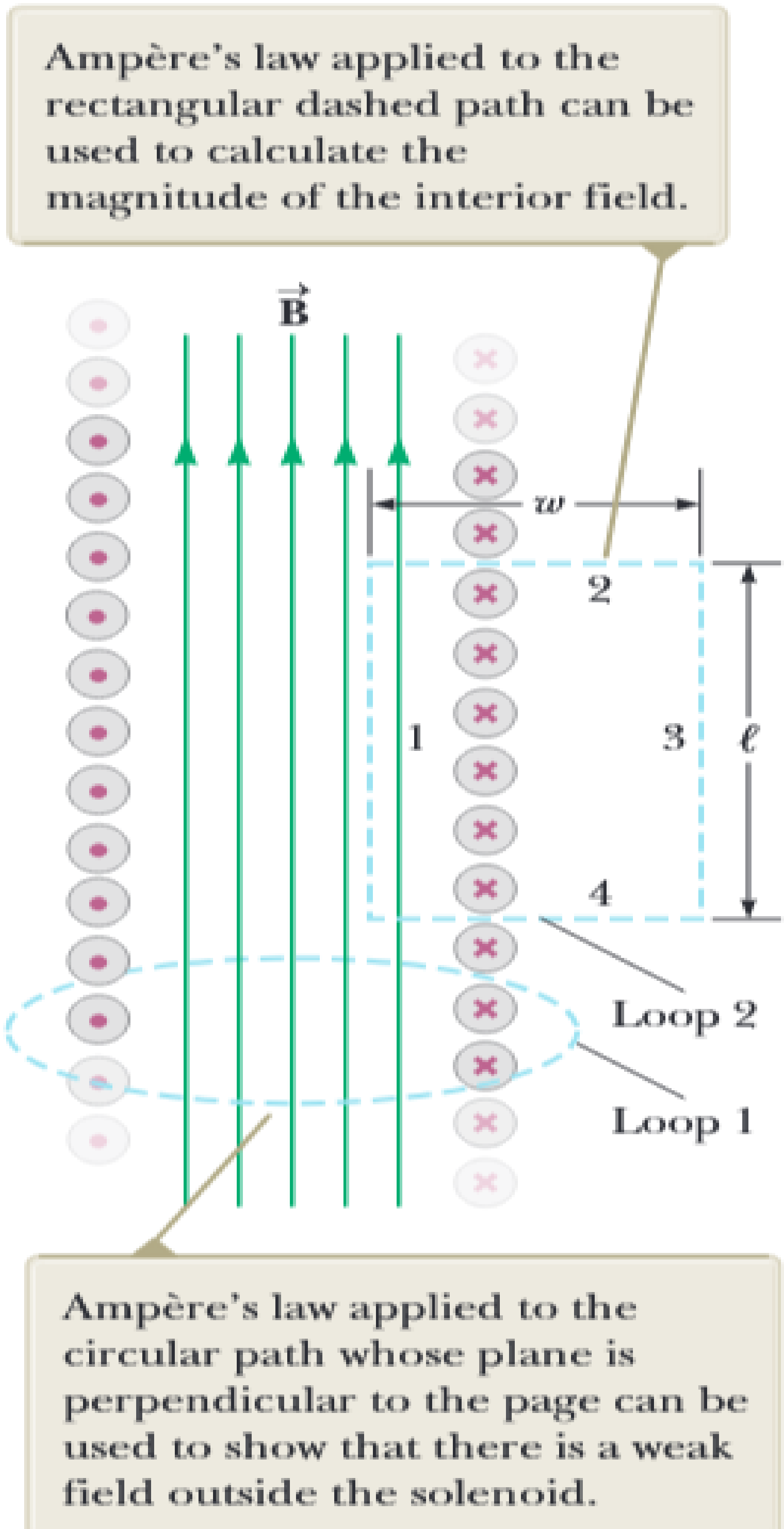


The magnetic field pattern of a bar magnet is displayed with small iron filings on a sheet of paper.

An *ideal solenoid is approached* when the turns are closely spaced and the length is much greater than the radius of the turns. In this case, the external field is zero, and the interior field is uniform over a great volume.


Ampère's law applied to the rectangular dashed path can be used to calculate the magnitude of the interior field.
$\vec{B}$
w
2
1
3
ℓ
4
Loop 2
Loop 1
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.

Because the solenoid is ideal, B in the interior space is uniform and parallel to the axis, and B in the exterior space is zero.

Consider the rectangular path of length and width shown in the Figure. We can apply Ampère's law to this path by evaluating the integral of **B.*ds*** over each side of the rectangle.

$$\oint \vec{B}.d\vec{s} = \int_{path1} \vec{B}.d\vec{s} = B \int_{path\ 1} ds = Bl \qquad 30.8$$

Why are the integrals over paths 2,3, and 4 zero?

If N is the number of turns in the length *l*, the total current through the rectangle is N*I*. Therefore, we can write 30.8 as follows,

$$\oint \vec{B}.d\vec{s} = Bl = \mu_0 I \qquad 30.9$$

So,
$$B = \mu_0 \frac{N}{l} I = \mu_0 nl \qquad 30.10$$

Where **n is the number of turns per unit length**.

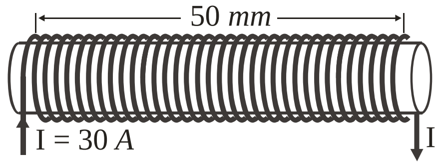
Applications of Solenoids

- **Electromagnets** (used in lifting magnets, MRI machines)
- **Relays and solenoid valves** (used in electronic and mechanical systems)
- **Inductors and transformers** (used in electrical circuits)
- **Magnetic resonance imaging (MRI)**
- **Particle accelerators** (guiding charged particles)

Q1- A solenoid of 1 m length has 1000 turns and a cross-sectional area of 16 cm2. What is the magnetic field inside the solenoid if the current through the coil is 1 A?

A) 1.256×10^{-3} B) 10^{-4} C) 7.85×10^{-5} D) 1.57×10^{-4}

Q2-If the total number of turns of the solenoid (N) is 34 turns, then the magnetic field strength inside it is:



A) 0.052 B) 0.026 C) 0.072 D) 0.036

Q3: What happens to the magnetic field inside if a ferromagnetic core (such as iron) is inserted into a solenoid?

A) It decreases due to resistance
B) It remains unchanged
C) It increases due to higher permeability
D) It disappears completely

Q4: Increasing the number of turns per unit length in a solenoid while keeping the current constant will:

A) Decrease the magnetic field inside
B) Increase the magnetic field inside
C) Have no effect on the magnetic field
D) Reverse the direction of the magnetic field

Q5: If the current in a solenoid is reversed, what happens to the direction of its magnetic field?

A) It remains the same
B) It reverses direction
C) It increases in strength but does not change direction
D) It disappears