PHY-112
Principles of Physics-II
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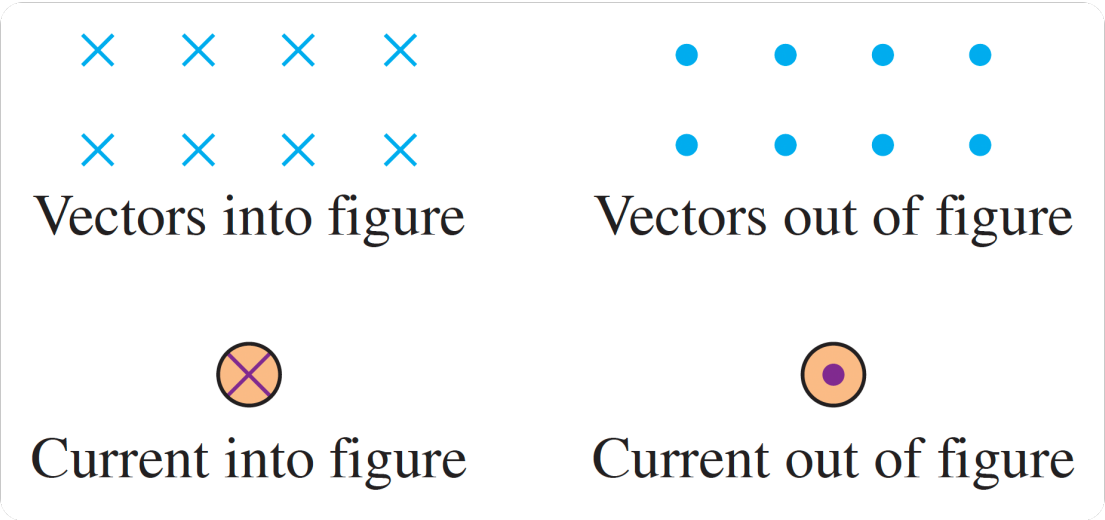
Spring-24 | Class-18

Magnetic Field Sources

Magnetism is an interaction between moving charges. One creates it, another experiences it. But both need to be ***moving***.

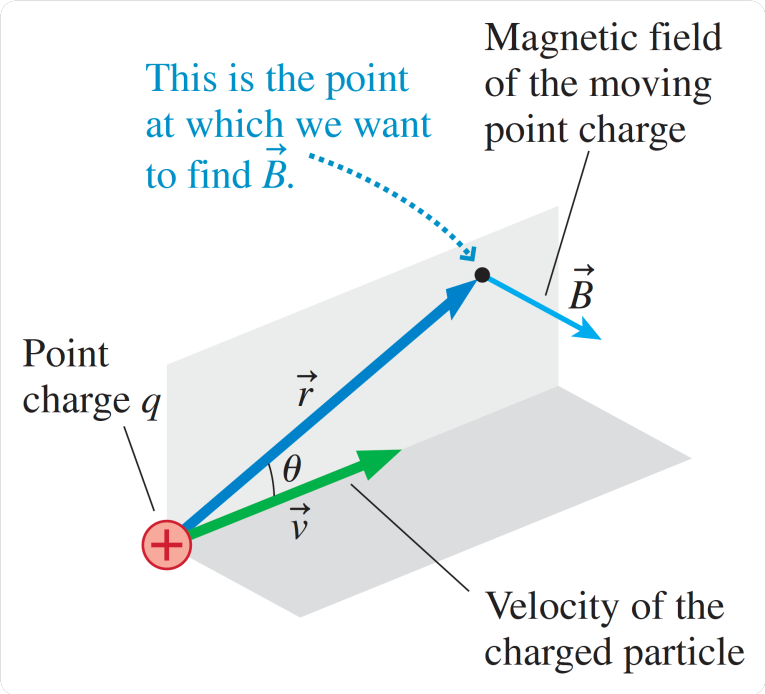
- A Magnetic field $\vec{B}$ is created by a moving charge
- Magnetic interactions are understood in terms of Magnetic poles: North and South
- Practical Magnetic fields are created by electric currents—collections of moving charges.

Essential Notations



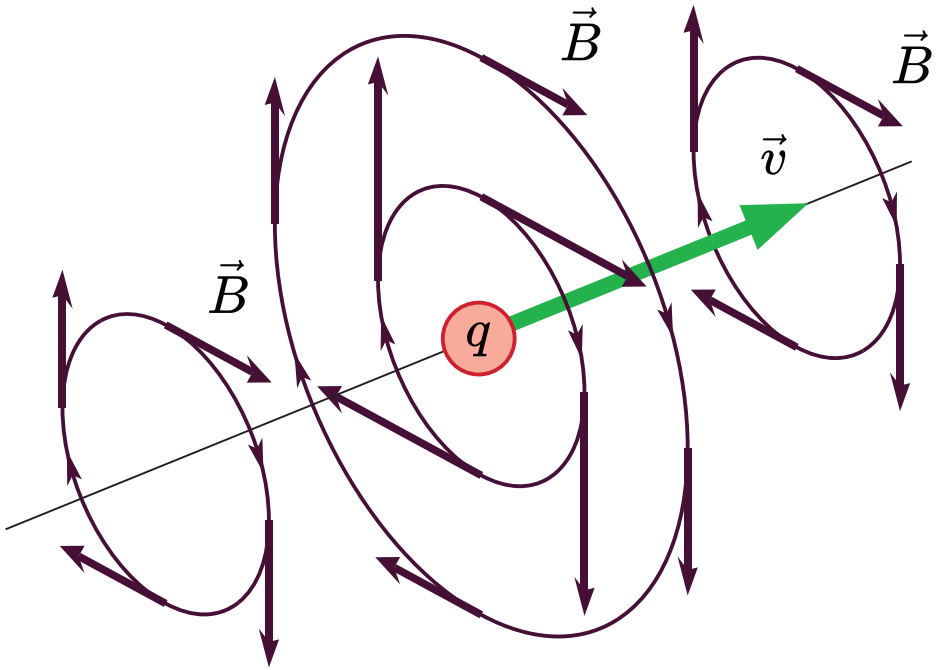
The Source of the $\vec{B}$-Field: Moving Charges

Biot-Savart (pronounce, *Bee-oh-Savah*) law measures the $\vec{B}$-field produced by a moving point charge.



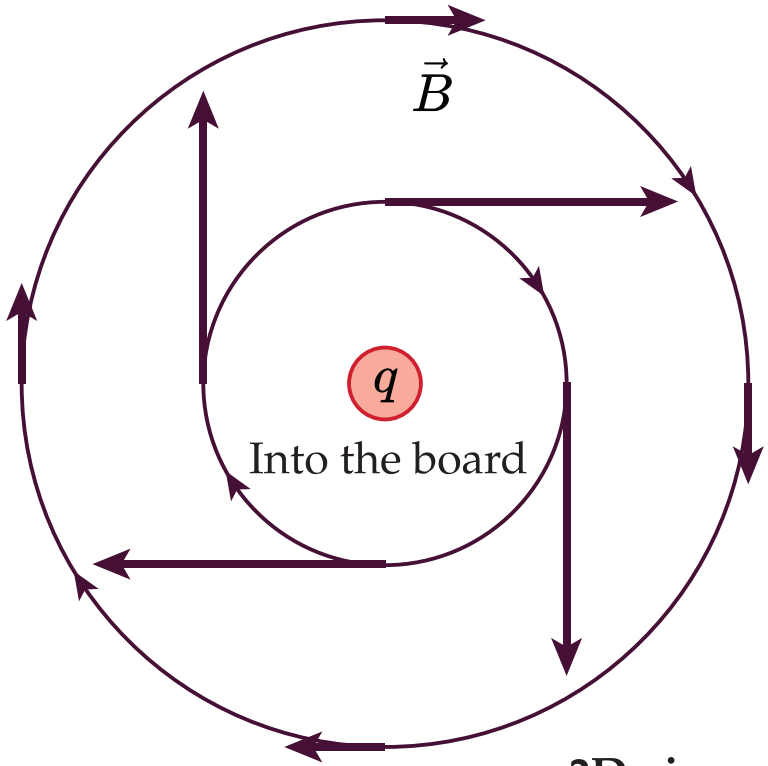
$$|\vec{B}|_{\text{point-charge}} = \frac{\mu_0}{4\pi}\left|\frac{q\vec{v}\times\hat{r}}{r^2}\right| = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$$

$\vec{B}$-field lines are circular for Single *moving* Point Charges



Line of motion

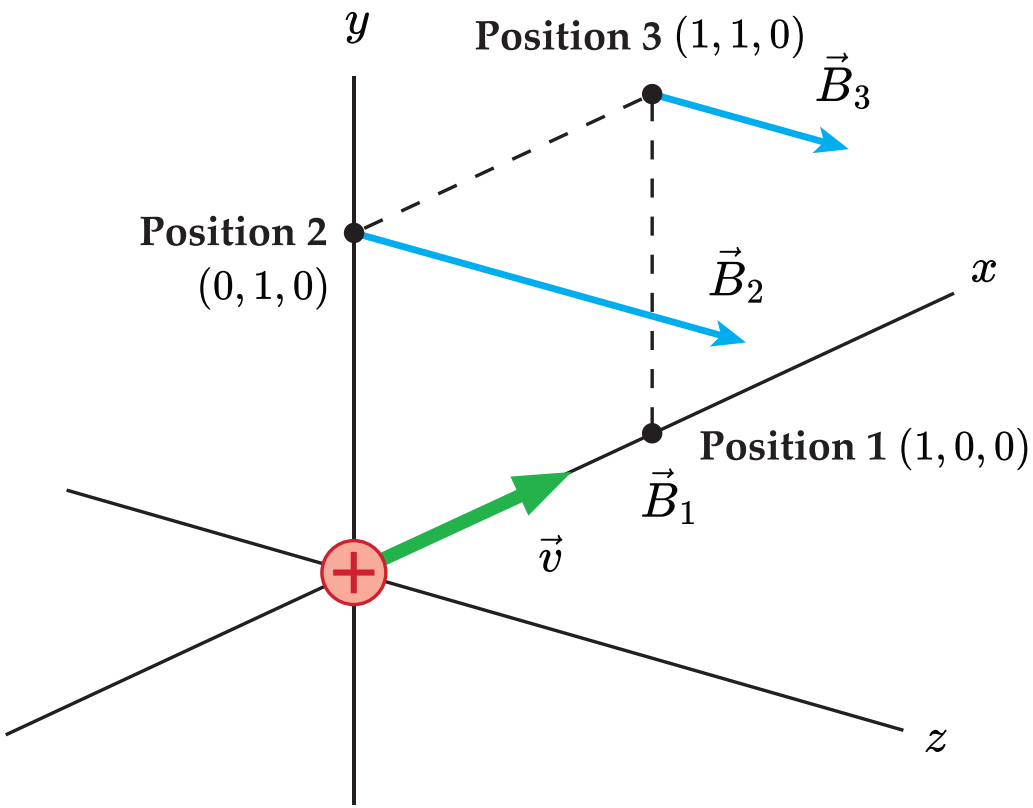
3D view



2D view

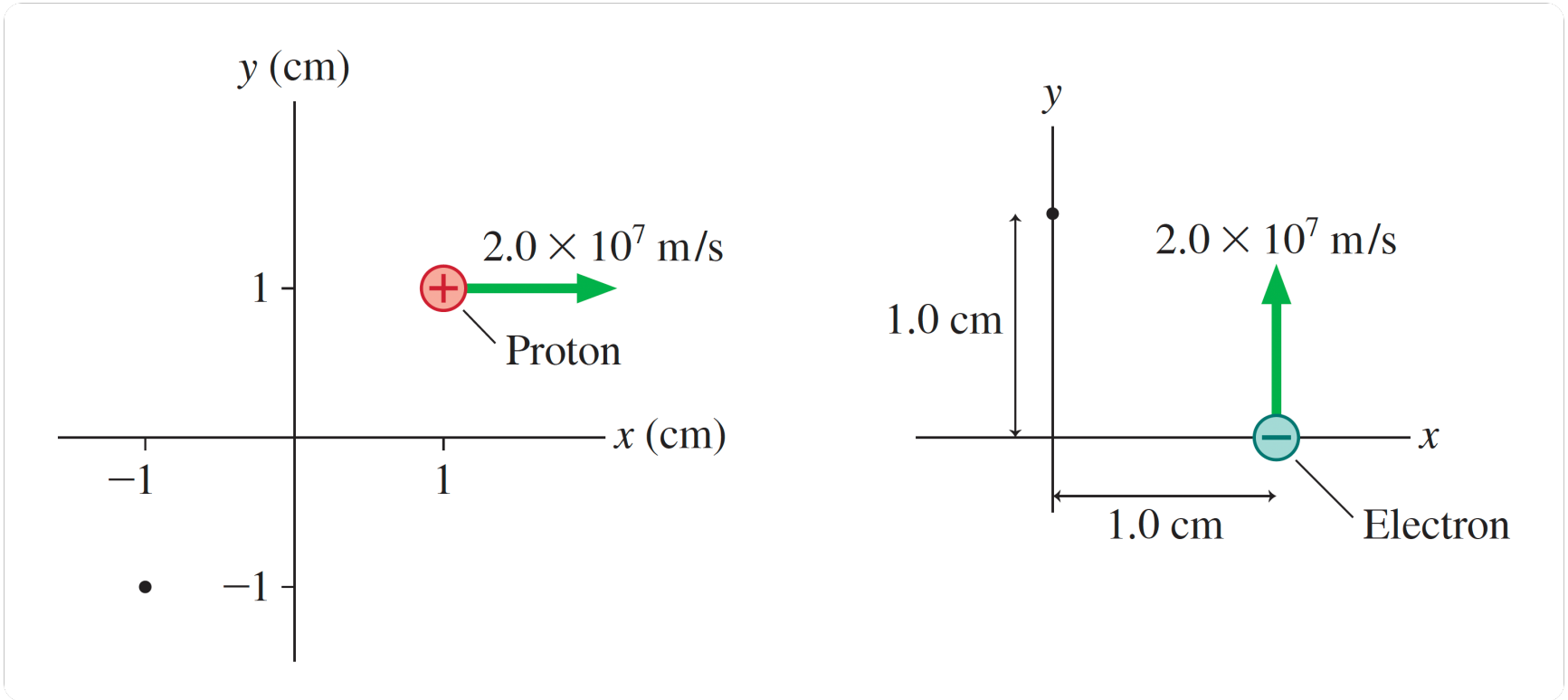
Testing Concepts (1)

Q: A proton moves with velocity $\vec{v} = (1.5 \times 10^7\,\hat{i})\,\mathrm{m\,s^{-1}}$. As it passes the origin, what is the Magnetic field at the three given positions?



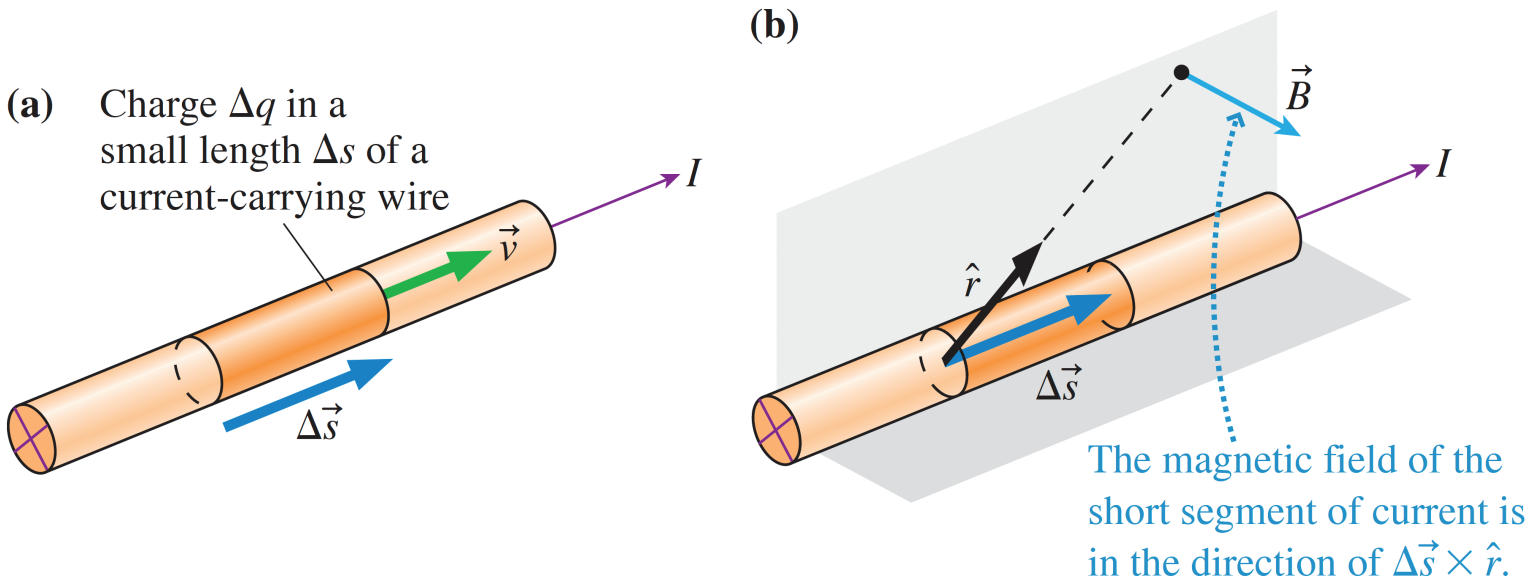
Testing Concepts (2)

Q: What is the Magnetic field at the position of the dot in both diagrams? Give your answer as a vector.



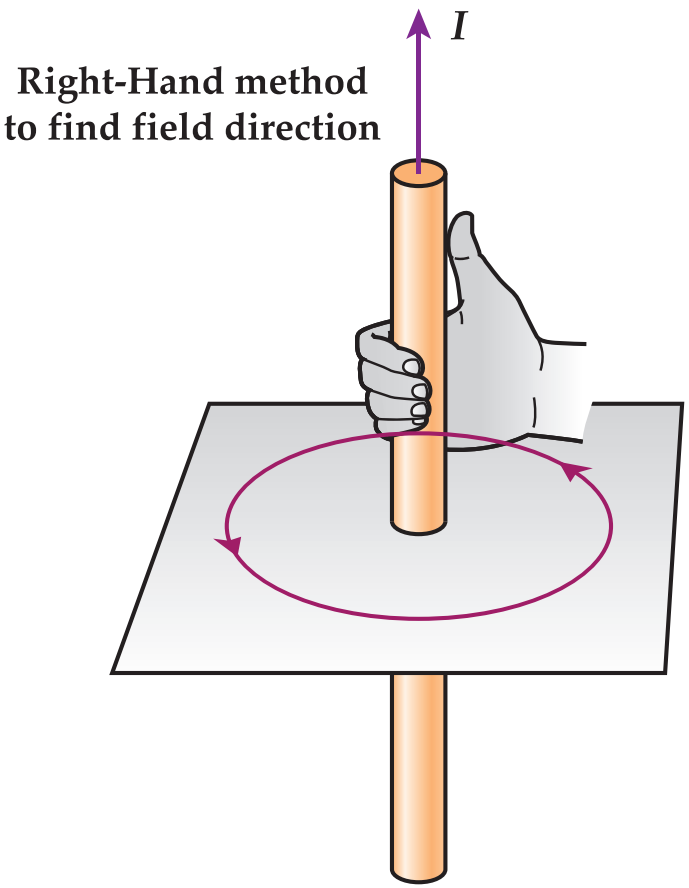
The Source of the $\vec{B}$-Field: Electric Current

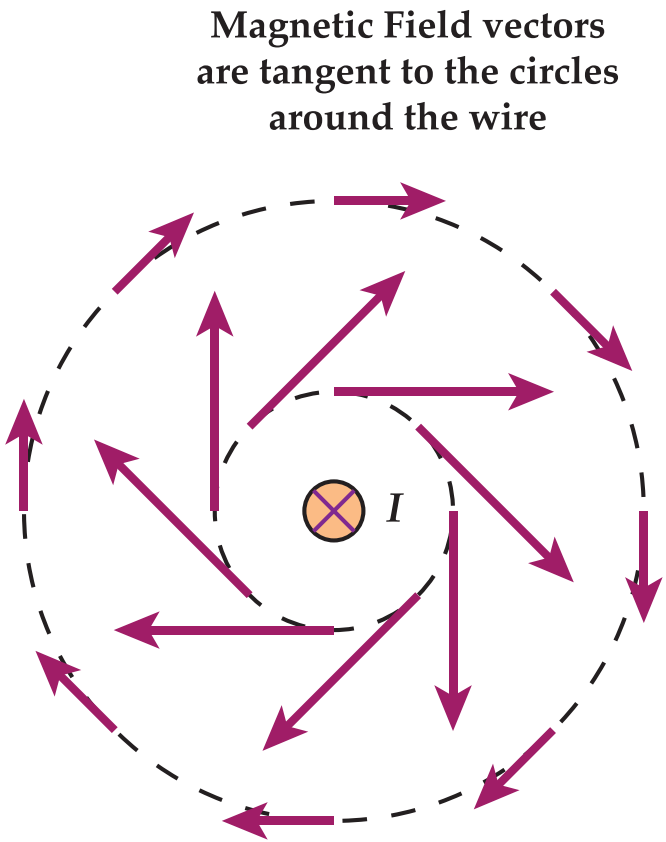
Use Biot-Savart law to measure the $\vec{B}$-field produced by a very short segment of current-carrying conducting wire.



$$|\vec{B}|_{\text{current-segment}} = \frac{\mu_0}{4\pi}\left|\frac{I\Delta\vec{s}\times\hat{r}}{r^2}\right| = \frac{\mu_0}{4\pi}\frac{I\Delta s\sin\theta}{r^2}$$

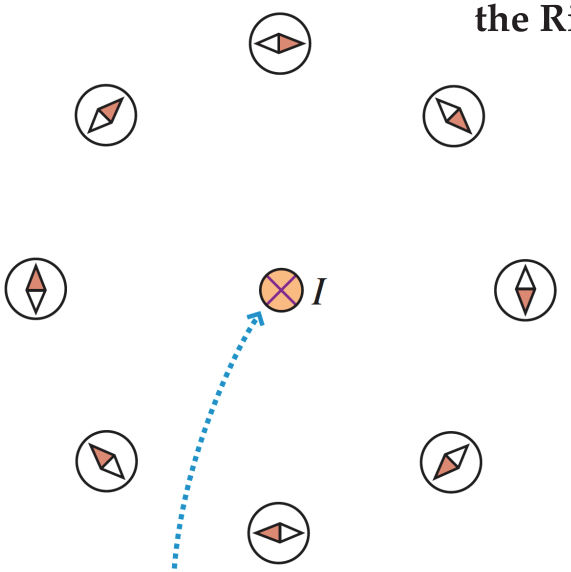
A few ways to find the $\vec{B}$-field direction due to a current (1)





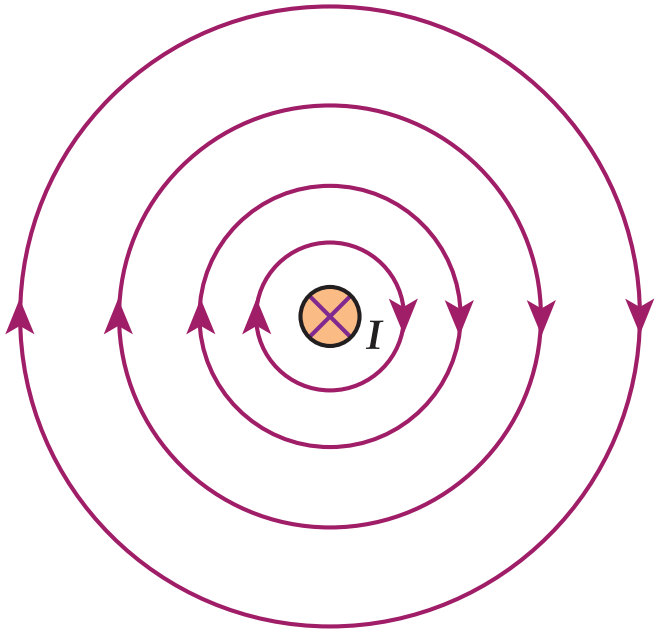
A few ways to find the $\vec{B}$-field direction due to a current (2)

The orientation of the compasses is given by the Right-Hand method.



Point your right thumb into the figure—the current direction; your fingers will curl cw.

Magentic Field Lines are *circular*

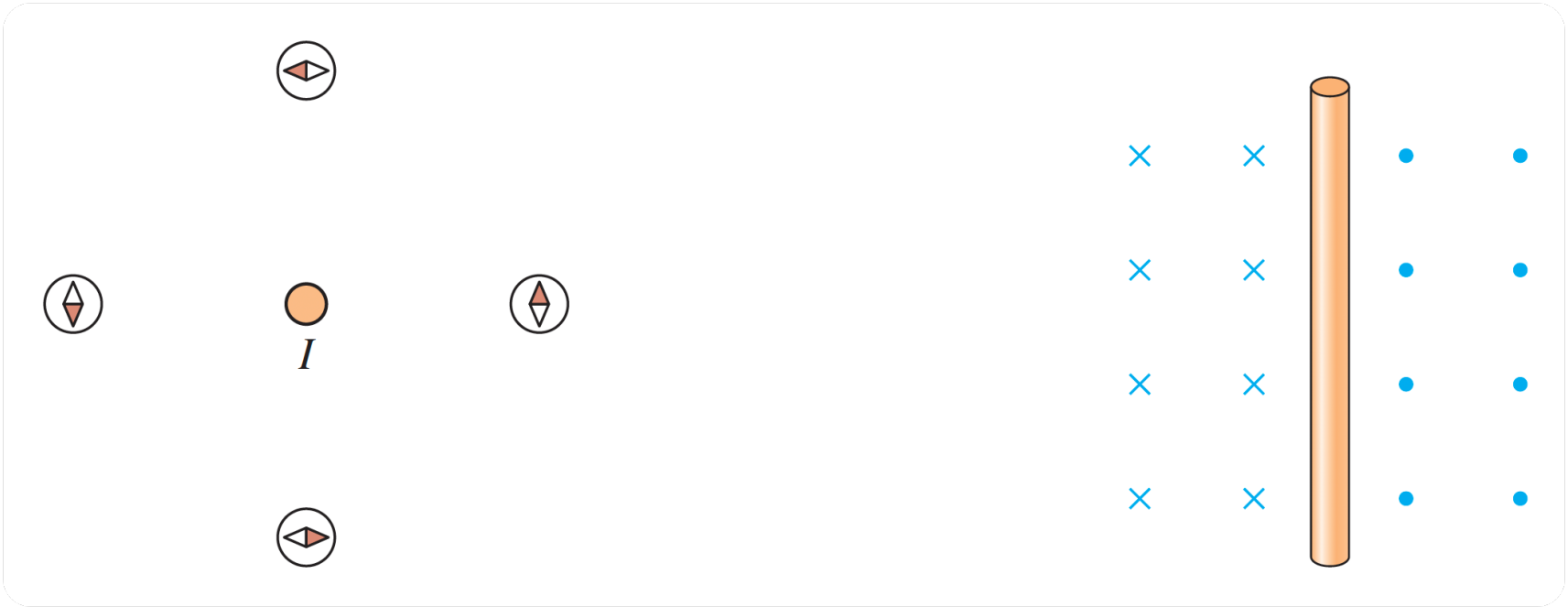


Testing Concepts (3)

Q: A 1.0 m-long, 1.0 mm-diameter Nichrome heater wire is connected to a 12 V battery. What is the magnetic field strength 1.0 cm (i) ahead, (ii) behind of the wire?

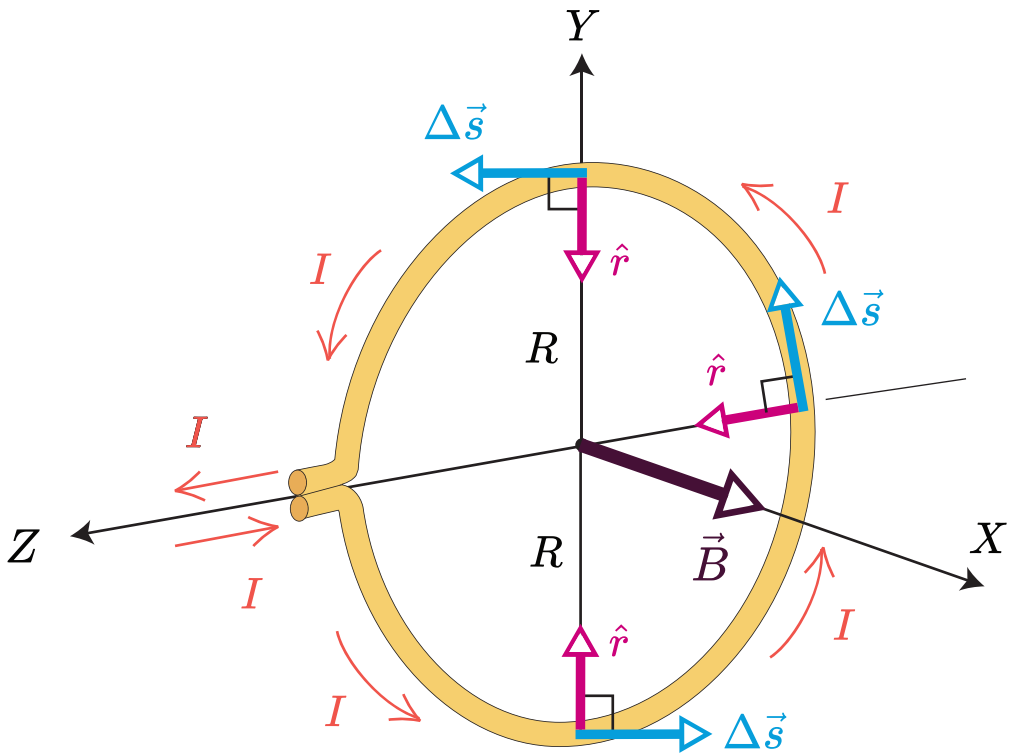
Testing Concepts (4)

Q: What is the current direction within the wire?



The Source of the $\vec{B}$-Field: Electric Current Loop

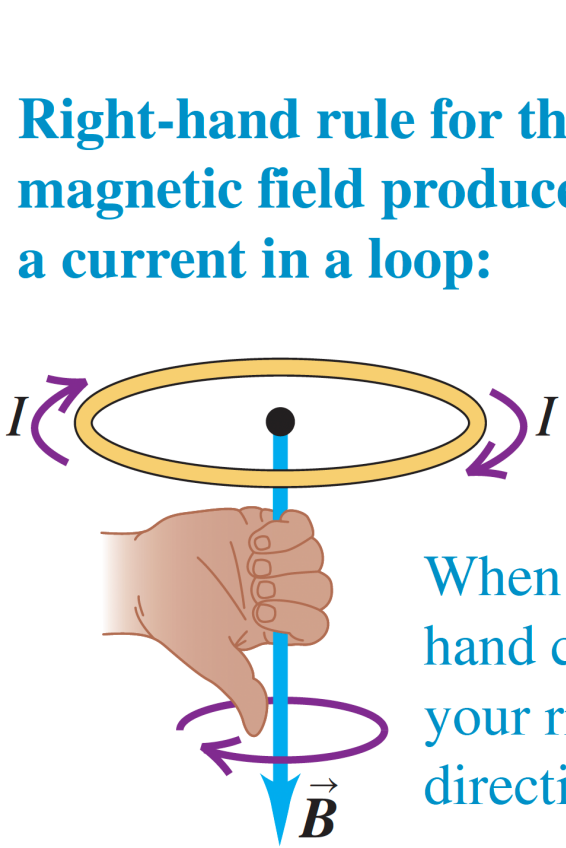
Use Biot-Savart law to measure the $\vec{B}$-field produced by a single loop of current-carrying conducting wire at its center.

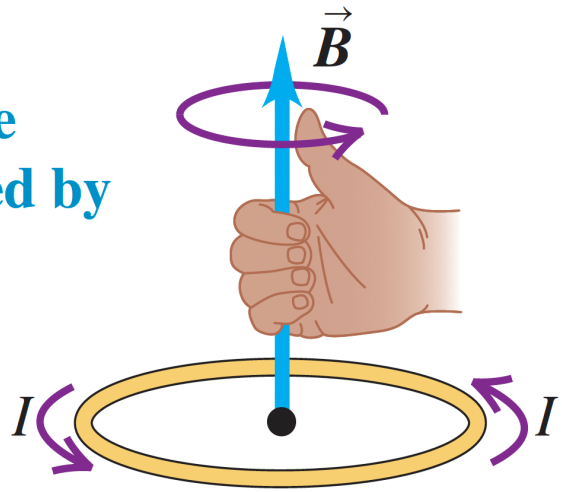


$$|\vec{B}|_{\text{current-loop}} = \frac{\mu_0 I}{2R}$$

A FAST WAY TO FIND THE $\vec{B}$-FIELD DIRECTION DUE TO A CURRENT LOOP

Right-hand rule for the magnetic field produced by a current in a loop:

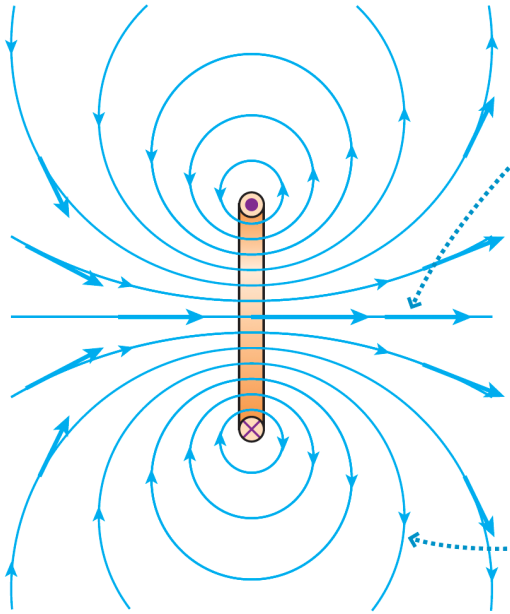




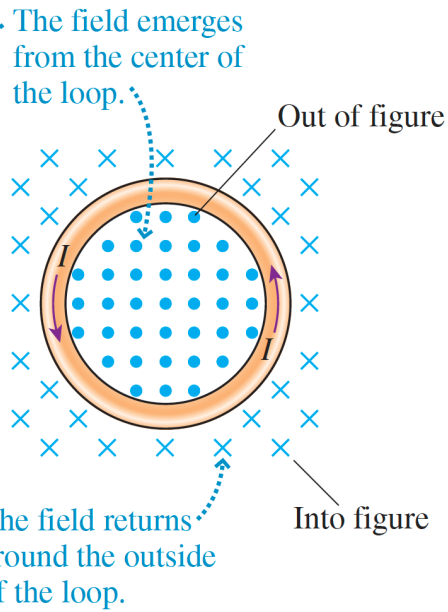
When the fingers of your right hand curl in the direction of I, your right thumb points in the direction of $\vec{B}$.

A FEW WAYS TO FIND THE $\vec{B}$-FIELD DIRECTION DUE TO A CURRENT LOOP

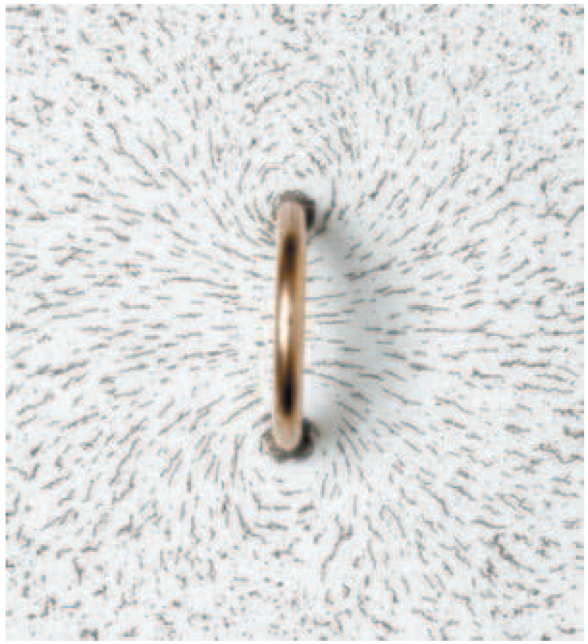
(a) Cross section through the current loop



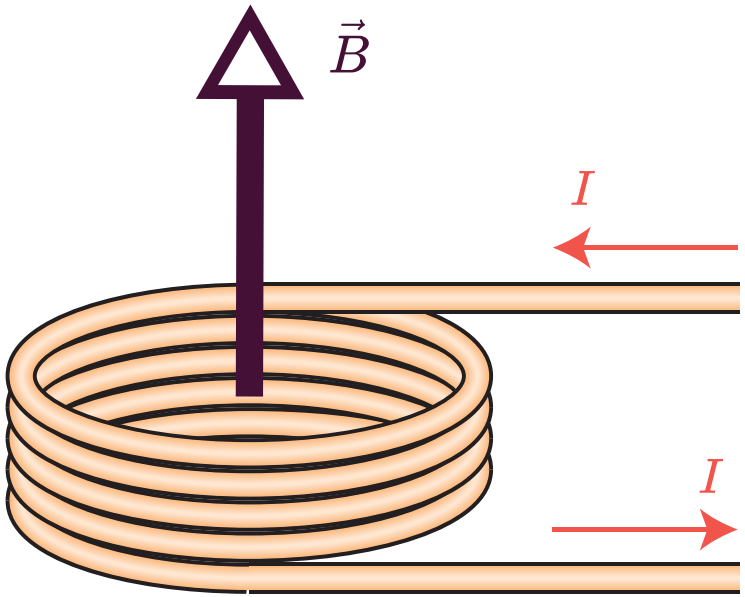
(b) The current loop seen from the right



(c) A photo of iron filings



What about a current loop with N turns?



$$|\vec{B}|_{\text{current-loop-with-turns}} = \frac{N\mu_0 I}{2R}$$

Testing Concepts (5)

Q: What current is needed in a 5-turn, 10 cm-diameter coil to cancel the Earth's magnetic field at the center of the coil? Take $B_{\text{Earth}} = 5.0 \times 10^{-5}$ T. Find the direction in which the current must be generated to achieve this.