

- Announcements

Last assignment will be next week

Faraday's law and inductance (Ch 13/14)

Omit Ch 16

- Last Time

Maxwell equations

Meaning of the math

Ampere's Law, field inside and outside a wire

Wire loops

- Today

Earth B-field (problem 7-3)

Ampere's Law – field in a solenoid

Magnetic properties

Problem 3: A power line carries a DC current of $I = 23$ A in a direction $\phi = 23^\circ$ east of magnetic north through an open field, in a location where the Earth's magnetic field is horizontal and its strength is $B = 0.61$ G.

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$$0.61 \text{ G} = 610 \text{ } \mu \text{ T}$$

Part (a) Calculate the magnitude of the magnetic force per unit length, F/l , in newtons per meter, exerted on the wire due to the Earth's magnetic field.

Numeric : A numeric value is expected and not an expression.

$F/l =$ _____ N/m

Part (b) In what direction does the force on the wire act? Be aware that the magnetic field of the Earth actually behaves in the opposite manner you would expect from a physical magnet. The Earth's magnetic field lines point from the Earth's south pole towards the Earth's north pole.

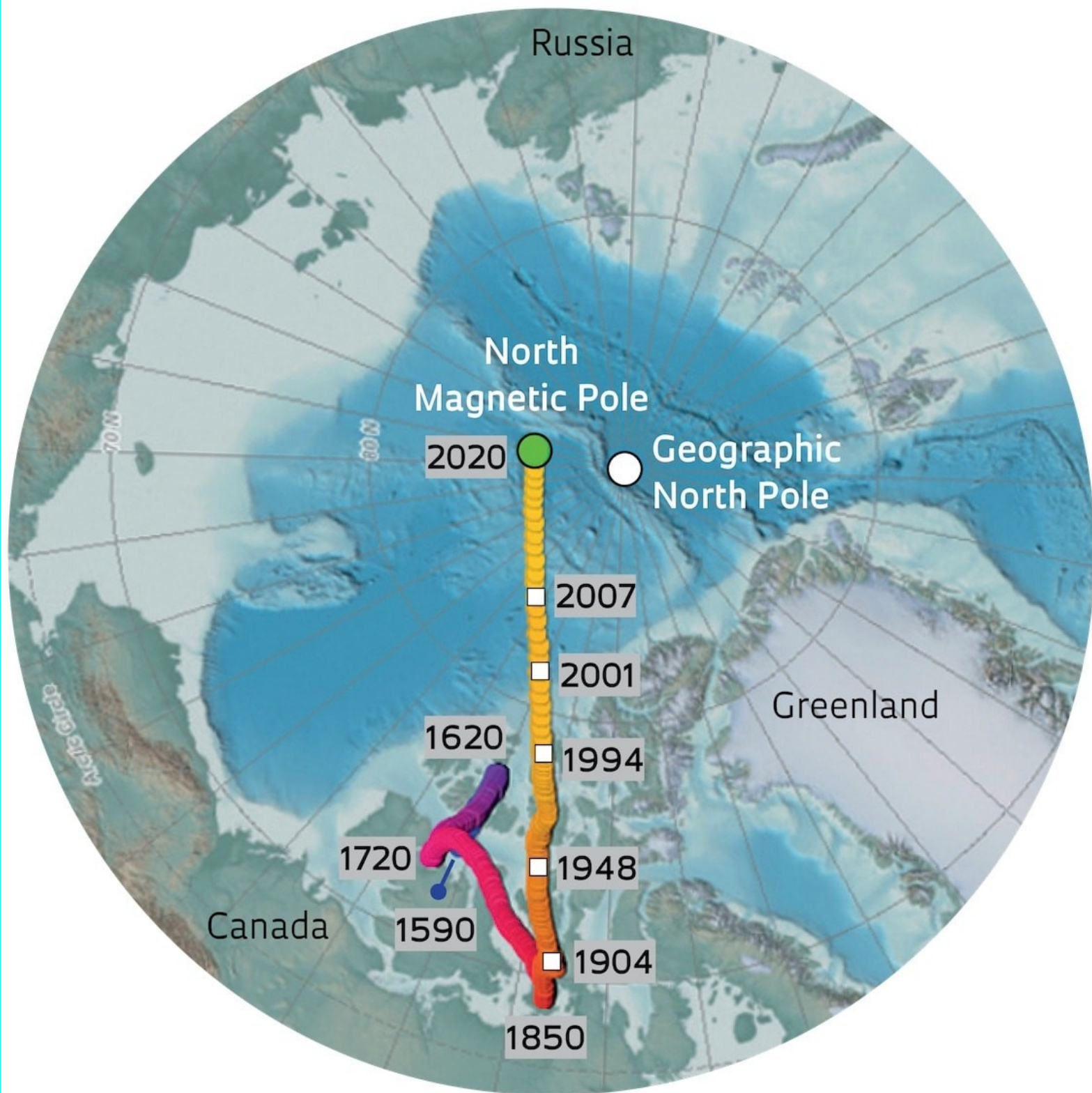
MultipleChoice :

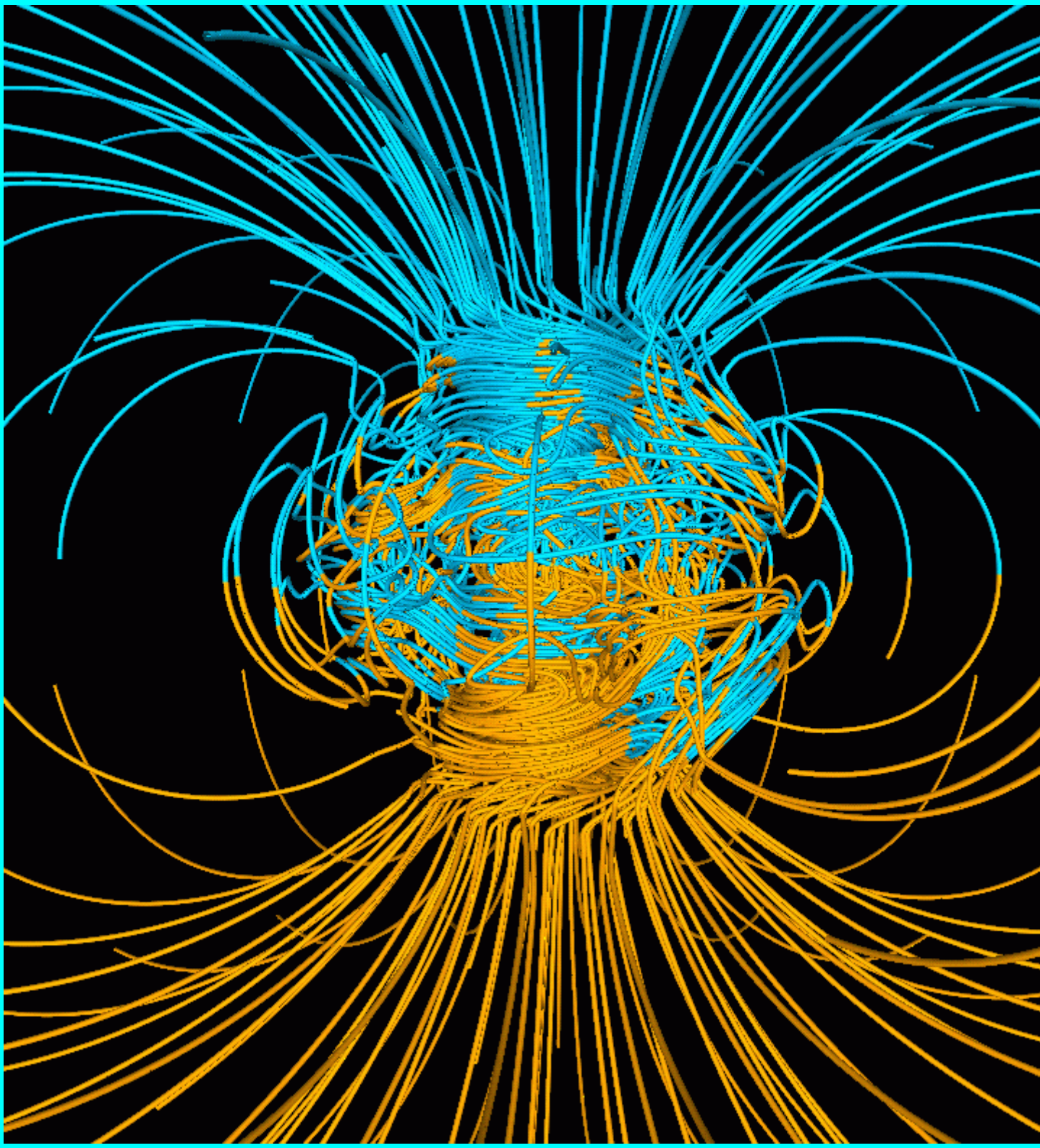
- 1) East of North
- 2) Up
- 3) There is no magnetic force on the wire
- 4) West of South
- 5) East of South
- 6) There is a magnetic force acting on the wire, but in a direction not listed.
- 7) West of North

One Gauss = 10^{-4} Tesla

The Gauss is the work of the devil

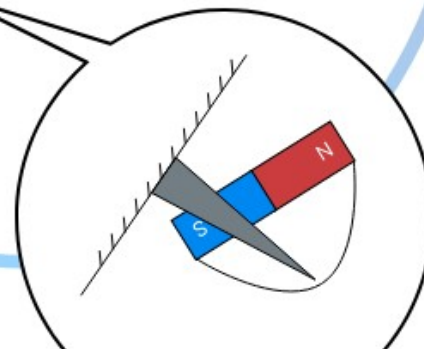
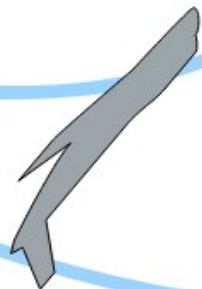
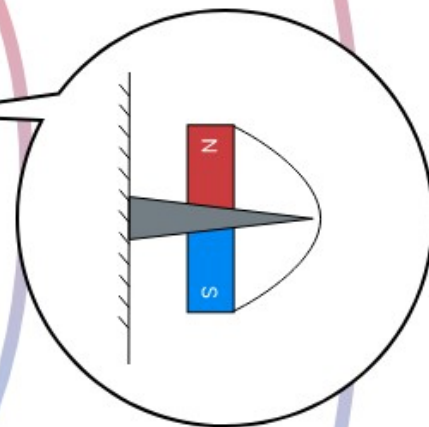
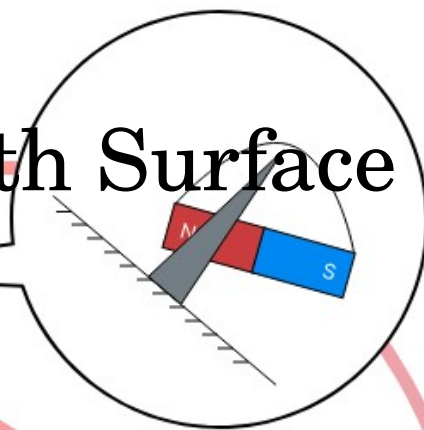
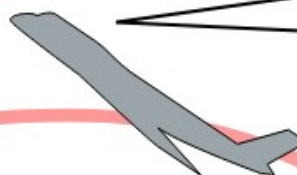
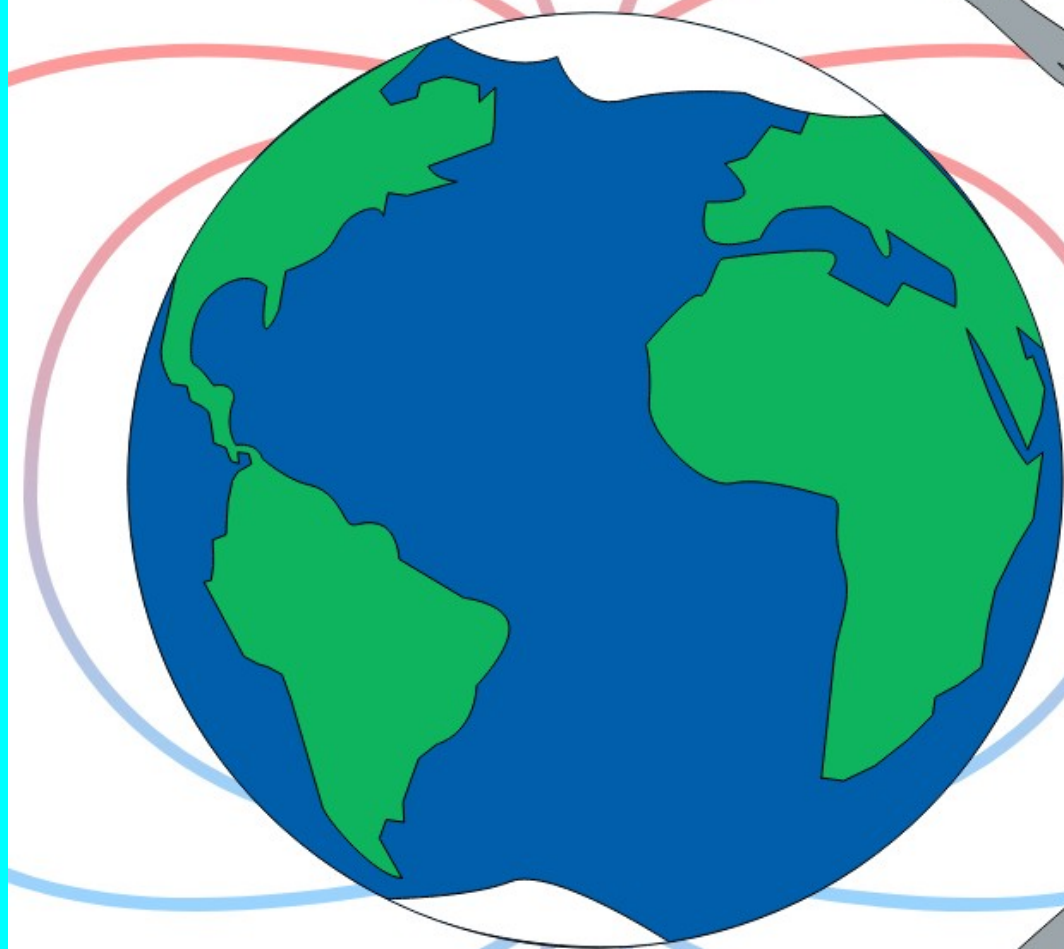
Righteous scientists and engineers use Tesla.





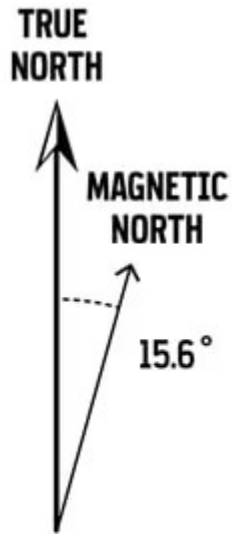
Ignore Dip Angle

Assume B-field parallel to Earth Surface



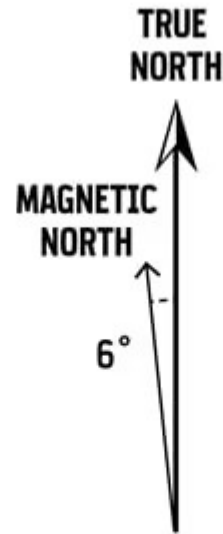
Ignore Declination

The question is about magnetic north



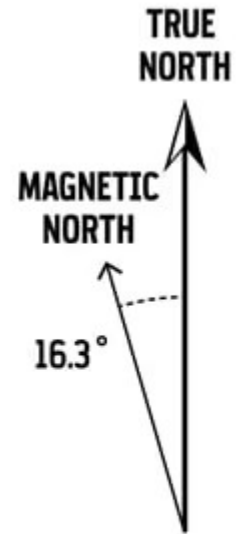
Mount Rainier NP

15.6° East



**Central Great Smoky
Mountains NP**

6° West



Acadia NP

16.3° West

Magnetic Field Calculators

Declination

U.S. Historic Declination

Reset My Compass

Registration

Declination is calculated using the most recent model available. For 1900 to 1999 the calculator is based on the [GUFM5](#) model. For 2000 to 2020 the calculator is based on the [World Magnetic Model \(WMM\)](#). The [Enhanced Magnetic Model \(EMM\)](#) is a research model compiled from satellite data that is more accurate than the WMM but is not available for all locations. The WMM is updated every 5 years. The EMM is updated every 1 year. The WMM is used for navigation purposes. The EMM is used for scientific purposes. **Registration is required to access this feature.**

Calculate Declination

Latitude:

Longitude:

Model: WMM (2019-2024) EMM (2000-2019)

Date: Year

Result format: HTML XML PDF

Calculate

Declination X

Model Used:	WMM-2020
Latitude:	34.07° N i
Longitude:	106.9° W
Date	Declination
2024-04-17	7.92° E ± 0.36° changing by 0.10° W per year

World Magnetic Model (WMM) is the most accurate model available. For 1590 to 1900 the calculator is based on the [GUFM5](#) model. For 1900 to 1999 the calculator is based on the [GUFM5](#) model. For 2000 to 2020 the calculator is based on the [World Magnetic Model \(WMM\)](#). The [Enhanced Magnetic Model \(EMM\)](#) is a research model compiled from satellite data that is more accurate than the WMM but is not available for all locations. The WMM is updated every 5 years. The EMM is updated every 1 year. The WMM is used for navigation purposes. The EMM is used for scientific purposes. **Registration is required to access this feature.**

Enter a location, address, or street intersection. For best information as possible with the calculator, use as much information as possible such as city, state, zip code.

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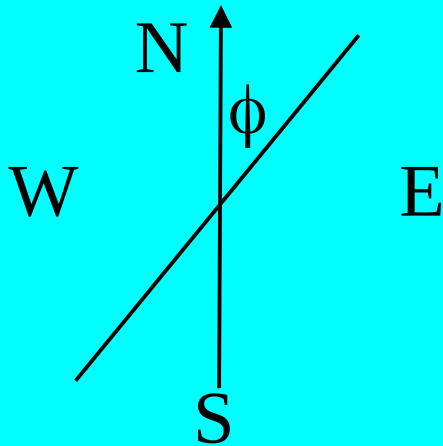
Numeric : A numeric value is expected and not an expression.

$F/l =$ _____ N/m

Part (b) In what direction does the force on the wire act? Be aware that the magnetic field of the Earth actually behaves in the opposite manner you would expect from a physical magnet. The Earth's magnetic field lines point from the Earth's south pole towards the Earth's north pole.

MultipleChoice :

- 1) East of North
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If anything is NOT at right angles, draw it on the page. Let the cross product be in or out from the page

In general, try something. If it's confusing, try something else. One of the vectors will ALWAYS be in/out of the page.

Equations of Magnetism (units check)

$$\vec{F} = Q \vec{v} \times \vec{B} \quad \text{Force on charge } Q$$

$$\vec{F} = I \vec{L} \times \vec{B} \quad \text{Force on current } I$$

$$\vec{F} = I_1 L \frac{\mu_0 I_2}{2 \pi r} \quad \text{Force between parallel wires}$$

$$\vec{B} = \frac{\mu_0 I}{2 \pi r} \hat{\phi} \quad \text{Field of Infinite wire}$$

$$\vec{B} = \frac{\mu_0 I r}{2 \pi R^2} \hat{\phi} \quad \text{Field inside a wire of radius } R$$

$$\vec{B} = \mu_0 n I \hat{z} \quad \text{Field of an infinite coil (solenoid)}$$

$$\vec{B} = \frac{\mu_0 I}{2 a} \hat{z} \quad \text{Field in center of wire loop}$$

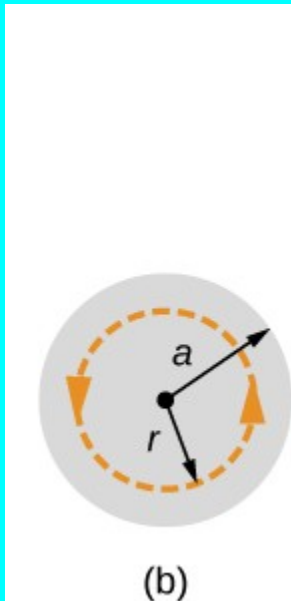
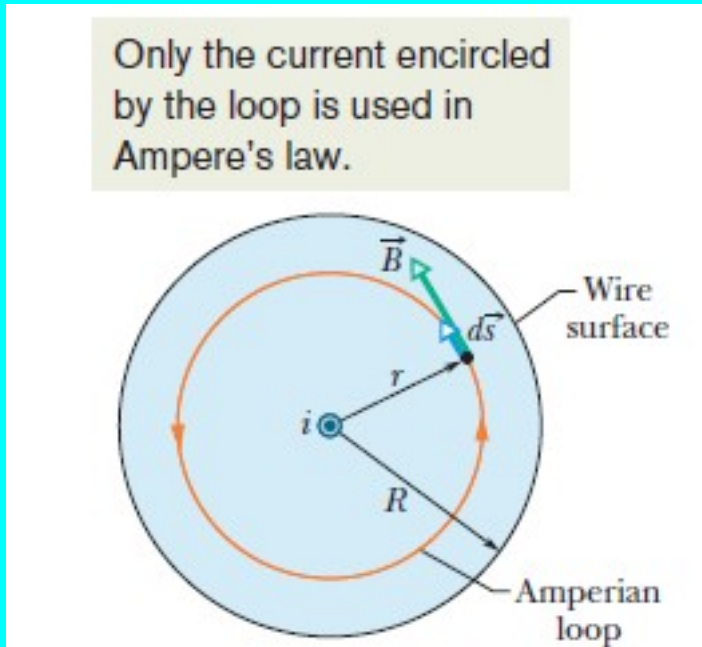
Equations from Ampere's Law

$$\vec{B} = \frac{\mu_0 I}{2\pi r} \hat{\phi} \quad \text{Field of Infinite wire}$$

$$\vec{B} = \frac{\mu_0 I r}{2\pi R^2} \hat{\phi} \quad \text{Field inside a wire of radius } R$$

$$\vec{B} = \mu_0 n I \hat{z} \quad \text{Field of an infinite coil (solenoid)}$$

Ampere applied inside of a wire



$$\vec{B} = \frac{\mu_0 I r}{2 \pi a^2} \hat{\phi}$$

Field inside a wire of radius a

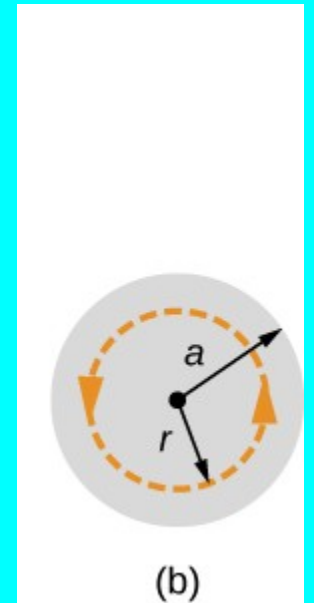
**A wire with radius “a” carries “I” Amperes
How many Amps are contained within
radius “r”?**

(A) I

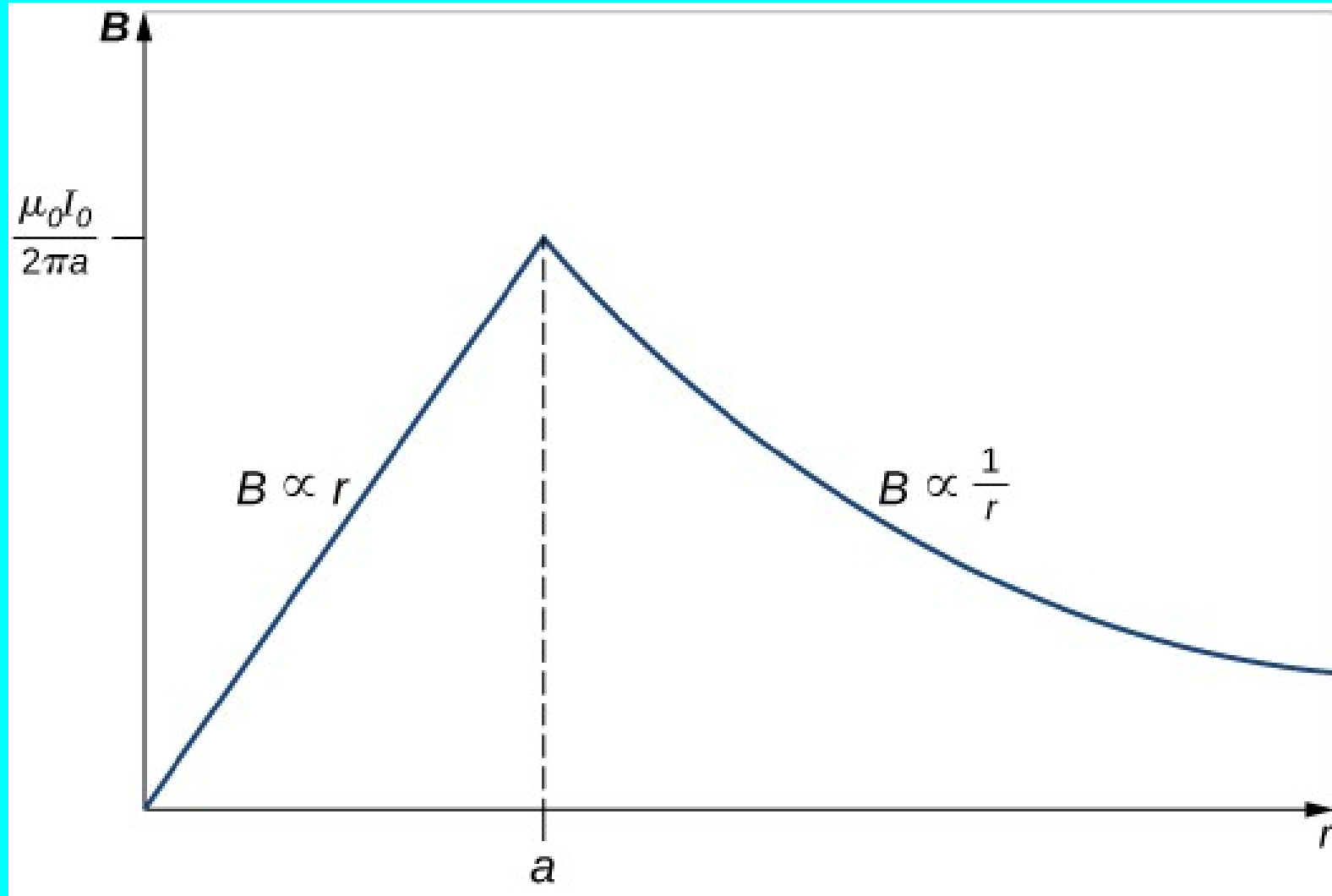
(B) $\frac{I}{4}$

(C) $I \frac{r}{a}$

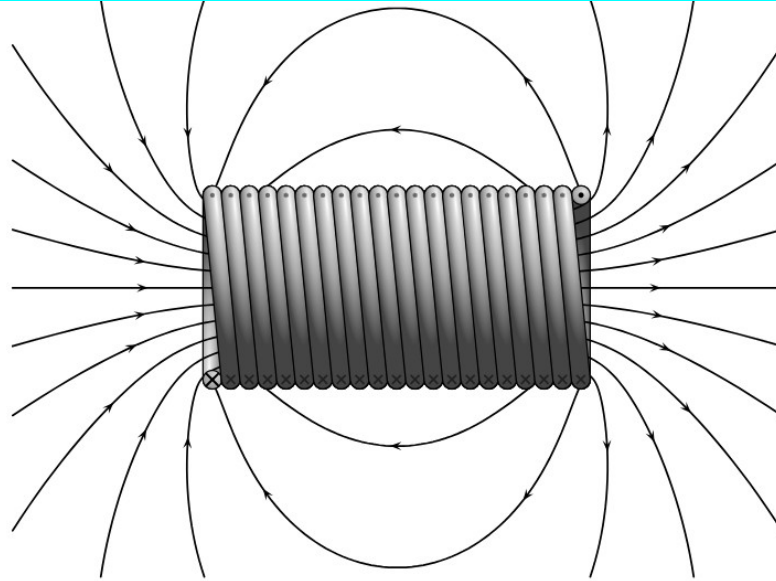
(D) $I \frac{r^2}{a^2}$



Ampere result inside and outside of a wire

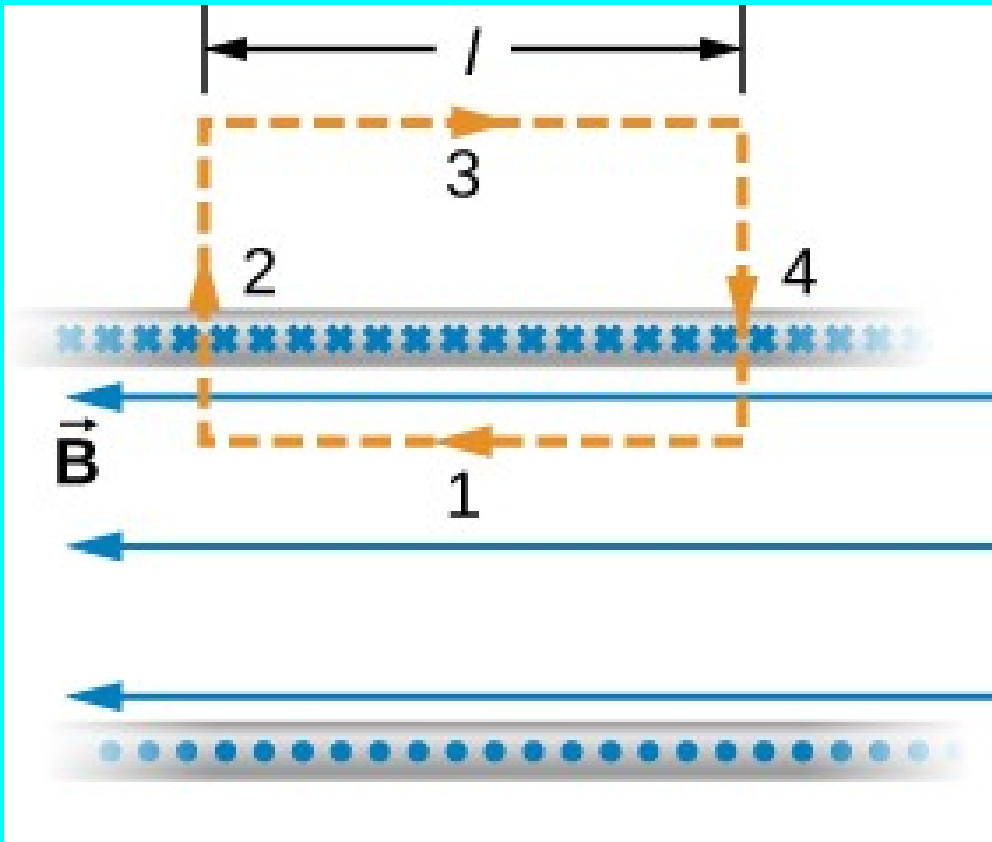


Derive field of a solenoid



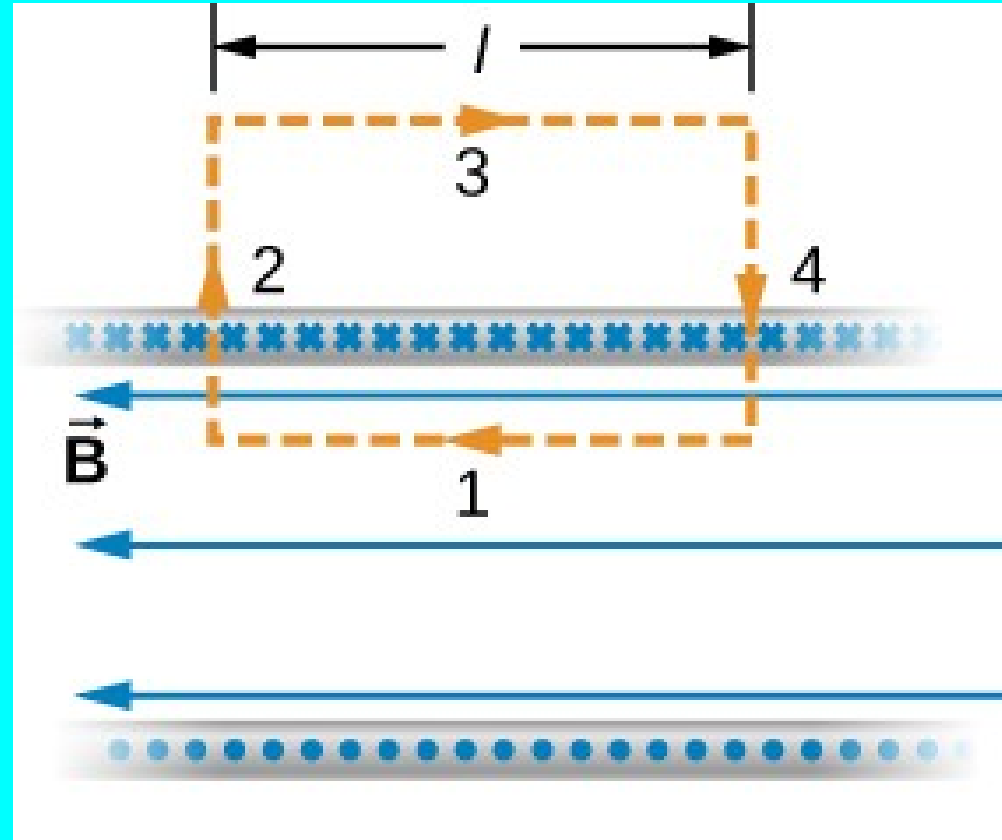
$\vec{B} = \mu_0 n I \hat{z}$ Field of an infinite coil (solenoid)



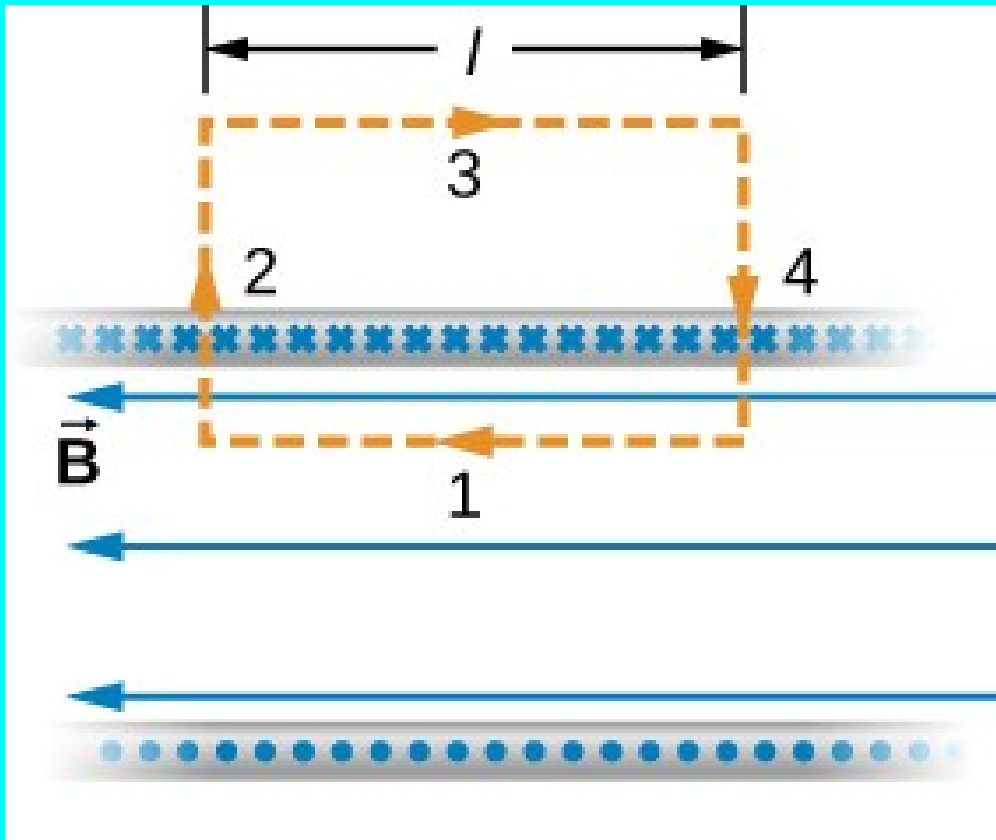


$\vec{B} = \mu_0 n I \hat{z}$ Field of an infinite coil (solenoid) 20

If the solenoid carries current “I” and there are “N” windings inside the amperian loop what is $\oint \vec{B} \cdot d\vec{l}$?



- (A) I
- (B) $\mu_0 NI$
- (C) $\mu_0 I/N$
- (D) $-\mu_0 I$



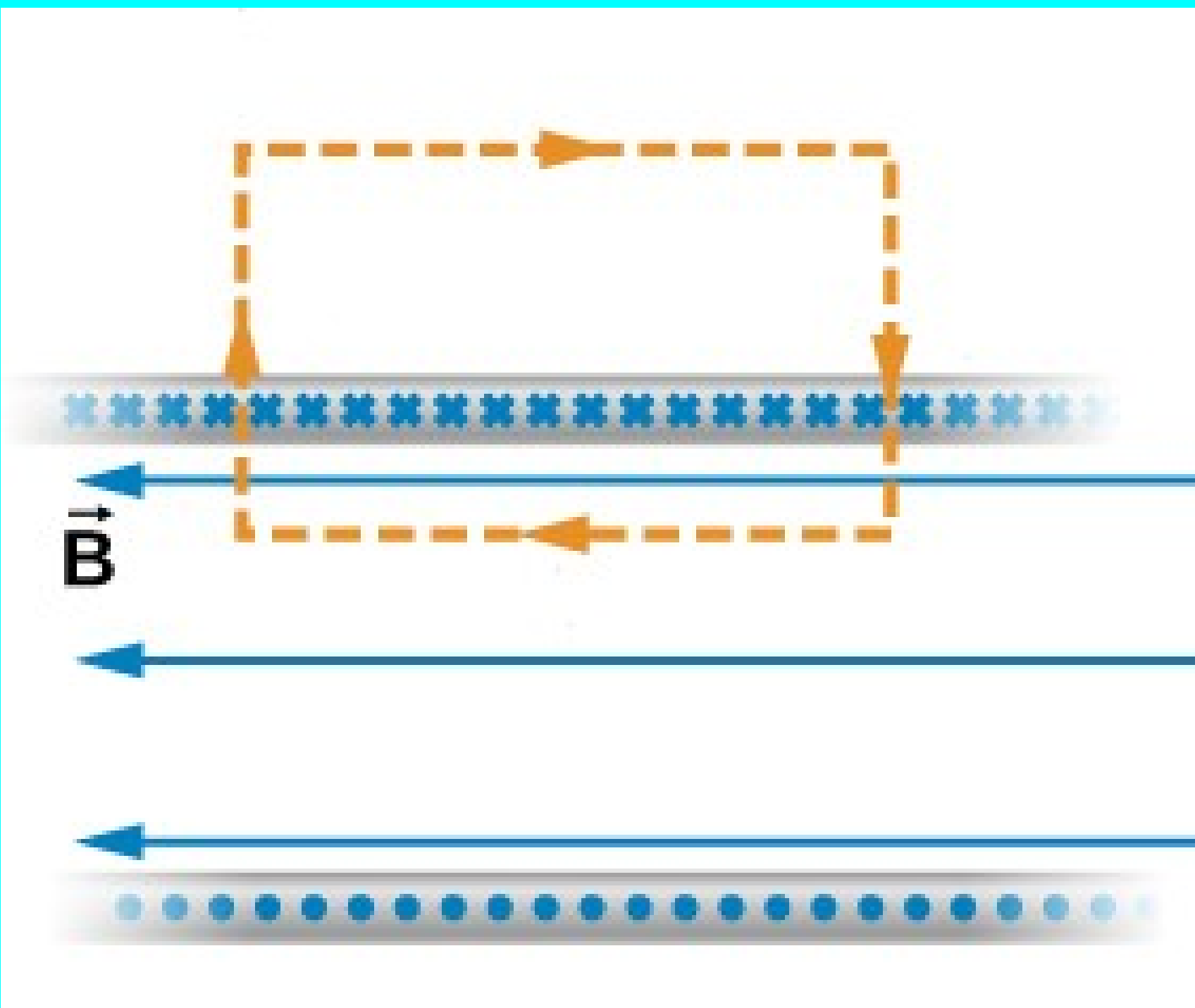
$B_{\text{outside}} = 0$ Top and bottom currents cancel (superposition)

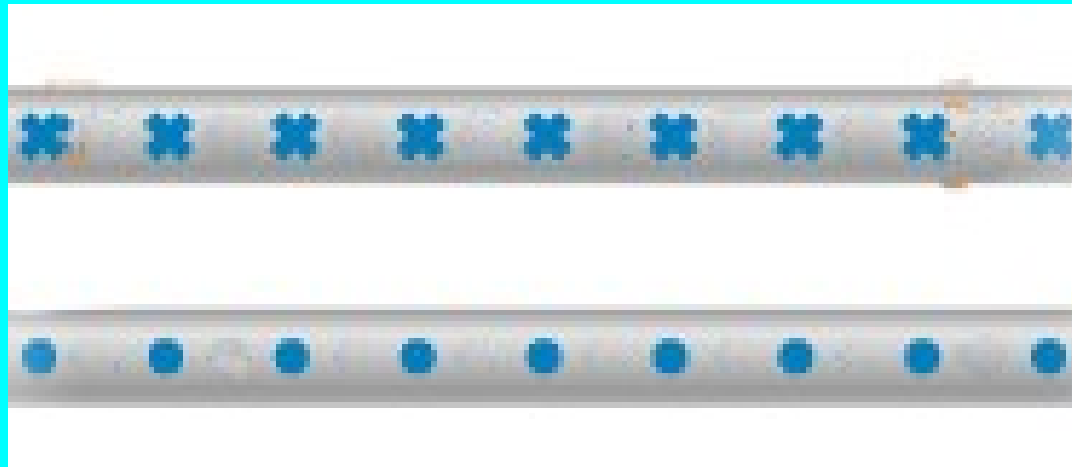
B_{inside} is independent of z (symmetry of infinite coil)

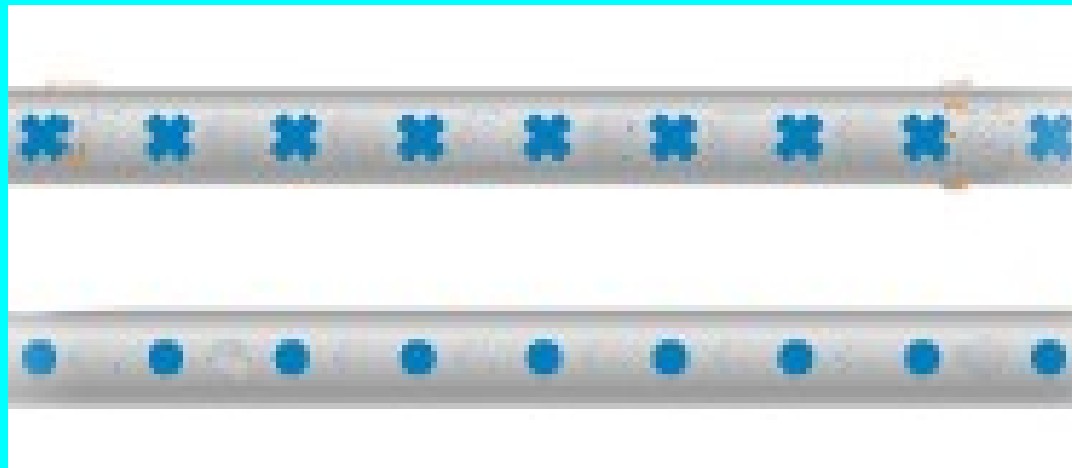
$B_{\theta} = 0$ (circular symmetry)

$B_r = 0$ (superposition)

If $B_r \neq 0$ Path 2 and 4 still cancel (superposition) 23







If the coil shown is 10 cm long and has a total of 4000 windings and carries two Amperes, what is the magnetic field inside?

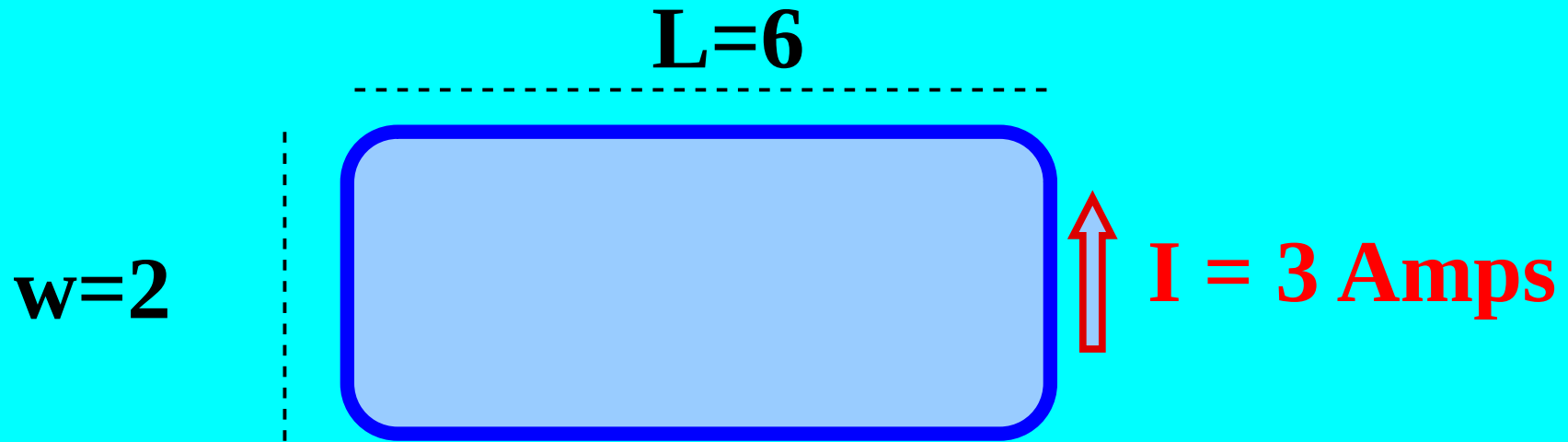


- (A) 0.25 T**
- (B) 0.025 T**
- (C) 1 T**
- (D) 0.1 T**

$$\vec{B} = \mu_0 n I \hat{z}$$

Remember magnetic moments?

$$\vec{m} = I \vec{A} \quad \vec{\tau} = \vec{m} \times \vec{B}$$



- (A) $\vec{m} = 3 \hat{x} \text{ Ampere} \cdot \text{meter}^2$
- (B) $\vec{m} = 3 \hat{z} \text{ Ampere} \cdot \text{meter}^2$
- (C) $\vec{m} = 36 \hat{z} \text{ Ampere} \cdot \text{meter}^2$
- (D) $\vec{m} = 3 \hat{y} \text{ Ampere} \cdot \text{meter}^2$

Dia/Para/Ferro Magnetic Materials

- Diamagnetic material

As in “Dielectric” the atomic current loops misalign to partially cancel the field. Weak effect.

$$\vec{M} = \chi \vec{B}, \quad \chi \sim -10^{-5} \quad \chi \stackrel{\text{def}}{=} \text{Magnetic Susceptibility}$$

- Paramagnetic material

Atomic current loops align to enhance field. Weak.

$$\vec{M} = \chi \vec{B}, \quad \chi \sim +10^{-5}$$

- Ferromagnet

Large groups of atomic current loops line up well to GREATLY enhance field.

$$\vec{M} = \chi \vec{B}, \quad \chi \sim +10,000$$

$$\vec{B} = \mu_0 n I \hat{z} \quad \text{Solenoid full of vacuum}$$

$\chi \stackrel{\text{def}}{=} \text{Magnetic Susceptibility}$

$\mu \stackrel{\text{def}}{=} (1 + \chi \mu_0) \text{Magnetic Permeability}$



$$\vec{B} = (1 + \chi) \mu_0 n I \hat{z} \quad \text{Solenoid full of air}$$

$$\vec{B} = (1 + 10^{-6}) \mu_0 n I \hat{z} \quad \text{Solenoid full of air}$$

$$\vec{B} = (1 - 10^{-5}) \mu_0 n I \hat{z} \quad \text{Solenoid full of water}$$

$$\vec{B} = (1 + 10,000) \mu_0 n I \hat{z} \quad \text{Solenoid full of iron}$$

What's the magnetic permeability of iron?

$$\mu_0 = 1.26 \times 10^{-6}$$

(A) $\mu \sim 1.26 \times 10^{-2} \frac{\text{N}}{\text{A}^2}$

(B) $\mu \sim 1.26 \times 10^{-6} \frac{\text{N}}{\text{A}^2}$

(C) $\mu \sim 10^{-5} \frac{\text{N}}{\text{A}^2}$

(D) $\mu \sim 10000 \frac{\text{N}}{\text{A}^2}$

If the coil shown is 10 cm long has a total of 4 windings, is full of iron and carries two Amperes, what is the magnetic field inside?



- (A) 0.25 T**
- (B) 0.025 T**
- (C) 1 T**
- (D) 0.1 T**

$$\vec{B} = \mu_0 (1 + \chi) n I \hat{z}$$

Faraday and Ampere in words

- **AMPERE:** A current produces a magnetic field circling around it.
- **FARADAY:** A changing magnetic flux produces an electric field circling around it.

Maxwell's Equations

$$\oiint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0} \quad \text{To calculate E for symmetrical charges.}$$

$$\oiint \vec{B} \cdot d\vec{A} = 0 \quad \text{Cannot have North magnet w/o a South pole.}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}} \quad \text{To calculate B for symmetrical currents.}$$

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi}{dt} \quad \text{Magnetic induction! Generators! Light!}$$

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

Maxwell's Equations

$$\oiint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0} \quad \text{To calculate E for symmetrical charges.}$$

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$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

How do I avoid an infinite formula sheet – really?

$$\Delta V = - \int \vec{E} \cdot d\vec{l} \quad \text{Definition of potential.}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0} \quad \text{Gauss Law (sphere/line/plane).}$$

$$Q = CV \quad \text{Def. of capacitance}$$

$$V = IR \quad R = \rho \frac{L}{A} \quad \text{Ohm's Law and origin of resistance}$$

$$U = qV \quad \text{Relation between potential and potential energy}$$

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B} \quad \text{Lorentz force Law}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I \quad \text{Ampere's law (wire/solenoid/current sheet).}$$

Recap Lecture 25

- Amperes law
- Field of a solenoid
- Magnetic Materials
- Faraday's Law