Lecture 25: 04/18/2024

- 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

$I = 23\,A \quad \phi = 23^{\circ}$

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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$$0.61\,\mathrm{G} = 610\ \mu\mathrm{T}$$

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.

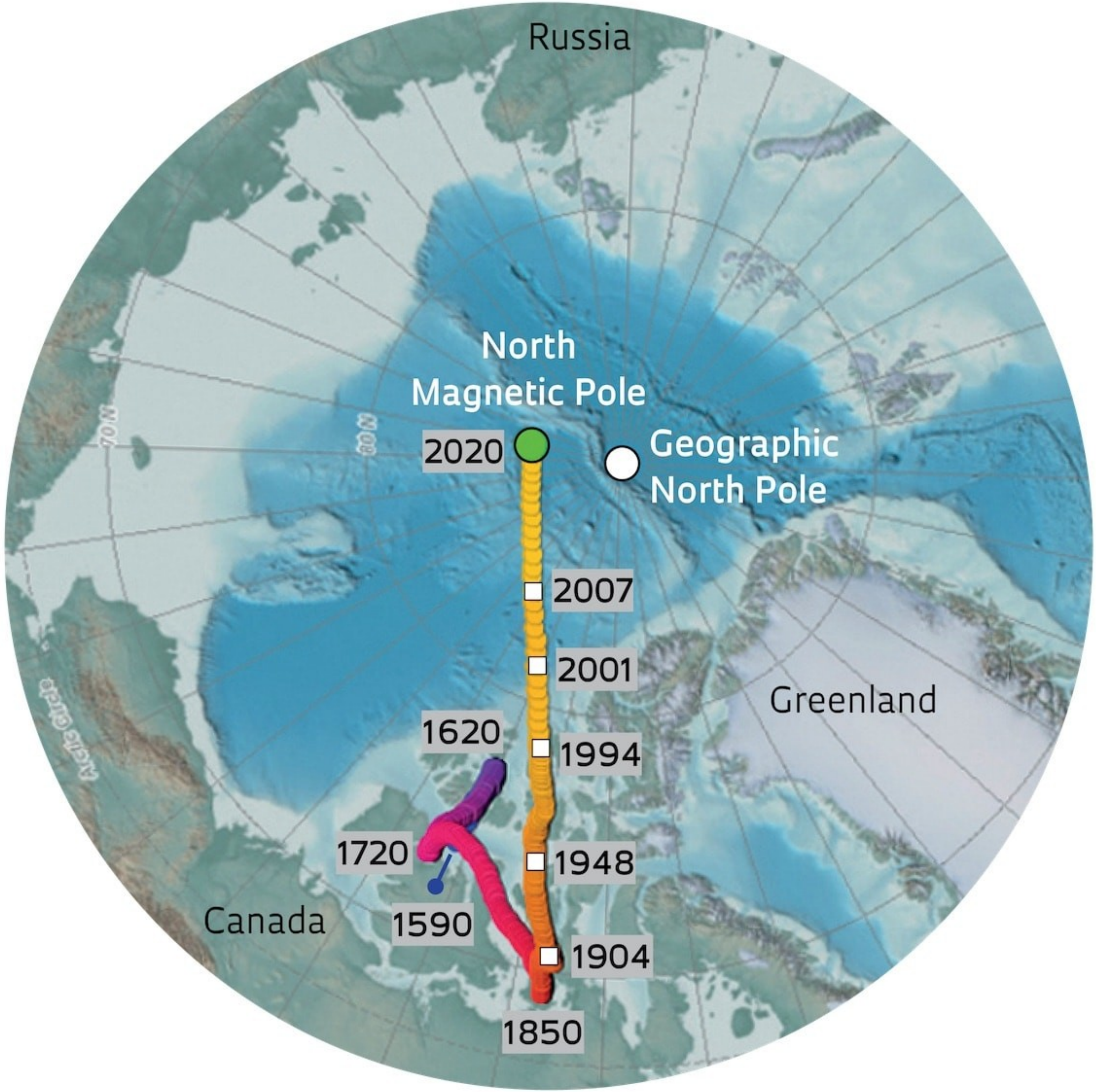
MultipleChoice :

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

$$\text{One Gauss} = 10^{-4}\ \text{Tesla}$$

The Gauss is the work of the devil

Rightous scientists and engineers use Tesla.


Russia
North
Magnetic Pole
2020
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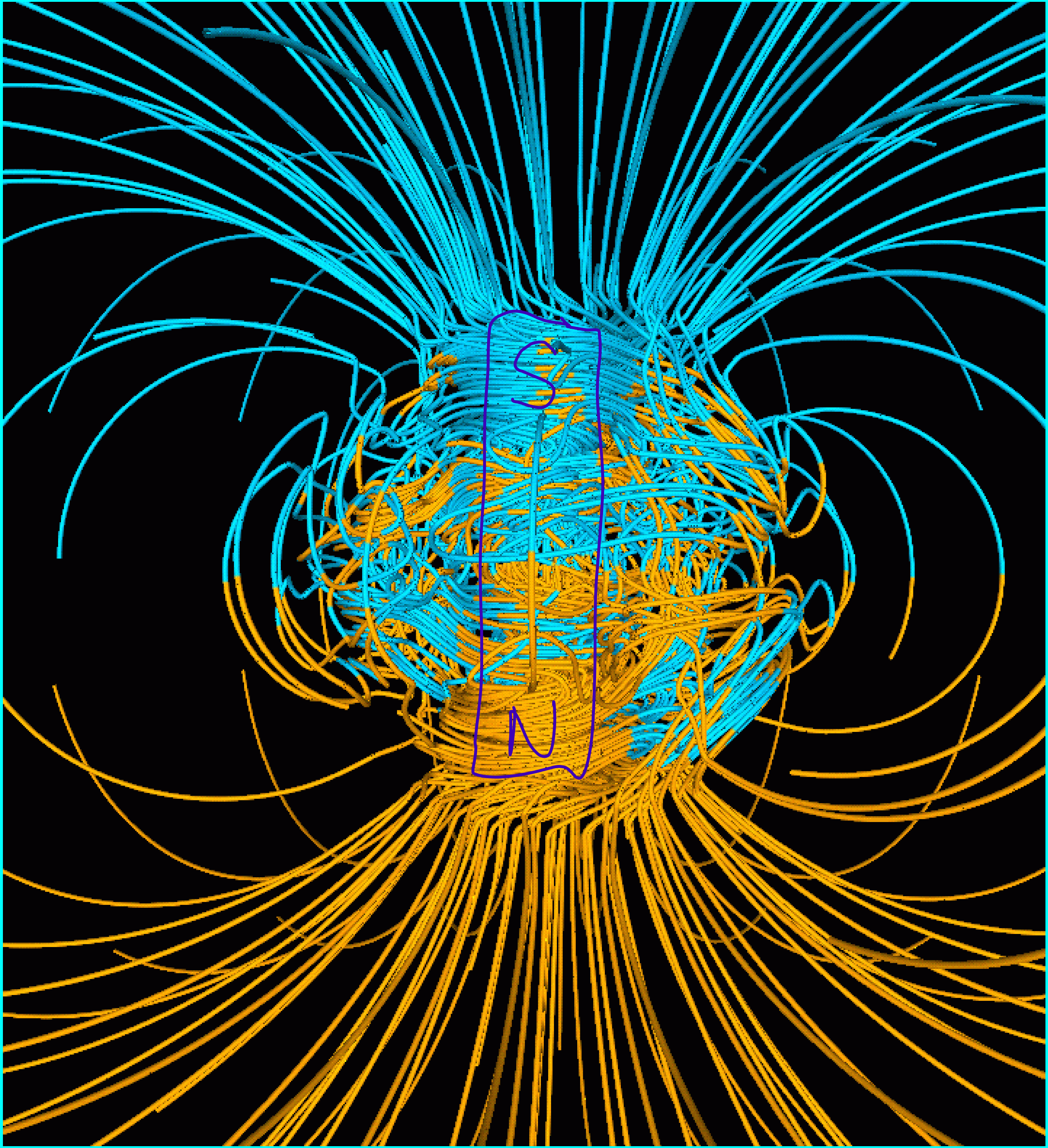
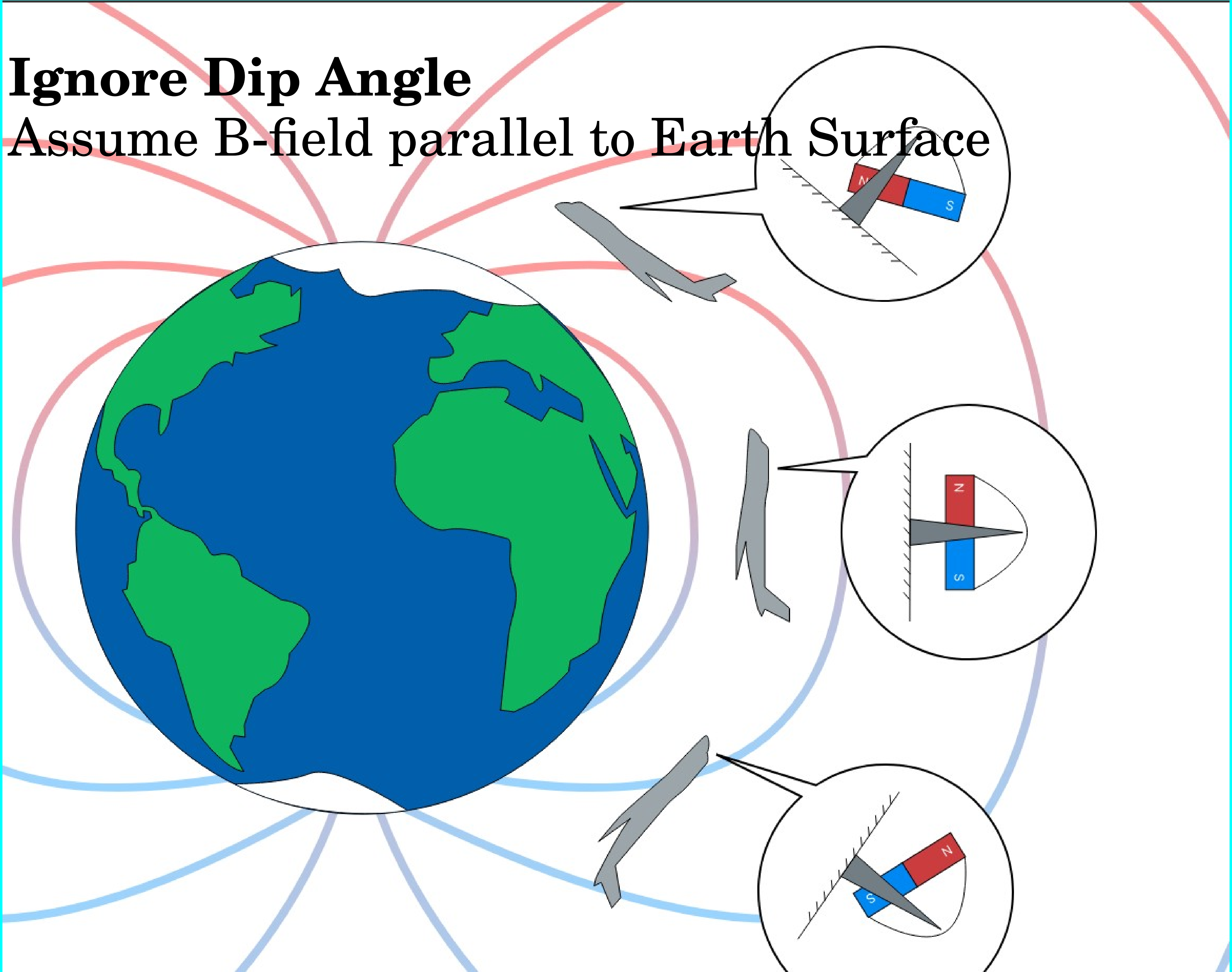

S
N

N
S

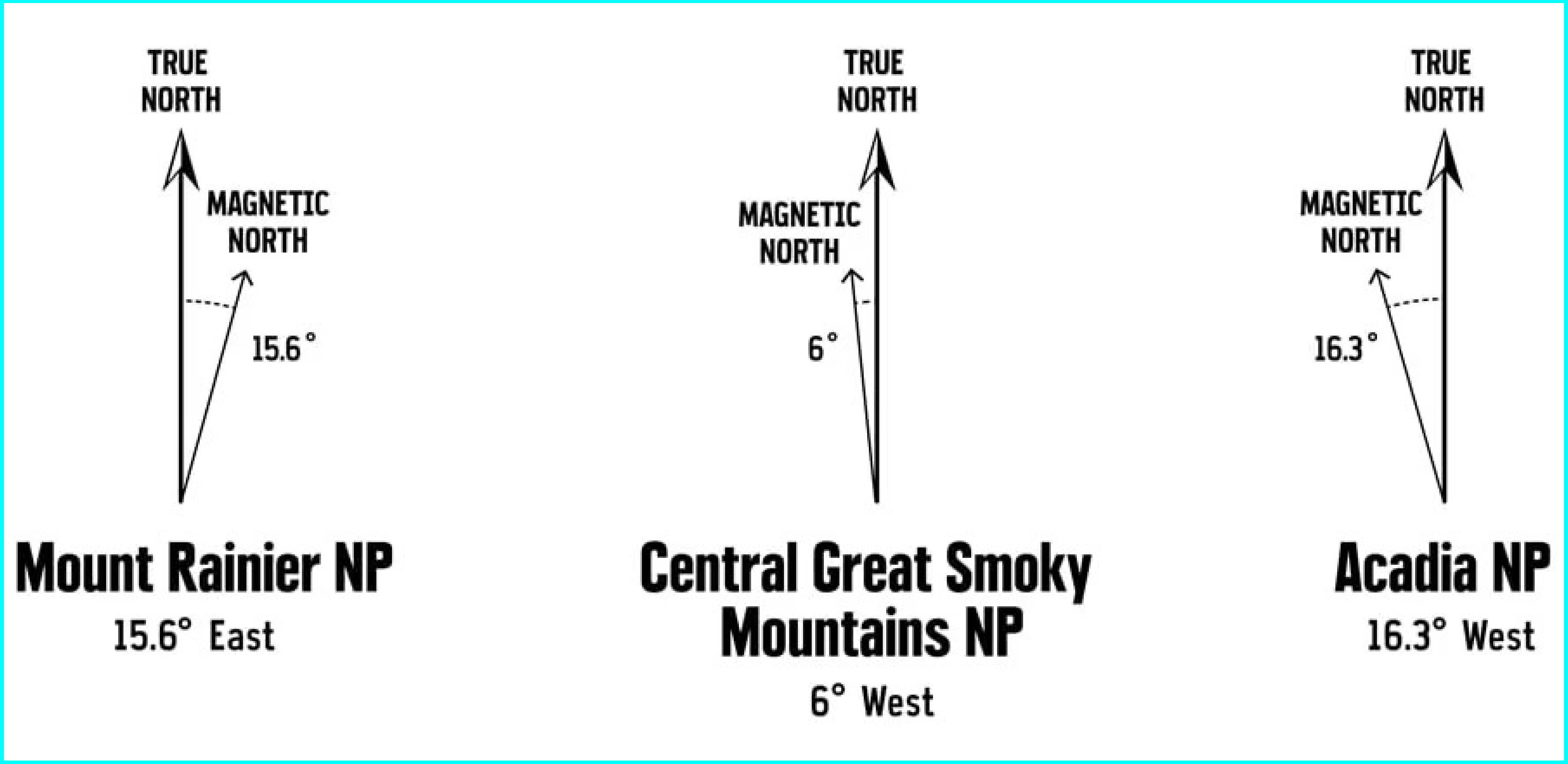
Ignore Dip Angle

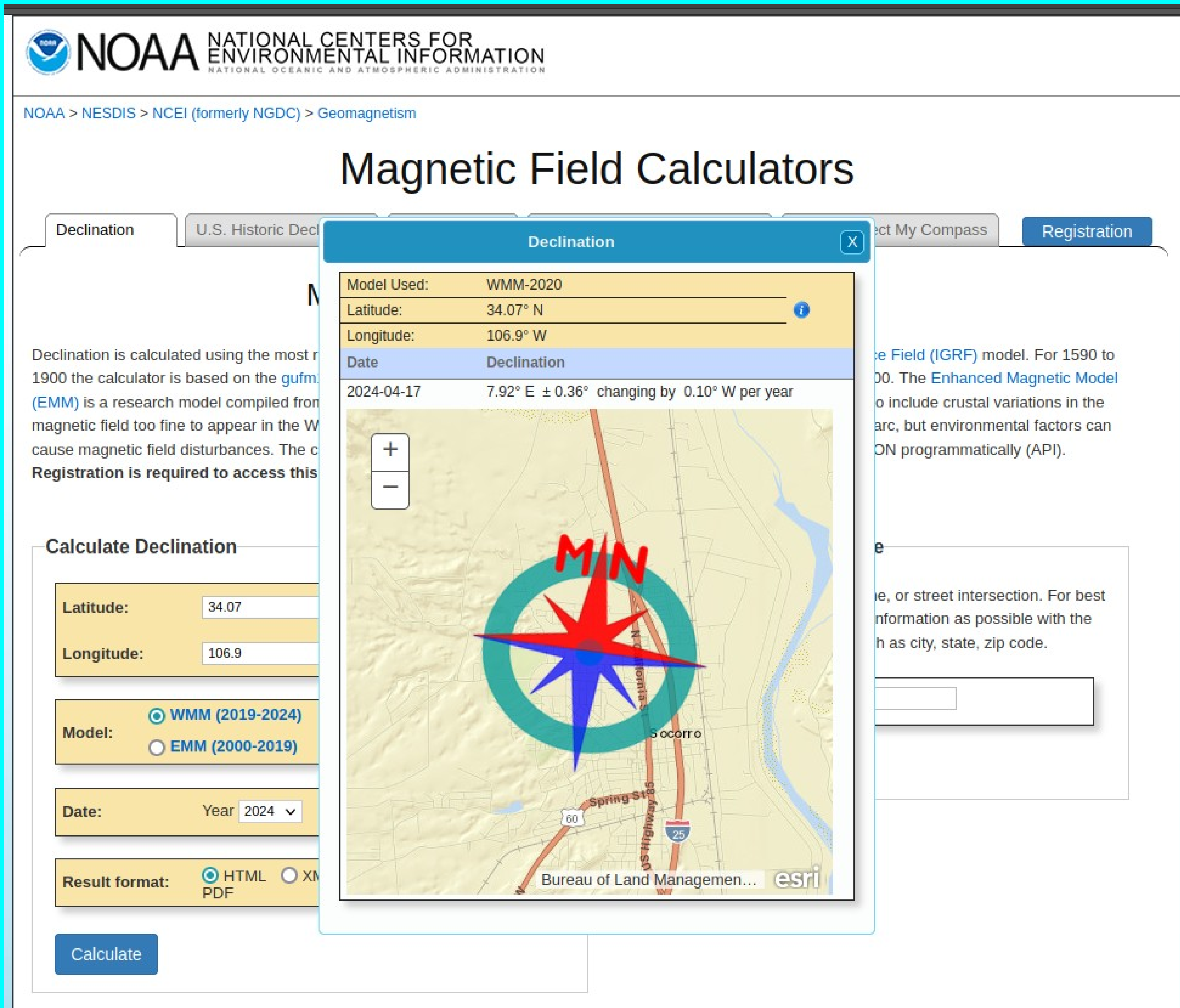
Assume B-field parallel to Earth Surface



Ignore Declination

The question is about magnetic north




NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA > NESDIS > NCEI (formerly NGDC) > Geomagnetism
Magnetic Field Calculators
Declination
U.S. Historic Decl
ect My Compass
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Declination is calculated using the most r
1900 the calculator is based on the gufm
(EMM) is a research model compiled fron
magnetic field too fine to appear in the W
cause magnetic field disturbances. The c
Registration is required to access this
e Field (IGRF) model. For 1590 to
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ON programmatically (API).
Calculate Declination
Latitude: 34.07
Longitude: 106.9
Model: WMM (2019-2024) EMM (2000-2019)
Date: Year 2024
Result format: HTML XM PDF
Calculate
e, or street intersection. For best
nformation as possible with the
h as city, state, zip code.
Declination
X
Model Used: WMM-2020
Latitude: 34.07° N
Longitude: 106.9° W
Date Declination
2024-04-17 7.92° E ± 0.36° changing by 0.10° W per year
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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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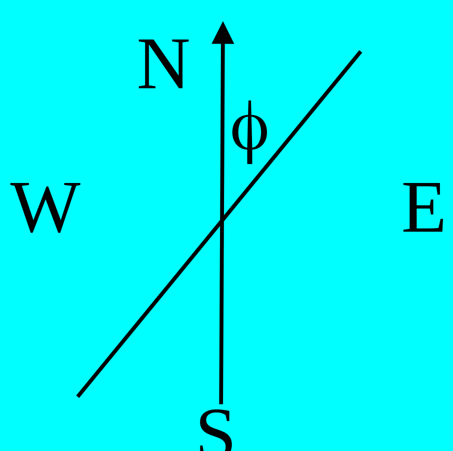
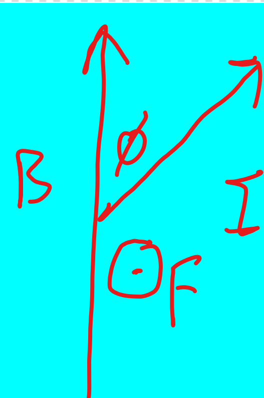


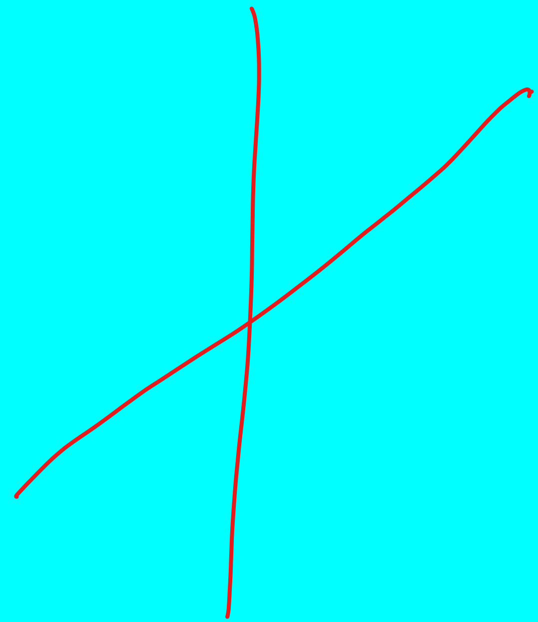


$F = I B \sin 23$

$\vec{F} = I \vec{L} \times \vec{B}$

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)

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

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

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

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

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

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

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

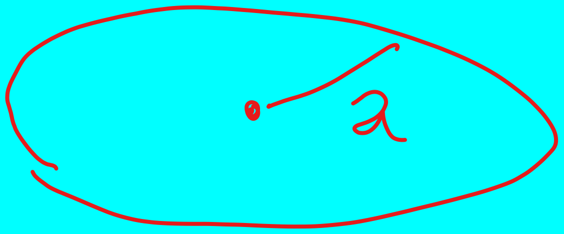
$$F = I L \frac{\mu_0 I}{r} = \frac{[A][m]\left[\frac{N}{A^2}\right][A]}{[m]}$$

$$B = \frac{\mu_0 I}{2\pi r} \rightarrow [T] = \left[\frac{N}{A^2}\right]\frac{[A]}{[m]} = \frac{N}{A \cdot m}$$

$$B = \mu_0 n I = \frac{[N]}{[A^2]}[A] = \frac{[N]}{[A]}$$

Equations from Ampere's Law

$$B = \frac{\mu_0 I}{2a}$$

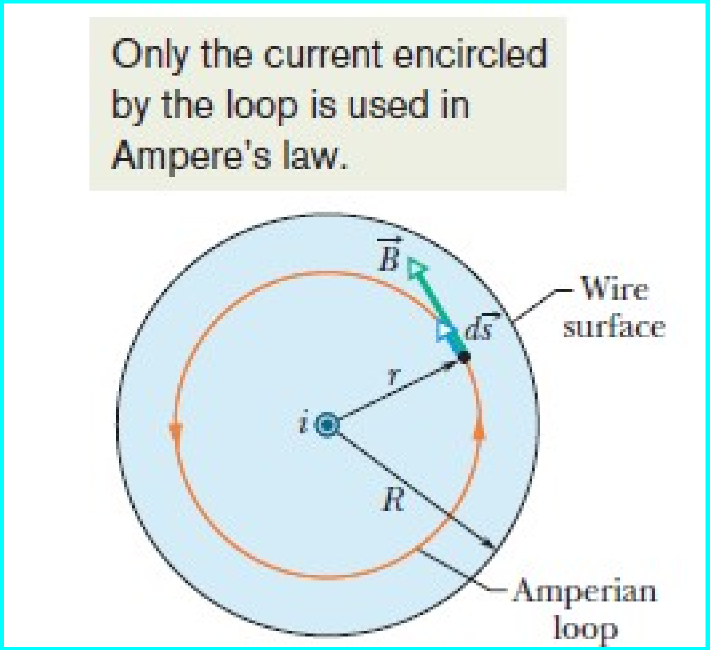


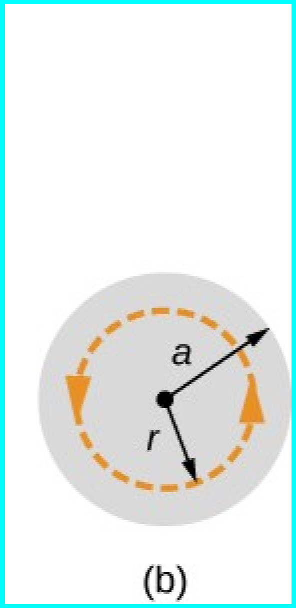
$$\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{\phi}$$ Field of Infinite wire

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

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

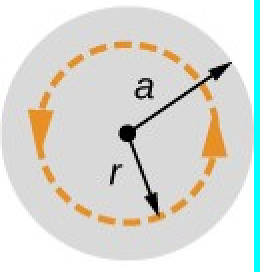
A wire with radius "a" carries "I" Amperes How many Amps are contained within radius "r"?

(A) I

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

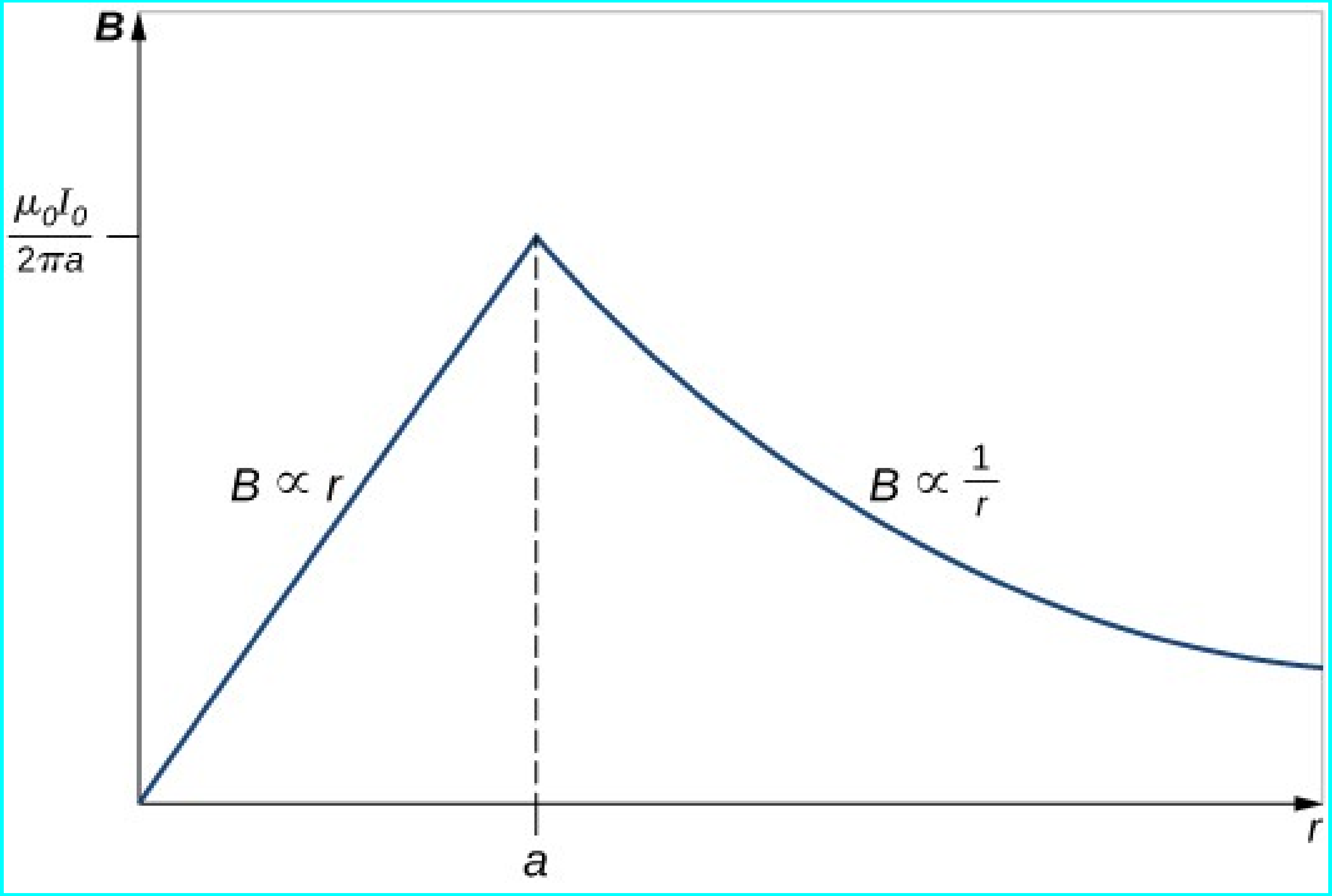
(C) $I\frac{r}{a}$

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

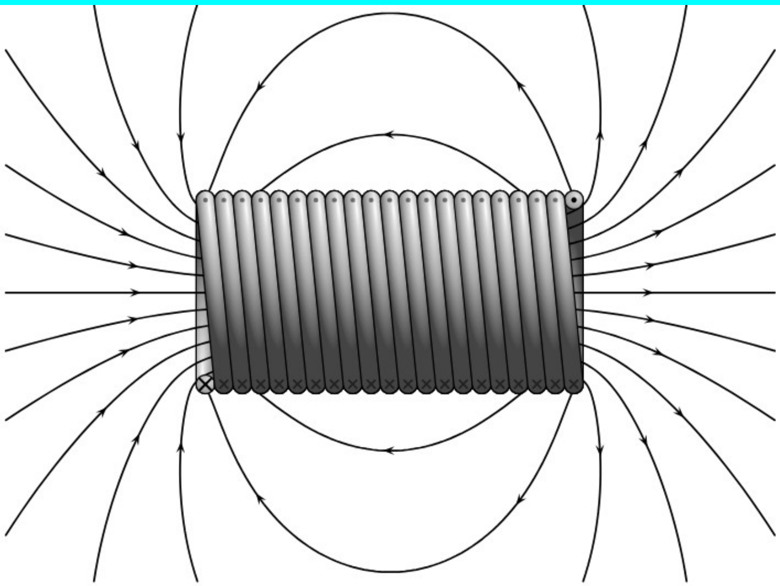


(b)

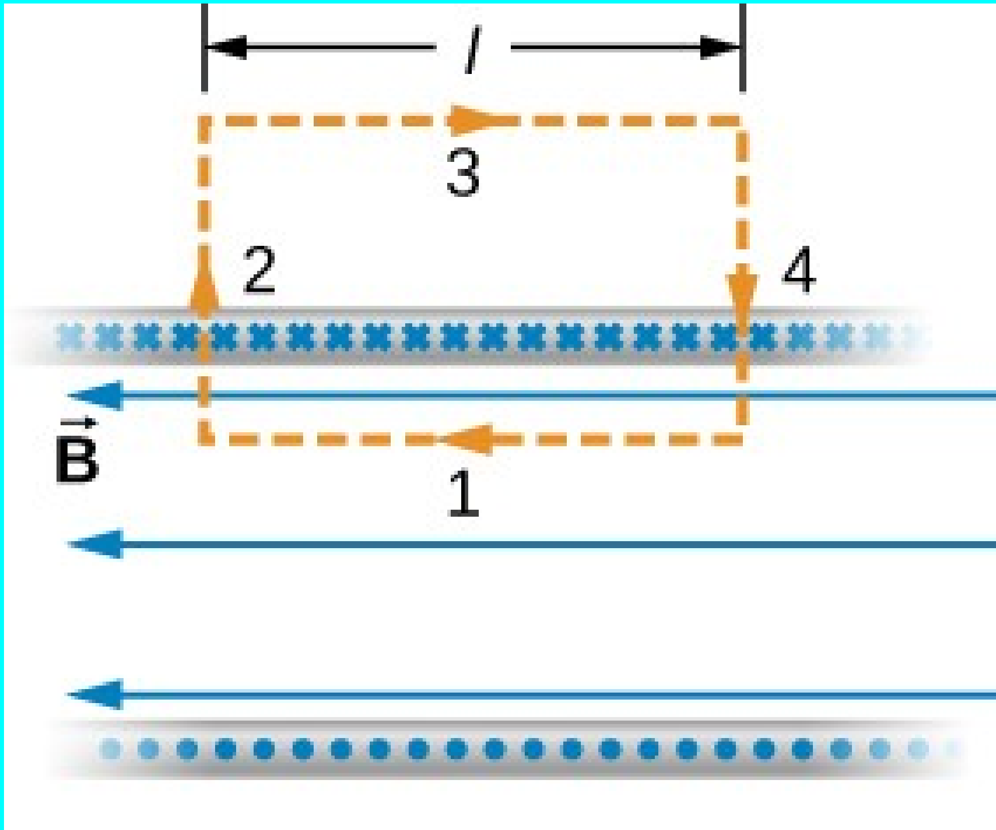
Ampere result inside and outside of a wire



Derive field of a solenoid



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



$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enclosed} = \mu_0 N I$$

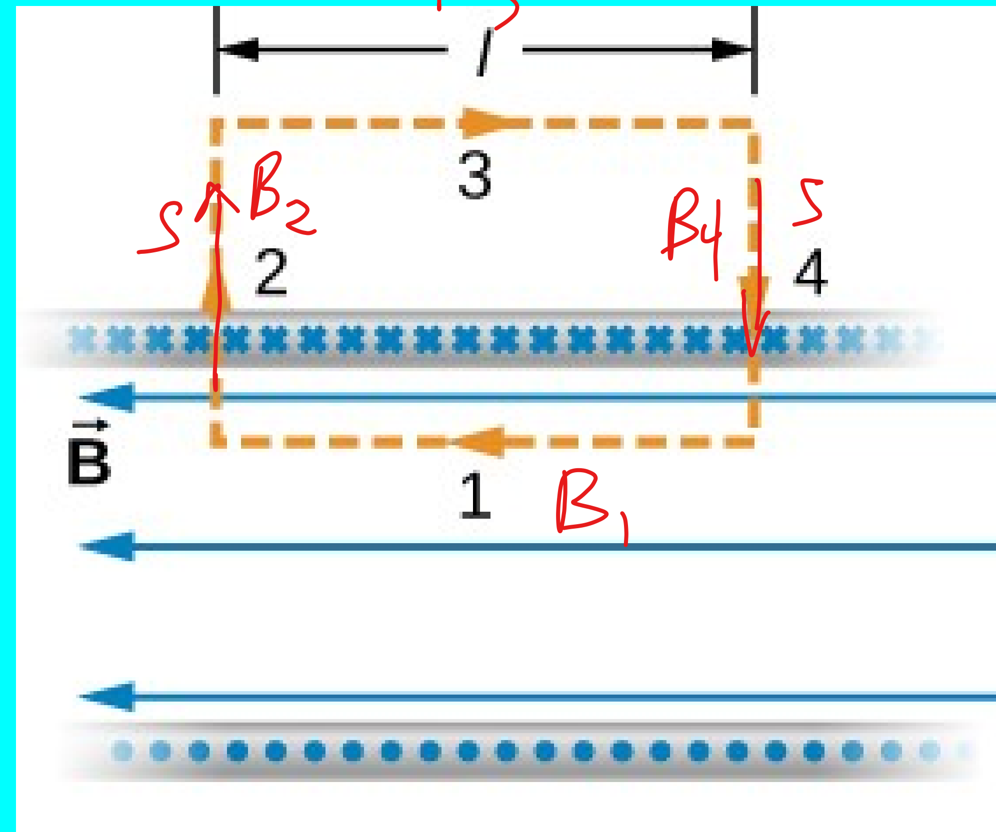
$$= \mu_0 \frac{N}{L} l I = \mu_0 n l I$$

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

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

$B_1 l + B_2 s - B_4 s + 0\, l$

$B_1 l = \mu_0 n l I$



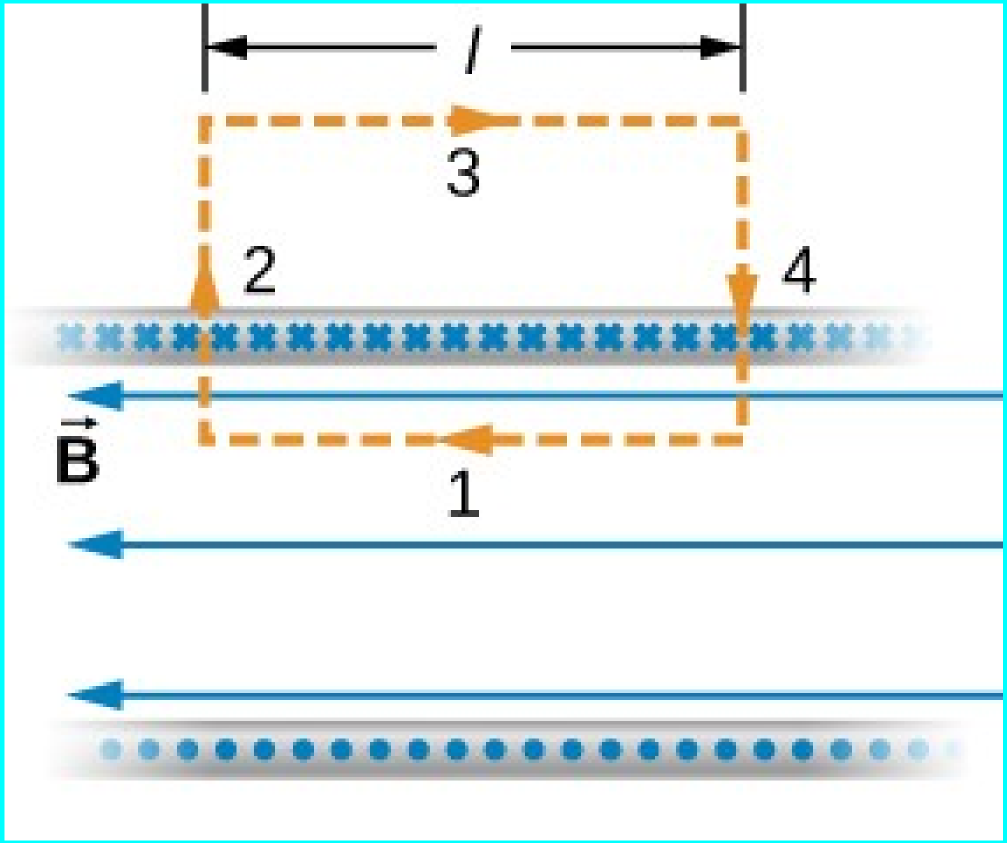
(A) I

(B) $\mu_0 N I$ $\mu_0 n l I$

(C) $\mu_0 I/N$

(D) $-\mu_0 I$

$B = \mu_0 n I$



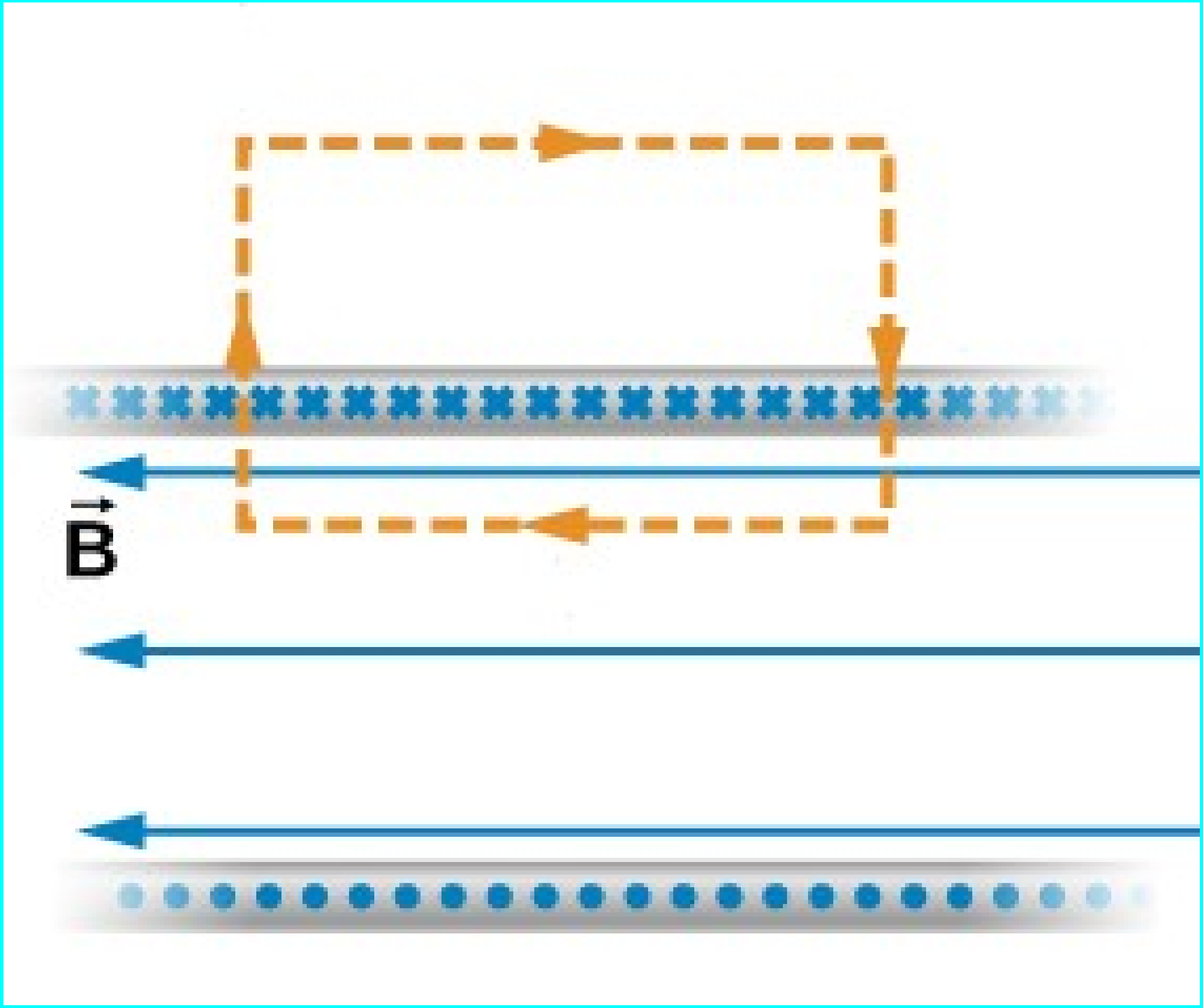
$B_{outside} = 0$ Top and bottom currents cancel (superposition)

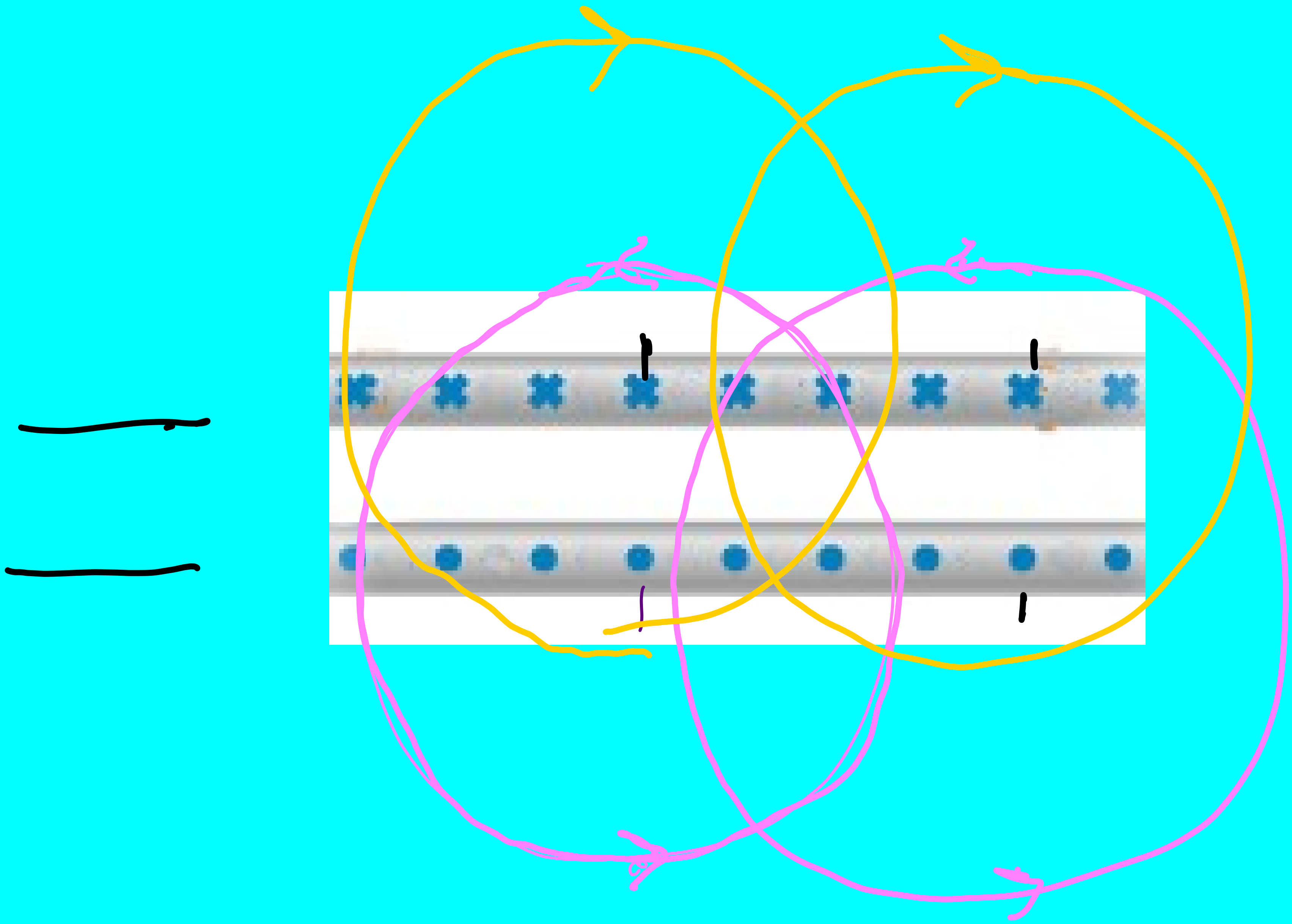
B_{inside} is independent of z (symmetry of infinite coil)

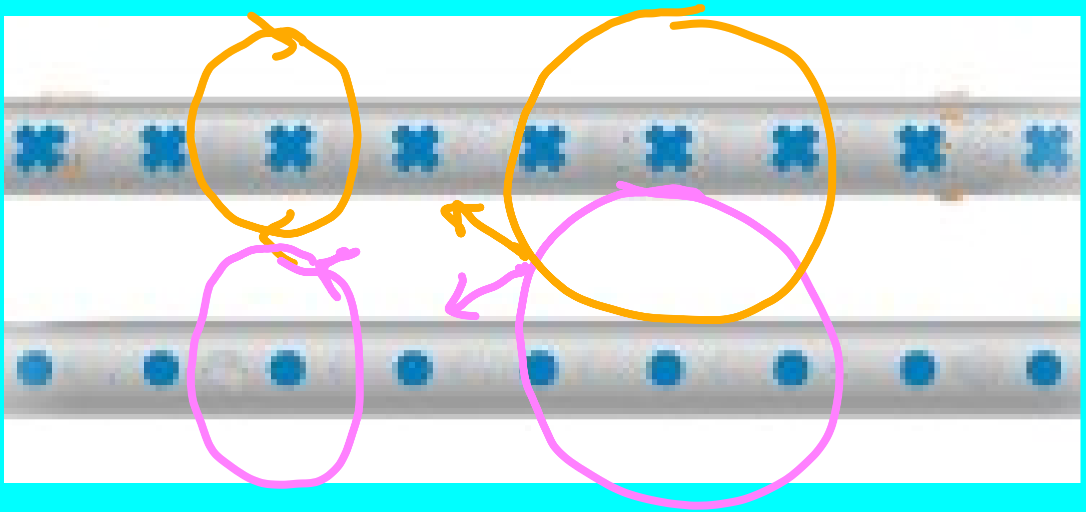
$B_\theta = 0$ (circular symmetry)

$B_r = 0$ (superposition)

If B_r not $= 0$ Path 2 and 4 still cancel(superposition)


$\vec{B}$





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?

$\mu_0 = 4\pi \times 10^{-7}$
$= 1.26 \times 10^{-6}$
4000 windings
10 cm
2 Amps

(A) 0.25 T

(B) 0.025 T $(1.26 \times 10^{-6})(4 \times 10^{4})(2)$

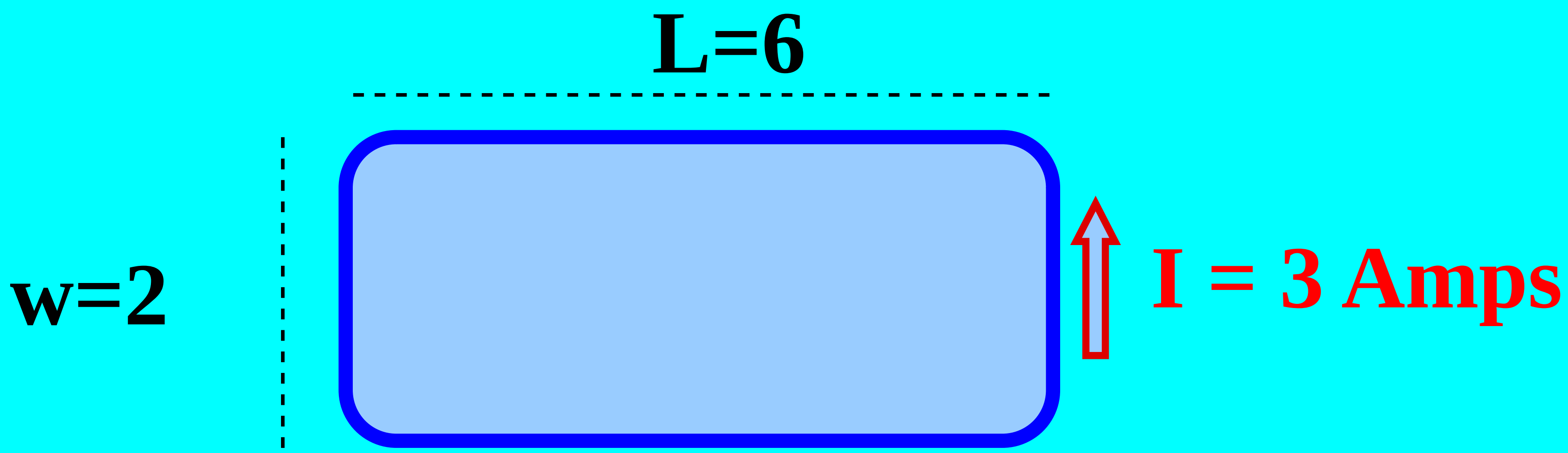
(C) 1 T

(D) 0.1 T $n = \frac{N}{L} = \frac{4000}{.1}$

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

Remember magnetic moments?

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



(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.

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

- PARAamagnetic 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.

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

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

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

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

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

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

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

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

What's the magnetic permeability of iron?

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

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

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

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

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

$$\mu = \mu_0 (1 + \chi)$$

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?

N=4

l=.1m

I=2

(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

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

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

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

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

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

Maxwell's Equations

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

How do I avoid an infinite formula sheet – really?

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

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

$Q = CV$ Def. of capacitance

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

$U = qV$ Relation between potential and potential energy

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

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

Recap Lecture 25

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