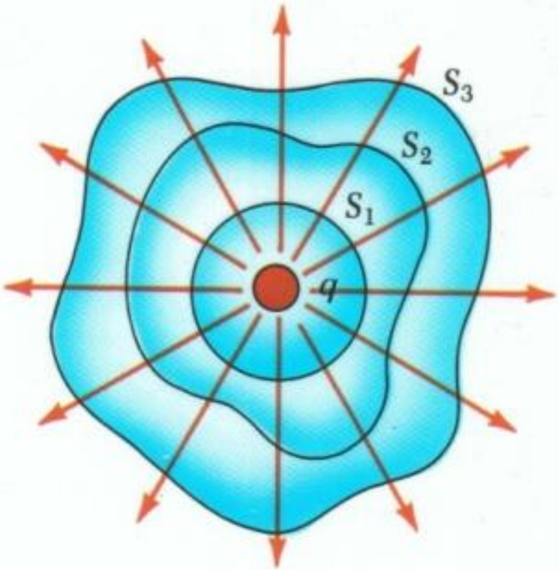
Last time

- Ampere’s Law

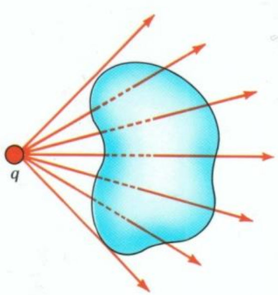
This time

- Applications of Ampere’s Law
- Solenoids
- Toroids

Electricity



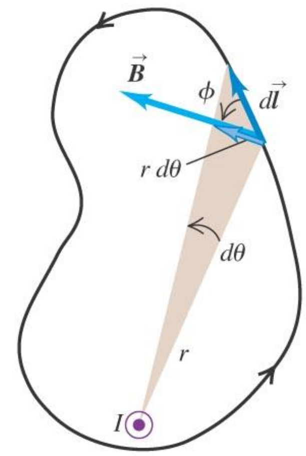
$$\oint \vec{E} \bullet d\vec{A} = \frac{Q_{\text{Enclosed}}}{\varepsilon_0} = \frac{q}{\varepsilon_0}$$



$$\oint \vec{E} \bullet d\vec{A} = \frac{Q_{\text{Enclosed}}}{\varepsilon_0} = 0$$

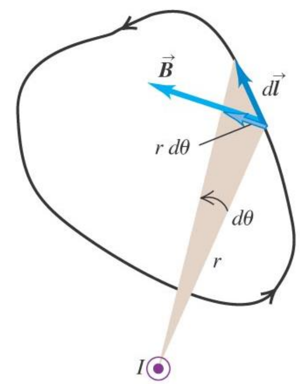
Magnetism

(a)



$$\oint \vec{B} \bullet d\vec{l} = \mu_0 I$$

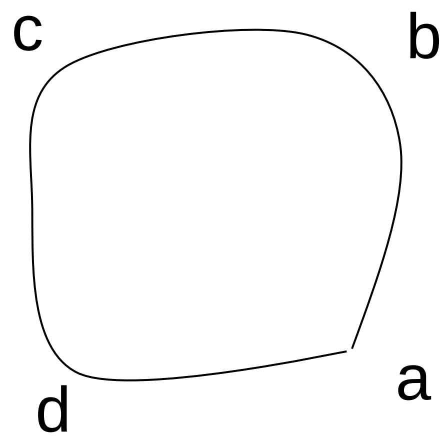
(b)



$$\oint \vec{B} \bullet d\vec{l} = 0$$

Gauss's Law

$$\oint \vec{E} \bullet d\vec{A} = \frac{Q_{\text{Enclosed}}}{\varepsilon_0}$$



Also

$$\oint \vec{E} \bullet d\vec{l} = 0$$ since $$V_a - V_c = \int_a^c \vec{E} \bullet d\vec{l} = \int_{abc} \vec{E} \bullet d\vec{l} = \int_{adc} \vec{E} \bullet d\vec{l}$$

$$\int_{abc} \vec{E} \bullet d\vec{l} - \int_{adc} \vec{E} \bullet d\vec{l} = 0 \Rightarrow \int_{abc} \vec{E} \bullet d\vec{l} + \int_{cda} \vec{E} \bullet d\vec{l} = \oint \vec{E} \bullet d\vec{l} = 0$$

A reflection of the fact that electrostatic field is a conservative field.

Ampere's Law

$$\oint \vec{B} \bullet d\vec{l} = \mu_0 I$$

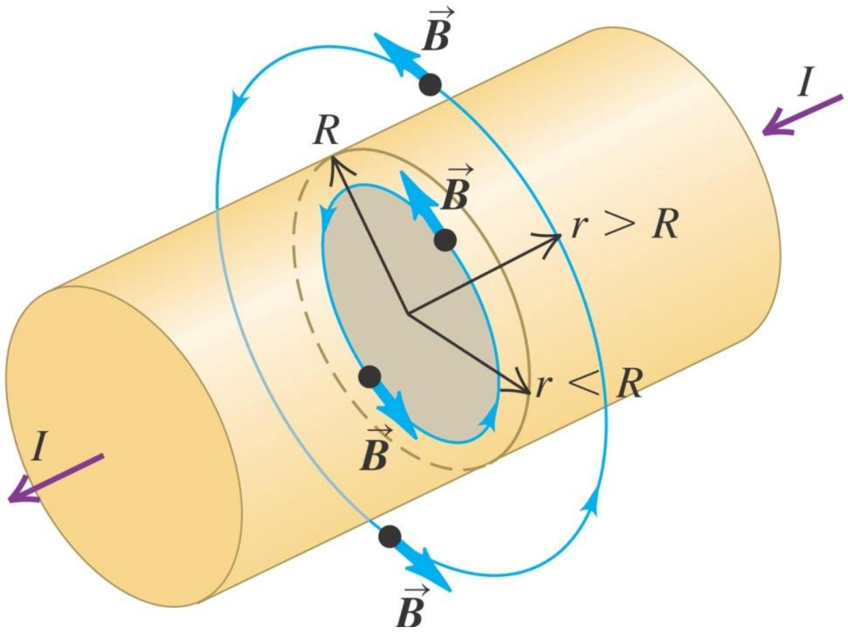
Also

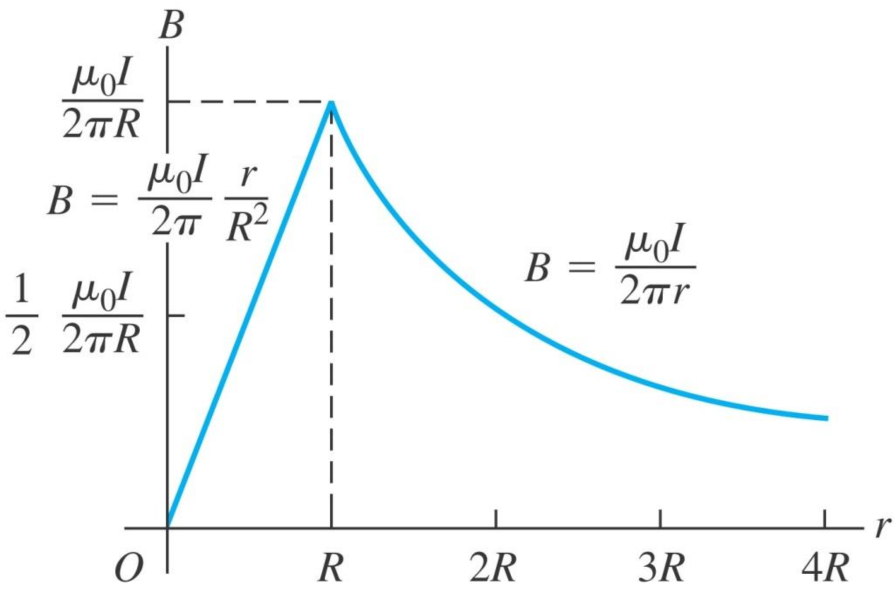
$$\oint \vec{B} \bullet d\vec{A} = 0$$

A reflection of the fact that magnetic field lines form closed loops.

Field inside a long cylindrical conductor

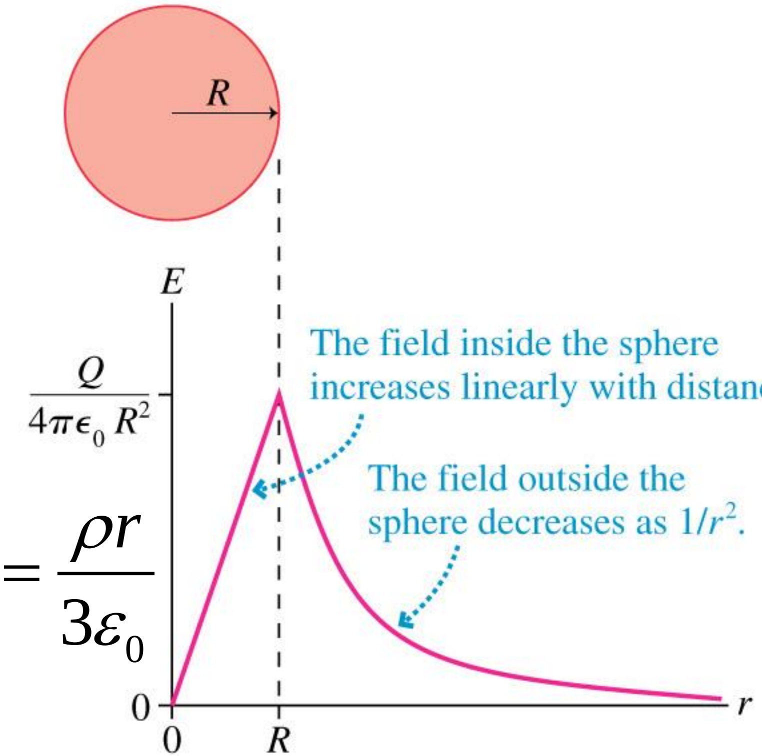
- A cylinder of radius R carrying a current I.





$$\oint \vec{B} \bullet d\vec{l} = \mu_0 I$$

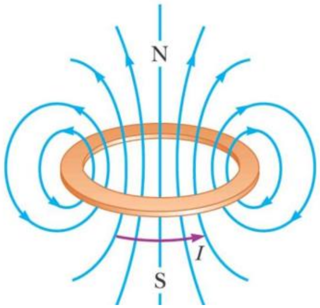
Plot of electric field as a function of the distance from the center of a uniformly charge sphere

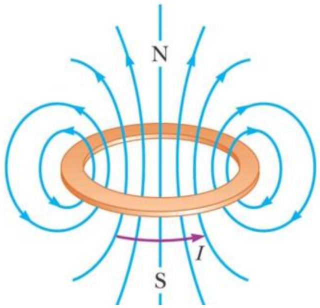


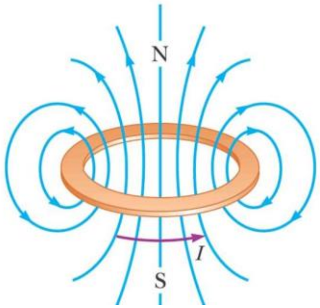
$$E = \frac{\rho r}{3\varepsilon_0}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

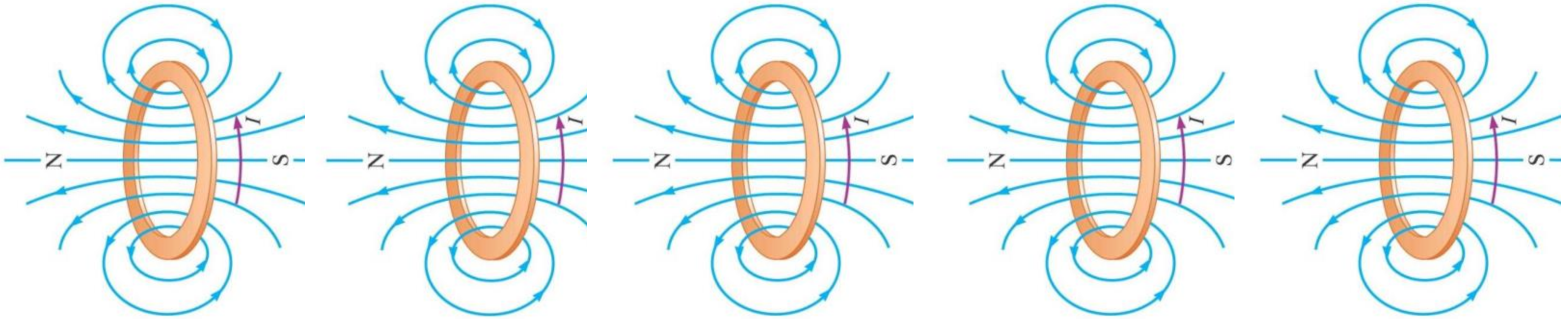
Magnetic field lines of current loop





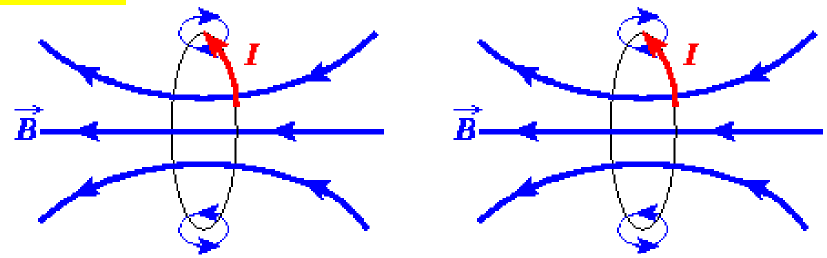


Magnetic field lines of many current loops closely spaced

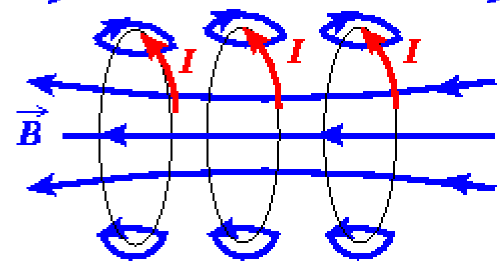


Solenoid

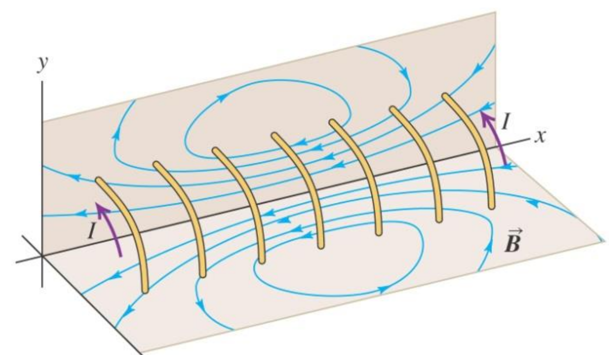
The magnetic field near the center of a single coil carrying a current I.

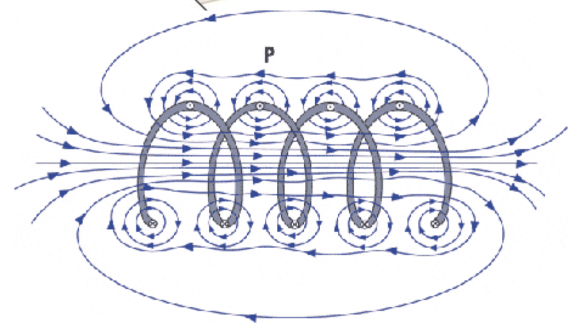


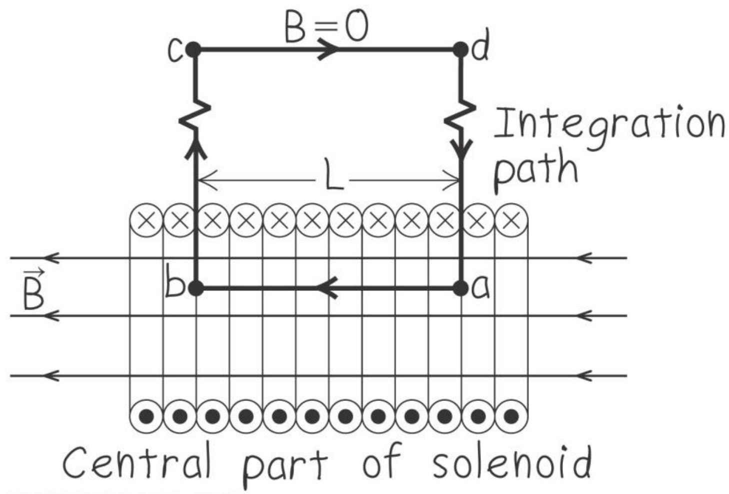
The magnetic field near the center of a set of three coils all carrying a current I.



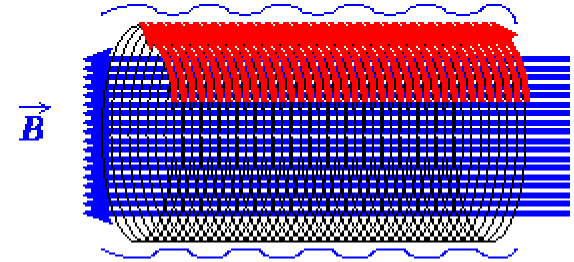
A solenoid approximates many current-carrying coils spaced much more closely than the coil diameter.

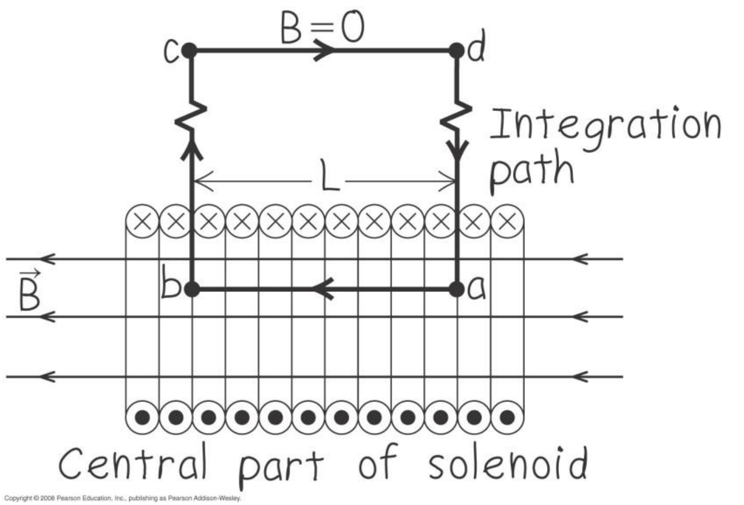





B = 0
c
d
Integration path
L
$\vec{B}$
b
a
Central part of solenoid

A perfect solenoid has coils so close together that the magnetic field is zero outside the solenoid and perfectly uniform inside.





$$\oint \vec{B}\bullet d\vec{l} = \mu_0 I$$

$$\oint \vec{B}\bullet d\vec{l} = \underbrace{\int_a^b \vec{B}\bullet d\vec{l}}_{\uparrow\uparrow} + \underbrace{\int_b^c \vec{B}\bullet d\vec{l}}_{\perp \text{ or } B=0} + \underbrace{\int_c^d \vec{B}\bullet d\vec{l}}_{B=0} + \underbrace{\int_d^a \vec{B}\bullet d\vec{l}}_{\perp \text{ or } B=0}$$

$$\int_a^b B dl = N\mu_0 I$$

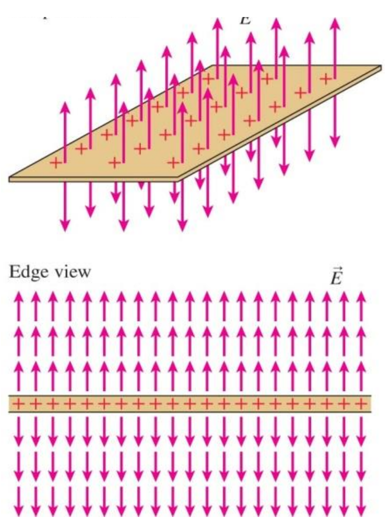
$$B\int_a^b dl = N\mu_0 I$$

$$Bl = N\mu_0 I \Rightarrow B = \frac{N}{l}\mu_0 I$$

$$B = n\mu_0 I$$

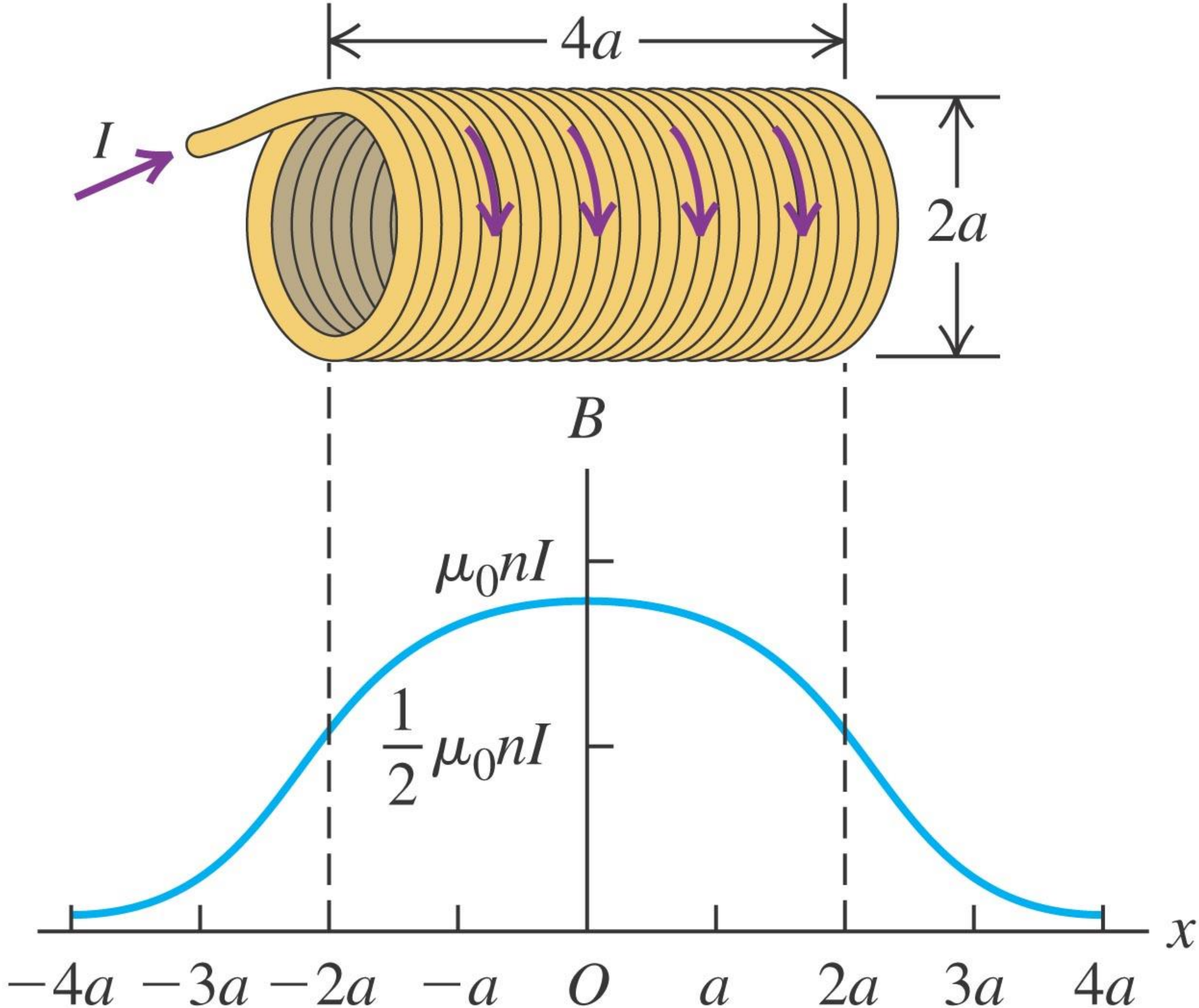
Along the axis of solenoid.

Solenoid is the magnetic analogue of infinite plane with uniform charge density

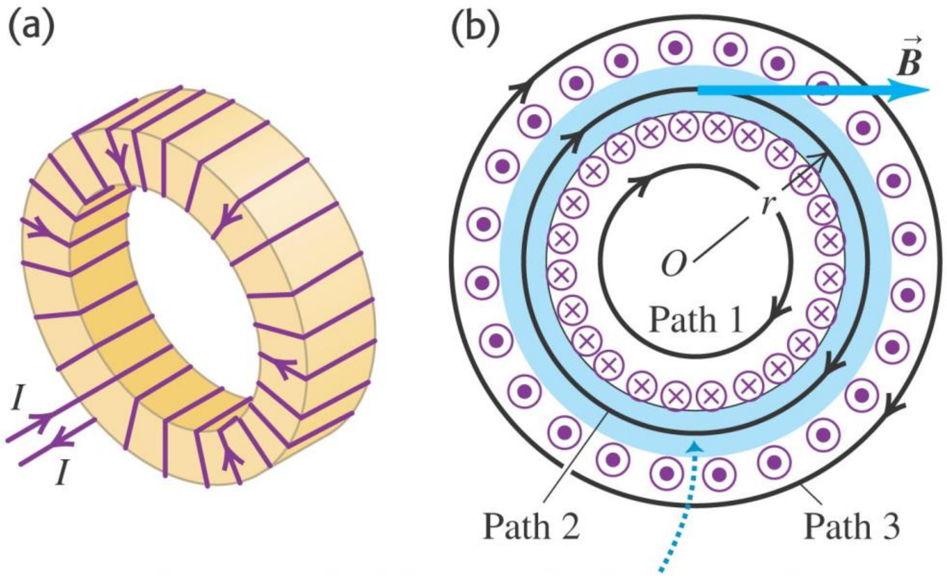


Valves

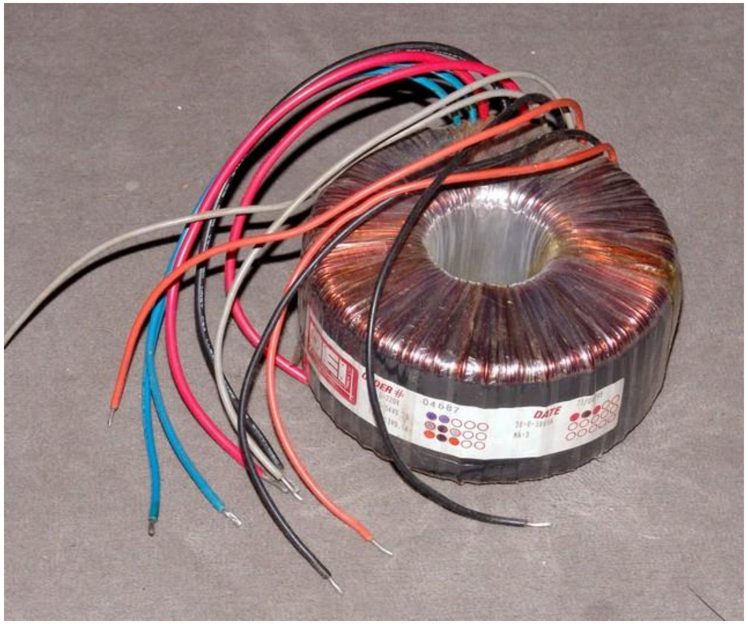
Starter



4a
I
2a
B
$\mu_0 nI$
$\frac{1}{2}\mu_0 nI$
x
−4a −3a −2a −a O a 2a 3a 4a



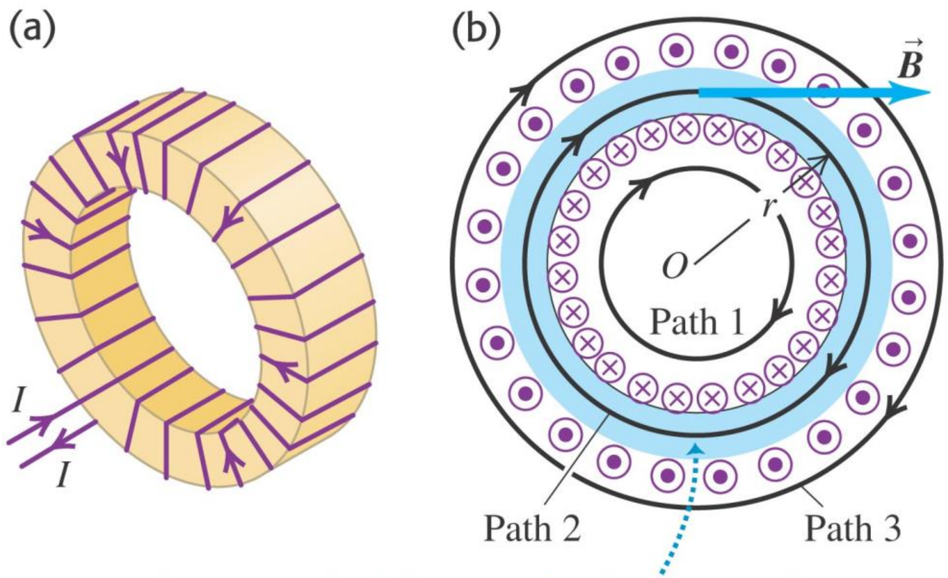
The magnetic field is confined almost entirely to the space enclosed by the windings (in blue).



$$\oint \vec{B} \bullet d\vec{l} = \mu_0 I$$

$$\oint \vec{B} \bullet d\vec{l} = \int_{\text{Path 1}} \vec{B} \bullet d\vec{l} = 0 \Rightarrow \vec{B} = 0$$

$$\oint \vec{B} \bullet d\vec{l} = \int_{\text{Path 3}} \vec{B} \bullet d\vec{l} = N\mu_0 I - N\mu_0 I = 0 \Rightarrow \vec{B} = 0$$



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

$$\oint \vec{B} \cdot d\vec{l} = \int_{\text{Path 2}} \vec{B} \cdot d\vec{l} = N\mu_0 I \Rightarrow B2\pi r = N\mu_0 I$$

$$B = \frac{N\mu_0 I}{2\pi r}$$

Nearly uniform if r is much larger than the difference between the inner and outer radii.

Some common applications that toroidal transformers are used in:

- Security Systems
- Medical Isolation Equipment
- Professional Audio and Audio Visual equipment
- Domestic Hi-Fi Audio and Audio Visual equipment
- Power Distribution equipment
- Telecommunication systems
- Automotive electronics
- Industrial Control Equipment
- LED Residential/Commercial Lighting
- LED Street Lighting
- LED Airport Runway Lighting
- Renewable energy inverter systems