

## 4.4 Electromagnetism



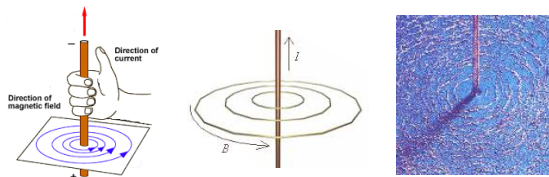
Read  
"Electromagnetism  
for Babies"

## Electromagnetism

Electricity/magnetism are linked - moving magnets move charges; moving charges make a B-field.

The B-field around a wire is circular, and a RHR exists: grasp a wire with your right hand so your thumb is in the hole current direction.

Your curled fingers indicate the B-field.



## B-Field Calculations

The magnitude of B-fields can be computed using intensely complex mathematics:

$$\begin{aligned}\vec{\nabla} \cdot \vec{B} &= 0 & \frac{\partial}{\partial x_i} B_i &= 0 \\ \vec{\nabla} \times \vec{E} + \frac{1}{c} \frac{\partial \vec{B}}{\partial t} &= 0 & \frac{\partial}{\partial x_i} E_j \epsilon_{ijk} + \frac{1}{c} \frac{\partial B_k}{\partial t} &= 0 \\ \vec{\nabla} \cdot \vec{E} &= 4\pi\rho & \frac{\partial}{\partial x_k} E_k &= 4\pi\rho \\ \vec{\nabla} \times \vec{B} - \frac{1}{c} \frac{\partial \vec{E}}{\partial t} &= \frac{4\pi}{c} \vec{J} & \frac{\partial}{\partial x_i} B_j \epsilon_{ijk} - \frac{1}{c} \frac{\partial E_k}{\partial t} &= \frac{4\pi}{c} J_k \\ \vec{B} &= \vec{\nabla} \times \vec{A} & B_j &= \frac{\partial}{\partial x_m} A_n \epsilon_{mnj} \\ \vec{E} &= -\vec{\nabla}\phi - \frac{1}{c} \frac{\partial \vec{A}}{\partial t} & E_k &= -\frac{\partial}{\partial x_k} \phi - \frac{1}{c} \frac{\partial A_k}{\partial t}\end{aligned}$$

## B-Field Calculations (single wire)

Luckily, the calculations are a little easier for you:

$B = \frac{\mu_0 I}{2\pi r}$	$\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$	AP Constant
AP Equation	= vacuum permeability	
	I = current (A)	
	r = distance from wire (m)	

Vacuum permeability is a material's ability to support the formation of a B-field within itself.

It is the magnetization a material obtains in response to an applied magnetic field.

## 1. B-Field Example

What is the B-field strength 15 cm away from a wire with a current of 16 amps?

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \text{ T}\cdot\text{m/A} \cdot 16 \text{ A}}{2\pi \cdot 0.15 \text{ m}} = 2.1 \times 10^{-5} \text{ T}$$

## 2. Alteration Example

By what factor does the B-field change when wire distance is tripled and current is doubled?

Set parameters:

Condition 1 : Condition 2		
r:	1	: 3
I:	1	: 2

$$B_1 = \frac{\mu_0 I}{2\pi r} \quad : \quad B_2 = \frac{\mu_0 2I}{2\pi 3r} = \frac{2}{3} \cdot \frac{\mu_0 I}{2\pi r}$$

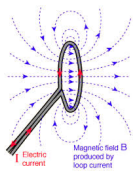
It reduces to 2/3 the original strength.

### B-Field Calculations (coil)

In a circular coil, the magnetic field direction inside the coil is such that if the right hand fingers curl in the direction of current, the thumb points in the direction of the B-field.

$$B = \frac{\mu_0 NI}{2r}$$

$\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$   
 $N$  = number of turns  
 $I$  = current (A)  
 $r$  = radius of coil (m)



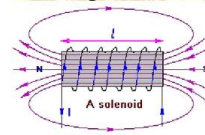
### B-Field Calculations (solenoid)

In a solenoid, a long helix of coiled wire, the length of coil starts playing a reducing role in magnetic field strength.

B-field at the center of a solenoid:

$$B = \frac{\mu_0 NI}{\ell}$$

$\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$   
 $N$  = number of turns  
 $I$  = current (A)  
 $\ell$  = length of solenoid (m)



Actuator Demos: washing machine lock and starter motor.



### 3. Solenoid Example

A 3.5 cm solenoid produces a 0.045 T B-field with 2.0 A of current.

How many coils are in the solenoid?

$$B = \frac{\mu_0 NI}{\ell}$$

$$N = \frac{B\ell}{\mu_0 I} = \frac{0.045 \text{ T} \cdot 0.035 \text{ m}}{4\pi \times 10^{-7} \frac{\text{T}\cdot\text{m}}{\text{A}} \cdot 2.0 \text{ A}} = 627 \text{ loops}$$

### 4. Turns Example

A 3.5 cm solenoid produces a 0.045 T electric field with 2.0 A of current with 627 loops.

If engineers must increase B-field strength by 17%, how many turns will the new solenoid need?

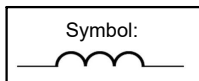
Since turns is directly proportional to B-field, increasing the original number by a factor of 1.17 gives the number of turns:

$$627 \text{ loops} \cdot 1.17 = 733 \text{ loops}$$

### More Components & Symbols

Inductors - wire coils that condition electric current using electric and magnetic interactions.

Symbol:

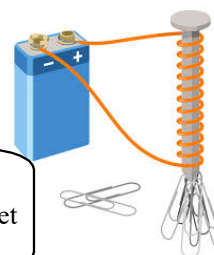


### Electromagnet Demo.

You'll be doing this lab soon!

See how current increases B-Field

Of note: the nail within the wire increases the B-field produced by the wires by a huge factor.



### Homework 4.4

Problems 4.4 in your Booklet  
 Due: Next Class