Magnetism

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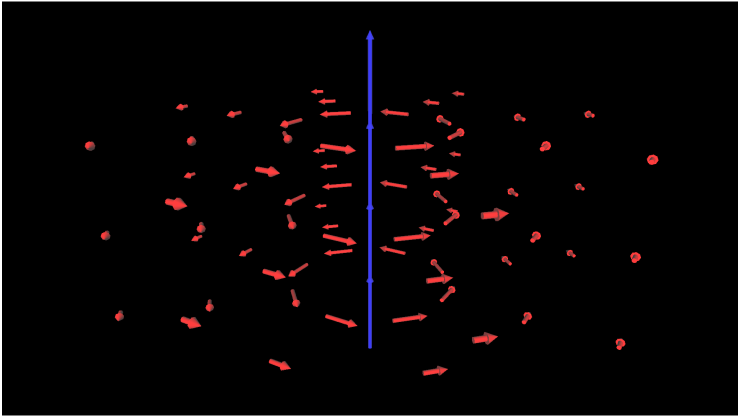
Certain things produce a magnetic field

- magnets (Giancoli 7th: 20-1)
- currents (Giancoli 7th: 20-2, 20-5, 20-7)
  - long straight wire
  - solenoid
  - current loop (qualitatively)
- moving charges

Certain things feel a force from a magnetic field

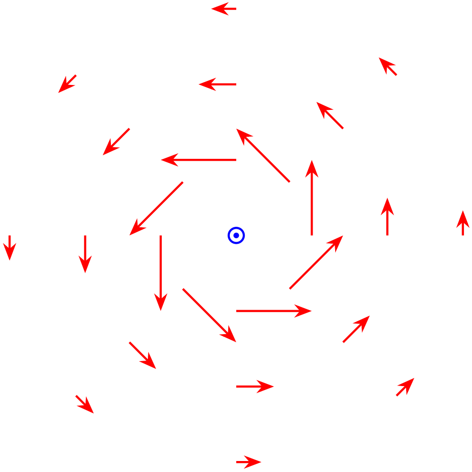
- magnets (Giancoli 7th: 20-1)
- currents (Giancoli 7th: 20-3, 20-6)
  - straight wire
- moving charges (Giancoli 7th: 20-4)

Magnetic field produced by a long straight wire



- Blue = current in the wire
- Red = magnetic field, $B = \frac{\mu_0 I}{2\pi r}$

Magnetic field produced by a wire: top view



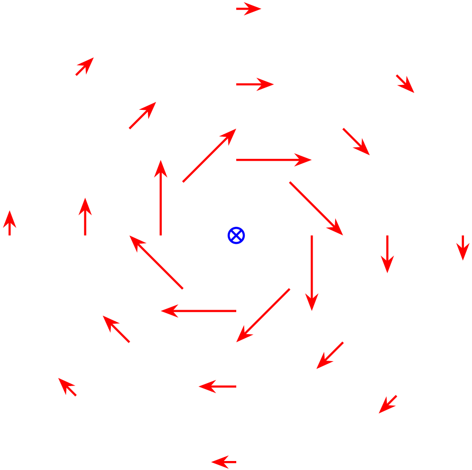
- Blue = current in the wire is coming toward us
- Red = magnetic field, $B = \frac{\mu_0 I}{2\pi r}$

Right-hand rule #1

To find the direction of the magnetic field produced by a wire:

1. Put your right hand in the strange posture I show you, in which your fingers are bent at 90° at the large knuckles, but otherwise straight, and your thumb is sticking straight out.
2. Put your thumb along the direction of the current.
3. Put your large knuckes at the place where you want to know the magnetic field.
4. Your fingers point in the direction of the magnetic field.

Magnetic field produced by a wire: opposite view



- Blue = current in the wire is flowing away from us
- Red = magnetic field, $B = \frac{\mu_0 I}{2\pi r}$

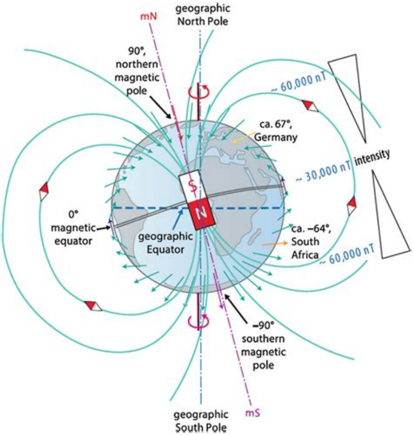
Magnetic field produced by a wire: equation

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

- B is the magnitude of the magnetic field (in Tesla)
- $\mu_0 = 4\pi \times 10^{-7}$ T m/A
- I is the current in the wire (in Amperes)
- r is the distance from the wire (in meters)

Magnetic field produced by Earth

Earth acts like a bar magnet.



- There is a place in the African country of Benin (latitude 12° north, longitude 3° east) where Earth's magnetic field points directly geographically north.

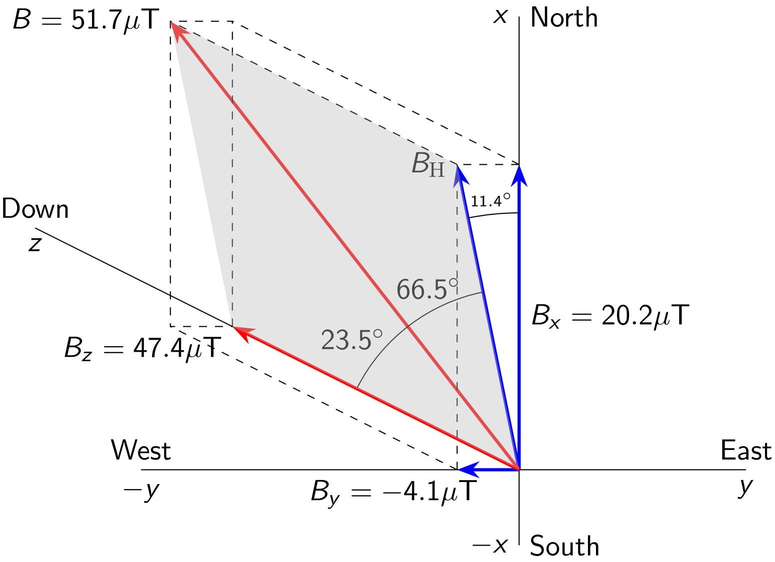
Earth's magnetic field in Annville, PA

B_x	$20.2\ \mu$T	x is North
B_y	$-4.1\ \mu$T	y is East
B_z	$47.4\ \mu$T	z is Down
Horizontal Intensity	$20.6\ \mu$T	
Total Field	$51.7\ \mu$T	
Inclination ($+$ D , $-$ U)	66.5°	
Declination ($+$ E , $-$ W)	-11.4°	

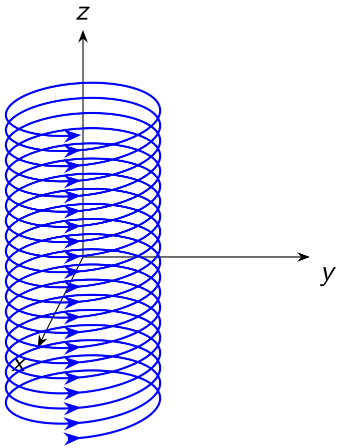
Data source:

https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfwmm

Earth's magnetic field in Annville, PA

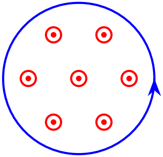


A solenoid consists of wire wrapped around a cylinder.



- Current flows counterclockwise as viewed from the positive z axis.

A solenoid creates a uniform magnetic field inside it.



$$B = \begin{cases} \mu_0 NI/\ell & , \quad \text{inside} \\ 0 & , \quad \text{outside} \end{cases}$$

- B is the magnitude of the magnetic field (in Tesla)
- N is number of turns in the solenoid
- I is the current in the solenoid
- ℓ is the length of the solenoid

Magnetic field exerts a force on a moving charged particle.

To use this equation, there needs to be a particle and a magnetic field produced by something *other than* the particle.

$$F = |q| \, vB \sin\theta$$

- B is the magnitude of the magnetic field (in Tesla)
- q is the charge of the particle
- v is the speed of the particle
- θ is the angle between the velocity of the particle and the direction of the magnetic field

Right-hand rule #2

To find the direction of the force a magnetic field exerts on a particle:

1. Put your right hand in ideal handshake position, in which your fingers point straight out from the palm, and your thumb is sticking straight out.
2. Put your fingers in the direction of the particle's velocity. (If the velocity is zero, the force is zero.)
3. Turn your hand at the wrist so that you can bend your fingers to point in the direction of the magnetic field.
4. Your thumb points in the direction of the force on a positively-charged particle. If your particle is negative, flip the direction.

Magnetic field exerts a force on a segment of wire.

To use this equation, there needs to be a wire and a magnetic field produced by something *other than* the wire.

$$F = I\ell B \sin\theta$$

- B is the magnitude of the magnetic field (in Tesla)
- I is the current flowing in the wire
- ℓ is the length of the wire
- θ is the angle between the direction of the current and the direction of the magnetic field

Magnetic Flux

- Magnetic flux, Φ_B, is how much "imaginary magnetic stuff" flows through a surface, if magnetic field represented the movement of something, like velocity does.
$$\Phi_B = BA\cos\theta$$
- B is the magnetic field
- A is the area of the surface
- θ is the angle between the magnetic field and a vector *perpendicular* to the surface. The vector perpendicular to the surface gives the surface an orientation, telling us which way counts as positive for magnetic flux.
- Units for magnetic flux are T m^2, or Wb (Weber).
- Magnetic flux through a loop is either into the loop or out of the loop.

emf

- emf, $\mathcal{E}$, describes how much electric "umph" is available to produce a current.
- emf is measured in volts (V).
- emf acts like a potential difference
- You can use emf in Ohm's law

$$\mathcal{E} = IR$$

- emf around a loop is either clockwise or counterclockwise

Faraday's Law: A changing magnetic flux produces an emf.

We apply Faraday's Law to a loop or a coil.

$$\mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t}$$

- $\Delta \Phi_B$ is the change in magnetic flux through the surface bounded by the loop or coil.
- Δt is the time over which this change takes place.
- N is the number of turns in the coil ($N = 1$ for a loop).
- $\mathcal{E}$ is the emf around the loop or coil.

Lenz's law, short version

- Nature abhors a change in magnetic flux.
- Nature will respond to a change in magnetic flux by creating (inducing) an emf whose current would create a magnetic field that opposes the change in flux.

Lenz's law, step by step

1. Magnetic flux changes for some reason.
2. Nature will attempt to induce (create, produce) a magnetic field to oppose the change. In what direction would this be? (Usually into or out of the page.)
3. In what direction would current need to flow to produce the induced magnetic flux of step 2? (Usually clockwise or counterclockwise.)
4. The direction of the emf is the same (clockwise or counterclockwise) as the direction of the hypothetical current in step 3. This induced emf exists whether or not the current exists.

Lenz's law, common situations

External magnetic flux	Induced magnetic flux	Induced emf
out of board, increasing	into board	clockwise
out of board, decreasing	out of board	counter-clockwise
into board, increasing	out of board	counter-clockwise
into board, decreasing	into board	clockwise