

# Physics Education Laboratory

## Lecture 13

### Content Knowledge for Electromagnetism

Francesco Longo - 01/12/22



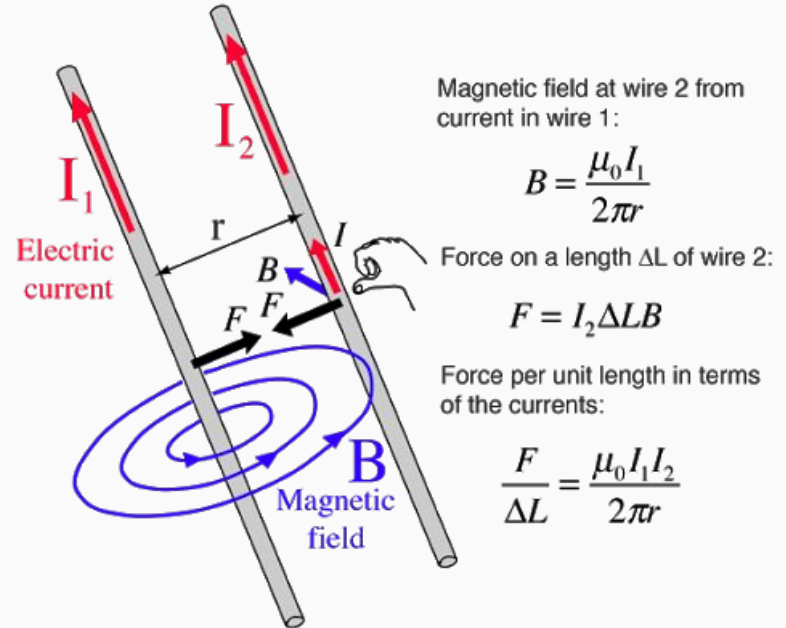


MAGNETIC DISCUSSION

*Bruno Zevi*

# Key concepts in (Electro)-Magnetism

- The magnetic field
- The magnetic dipole
- Forces on charges in motion
- Interaction of B field and currents
- The sources of the magnetic field
- The flux of magnetic field
- The Faraday-Lenz Law
- Electromagnetism
- Alternate currents



# Key concepts in Magnetism

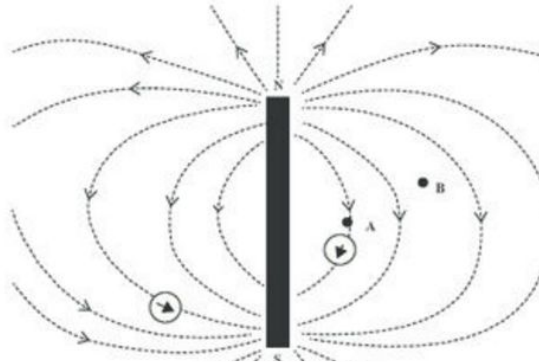
1. The idea of field lines to describe a magnetic field.
2. The idea that relative density of the field lines gives an indication of the strength of the field at various points in the field.
3. The shape of the magnetic field around a bar magnetic.

# Key concept in Magnetism

1. that the lines of force show the direction of the force on a unit N pole, but since there is no such thing as a unit N pole (or S pole come to that) the statement is merely a convention to draw the arrows from N to S.

# Key concept in Magnetism

2. that the density of the lines of force indicates the strength of the magnetic field. This is only partly true and rather misleading, since the lines of force which I choose to draw are arbitrary. For example on the diagram of the magnet, I chose to put the compass at a particular point, say A, and follow it along to draw that line of force, but I could also have put my compass on point B and drawn another line there.



# Key concept in Magnetism

But drawing in more lines does not make the field any stronger. However, it is true that because the same lines of force are denser at the poles than at the sides of the magnet, the field strength at the poles is greater than at the sides. Similarly, because the same lines of force spread out as they leave the poles; the further away from the poles, the weaker the field. The point is that the relative density of the lines of force in a particular field is an indication of whether the field is stronger or weaker at a particular point.

# Key concept in electromagnetism



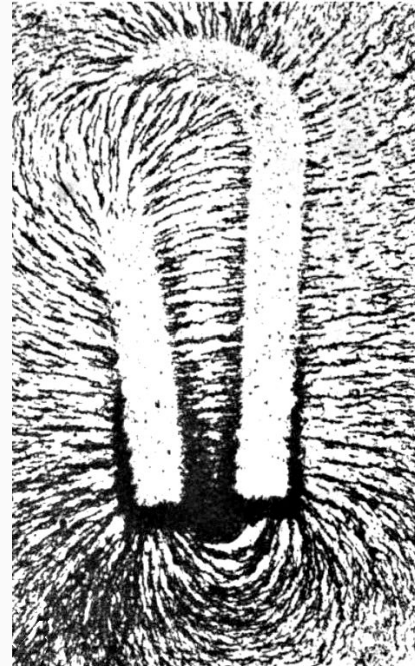
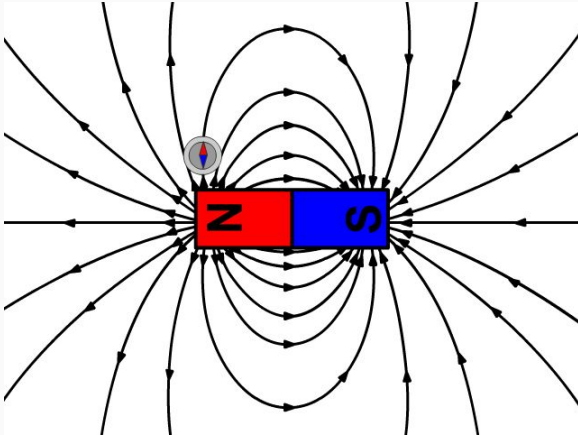
1. A current in a wire creates a magnetic field.
2. The field is in the plane at right angles to the wire, and consists of concentric circles with the wire as the centre.
3. The flux density is proportional to  $1/a$ , where “a” is the distance from the wire.
4. The direction on the field lines can be remembered by the diagram above.
5. The flux density is proportional to the size of the current.

Flux density  $\rightarrow$  B field strength



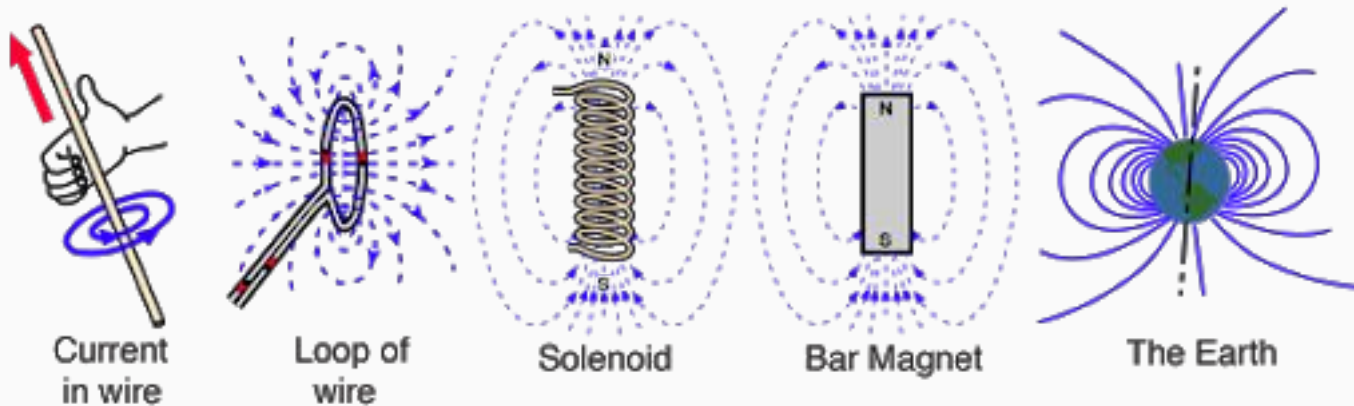
# Key concepts in Magnetism

- The magnetic field lines
- The difference with electric field
- Direction of field lines



# Key concepts in Magnetism

- Sources of magnetic field

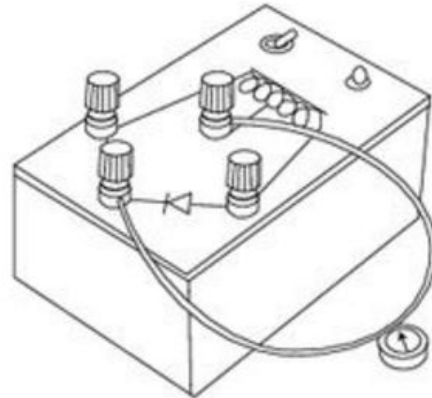
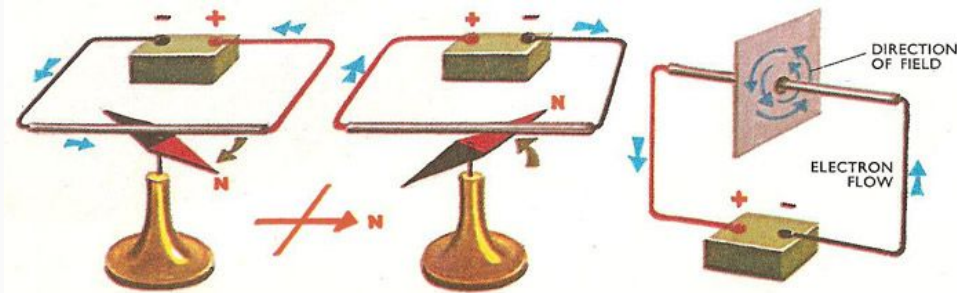


Magnetic Field Sources

# Key concepts in Electromagnetism

- Currents generating the B field

It was a Danish physicist, Oersted, in 1820, who first noticed that a compass needle placed near a wire carrying a current, moved; indicating that the current in the wire created a magnetic field.

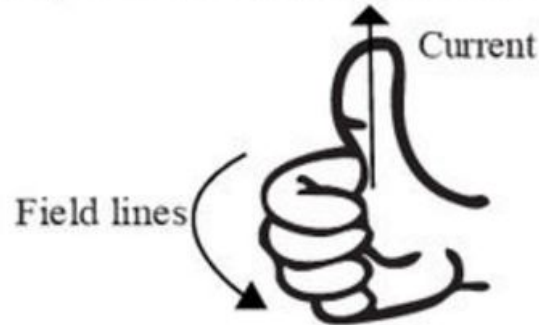


# Key concepts in Electromagnetism

- The “right-hand” rule

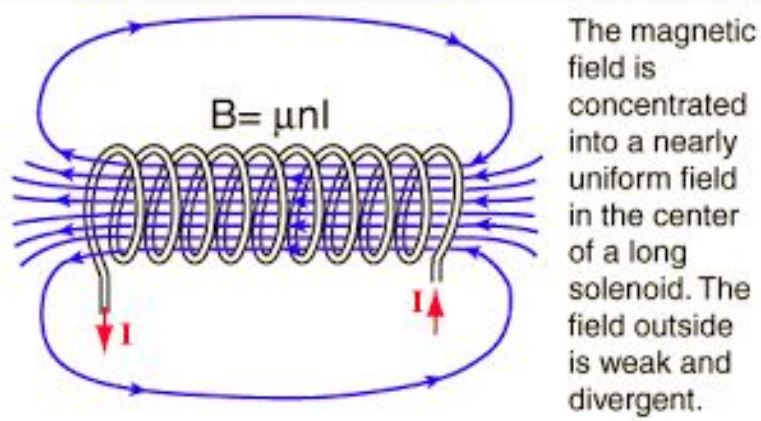
A convenient way to remember the direction of the field lines is to use the right hand as shown:

Help to remember direction of field lines

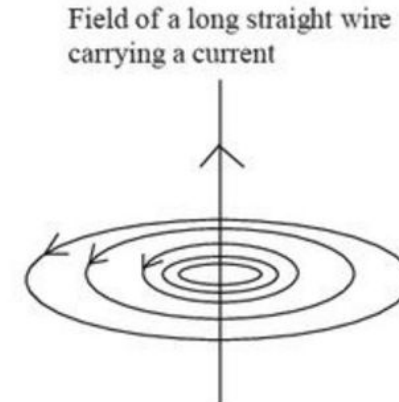


# Key concepts in Electromagnetism

- The Biot-Savart law
- The field in the solenoid



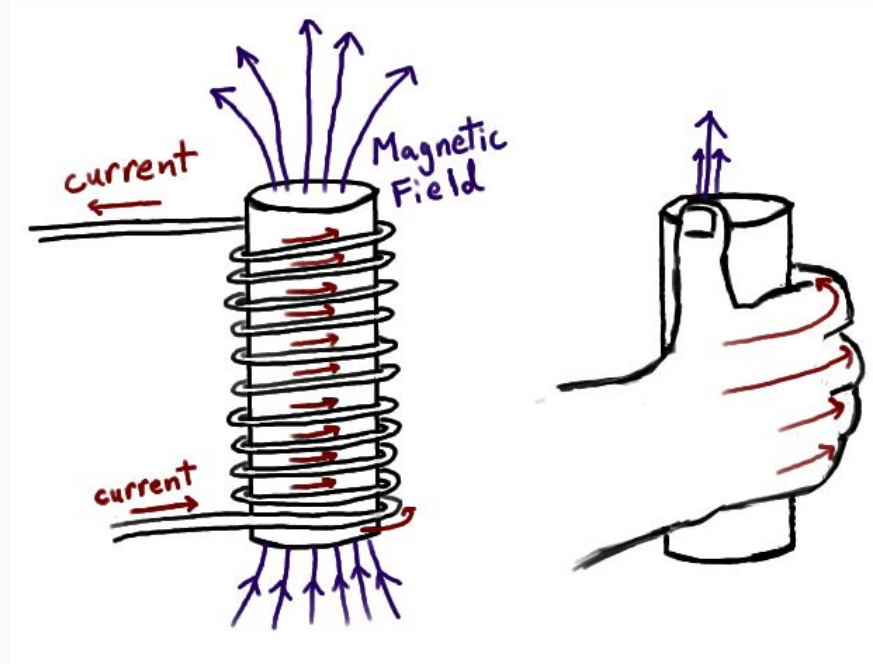
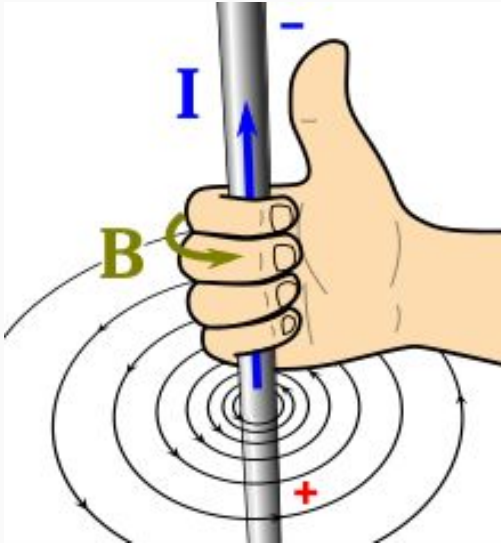
1. The field is in a plane at right angles to the wire.
2. The lines of force are concentric circles with the wire as the centre.



3. The Flux density (field strength) drops off in the ratio  $1/a$  where " $a$ " is the distance from the wire.
4. The field lines can be shown as anticlockwise if you are looking at the end of the wire with the conventional current coming towards you.

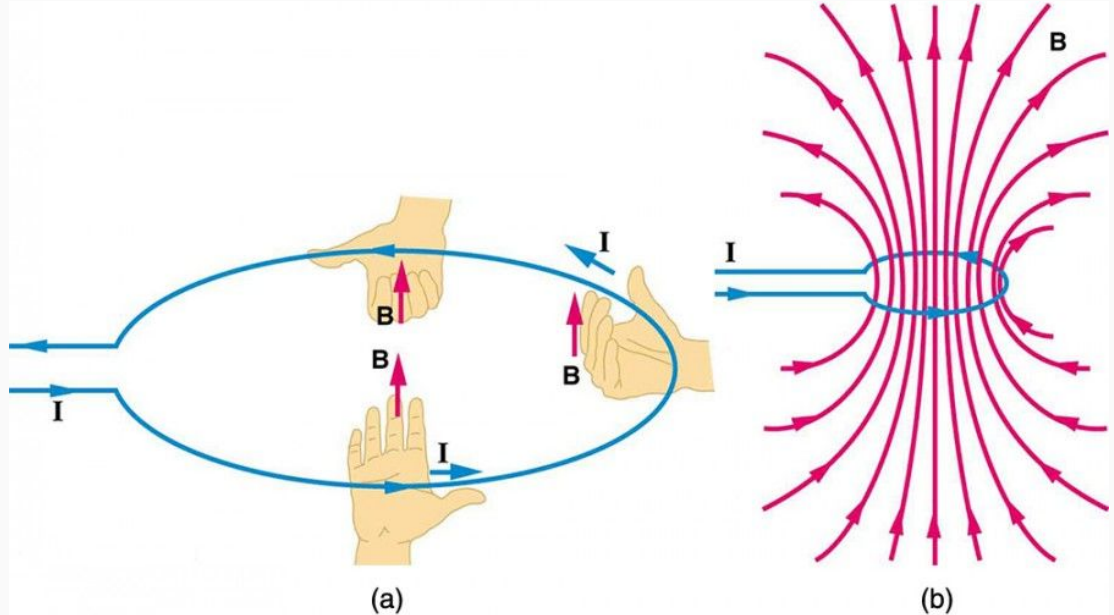
# Key concepts in Electromagnetism

- The “right hand” rule



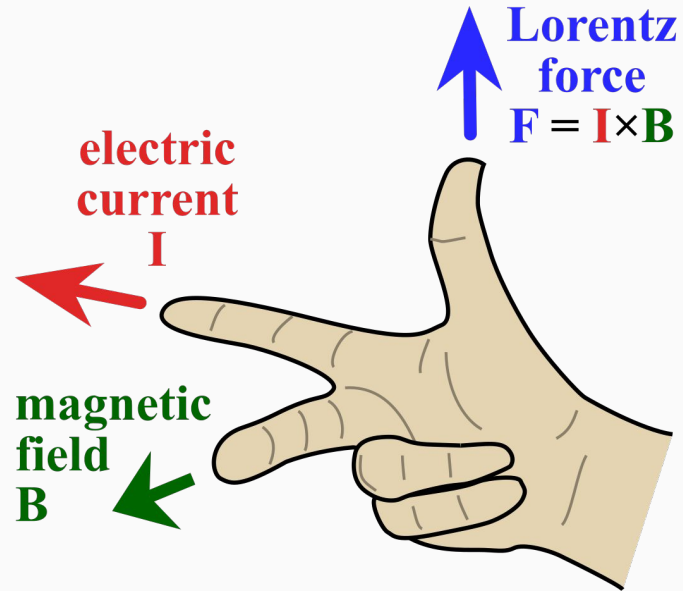
# Key concepts in Electromagnetism

- The “right hand” rule



# Key concepts in Electromagnetism

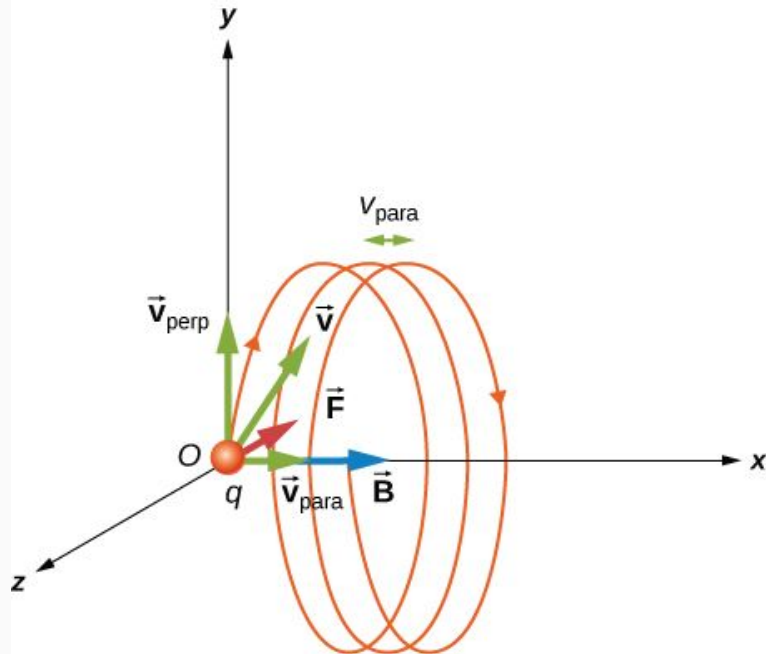
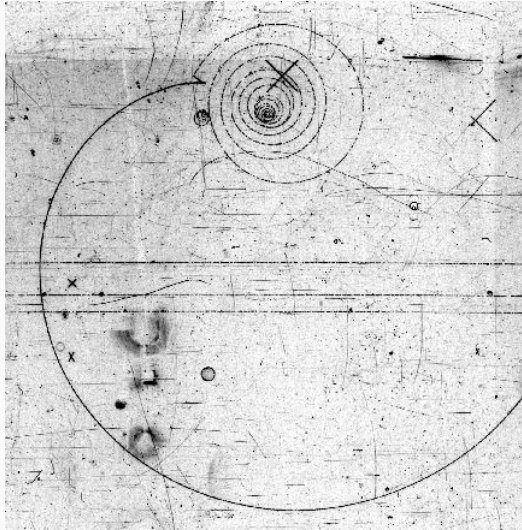
- The Lorentz Force





# Key concepts in Electromagnetism

- Motion in B fields



# Key concepts in Electromagnetism

- Forces on currents

$$\vec{F}_{\text{wire}} = I\vec{l} \times \vec{B}$$

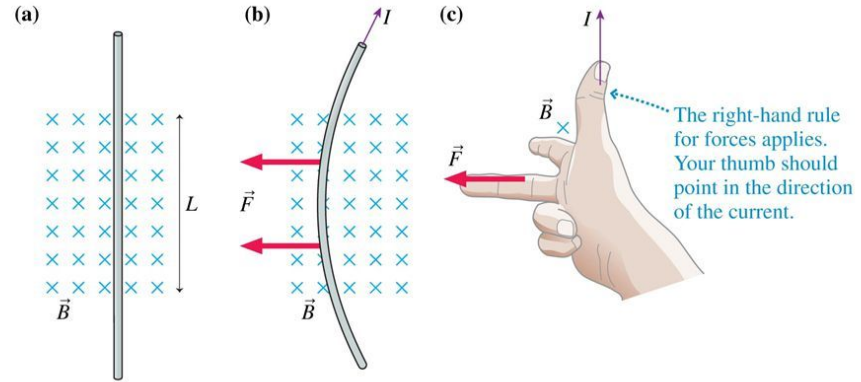
$I$  = current (in Amps)

$\vec{B}$  = magnetic field

$\vec{l}$  = length of wire

(direction is the direction of the current)

## Magnetic Fields Exert Forces on Currents



A wire is perpendicular to an externally created magnetic field.

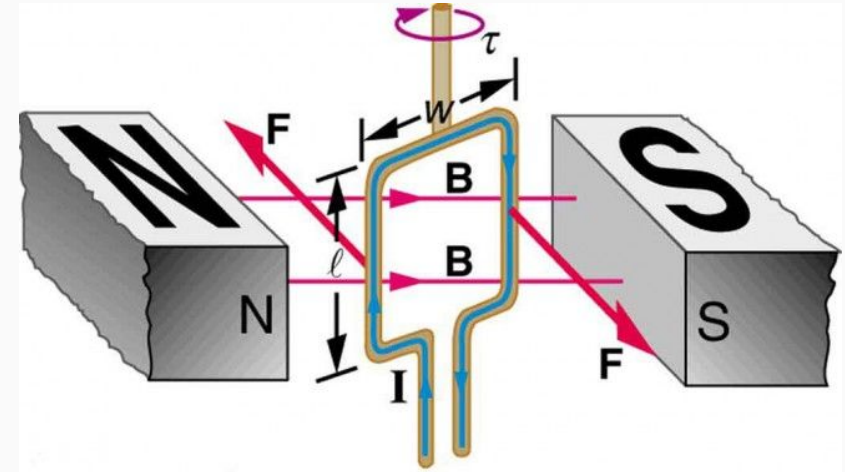
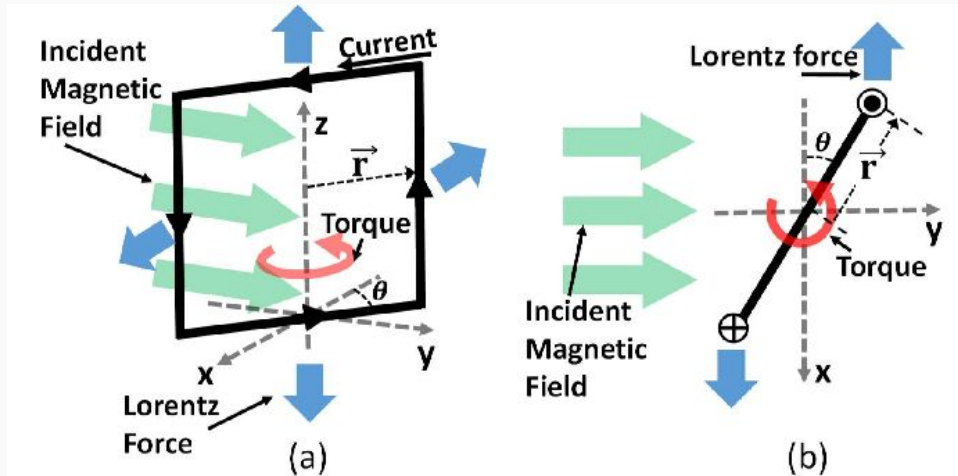
If the wire carries a current, the magnetic field will exert a force on the moving charges, causing a deflection of the wire.

$$F_{\text{wire}} = ILB$$

Magnitude of the force on a current segment of length  $L$  perpendicular to a magnetic field

# Key concepts in Electromagnetism

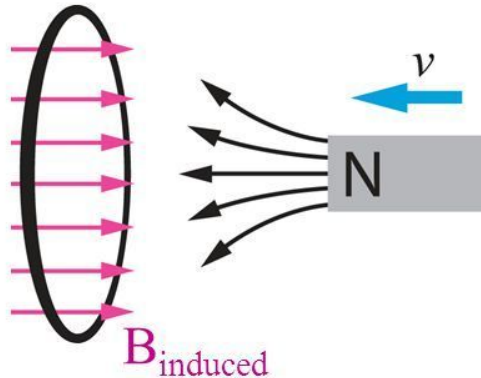
- Torques on loops



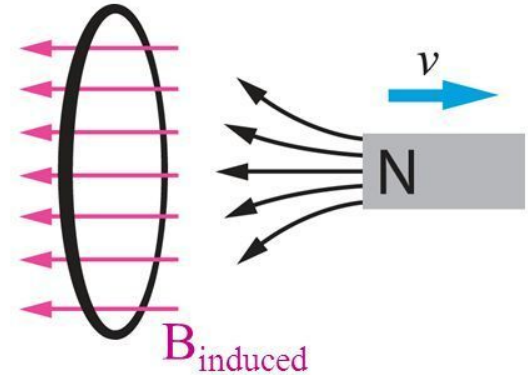
# Key concepts in Electromagnetism

- The Faraday - Lenz law

If you try to **increase** the flux through a loop, the induced field will oppose that increase!

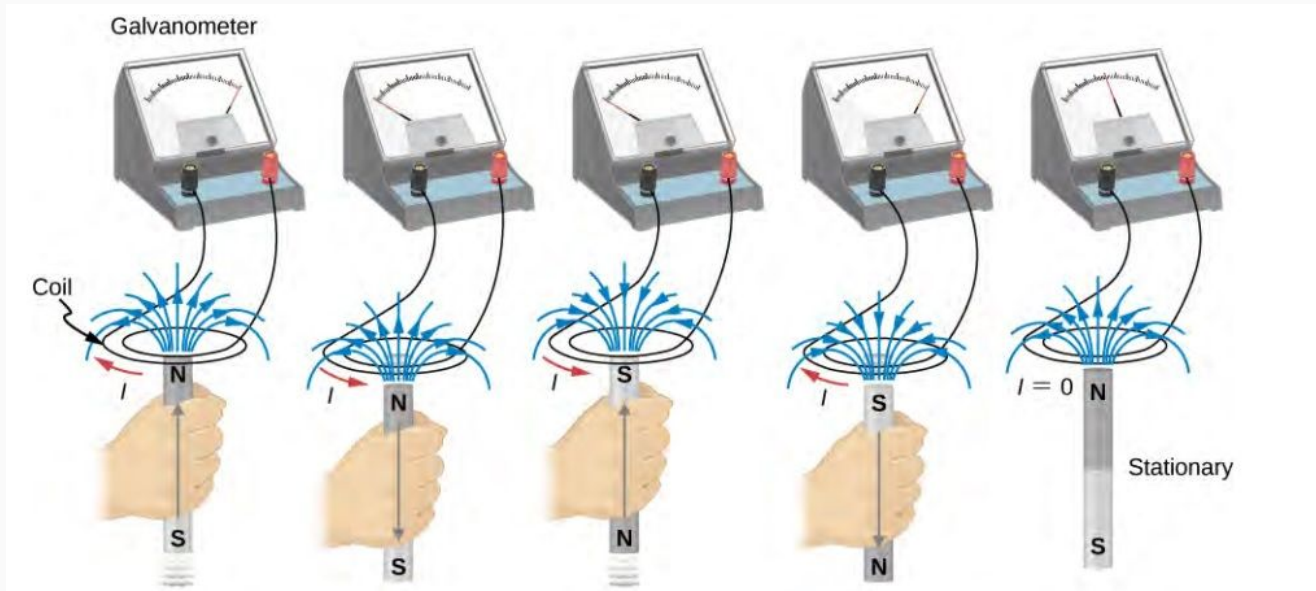


If you try to **decrease** the flux through a loop, the induced field will replace that decrease!



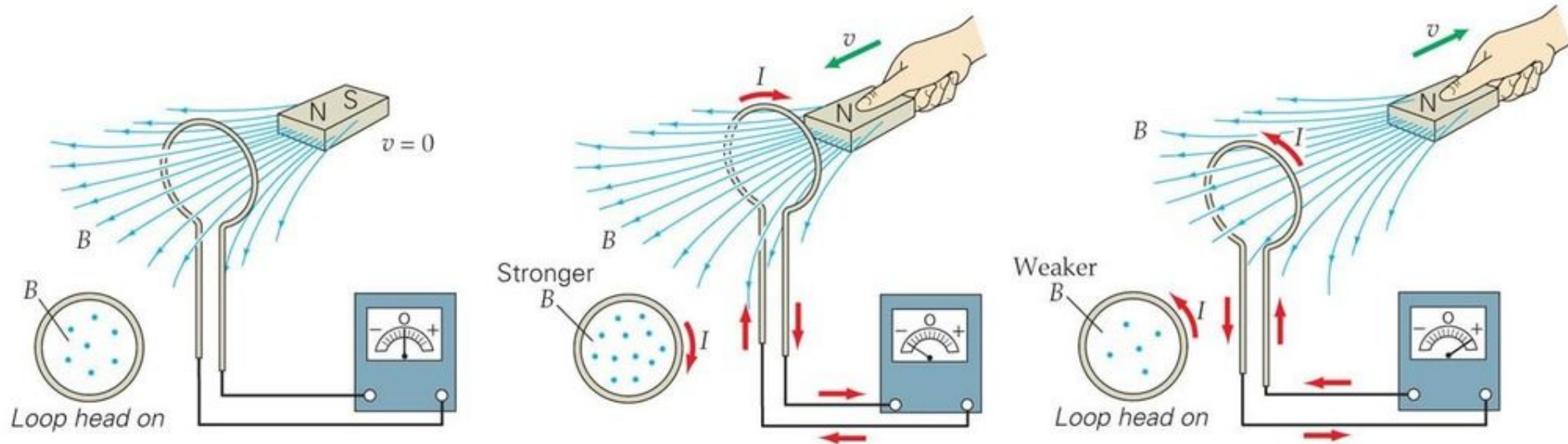
# Key concepts in Electromagnetism

- The Faraday - Lenz law



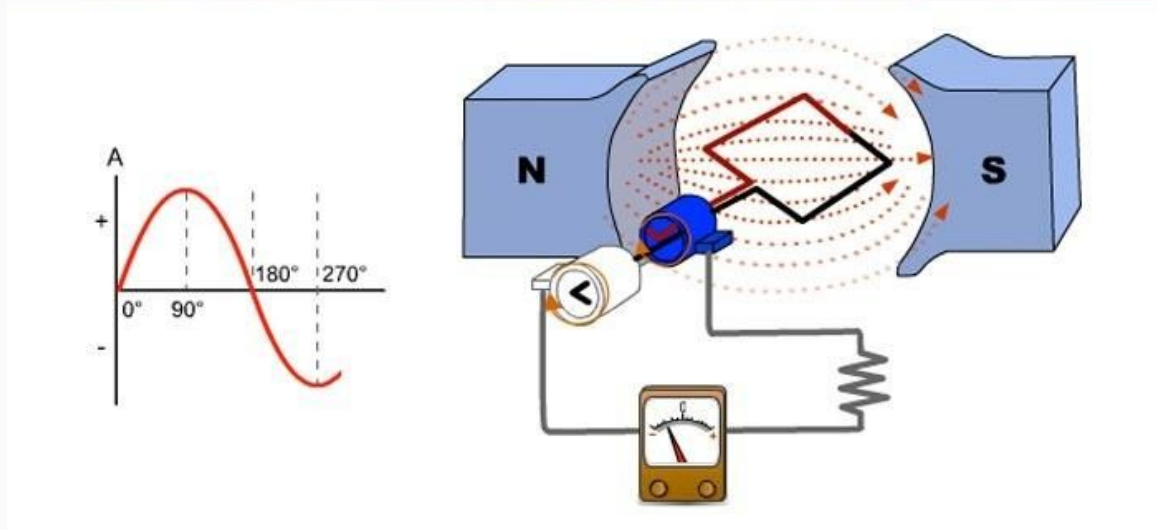
# Key concepts in Electromagnetism

- The Faraday - Lenz law



# Key concepts in Electromagnetism

- Generation of alternating currents



# Some learning objectives for (Electro)Magnetism

- To acquire familiarity with basic magnetic phenomena.
- To develop a dipole model of magnetism, analogous to the charge model of electricity, that allows students to understand and reason about basic magnetic phenomena.
- To learn the magnetic fields due to currents in wires, loops, and solenoids.
- To study the motion of charged particles in magnetic fields.
- To understand the magnetic forces and torques on current loops.
- To connect the theory of electromagnetism to the phenomena of permanent magnets.
- To connect the variation of magnetic flux with Electromotive force
- To understand the alternate currents





**Figure 1.** An example of the concept network of 55 nodes made by one pre-service student (redrawn and translated for clarity). The nodes with bolded borders are different facets (force, energy and source facets, I-III respectively) of field concept. Note that fourth facet (dynamic, IV) is also shown but not considered further here.

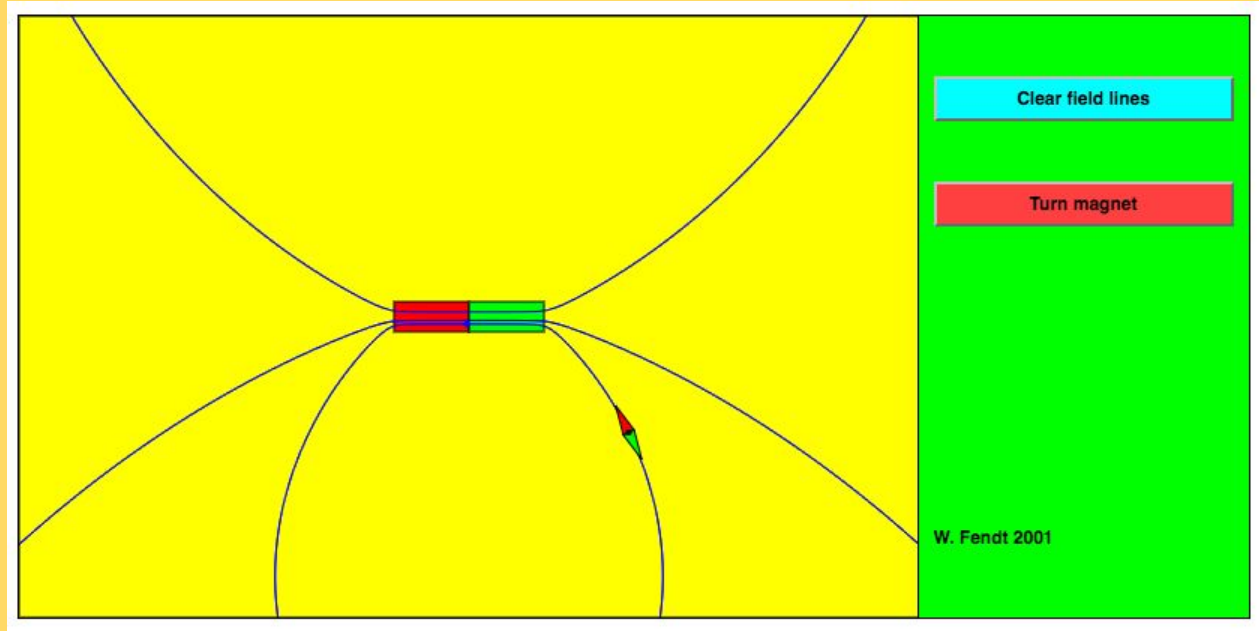
**Table 1.** Examples of concepts and other conceptual elements appearing in concept networks and as they are classified as force, energy and sourcebased classes. Only some most central concepts and conceptual elements out of all 121 ones found in the 12 networks are listed.

| Force facet                  | Energy facet                 | Source facet               |
|------------------------------|------------------------------|----------------------------|
| Force                        | Work                         | Electric charge $Q$        |
| Coulomb's law                | Work done to move a charge   | Millikan's experiment      |
| Coulomb's experiment         | Energy conservation          | Charge distribution        |
| Gravitation law (analogy)    | Potential energy $V$         | Gauss's law                |
| Field-line experiment        | Electric potential $U$       | Electric flux density $D$  |
| Electric dipole (force on)   | $E = -\text{grad } U$        | Electric flux              |
| Point charge (force on)      | Equipotential surface (exp.) | Electric current $I$       |
| Homogeneous field            | Voltage                      | Electric current density   |
| Electric force $F=qE$        | Work done to rotate a coil   | Magnetic dipole moment     |
| Electrostatic equilibrium    | Magnetic potential energy    | Ampere and Laplace law     |
| Torque                       | electromotive force (e.m.f.) | Biot-Savart law            |
| Force/torque between magnets | Power related to induction   | Biot-Savart experiment     |
| Ampere's law                 | B as non-conservative field  | Ampere's circuital law     |
| Ampere's experiment          | Resonance circuit (exp)      | Ampere's circ. law (model) |
| Lorentz's force              | Energy in resonance circuit  | Current element            |
|                              |                              | M. Nousiainen, 2017        |

# Misconceptions in Magnetism

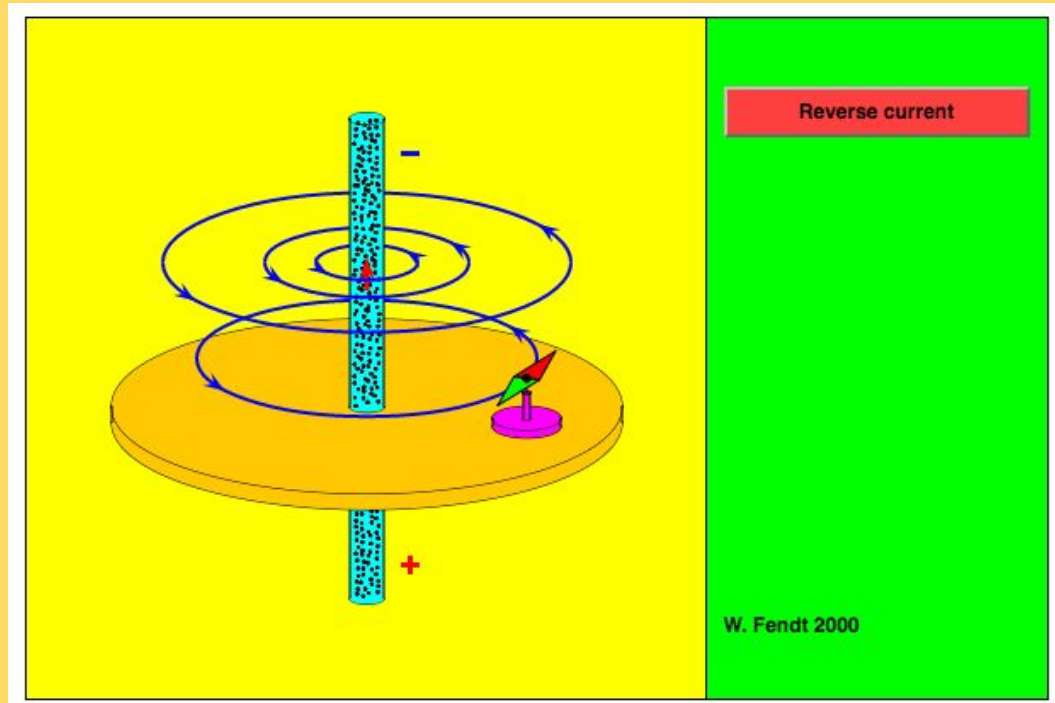
- Field lines and magnetic forces
- How to generate a magnetic field in a permanent magnet?
- The right hand rule - it is just a convention ... for the field or for the current?
- The field could be generated by solenoids or magnets only ..
- $I$  is a vector?
- The motions of particles in  $B$  field are always/only circular?
- Misconceptions on torques as vectors
- Magnetic flux and variation of magnetic flux in time
- Electromotive force and currents

# Magnetic Field of a Bar Magnet



[https://www.walter-fendt.de/html5/phen/magneticfieldbar\\_en.htm](https://www.walter-fendt.de/html5/phen/magneticfieldbar_en.htm)

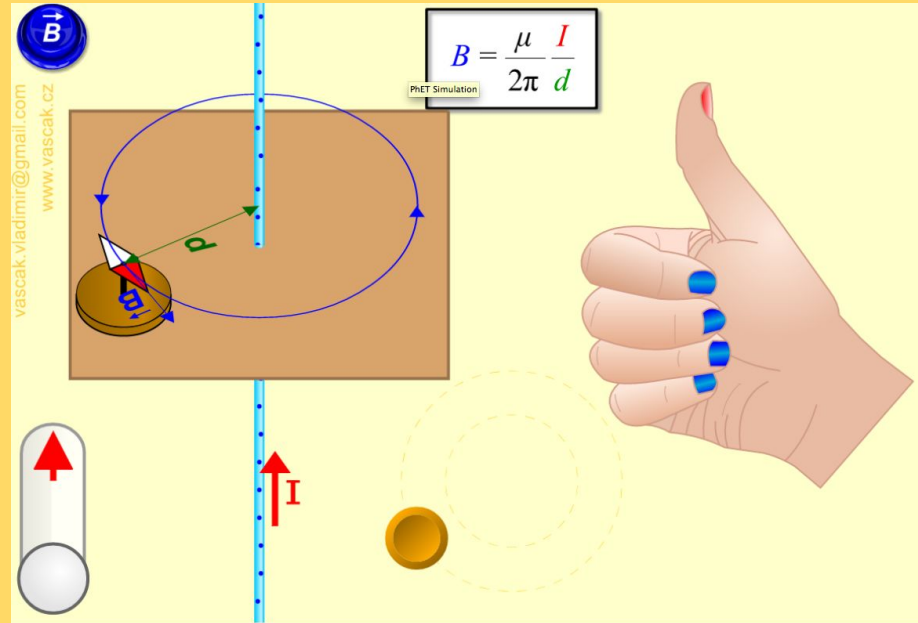
# Magnetic Field of a Straight Current-Carrying Wire



[https://www.walter-fendt.de/html5/phen/magneticfieldwire\\_en.htm](https://www.walter-fendt.de/html5/phen/magneticfieldwire_en.htm)



# Magnetic Field of a Straight Current-Carrying Wire



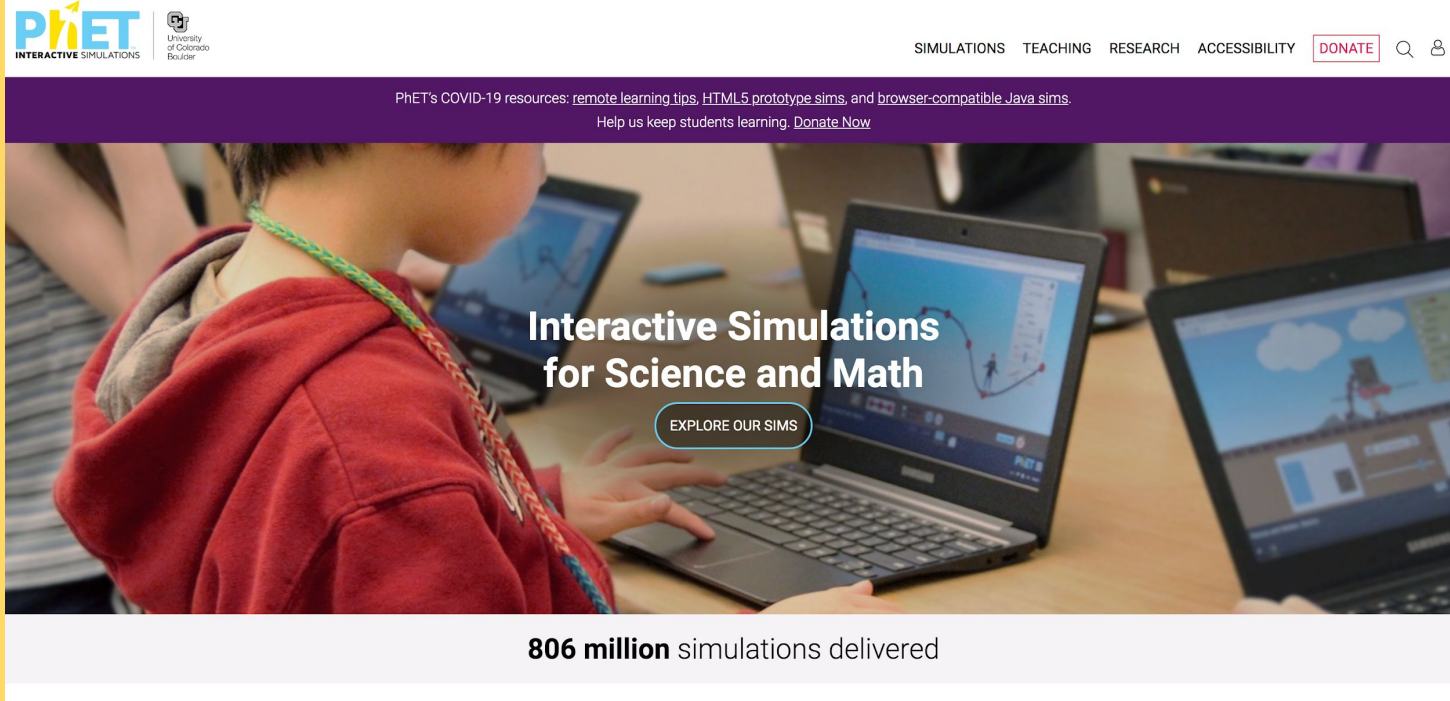
[https://www.vascak.cz/data/android/physicsatschool/template.php?s=mag\\_vodic&l=en](https://www.vascak.cz/data/android/physicsatschool/template.php?s=mag_vodic&l=en)

**FISICA A SCUOLA:**

**<https://www.vascak.cz/?id=22&language=it>**



# Materials for Physics education



The image shows the top portion of the PhET Interactive Simulations website. At the top left is the PhET logo with the text 'INTERACTIVE SIMULATIONS' and the University of Colorado Boulder logo. To the right are navigation links: SIMULATIONS, TEACHING, RESEARCH, ACCESSIBILITY, and a pink DONATE button. Further right are search and user icons. Below the navigation is a purple banner with white text providing COVID-19 resources and a link to donate. The main hero section features a background image of a student in a red hoodie using a laptop. Overlaid on this image is the text 'Interactive Simulations for Science and Math' and a button that says 'EXPLORE OUR SIMS'. At the bottom of the hero section, a white bar contains the text '806 million simulations delivered'.

PhET  
INTERACTIVE SIMULATIONS

University of Colorado Boulder

SIMULATIONS TEACHING RESEARCH ACCESSIBILITY [DONATE](#) 🔍 👤

PhET's COVID-19 resources: [remote learning tips](#), [HTML5 prototype sims](#), and [browser-compatible Java sims](#).  
Help us keep students learning. [Donate Now](#)

## Interactive Simulations for Science and Math

[EXPLORE OUR SIMS](#)

**806 million** simulations delivered

<https://phet.colorado.edu/>

# Materials for Physics education

**PHET** | SUBJECT × 106 Results SIMULATIONS TEACHING RESEARCH ACCESSIBILITY

☒ Physics

- ☒ Motion
- ☒ Sound & Waves
- ☒ Work, Energy & Power
- ☒ Heat & Thermo
- ☒ Quantum Phenomena
- ☒ Light & Radiation
- ☒ Electricity, Magnets & Circuits

☐ Chemistry

- ☐ General Chemistry
- ☐ Quantum Chemistry

☐ Math

- ☐ Math Concepts
- ☐ Math Applications

☐ Earth Science

☐ Biology

GRADE LEVEL +

COMPATIBILITY +


ACCESSIBILITY +

LOCALE +

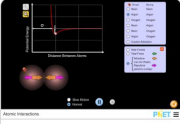
[Clear Filters](#)

**Physics** ×


**Alpha Decay**




**Atomic Interactions**



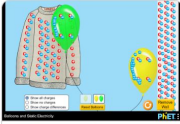
**Balancing Act**



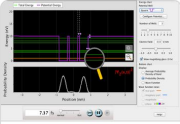
**Balloons & Buoyancy**



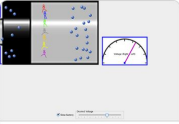
**Balloons and Static Electricity**




**Band Structure**



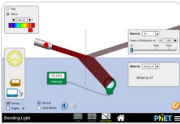
**Battery Voltage**



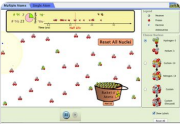
**Battery-Resistor Circuit**



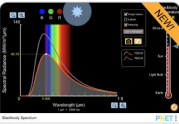
**Bending Light**




**Beta Decay**



**Blackbody Spectrum**



**Build an Atom**



<https://phet.colorado.edu/>

# Materials for Physics education



<https://phet.colorado.edu/en/teaching-resources/tipsForUsingPhet>

The conceptual representation  
using computer based simulations  
**- inquiry based approach**  
**(Inquiry-based learning with**  
**Interactive Simulation)**

# What Levels of Guidance Promote Engaged Exploration with Interactive Simulations?

[https://phet.colorado.edu/publications/PERC\\_Interview\\_Guidance.pdf](https://phet.colorado.edu/publications/PERC_Interview_Guidance.pdf)

(Adams et al. 2008)

# Materials for Physics education



## Using [PhET Interactive Simulations](https://phet.colorado.edu/) in College Lecture

Ideas for engaging students through inquiry in lecture settings

**University of Colorado's PhET Project** has developed over 100 interactive simulations for teaching and learning science. These simulations provide animated, interactive, and game-like environments which enable scientist-like exploration. They emphasize the connections between real life phenomena and the underlying science, make the invisible visible (e.g. atoms, molecules, electrons, photons), and include the visual models that experts use to aid their thinking. **More, including examples, at [phet.colorado.edu](https://phet.colorado.edu/)**

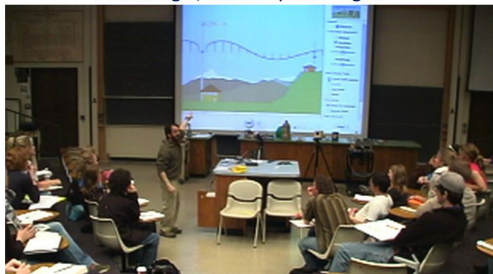
### Visual Aids and Demos

By using sims as an animated illustration, instructors find that it is easier to communicate effectively with their students. The sims **show dynamic processes** and these **can be slowed down, sped up, or paused**, depending on the concept being shown; the **invisible is made visible**; and **multiple representations are linked**. Finally, the sims are **easily adjusted** by the instructor during the discussion. These features often make sims more effective for learning and more practical to use than static drawings or live demos.

### Student-driven Discussions

PhET is designed to help students develop science inquiry skills by exploring cause-and-effect relationships. Instructors can facilitate **whole-class inquiry** by creating a scenario in the simulation, and asking students to predict the effect of manipulating variables. In such classrooms, students often spontaneously ask **many more, and deeper questions**. It is common for students to ask a series of **"what-if" questions** and direct the teachers' use of the sim.

The [Radio Waves](https://phet.colorado.edu/simulations/sim.php?id=300) sim helps faculty **communicate ideas** about: creating electromagnetic waves, oscillating electric field strength, and the speed of light.



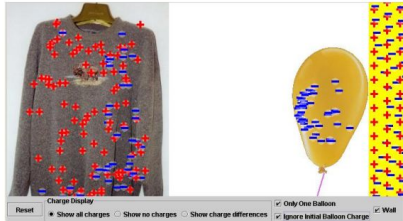
# Materials for Physics education

## Student-driven Discussions



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A short demo of charge transfer and polarization with [Balloons and Buoyancy](#) generates a series of student questions:

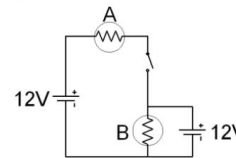


Students say:

*If you rub the sweater on the balloon (rather than balloon on sweater) will electrons transfer the other way?  
Can you polarize something where the protons move?  
Are there any situations in which the +’s move?*

An in-class question at right resulted in a class-led “what if” exploration with the [Circuit Construction Kit](#). (Only 25% correctly answer D)

The light bulbs in the circuit are identical. When the switch is closed,



- A: bulb A glows, and bulb B changes brightness
- B: bulb A glows, and bulb B stays the same
- C: bulb A does not glow, and bulb B changes brightness
- D: bulb A does not glow, and bulb B stays the same

Students say:

*I don't get it. It's a closed circuit.*

*Can you explain one more time why Bulb A doesn't light ?*

*What if that battery is increased in voltage?*

(Instructors says “let’s try it. Which way will current flow?”)

*What happens to Bulb B current? Does it get brighter?*

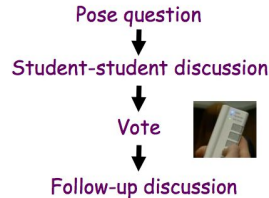
*What happens if you flip one (of the batteries) over?*



# Materials for Physics education

## Concept or “Clicker” Questions

Concept tests give students an opportunity to discuss and make sense of concepts related to the simulation.



## Strategies for Writing Questions\*

1. Predict an outcome of an “experiment” with the simulation (e.g., what will happen if? Which change in the sim setup would result in the desired behavior?)
2. Rank cases (e.g. which bulb will be brightest).
3. Compare contrasting cases (e.g., two different waves)
4. Interpret different representations (e.g. graphs, pictures, vectors).
5. Connect to real-world applications

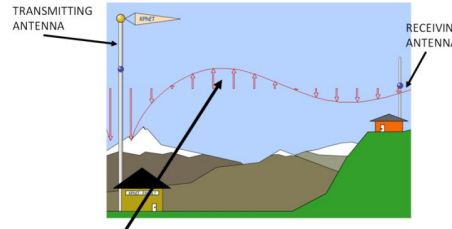
\*adapted from Beatty et al., AJP, 2006

## Interactive Lecture Demos (ILDs)\*

ILD's increase student learning from demos by having students actively identify expectations, and resolve

Instructor **probes common student difficulty** and then helps students' visualize speed of light with the [Radio Waves](#) sim.

How do you measure the propagation speed of the wave (signal)?



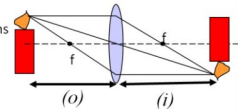
The speed of the wave (signal) is measured as...

- a. how fast this peak moves towards antenna.
- b. how fast this peak moves up and down.
- c. both a or b

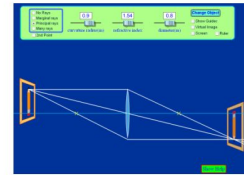
What will happen to image if we **increase** focal length of lens?

(Keeping the object distance fixed)

- a. Image is same size, same place
- b. Image is same size and further from lens
- c. Image is bigger and further from lens
- d. Image is smaller and closer to lens



After peer discussion and voting, instructor **elicits student reasoning** and then settles debate by “doing the experiment” with PhET's [Geometric Optics](#) simulation.





# Materials for Physics education

## Interactive Lecture Demos (ILDs)\*

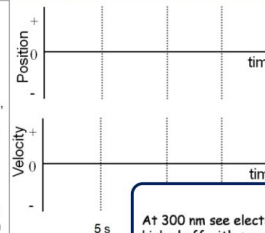
ILD's increase student learning from demos by having students actively identify expectations, and resolve any inconsistencies.

Pose scenario  
↓  
Students make individual predictions  
↓  
Student-student discussions.  
Revise predictions.  
↓  
Instructor elicits predictions and reasoning  
↓  
Instructor conducts "experiment" with simulation  
↓  
Students record result and how different from prediction.  
↓  
Whole class discussion with student participation. Focus on reasoning.

settles debate by "doing the experiment" with PhET's *Geometric Optics* simulation.



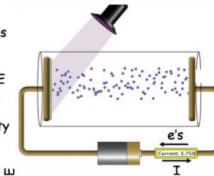
**Demo 4:**  
Sketch **position vs time** and **velocity vs time** graphs for when Moving Man:  
walks steadily towards the tree for 6 seconds,  
then stands still for 6 seconds,  
and then towards the house twice as fast as before for 6 seconds.



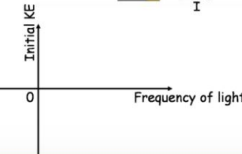
Do yours as a dashed line. Compare with team members then make solid line based on group.

Question elicits students ideas about graphs. Sim then allows instructor to **dynamically generate** graph, and **play back** motion during further discussions

At 300 nm see electrons kicked off with some initial KE. Predict what happens to the initial KE of the electrons as the frequency of light changes? (Light intensity is constant)



Predict shape of the graph



Many students will predict a linear graph starting at origin. The sim "experiment" dramatically shows that below a certain frequency, no electrons are kicked off even at high intensities.

\*see Sokoloff and Thornton, *Physics Teacher*, 35, 340–346 (1997)

## Magnets-Introduction (Inquiry Based) ★



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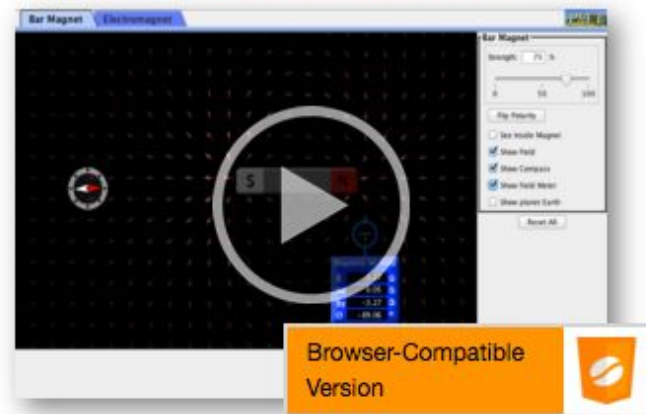
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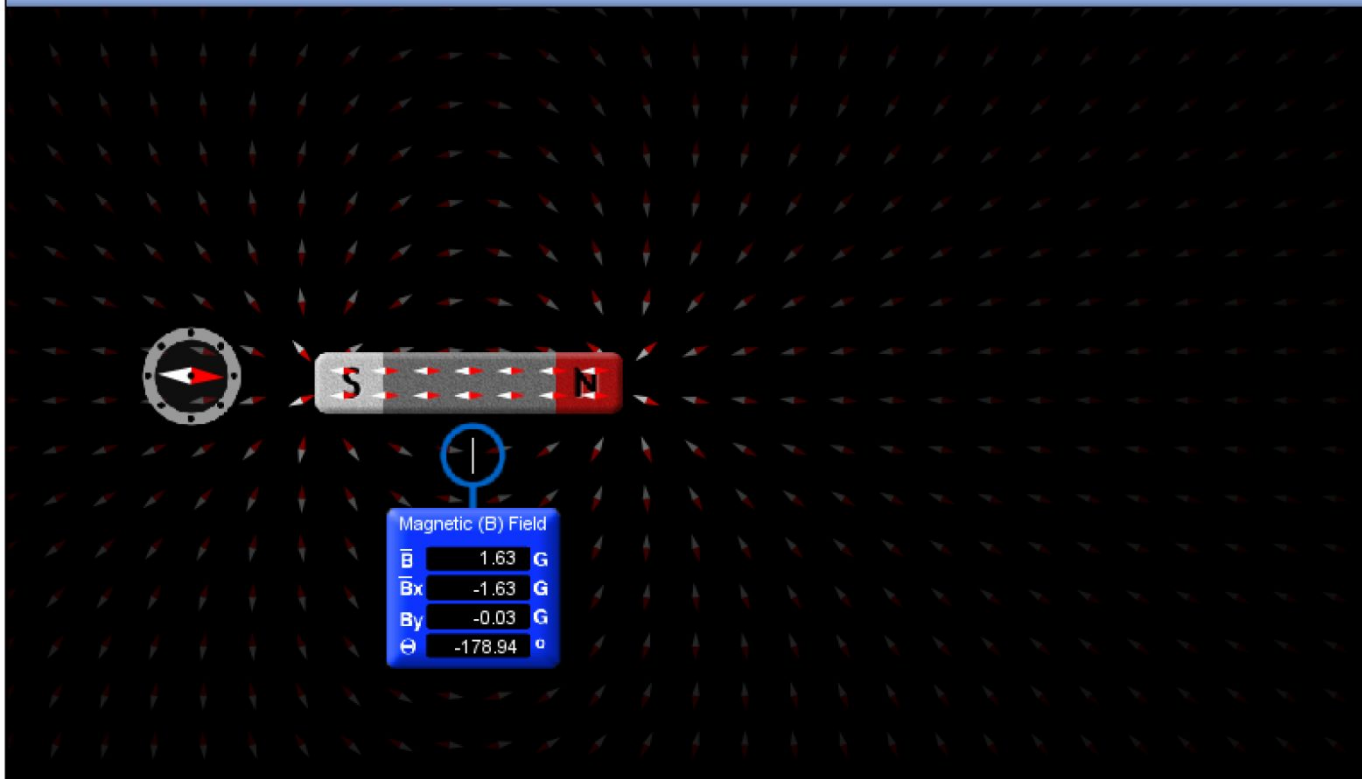
## Magnets and Electromagnets



<https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets>

Bar Magnet

Electromagnet



Bar Magnet

Strength: 37 %



Flip Polarity

☒ See Inside Magnet☒ Show Field☒ Show Compass☒ Show Field Meter☐ Show planet Earth

Reset All

LET'S TRY NOW ...