Physics Education Laboratory
Lecture 15

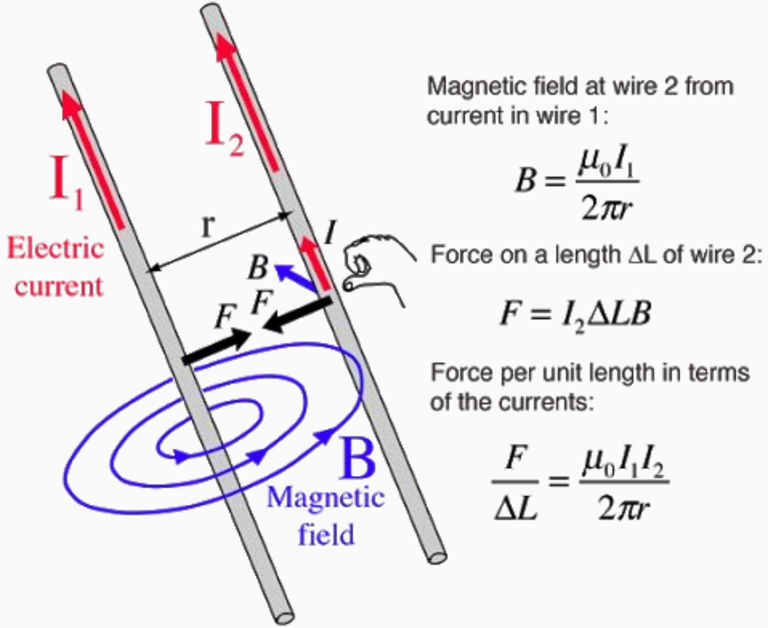
Content Knowledge for Electromagnetism

Francesco Longo - 29/11/21

MAGNETIC DISCUSSION

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

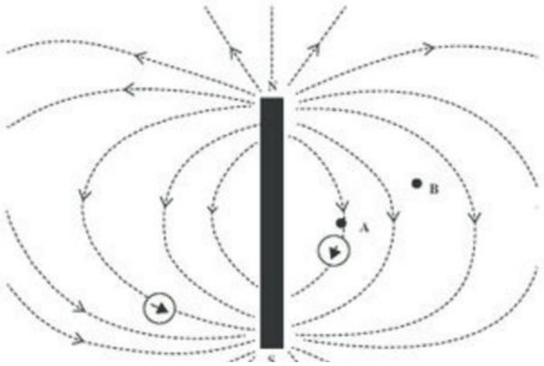
1. The idea of field lines to describe a magnetic field.
2. The idea that relative density of the field lines gives an indication of the strength of the field at various points in the field.
3. The shape of the magnetic field around a bar magnetic.

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.

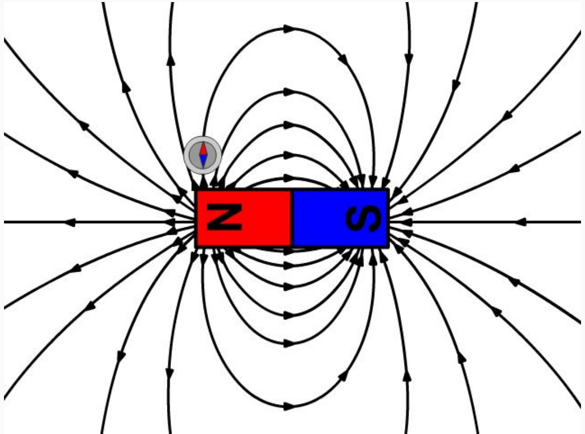
Key concept in electromagnetism

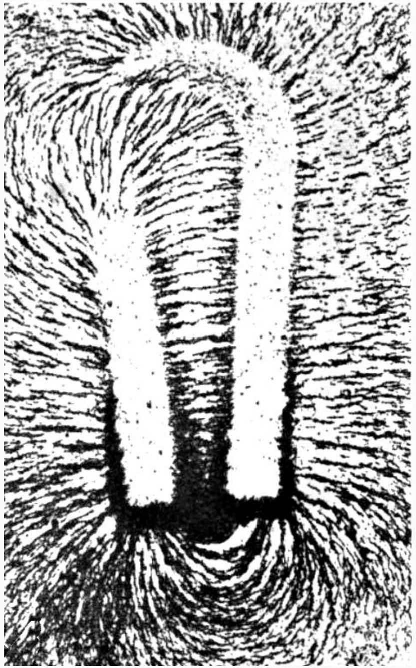
1. A current in a wire creates a magnetic field.
2. The field is in the plane at right angles to the wire, and consists of concentric circles with the wire as the centre.
3. The flux density is proportional to 1/a, where "a" is the distance from the wire.
4. The direction on the field lines can be remembered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

Flux density → B field strength

Key concepts in Magnetism

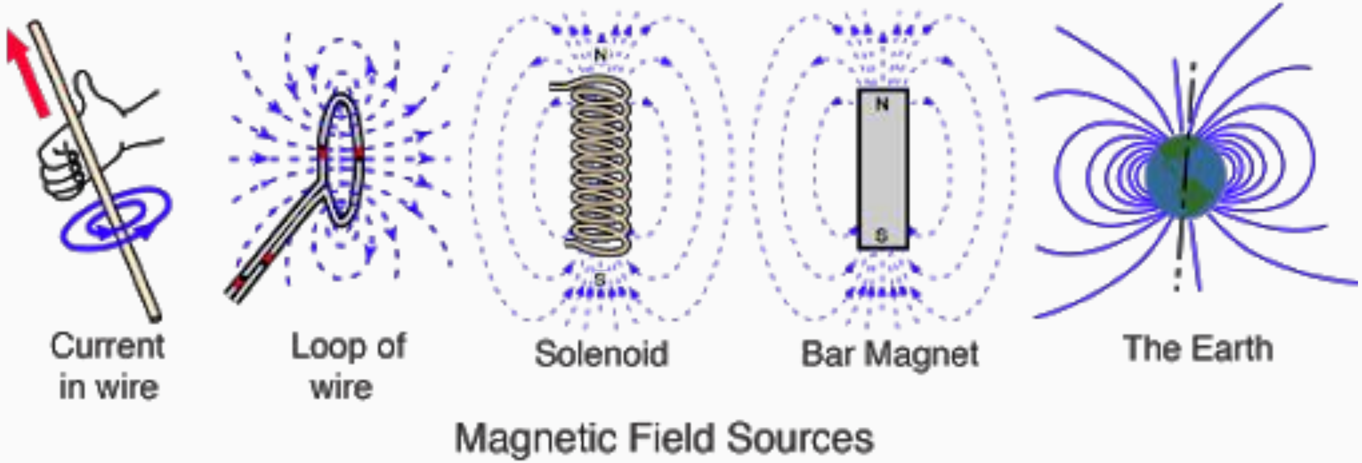
- The magnetic field lines
- The difference with electric field
- Direction of field lines





Key concepts in Magnetism

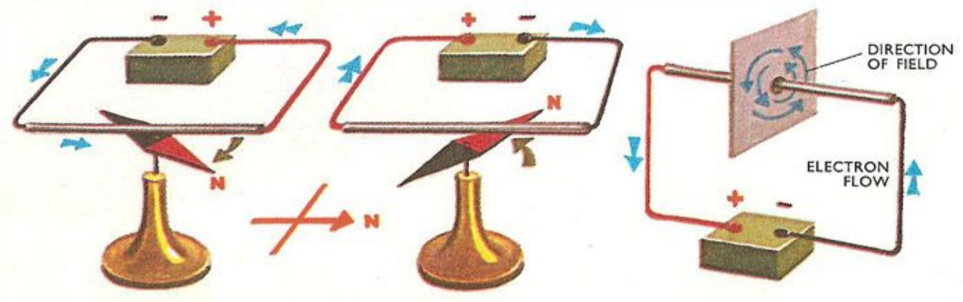
- Sources of magnetic field

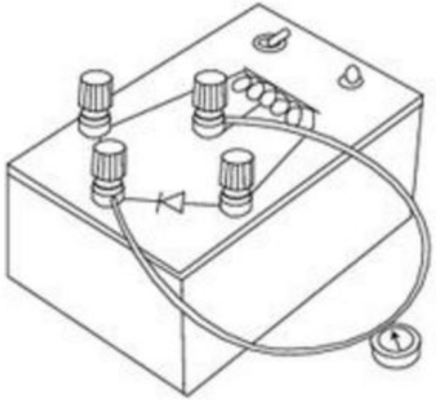


Key concepts in Electromagnetism

- 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.



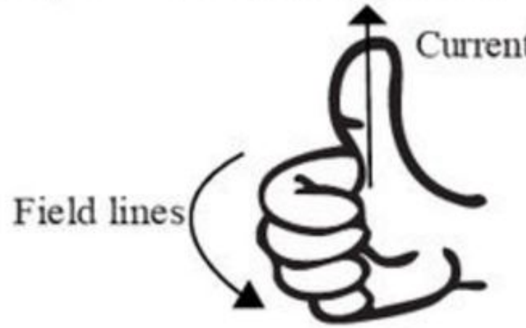


Key concepts in Electromagnetism

- The “right-hand” rule

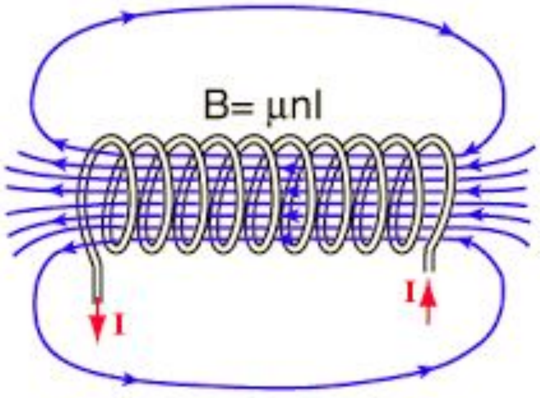
A convenient way to remember the direction of the field lines is to use the right hand as shown:

Help to remember direction of field lines



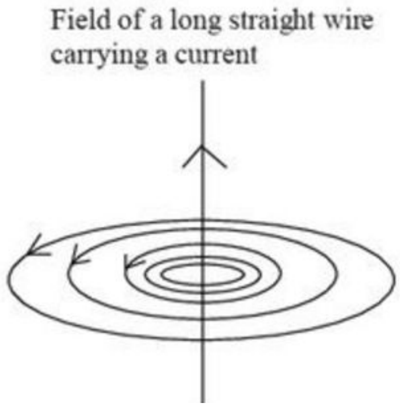
Key concepts in Electromagnetism

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



The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weak and divergent.

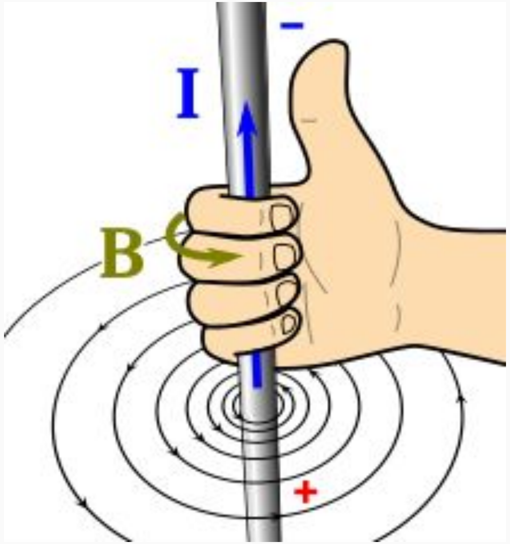
1. The field is in a plane at right angles to the wire.
2. The lines of force are concentric circles with the wire as the centre.

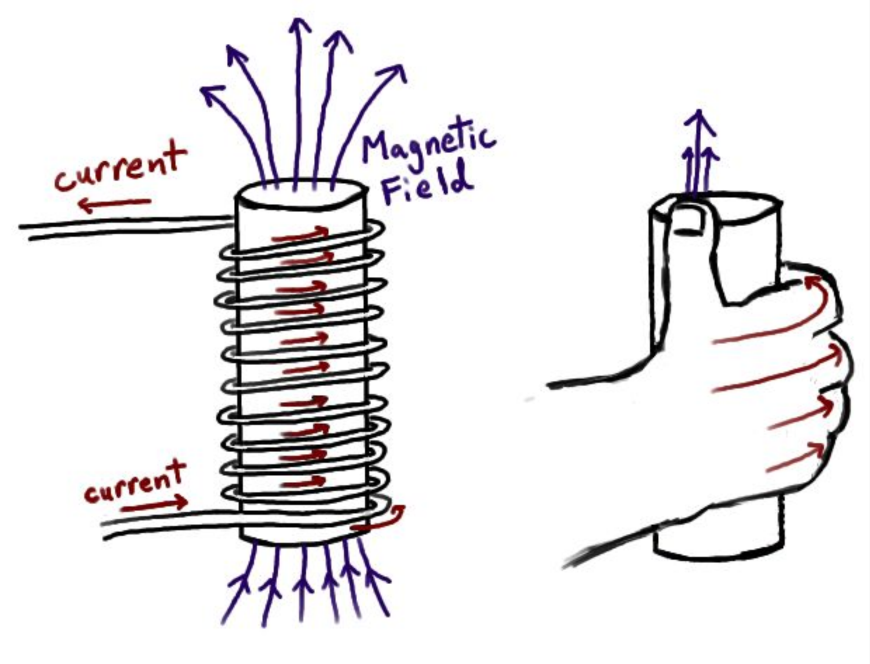


3. The Flux density (field strength) drops off in the ratio *1/a* where *"a"* is the distance from the wire.
4. The field lines can be shown as anticlockwise if you are looking at the end of the wire with the conventional current coming towards you.

Key concepts in Electromagnetism

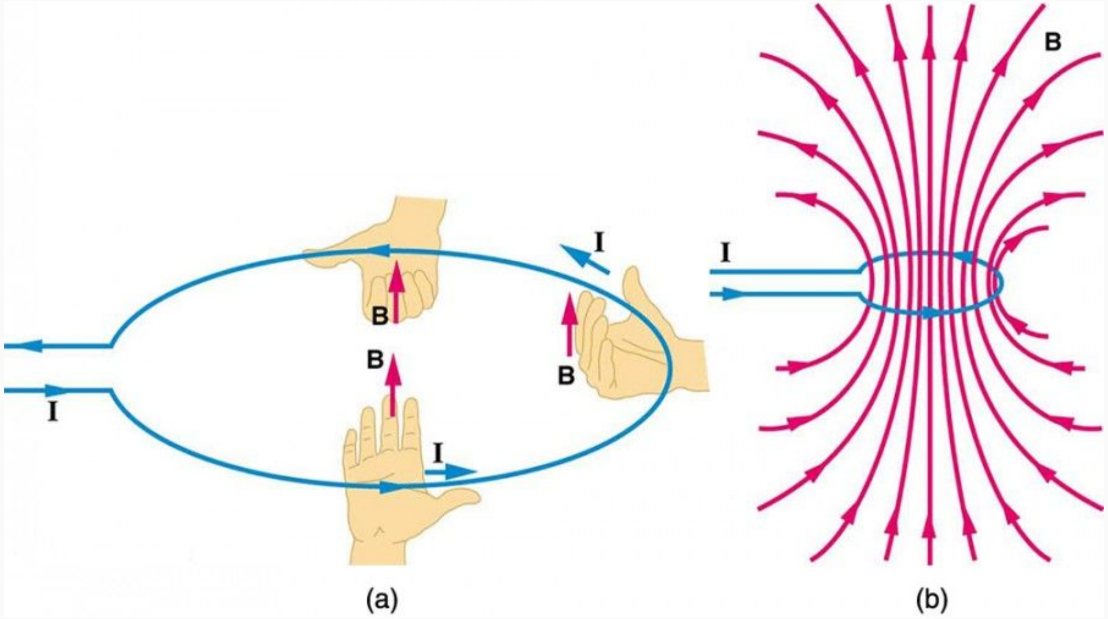
- The "right hand" rule





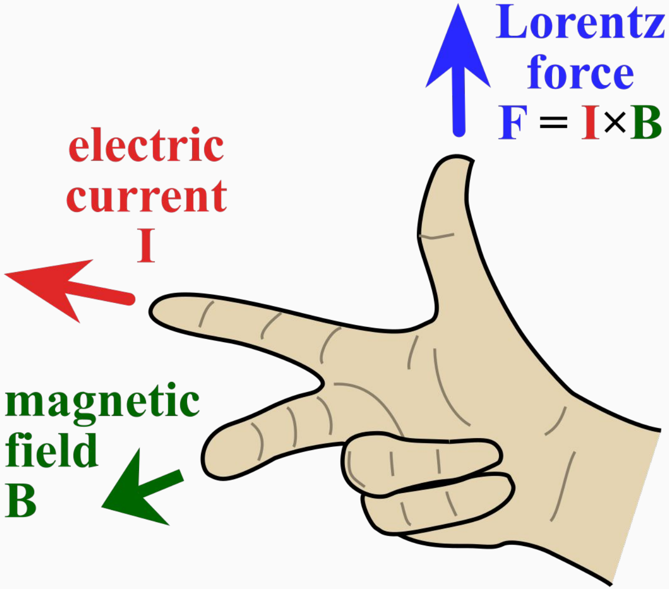
Key concepts in Electromagnetism

- The “right hand” rule



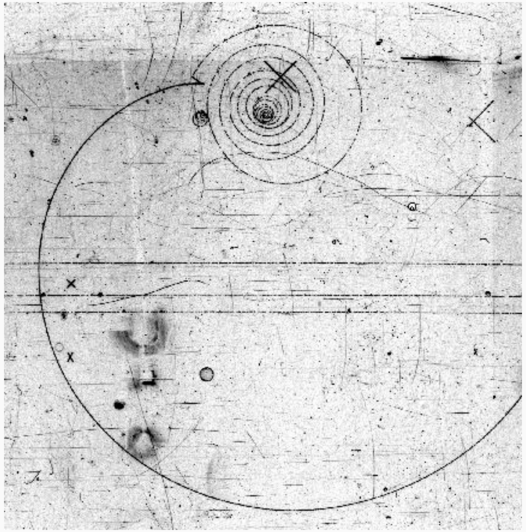
Key concepts in Electromagnetism

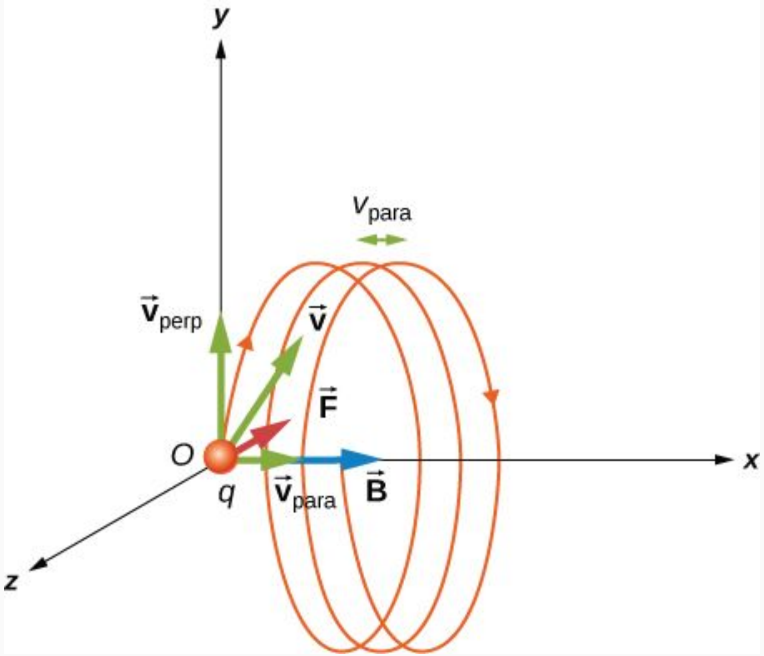
- The Lorentz Force



Key concepts in Electromagnetism

- Motion in B fields





Key concepts in Electromagnetism

- Forces on currents

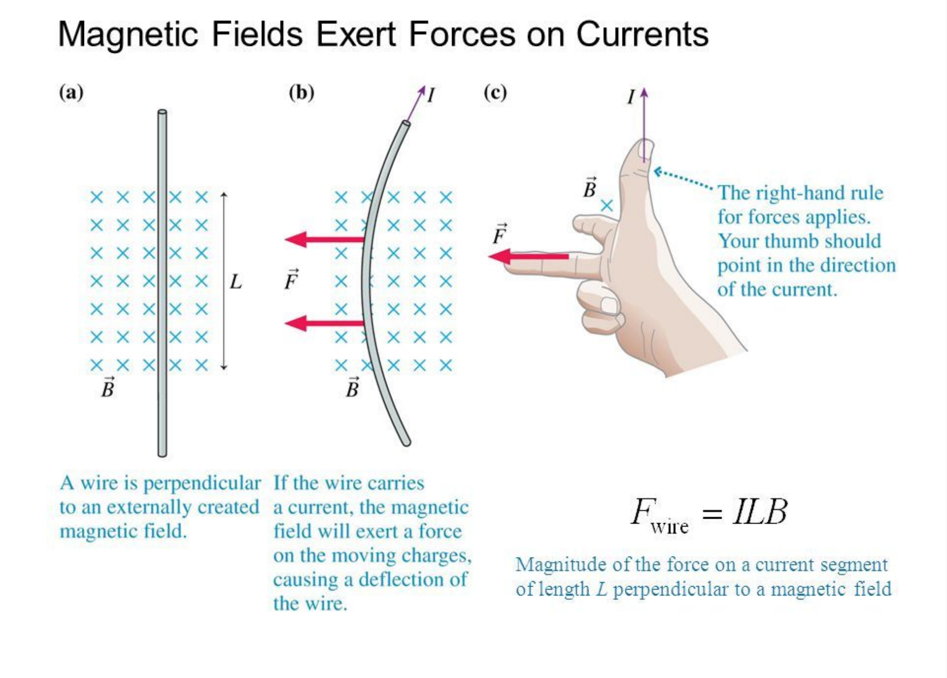
$$\boxed{\vec{F}_{wire} = I\vec{l} \times \vec{B}}$$

I = current (in Amps)

$\vec{B}$ = magnetic field

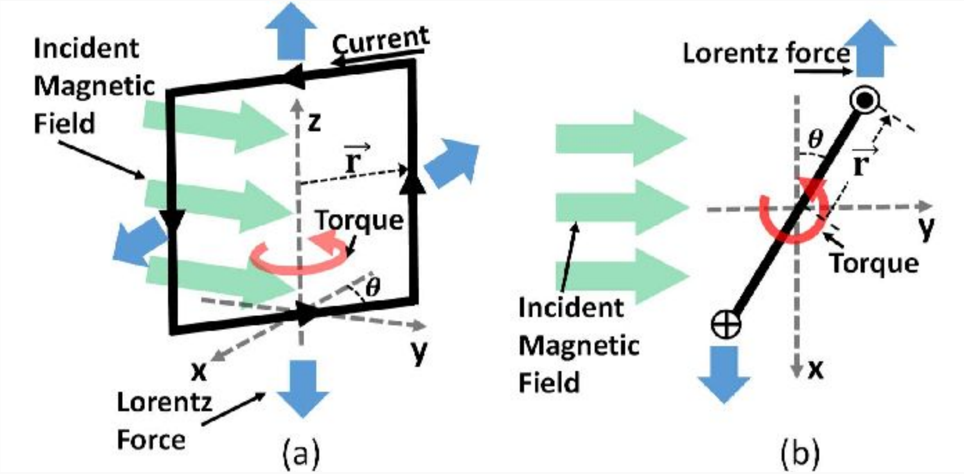
$\vec{l}$ = length of wire

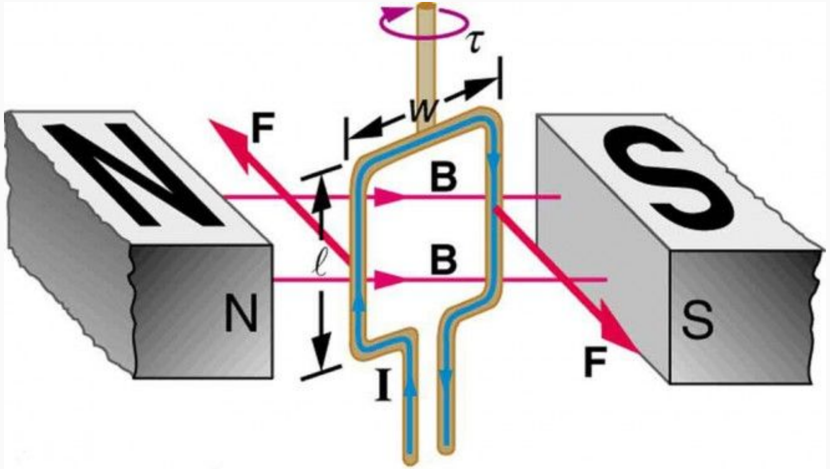
(direction is the direction of the current)



Key concepts in Electromagnetism

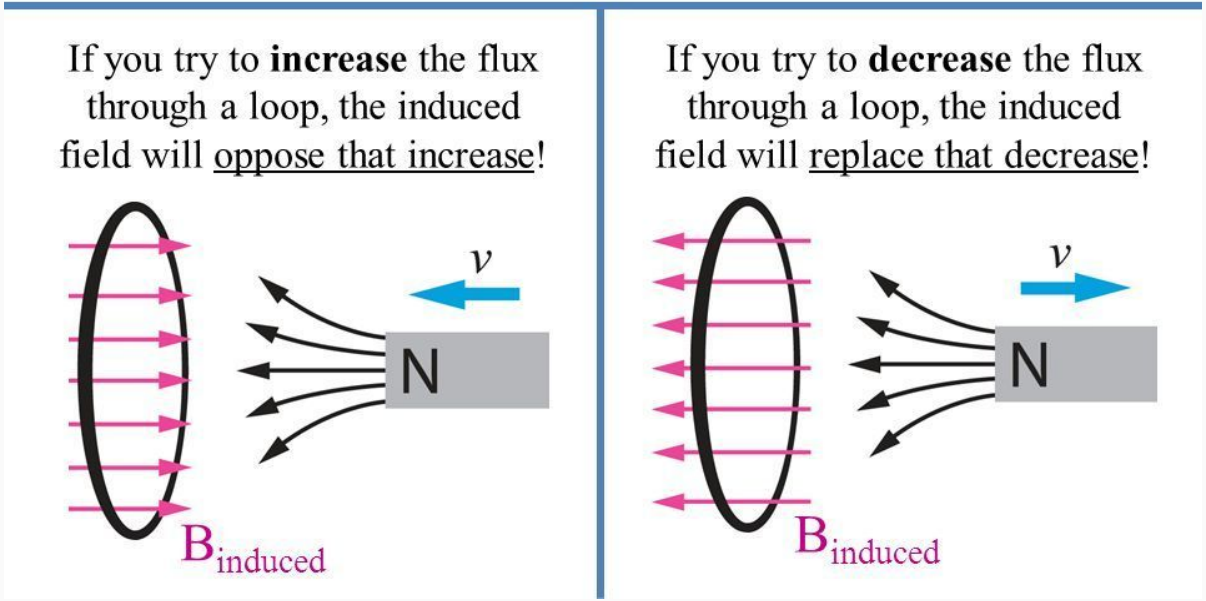
- Torques on loops





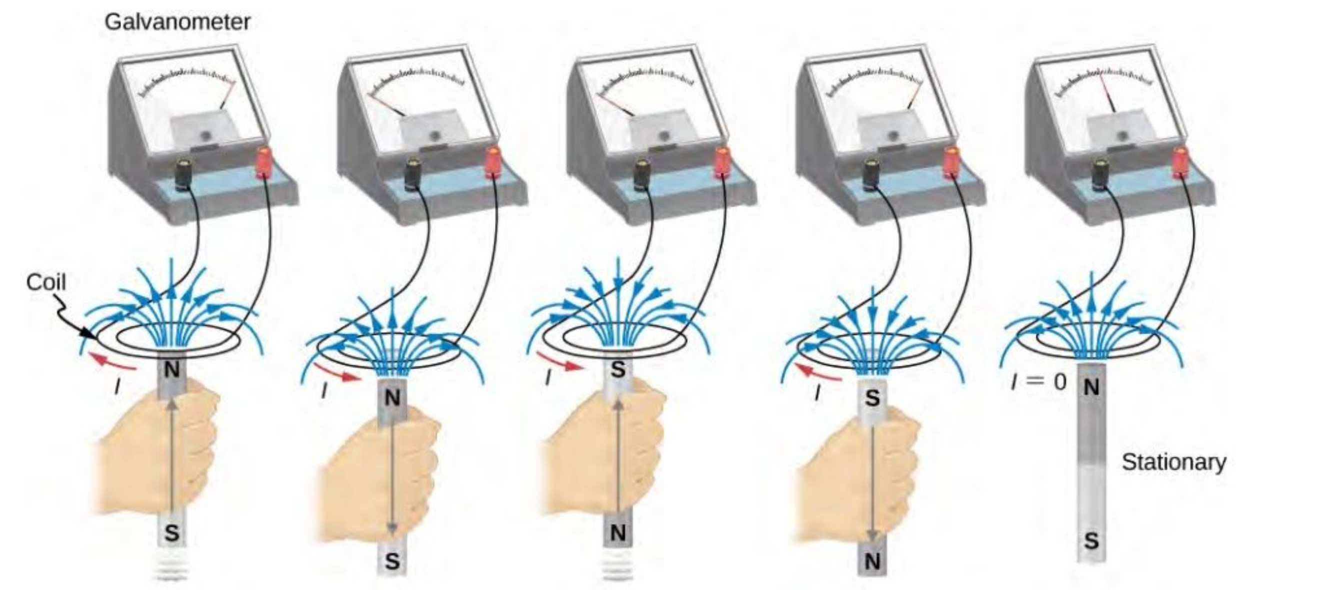
Key concepts in Electromagnetism

- The Faraday - Lenz law



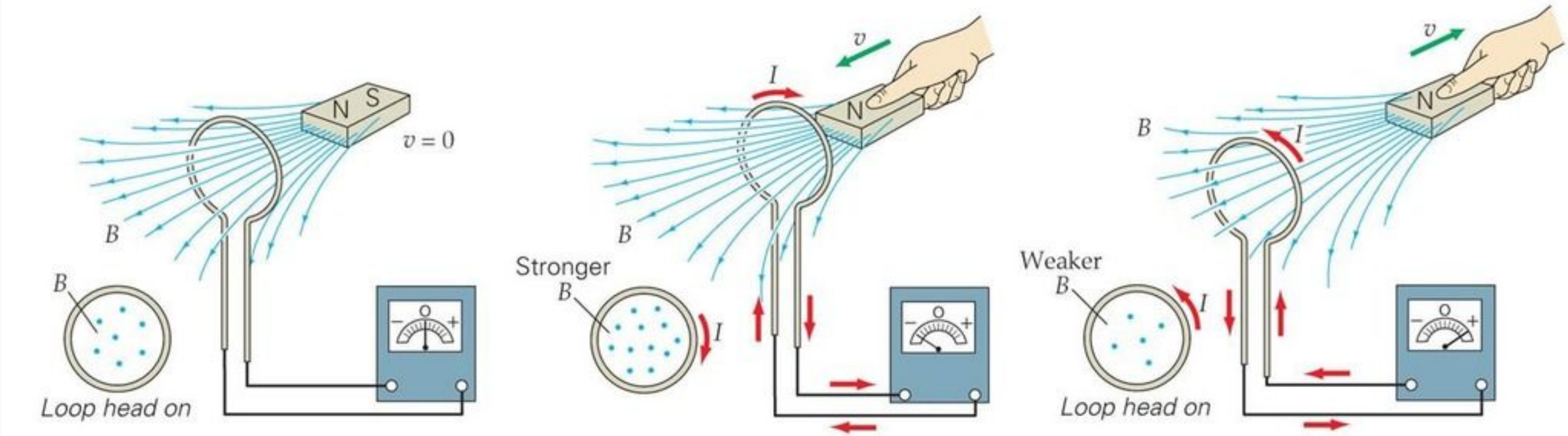
Key concepts in Electromagnetism

- The Faraday - Lenz law



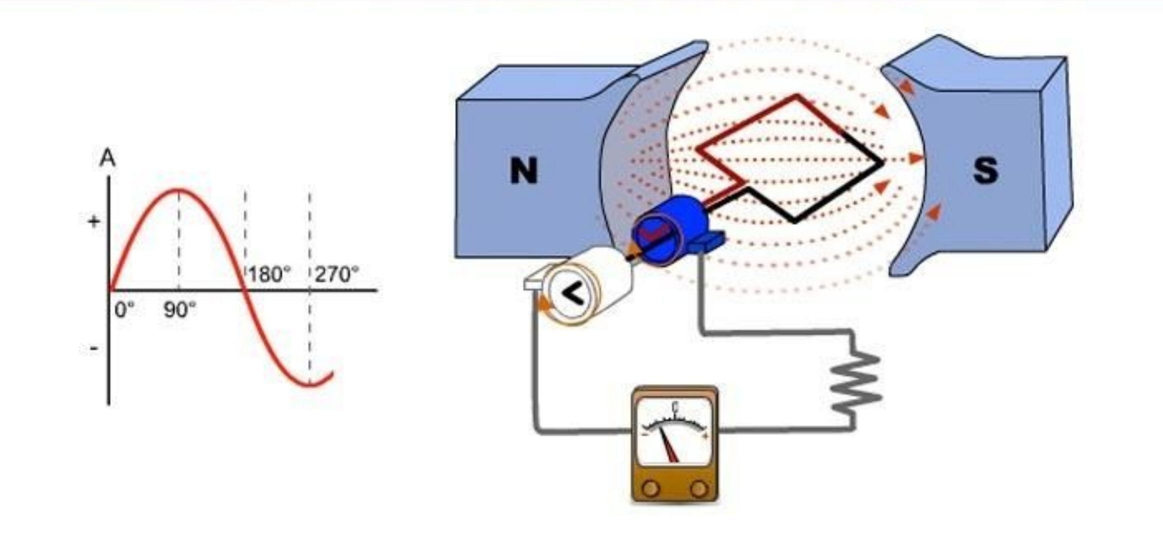
Key concepts in Electromagnetism

- The Faraday - Lenz law



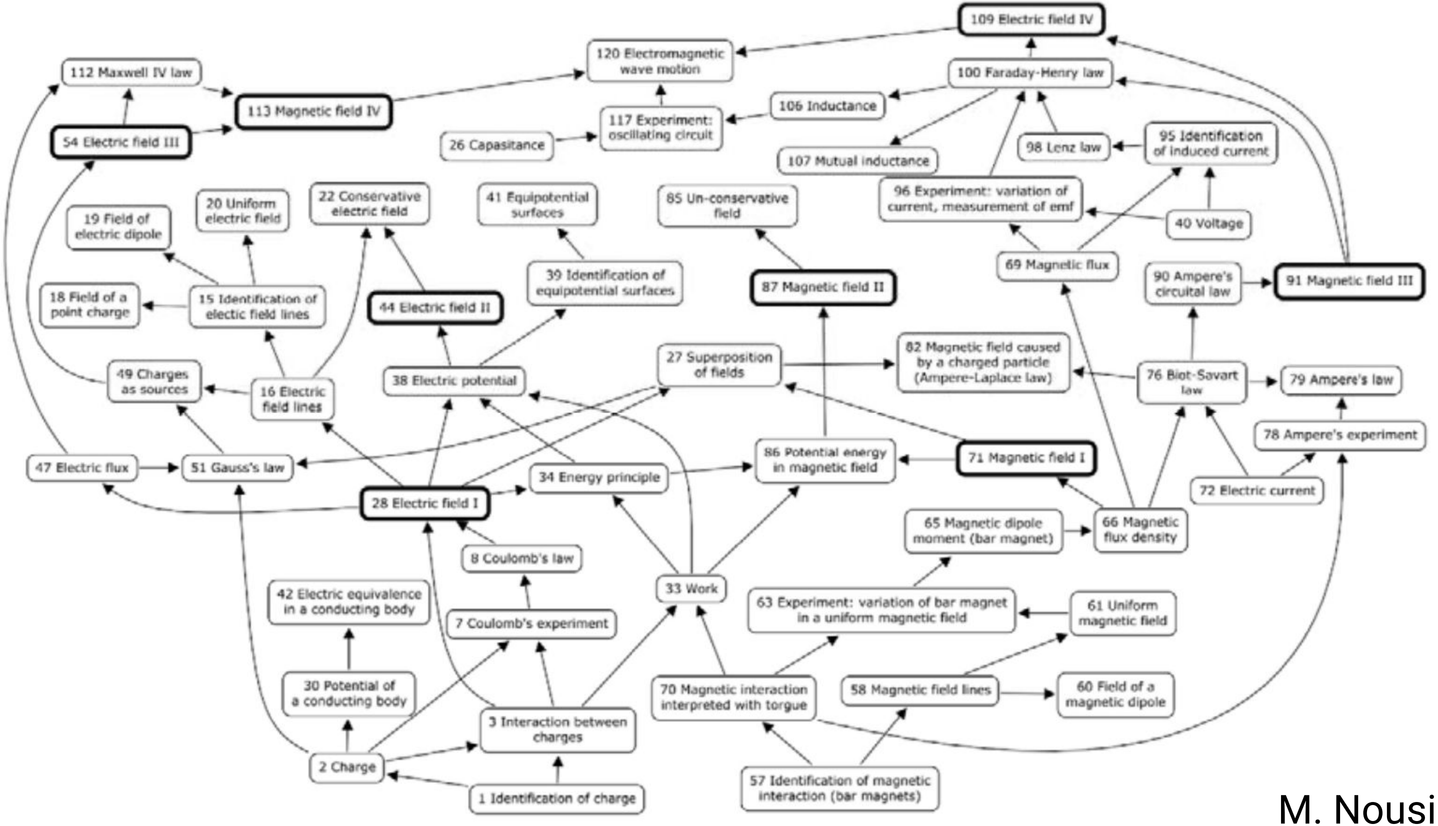
Key concepts in Electromagnetism

- 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



M. Nousiainen, 2017

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 sourcefacets, 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 =- 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

REFERENCES - Understanding key-concepts and misunderstandings

T. M. Scaife and A. F. Heckler, Student understanding of the direction of the magnetic force on a charged particle, Am. J. Phys. 78, 869 (2010)

Cristian Raduta. «General Students' Misconceptions Related to Electricity and Magnetism». Ohio State University, 2005.

Kristina Zuza et al. «Introductory university physics students' understanding of some key characteristics of classical theory of the electromagnetic field». In: Phys. Rev. Phys. Educ. Res 14.2 (2018)

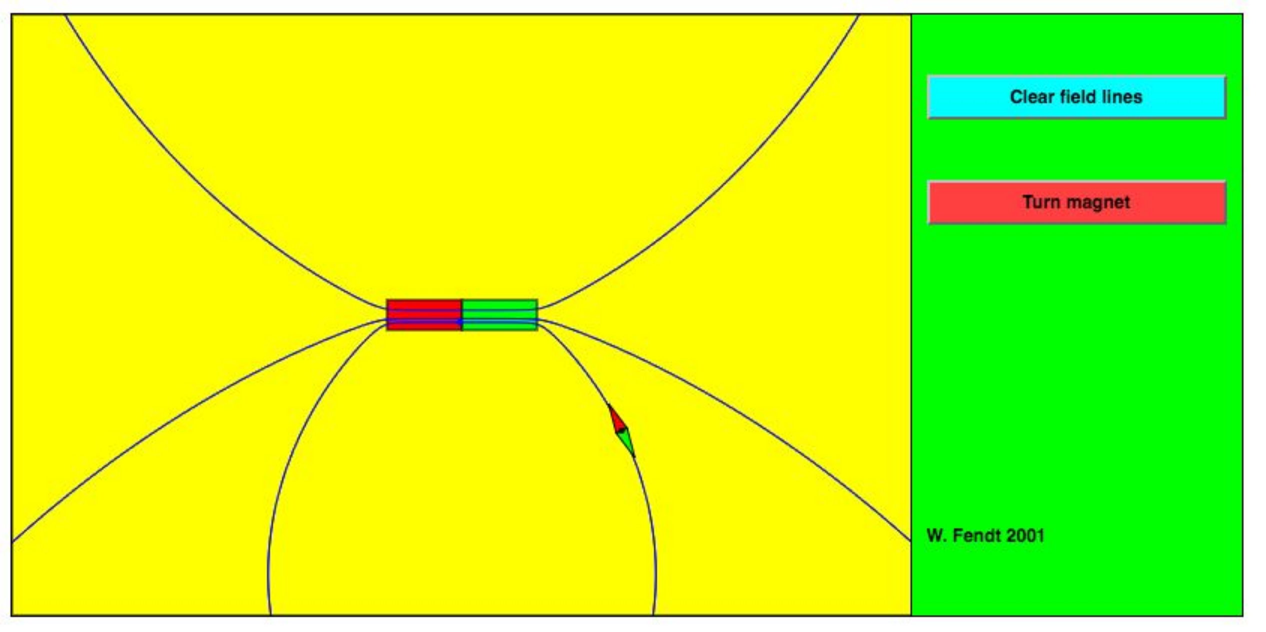
M. Nousiainen and I.T. Koponen, Pre-service physics teachers' content knowledge of electric and magnetic field concepts: Conceptual facets and their balance, Eur. J. Sci. Math. Educ. 5, 74 (2017)

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

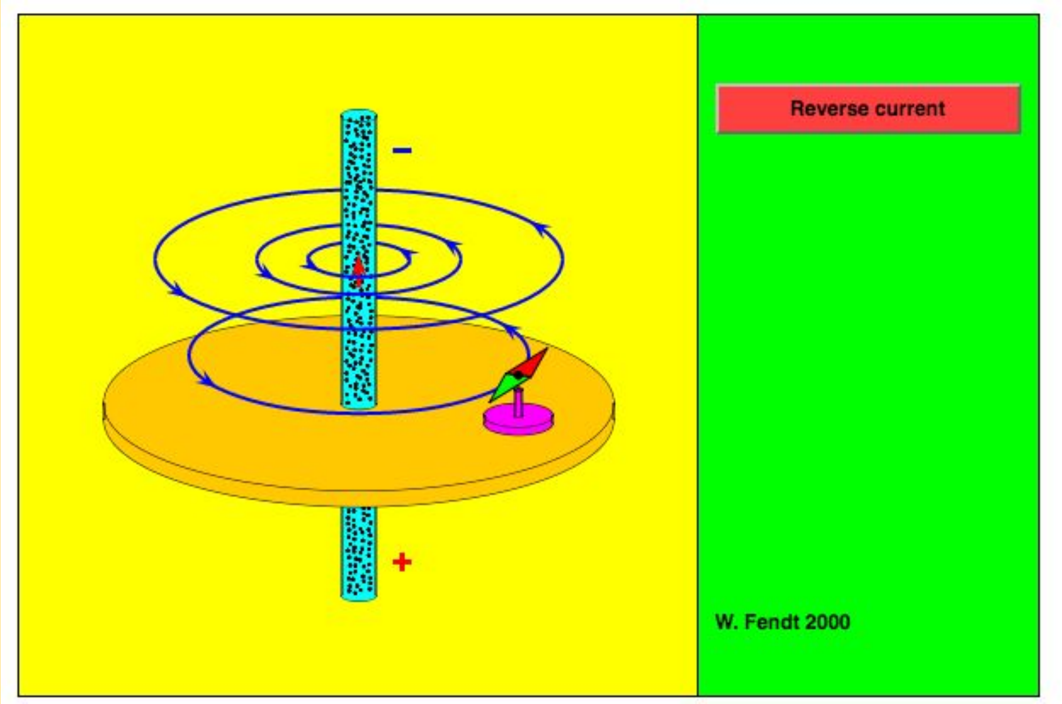
(Adams et al. 2008)

Magnetic Field of a Bar Magnet



https://www.walter-fendt.de/html5/phen/magneticfieldbar_en.htm

Magnetic Field of a Straight Current-Carrying Wire

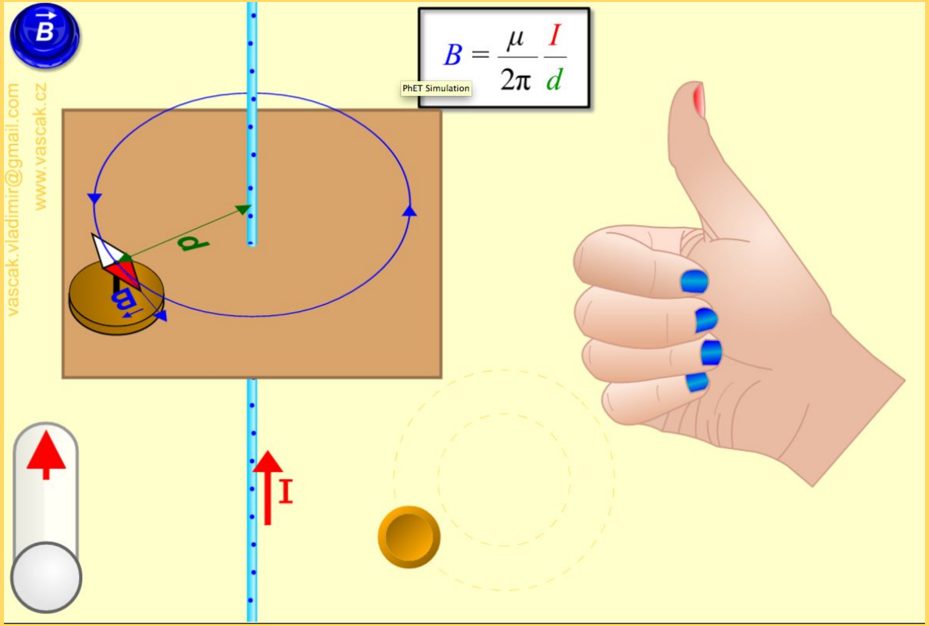


https://www.walter-fendt.de/html5/phen/magneticfieldwire_en.htm

https://www.walter-fendt.de/html5/phen/index.html

FOLDER WITH 55 HTML PHYSICS APP SIMULATIONS (**Walter Fendt, 2021**)

Magnetic Field of a Straight Current-Carrying Wire



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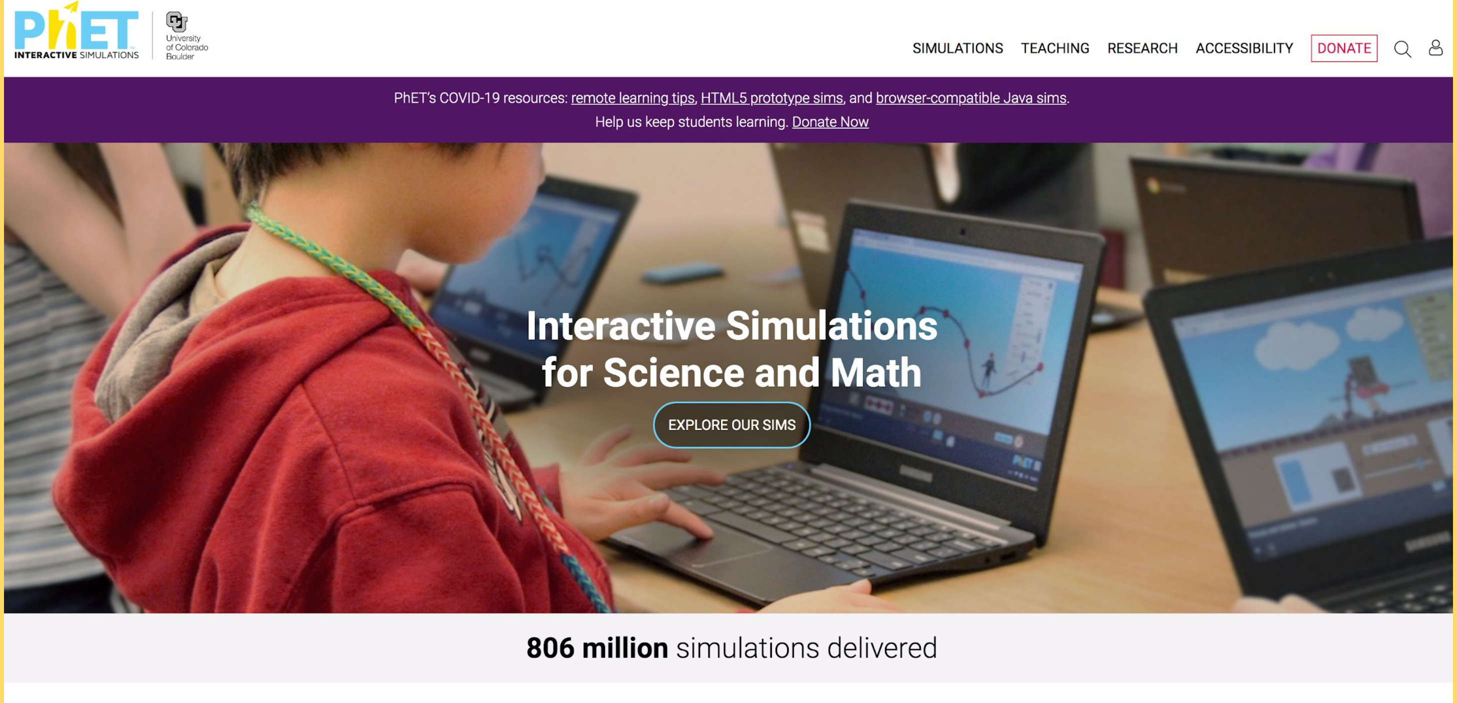

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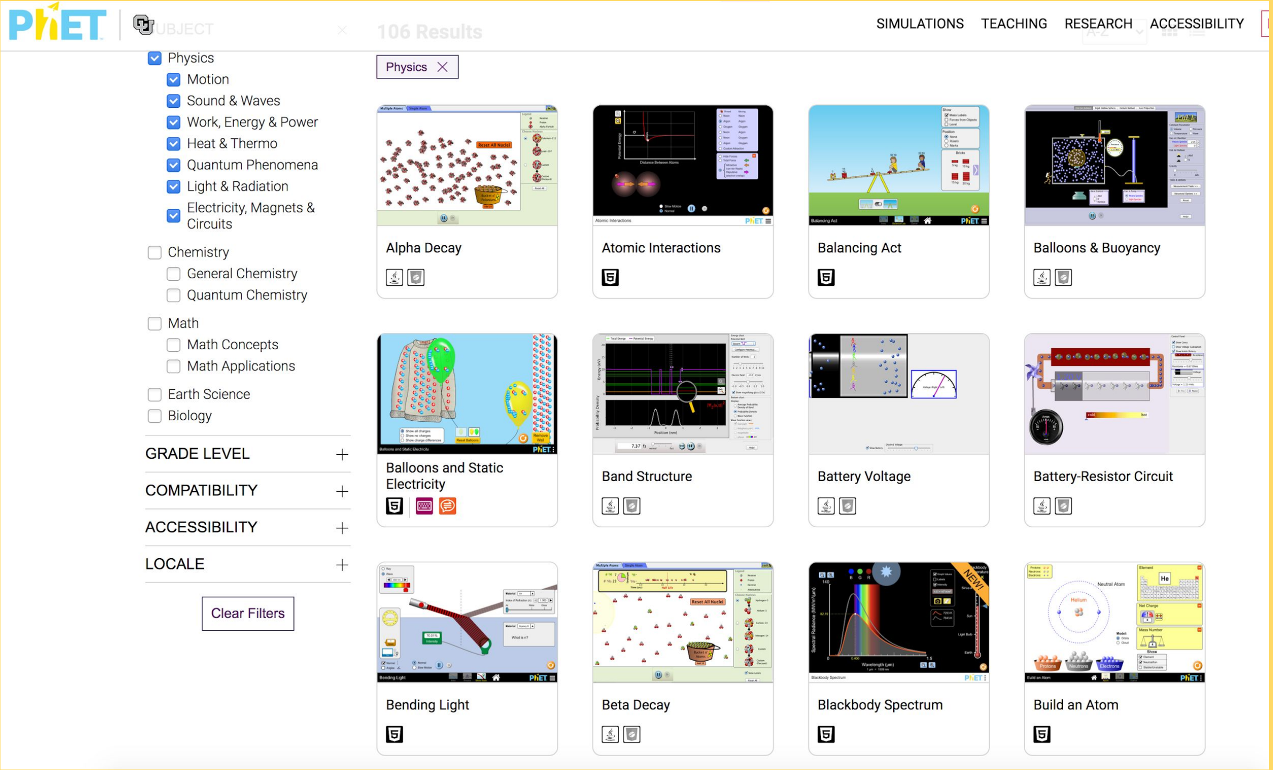

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https://phet.colorado.edu/en/teaching-resources/tipsForUsingPhet

Materials for Physics education

Using PhET Interactive Simulations in College Lecture

PhET INTERACTIVE SIMULATIONS

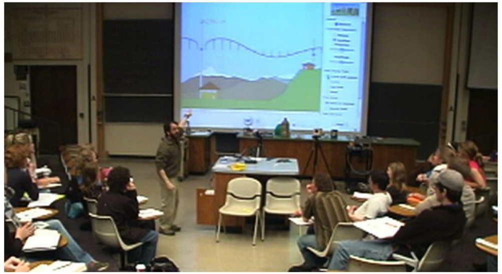
Ideas for engaging students through inquiry in lecture settings

University of Colorado's PhET Project has developed over100 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**

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.

The *Radio Waves* sim helps faculty **communicate ideas** about: creating electromagnetic waves, oscillating electric field strength, and the speed of light.



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.

https://phet.colorado.edu/

Materials for Physics education

Student-driven Discussions

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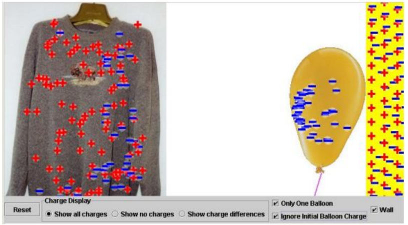
A short demo of charge transfer and polarization with *Balloons and Buoyancy* **generates a series of student questions**:



Students say:

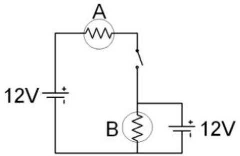
If you rub the sweater on the balloon (rather than balloon on sweater) *will electrons transfer the other way?*

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?

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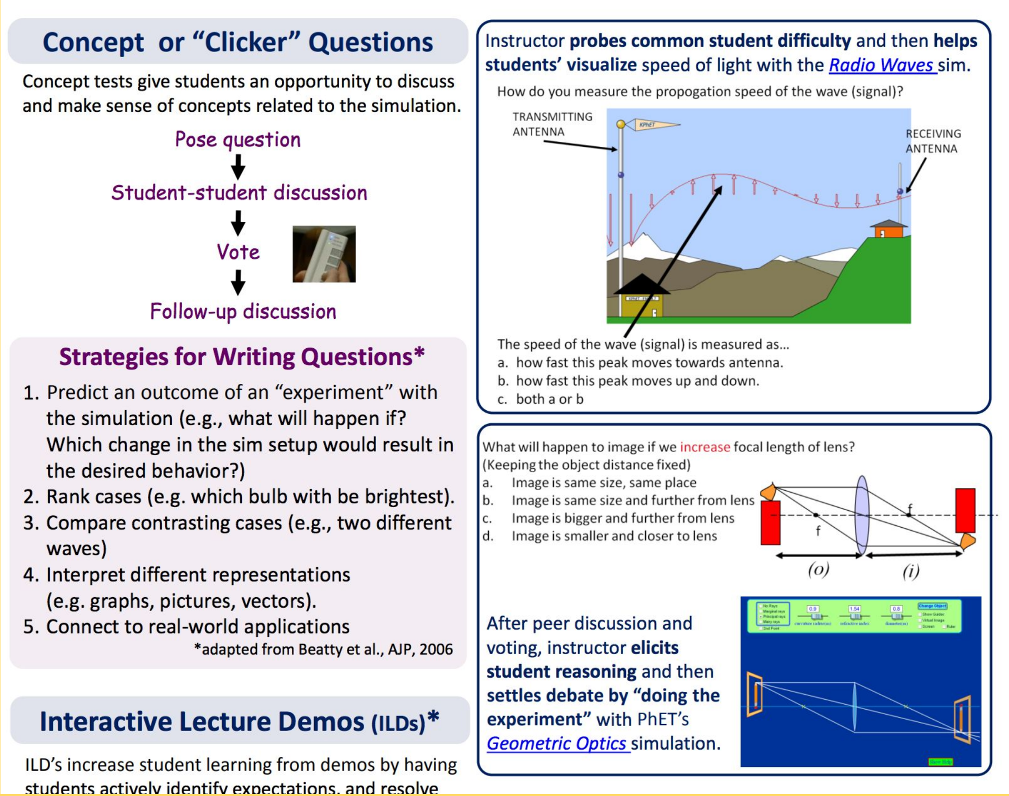

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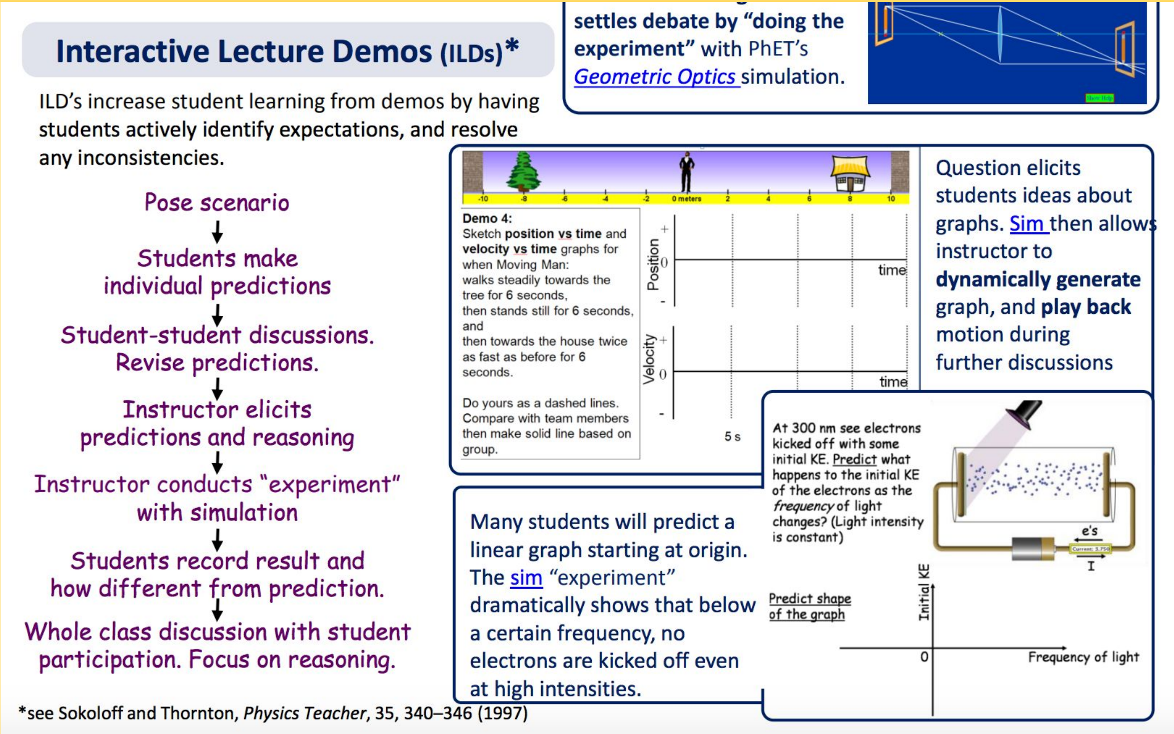

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Magnets-Introduction (Inquiry Based)

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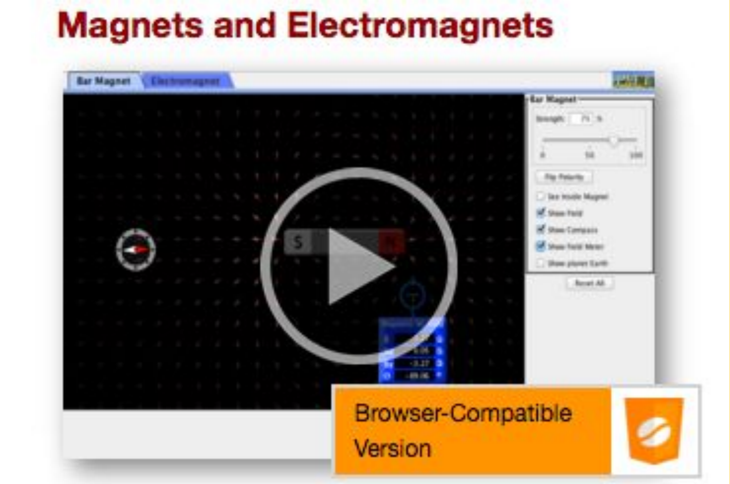

https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets