Tesla Tales

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This presentation is available to download at:
https://nationalmaglab.org/education/

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About Us
National MagLab

• One of 7 high magnetic field labs in the world
  • Only one in western hemisphere
  • Largest and highest powered in the world
National MagLab

• User laboratory
  • Over 1615 user visits (2016)
  • NSF & State of Florida funded
  • Research free to scientist
    • Must share research

• Research in many fields (Not just magnets!!)
• Materials – Energy - Life
  • Includes materials science, physics, engineering, chemistry, biology, biomedical, geochemistry, microscopy, etc...
MagLab on Social Media

• Facebook:
  • facebook.com/NationalMagLab/

• YouTube:
  • youtube.com/user/nhmfl/featured

• Twitter:
  • @NationalMagLab

• Instagram:
  • @nationalmaglab
Center for Integrating Research & Learning

- Educational component of NHMFL’s grant
- RET programs (more on that later...)
- K-12 education outreach
- 8,000 students visited this school year
- Professional development
- Workshops and conferences
- CIRL on Facebook
Superconducting, Resistive, Hybrid, and Pulsed Magnets

Records when MagLab was created (1990)

101T MagLab Short Pulse

60T MagLab Long Pulse

45T MagLab Hybrid

41.4T MagLab Resistive

36T MagLab Series Connected Hybrid

32T MagLab HTS

21T MagLab 900 MHz Superconducting

Magnetic Field (T)

Year


MagLab Records
About Magnets
Magnet Review

- **Gauss**
  - Measurement of magnetic field
  - Named for Carl Friedrich Gauss

- **Tesla**
  - Measurement of larger magnetic fields
  - Named for Nikola Tesla
  - 10,000 Gauss = 1 Tesla
Some Magnetic Fields (In Tesla)

- Refrigerator magnet: 0.03 T
- Earth’s magnetic field: 0.000045 T
- Person’s magnetic field: $3 \times 10^{-13} \text{T}$
- Junkyard magnet: 1 T
- MRI magnet: 2-3 T
Some NHMFL Magnetic Fields

- ICR magnet: 21 T
  - Ion Cyclotron Resonance
- 900 Mhz NMR 21 T
  - Nuclear Magnetic Resonance
- Typical resistive magnet 20-40 T
- Split cell 25 T
- World record water cooled DC magnet 41.5 T
- Hybrid magnet (33 MW) 45 T
  - Resistive and superconducting
- Series Connected Hybrid (14 MW) 35 T
  - 1.5 Ghz NMR
- NHMFL pulse magnet 100.7 T
  - Not continuous field
The History of Magnets
1269: Petrus Peregrinus de Maricourt

- Epistola de magnete
- Part 1 discusses the physical (not occult) properties of magnets
  - Magnetic fields can act at a distance
  - Magnets can only act on other magnetic materials
  - Opposite poles attract and like poles repel
  - When suspended, north poles point North and south poles point South.
- Part 2 discusses the use of magnets in devices
  - Wet and dry compass
1600: William Gilbert

• Published *De Magnete*
  • Earth is a magnet

• First critical research on magnets
  • Used lodestone
  • Dispelled superstitions and myths
1820: Hans Christian Ørsted

- An electrical current can create a magnetic field
- Ørsted set up lecture demonstration
  - Used battery to supply current
  - Showed compass needle deflecting near the wire
1820: André-Marie Ampère

- Moving electrical charges produce magnetic fields
- Simple experiment
  - Two straight wires with current passed through
  - Wires bowed toward or away
- Led to electromagnets
1824: William Sturgeon

- First electromagnet
  - Curved iron rod
  - Bare copper wire
  - Electricity
  - 18 total turns of wire
- Lifted 9 pounds
  - Magnet weighed 7 ounces
1827: Joseph Henry

- Improved the electromagnet
  - Larger iron rod
  - Copper wire
    - Insulated with silk
  - Electricity
- An electromagnet using two electrodes attached to a battery, best to wind coils of wire in parallel
- But an electromagnet using with multiple batteries, should use only one single coil
1831: Michael Faraday

- Wrapped wires around opposite sides of an iron ring
  - Change in magnetic field produces an electric current
  - Induction
- Magnetic Flux: The change needed to induce current
  - Move a magnet in and out of a coil of wires
- Originally rejected: Not formulated mathematically
  - James Clerk Maxwell (1862): Maxwell-Faraday equation
1834: Emil Lenz

- Lenz’s Law: An induced current in a wire (by flux) will flow to create a field that opposes the flux
- Eddy currents created
- Used in magnetic braking systems
  - Rollercoasters
  - Electric car braking feedback
1900: Free Electron Theory

- Electrical conduction in a solid is caused by the bulk motion of electrons
  - Each metal atom contributes an electron that is free to roam
  - Voltage briefly accelerates the electrons
    - Resistance is friction
  - Electrons don’t actually move down the wire
    - The charge moves
    - Like a wave in a pool
1900: Superconductors

Graph showing the resistance of traditional metals and superconductors as a function of temperature. The transition temperature $T_c$ is indicated where resistance drops to zero at 0 Kelvin.
1957: BCS Theory

- **BCS**: Bardeen, Cooper, Schreiffer
- At low temperatures, some metals lose resistance
  - Atoms nearly stationary
- Superconductivity results from the formation of Cooper pairs
  - Two electrons partnered
  - One follows the other
- Results in frictionless flow of electrons
The Science of Magnetism
Magnets

- All magnets have poles
  - North & South
  - Opposites attract; Like repels

- But not really: Magnetic monopole
  - Research ongoing...

- All magnets have magnetic fields
- Magnetic field is a vector field
  - Has direction and magnitude
Magnetic Fields

Magnets Repel

Magnets Attract
Magnetic Fields

- Magnetic fields invisible to humans
- Many animals can sense magnetism
  - Sea turtles
  - Migratory birds
  - Sharks
- Rare animals can see magnetism
  - Robins
  - Orangutans
  - Family Canidae
    - Wolves, foxes, coyotes, dogs
Magnetic Materials

- 3 metals are naturally magnetic at room temperature
  - Iron
  - Nickel
  - Cobalt
- Two more are magnetic at lower temperatures
  - Gadolinium (65 F and below)
  - Dysprosium (-301 F and below)
- Many are magnetic as alloys
  - Rare-Earth
Magnetite & Lodestone

- Magnetic mineral
- Iron (II, III) Oxide
  - $\text{Fe}_3\text{O}_4$
- Poor temporary magnet
- Largest US deposit in NY (Adirondacks)
- Lodestone is magnetized piece of magnetite
- Lodestone led to first compass
Permanent & Temporary Magnets

• Permanent magnets: *Almost* always keep their field
  • Fields can be lost
    • Curie point (Heat)
    • Electric current (Degauss)
    • Hitting it (Blunt force)

• Temporary magnets: Will keep magnetic field until tampered with
  • Examples: Paperclips, scissors, staples, thumb tacks, pins, screwdrivers, refrigerator door, car doors, etc...
  • Anything that is magnetic, but will not keep its field
Atomic Theory

- Atomos
  - Indestructible...
  - But not really

- The atom
  - Proton
  - Neutron
  - Electron
Magnetism

• Motion of charges particles creates magnetic fields
• In most atoms, disorganized spins cancel out
  • Magnetic domains: when electrons line up
• Magnetic field is produced when all electrons spin the same direction:
  • More electrons lined up: more magnetism
Electricity and Magnetism

• The two are so closely related
• Where there is electricity, there is a magnetic field
  • When electrons flow, they line up (Ørsted)
• Where there is a magnetic field, electricity can be created (Faraday)
  • Magnetic flux can create movement of electrons
Creating Magnetism From Electricity

- Electricity is the flow of electrons
- In DC electricity electrons flow in one direction
- This alignment of electrons creates a magnetic field around the conductor
  - Similar to electrons lining up in a permanent magnet
  - So every wire carrying electricity has a weak magnetic field around it
- Coiling the wire concentrates the magnetic field inside the coil
Bitter Plates
Electromagnetism Activities For Your Classroom
Electromagnets

- Materials
  - Copper wire
  - Iron rod
  - Battery

- Extensions:
  - 2 batteries
    - In line?
  - Aluminum, wooden rod
    - Will they work?
Electromagnets Extensions:

- Right hand rule
  - Direction of field
- Poles (Winding direction)
- Variables:
  - Neatness
  - Number of winds
  - Wire gauge
  - Battery strength
  - Temperature
  - Precision
The Magnetic Hedgehog

• Ferrofluids aka liquid magnets
  • Suspension of iron nanoparticles
• Fluid adheres to magnetic field lines
• Incredibly attractive (BE CAREFUL)
Make a Speaker

- Speakers work with a permanent magnet in an electromagnet coil.
- Music sent as electrical current creates flux in the coil, causing the magnet to vibrate.
- Vibration creates the sound we hear.
AC/DC Device

- Alternating Current; Direct Current Detector
  - MagLab DC Magnets
- Device shows AC current

**Materials**

- Bi-color LED
- ½ Watt, 400-500 ohm resistor
- Lamp cord
- 2-prong plug
- 2-prong socket
- Electrical tape/solder
- 9-volt AC adaptor/transformer
Induction by Gravity Part I

• Movement of magnetic field by a conductor creates motion of electrons
  • Current is induced
  • Basis of electric generators

• Gravity pulls magnet past conducting coil

• Induced current in copper tube created Eddy currents
  • Currents repel magnet
Induction by Gravity Part II

- Movement of magnetic field by a conductor creates motion of electrons
  - Current is induced
  - Basis of electric generators
- Gravity pulls magnet past conducting coil
- Induced current lights LED
Plotting Electric Field Lines

Detailed instructions for teachers on conducting a hands-on lesson on plotting electric field lines.

Concepts covered
- Electric fields
- Forces

Time
This activity requires about 1-1.5 hours to complete.

Background
There are four fundamental interactions that occur in nature: in physics they are referred to as fundamental forces. The four forces are gravitational, electromagnetic, strong nuclear and weak nuclear. For this lesson we will focus on the electromagnetic force, specifically the force produced by an electric field (E).

The concept of the electric field is a bit esoteric compared to, let’s say, a gravitational field because we can interact much more easily with a gravitational field than we can with an electric field. If we take a ball (basketball, golf ball, baseball, etc.) and drop it, we see that it falls toward the Earth. This happens because the ball is in a gravitational field and the gravitational field produced by the Earth interacts with the mass of the ball. We assume, for the most part, that the gravitational field experienced by the ball is uniform, therefore, the ball falls straight from your hand to the ground. The force exerted by the field on the ball is \( F = mg \) (force = mass of the ball x gravity) Figure 1.

Uniform gravitational field, g
More Lesson Ideas

- Electric Motors
- Ion Motors
- Making Microphones
Stop Faking It
Bill Robertson

Driving Force
James D. Livingston
Literature

A Short History of Nearly Everything
Bill Bryson

The Nature of Science
James Trefil
The Cold Wars
Jean Matricon & Georges Waysand
Research Experience for Teachers 2019

- 6 weeks in the summer
- $3600 stipend

- June 17th – July 26th
- What do you have to do?
  - Complete online application
  - Complete program surveys and submit all research data
  - Send in supporting documents (letter of rec, etc.)
Research Experience for Teachers 2019

What does RET entail?

- Real world science:
  - Superconductivity materials testing
  - Electricity & magnetism research
  - Designing/constructing research instruments
  - Running samples in Electron Paramagnetic Resonance (EPR) or Nuclear Magnetic Resonance (NMR)
RET Logistics and Arrangements

- Housing
- Stipend
- Travel
- Program is open to Elementary, Middle, and High School teachers
- Pre-service teacher positions available

- Focus of the program
  - Nature of Science
  - Inquiry
  - Communicating in science
  - Experimental Design

- Topics for research
  - Superconductivity
  - Electron Scanning Microscopy
  - Condensed Matter
Before I Forget

• Business cards
  • Please do not hesitate to contact us with questions, ideas, suggestions, etc...

• RET applications:
  • [https://nationalmaglab.org/education/](https://nationalmaglab.org/education/)
Thank You

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