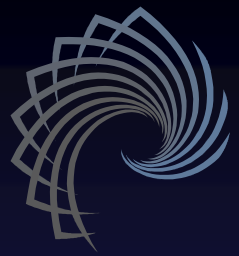


The Magnetic Field and Magnetic Permeability of Magnetic Materials

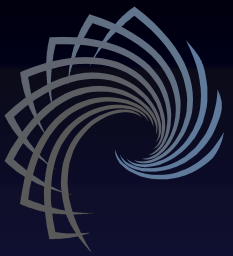
Presented by George J Bugh

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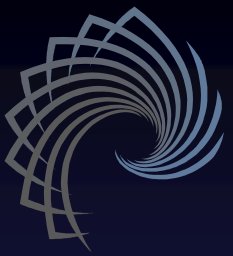
How Special Relativity connects the Electric Field and the Magnetic Field

- As presented in Einstein's paper: On the Electrodynamics of Moving Bodies; The magnetic field is just the electric field that is experiencing the effects of length contraction-time dilation when there is relative motion. The electric field force vectors get morphed in direction to become the magnetic field forces. These links below present this Special Relativity theory better:
- http://galileo.phys.virginia.edu/classes/252/rel_el_mag.pdf
- https://ocw.mit.edu/courses/materials-science-and-engineering/3-a08-attraction-and-repulsion-the-magic-of-magnets-fall-2005/assignments/mag_relativity.pdf
- http://www.hep.uiuc.edu/home/g-gollin/relativity/p112_relativity_14.html



The Purpose of this Presentation is to:

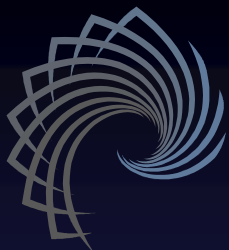
- Explain what magnetic permeability is.
- Discuss misconceptions about relative permeability.
- Discuss the processes involved within magnetic materials.
- Discuss insights and advancements possible when using a more correct explanation of the relative permeability of magnetic materials.



Why bother with a more correct explanation of the processes?

It is important to understand the actual processes taking place ... :

- when working at very high frequencies.
- when there are propagation delays between changes in external magnetic fields and when the changes arrive at a magnetic material's location.
- when magnetic fields propagate from a magnetic material back to an external electric circuit that stimulated the magnetic fields.



Magnetic Permeability and Relative Permeability

From Wikipedia:

- **Magnetic Permeability:**

“... is the measure of the ability of a material to support the formation of a magnetic field within itself. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field. Magnetic permeability is typically represented by the (italicized) Greek letter μ . The term was coined in September 1885 by Oliver Heaviside.

In SI units, permeability is measured in Henries per meter (H/m or $\text{H}\cdot\text{m}^{-1}$), or equivalently in Newtons per ampere squared ($\text{N}\cdot\text{A}^{-2}$). The permeability constant (μ_0), also known as the magnetic constant or the permeability of free space, is a measure of the amount of resistance encountered when forming a magnetic field in a classical vacuum. The magnetic constant has the exact (defined) value ($\mu_0 = 4\pi \times 10^{-7} \text{ H}\cdot\text{m}^{-1} \approx 1.2566370614 \dots \times 10^{-6} \text{ H/m or N}\cdot\text{A}^{-2}$).”

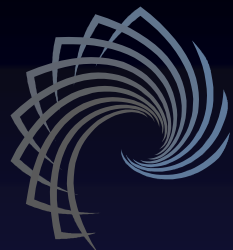
Notes to myself: In the formula $\mu = H/m$, the distance or length m in meters is in what direction?

- **Relative Permeability:**

“... denoted by the symbol μ_r , is the ratio of the permeability of a specific medium to the permeability of free space μ_0 :

$$\mu_r = \mu/\mu_0$$

where $\mu_0 = 4\pi \times 10^{-7} \text{ N}\cdot\text{A}^{-2}$.”



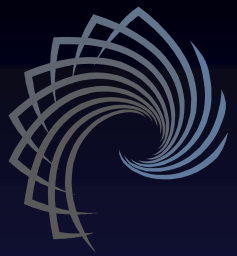
History of the term: “Relative Permeability”

- The term “Relative Permeability” was in use in the 1800’s to indicate, for example, how easily water could permeate one type of porous mortar versus some other type of less porous mortar.
- As mentioned already, Oliver Heaviside coined the term “magnetic permeability” in 1885.
- In the 1890’s people were using the term relative permeability in relation to the attributes of magnetic materials that appeared to allow a magnetic field to permeate the material with more or less ease compared to a magnetic field’s ability to permeate empty space.
- All this was prior to people having a good understanding of where or how a magnetic field originates.
- It was 1905 when Einstein wrote his paper: “On the Electrodynamics of Moving Bodies” which included his theory and math regarding magnetic fields being a relativistic translation of electric fields of electric charges in relative motion.



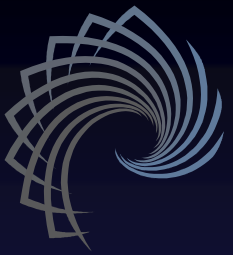
What we now know about magnetic processes

- Scientists now know that the strength of a magnetic field from moving charges is **NOT** dependant on the magnetic properties of magnetic materials in the area but rather dependant on the amount of electric charges and their rate of relative motion.
- Other magnetic materials in the area develop their own magnetic fields and these can be influenced by magnetic fields external to the magnetic materials.
- Changes in the magnetic fields from a magnetic material can propagate back to an electric circuit and induce a decrease in the the rate of relative motion of electric charges in that circuit but still the magnetic field of the electric circuit comes from the amount of electric charges in the circuit and their rate of relative motion.
- The total magnetic field flux density at any particular location within a magnetic material is the vector summation of all external magnetic fields (often generated by electric circuits) plus the magnetic material's own internally created magnetic fields which are caused by its own internal processes.



What's wrong with the term "Relative Permeability"

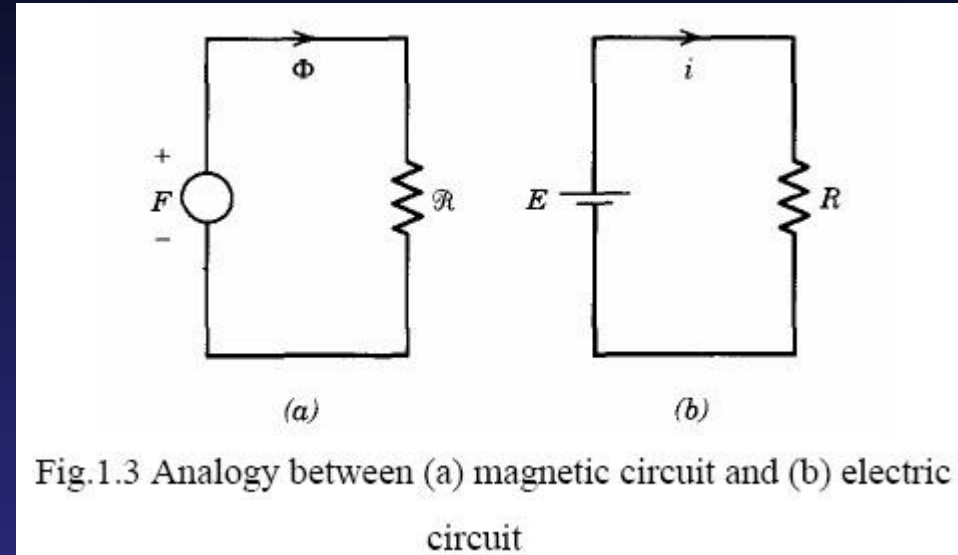
- The term "Relative Permeability" was originally used when there was a false assumption that the source of the total magnetic field was an external magnetizing electric circuit.
- This incorrectly implies that a magnetic material can have the ability to let an external magnetic field permeate it more easily than it can permeate free space and thus increase the magnetic flux density through the magnetic material.
- In fact, the processes taking place within a magnetic material will create a greater or lesser magnetic field density but this is not caused by making it easier or more difficult for the original external magnetic field source to permeate the magnetic material.
- A magnetic circuit is often incorrectly compared to an electric circuit in which objects along the circuit path with greater or lesser conductivity allow the flow of more or less electric current from a current source like a battery.
- This inaccurate way of explaining relative permeability is wide spread in today's college textbooks and amateur radio handbooks.



Examples of the incorrect way of visualizing magnetic processes:

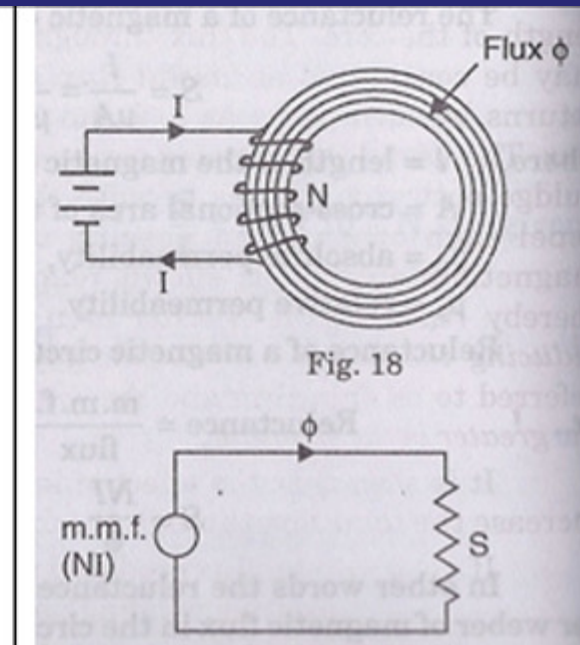
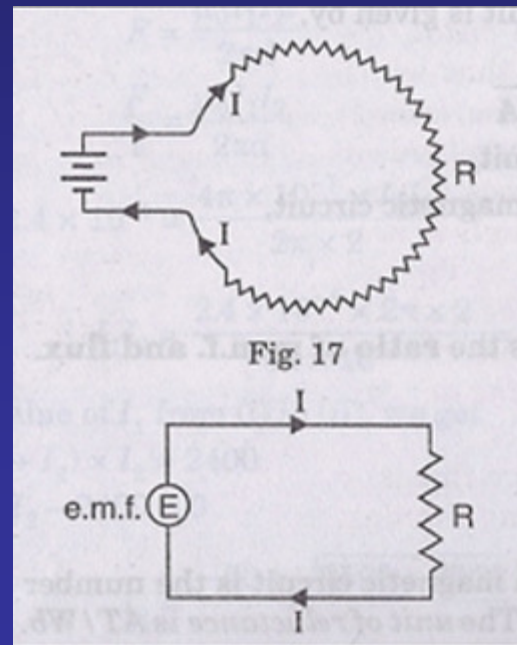
From:

http://1.bp.blogspot.com/_Gky8ltNWVfk/ScCYgLRqoMI/AAAAAAAAAEM/4hF79D35MIM/w1200-h630-p-k-nu/Magnetic+versus+Electrical+circuits+01.JPG



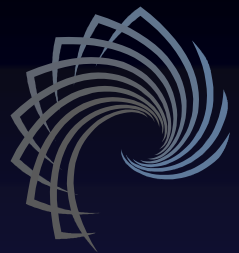
From:

<http://www.electrical-engineering-assignment.com/wp-content/uploads/2013/05/114.png>



See also:

http://processmodeling.org/model_em/em_heat/res/electric%20magnetic%20fields%20analogy.gif



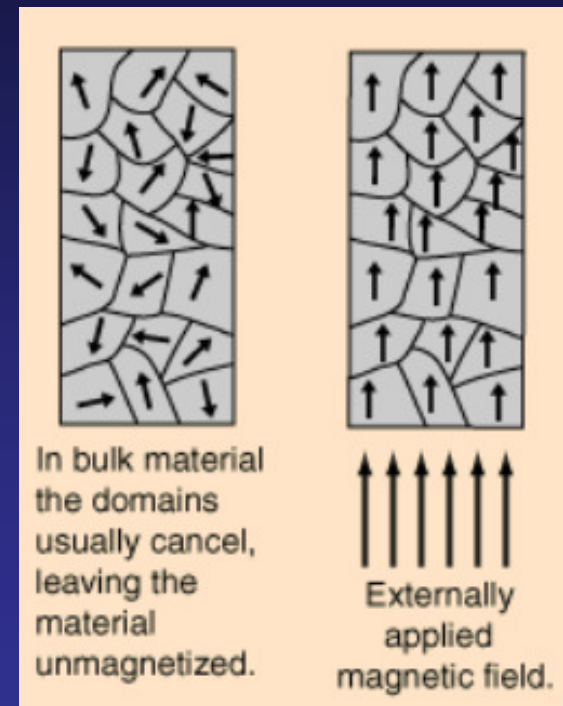
How Magnetic Materials emulate having greater permeability

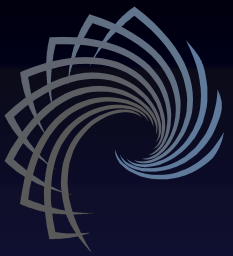
- The individual magnetic domains within a paramagnetic or ferromagnetic material will re-orient to align with an external magnetic field.

Example from:

<http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/ferro.html#c4>

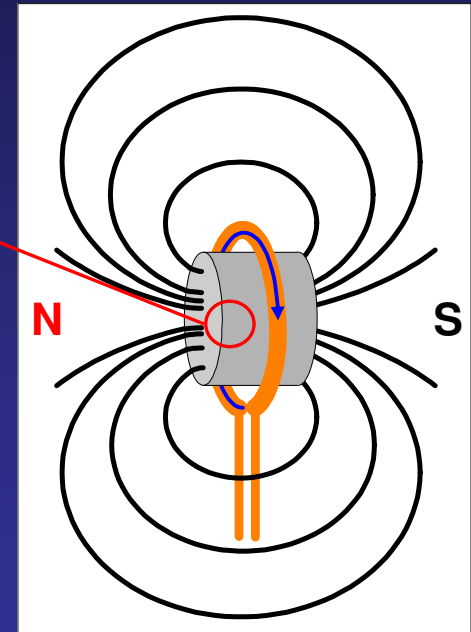
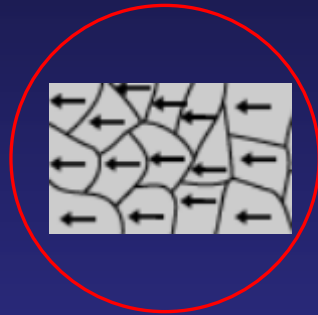
- The total magnetic field strength and direction at any particular location is the vector summation of all external and internal magnetic fields at that location.
- In the actual processes occurring, the external magnetic field source does **NOT** output greater magnetic flux in response to a magnetic material that becomes more easy to permeate.
- **Typically, it is the magnetic material itself that becomes the source of the majority of the stronger magnetic field.**



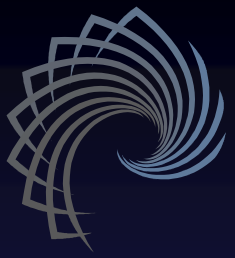


Who does the work and where does the energy come from?

- When an EMF is applied to a loop of wire it causes a current flow through the wire which causes a magnetic field from the loop which magnetizes a core magnetic material.
- Work is performed to change the orientation of magnetic domains within the magnetic material.

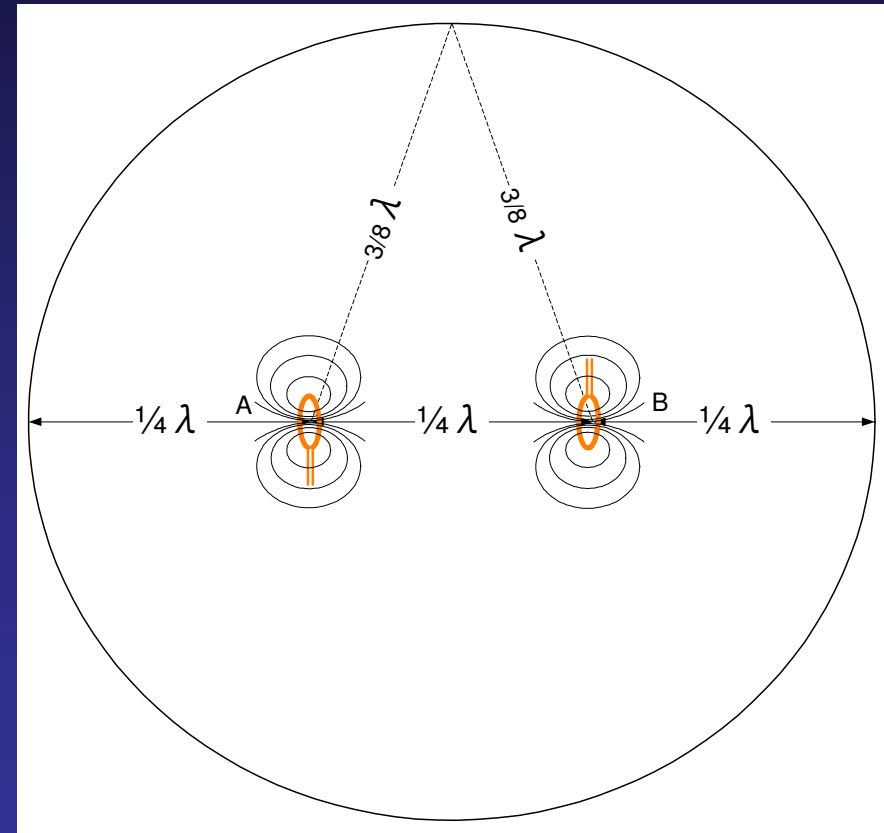


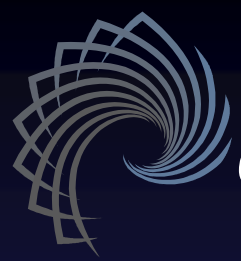
- The energy used to perform this work is presumed to come from the EMF source that causes current flow through the loop of wire.
- This energy is presumed to be converted to the energy stored in the magnetic field of the magnetic material's core.
- As the core becomes magnetized, its magnetic field expands out and induces counter EMF in the current loop around the core which extends the time for current flow to build up after an initial EMF is applied to the current loop.



What if there are significant propagation delays between the coil and the core?

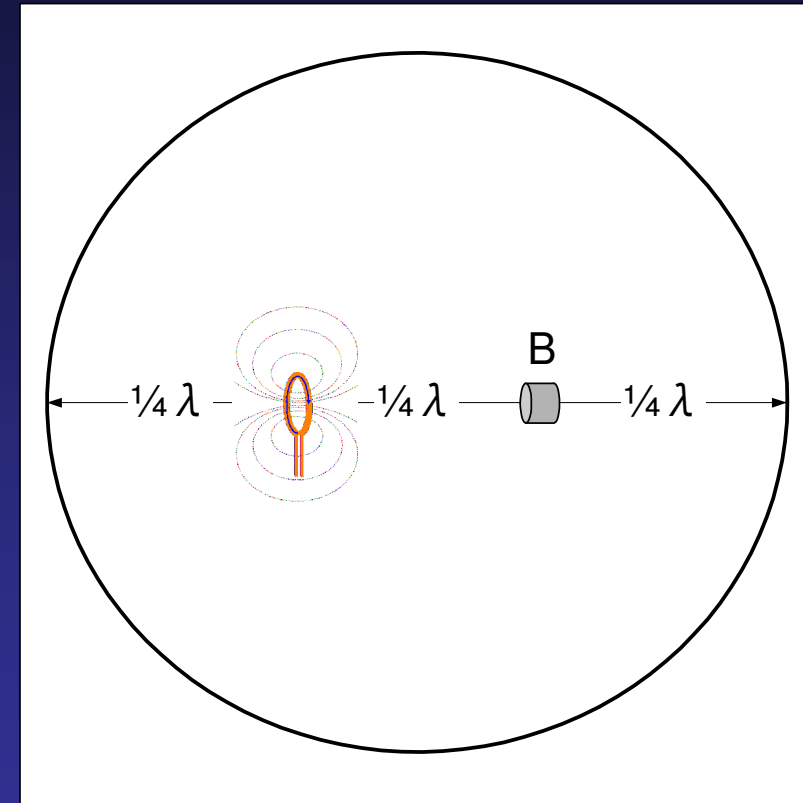
- Reference this side view cross section of an ellipsoid reflective cavity
- In an ellipsoid, waves propagating from one foci will reach the other foci all at the same time because all reflecting propagation paths are of equal total distance.
- RF energy propagating from a wire coil at the ellipsoid foci A will also seem to come from a virtual image of the wire coil at foci B.





What if there are significant propagation delays between the coil and the core continued ?

- If we apply an RF AC current to a wire loop at foci A and at a frequency with wavelength " λ ",
- then the magnetic core at foci B will not know that the RF energy did not originate from the virtual wire coil at foci B.
- In fact, the magnetic core will not respond until a $\lambda/4$ time delay after the signal leaves foci A.
- In this configuration, rather than performing "WORK" as usual on the magnetic core, the energy from the virtual coil provides stimulation to make the magnetic core emit a magnetic field that is in phase with the signal that stimulates its emission.
- If the magnetic core has a coefficient of relative permeability of 100, for example, and if it is made of a magnetic material capable of responding at high frequencies,
- then electromagnetic energy of a magnetic field approximately 99 times stronger will begin propagating back to the real wire coil at foci A.



The magnetic core material becomes a source of excess power output?

- By the time this signal arrives at A, rather than opposing the change in current in the wire loop, it generates a larger current flow in the same direction as is flowing in the loop already.

