Ferrite Superconductivity-RTS

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Maxwell's Equation

Differential Form

(1)	$\nabla \cdot \vec{D} = \rho$	or	$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$	Gauss's law
(2)	$\nabla \cdot \vec{B} = 0$			Gauss's law for magnetism
(3)	$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$			Faraday's law of induction
(4)	$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$	or	$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$	Ampère's law

- Together with the Lorentz force these equations form the basic of the classic electromagnetism

$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ Lorentz Force

$\vec{D} = \epsilon_0 \vec{E}$

ϵ_0=permittivity of free

$B = \mu_0 H$

μ_0=permeability of free space

ρ = electric charge density (As/m^3)

J = electric current density (A/m^2)

D = electric flux density/displacement field (Unit: As/m^2)

E = electric field intensity (Unit: V/m)

H = magnetic field intensity (Unit: A/m)

B = magnetic flux density (Unit: Tesla=Vs/m^2)

Maxwell Equations dependence on Material medium

- It should be noted that the Maxwell equation's application incorporates material characteristic parameters by nature

- In the equations given as mentioned, permeability and permittivity of free space are given .

- In the Magneto-hydrodynamic terms, Permeability is the inverse pressure in the medium and permittivity is the density of the medium.

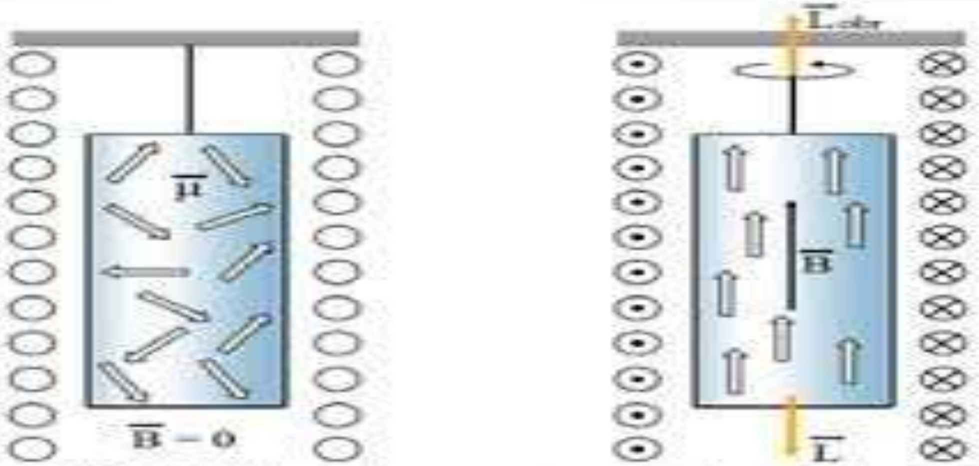
What is Permittivity and Permeability?

- Permittivity is the ease in which the material can be polarized in reponse to an electric field.It is more related to charge density.Stationary charges create electric field.

- Permeabilty is the ease in which the material can be magnetized in response to the magnetic field.It is closely related to kinetic energy.Moving charges create magnetic field.

Negative Permeability Materials

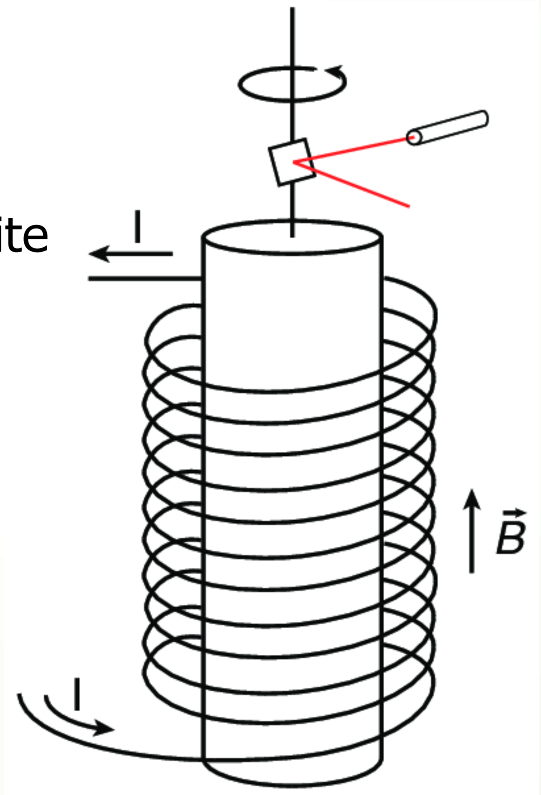
Einstein de-Haas Experiment



Pic. 5.6. Magnetic moment vectors in a probe.

Proposed Arrangement

Microwave excitation to achieve Ferromagnetic resonance for negative μ



Ferrite core

DC voltage to be applied

Description

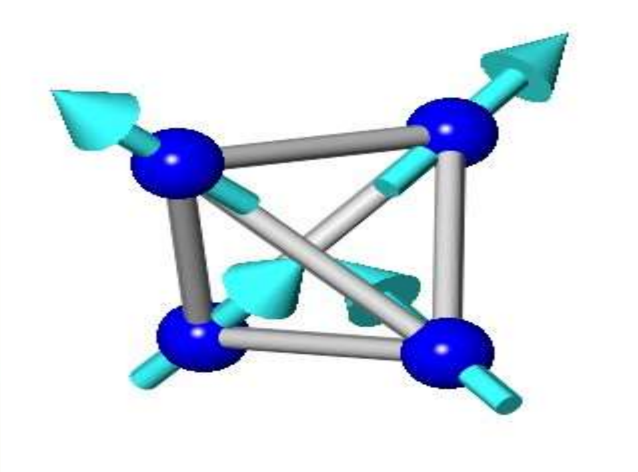
Microwave excitation is given to the coil which is wound around the ferrite core in order to achieve ferromagnetic resonance.

An FMR signal is observed due to the effect of spin precession on the macroscopic magnetization as it is driven by an external AC magnetic field, which is generated using microwave power-
Ref-Ko-Wei Lin, in Solid State Physics, 2020

FMR- The resonant frequency depends on a number of magnetic properties including gyromagnetic ratio, saturation magnetization, magnetic anisotrophy, and applied external field

Ferromagnetic Resonance

- FMR occurs when the frequency of the alternating magnetic field matches the natural precessional frequency of the magnetic moments in the material
- Magnetic moments in a ferromagnetic material naturally precess around an external magnetic field due to the torque exerted by the field



Explanation

- The orientation of the magnetic moments (light blue arrows) considering a single tetrahedron within the spin ice state, as in figure
- Here, the magnetic moments obey the two-in, two-out rule: there is as much "magnetization field" going in the tetrahedron (bottom two arrows) as there is going out (top two arrows). The corresponding magnetization field has zero divergence. There is therefore no sink or source of the magnetization inside the tetrahedron, or no *monopole*.
- If a thermal fluctuation caused one of the bottom two magnetic moments to flip from "in" to "out", one would then have a 1-in, 3-out configuration; hence an "outflow' of magnetization, hence a positive divergence, that one could assign to a positively charged monopole of charge +*Q*. Flipping the two bottom magnetic moments would give a 0-in, 4-out configuration, the maximum possible "outflow" (i.e. divergence) of magnetization and, therefore, an associated monopole of charge +2*Q*.

Divergence of Magnetic field

- Divergence of magnetic field exists.
- There will be net inward flow of flux or outward flow of flux either into the material or out of the material.
- $\nabla . B \neq 0$

Description

The negative permeability appears when the ferromagnetic resonance (FMR) of the ferrite taking place.

Ref: Bi, K., Guo, Y., Zhou, J. *et al.* Negative and near zero refraction metamaterials based on permanent magnetic ferrites. *Sci Rep* **4**, 4139 (2014).

If the external field is applied to the ferrite core, due to negative permeability, it will oppose the applied field.

B inside the material opposes the external magnetic field

In certain scenarios, negative permeability can indeed lead to the expulsion of magnetic fields resulting in B=0.

This phenomenon is somewhat analogous to the Meissner effect observed in superconductors, where magnetic fields are expelled from the interior of the material.

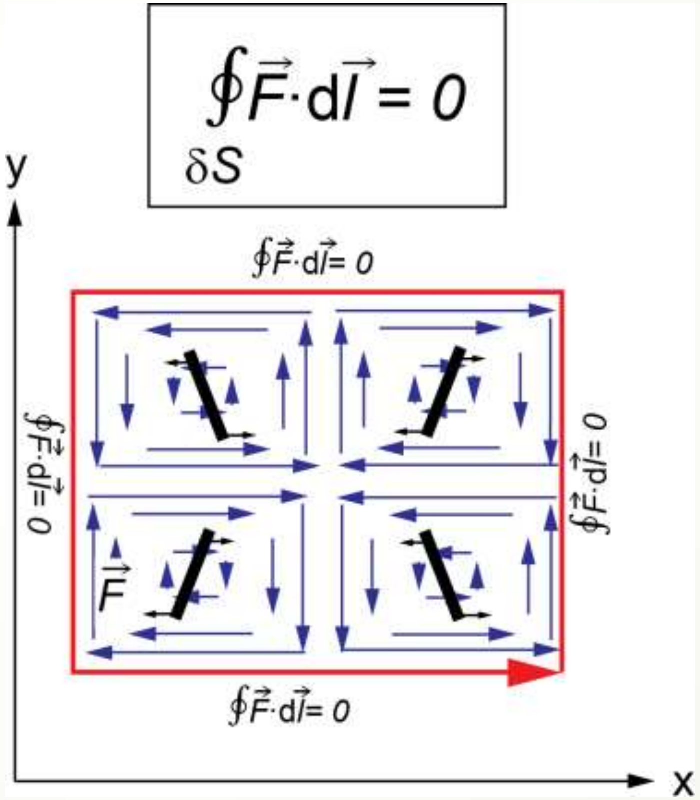
In the case of negative permeability, the negative magnetic response effectively shields the interior of the material from external magnetic fields

Inference

- Unlike normal superconductors, the superconductivity in this case can be achieved at a normal ambient temperature.
- At the negative permeability state of ferrite(rotation exists), on applying DC electric field ,the magnetization due to it results in cancellation of the inherent magnetization in the material resulting in B=0 and the core stops rotating and this state of the core where it attains its superconductivity
- Curl equation of B=0 ànd no net torque on the moving charge carriers
- Radius of curvature of the moving charge carrier in a finite magnetic field, r=mv/qB, where B=0
- r=∞ , which is a straight line. The ferrite core will remain stationary and there will be no rotation.

$$F=q.(v \times B)$$

Curl equation for superconductor=0 -no net force on the moving charges



Application

- Possibility of existence of magnetic monopoles

- Major breakthrough application-

Room temperature Superconductors

CD-Maxwell Equation

- Normally, the curl of magnetic field exists but in this case , the curl of magnetic field is zero.(μ=-ve)

$$\nabla X B=0$$

The divergence of magnetic field exists, it may indicate the presence of magnetic monopole.But it is not free in nature , it is confined inside the core under ferromagnetic resonance under the application of no DC electric field.

$$\nabla . B \neq 0$$

Ref:Superinsulators:The Hideout of Magnetic Monopoles

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Thank you

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Any Questions? Please....