

COMPUTER MODEL OF THE TORQUE IN A WEAK MAGNETIC MEDIUM DEPENDING ON THE DIRECTION OF THE EXTERNAL MAGNETIC FIELD

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Abstract: In this work, the behavior of weakly magnetic materials under the influence of an external magnetic field was studied based on a computer model. The angular dependence of the torque acting on the magnetic dipole and the net force under conditions of a homogeneous and gradient magnetic field was analyzed by numerical modeling. The influence of the angle between the magnetic moment and the external field on the angular momentum was determined, and the characteristic differences for paramagnetic and diamagnetic materials were shown. It was confirmed that the obtained results correspond to the laws of classical electromagnetism.

Keywords: weak magnetic material, magnetic dipole moment, torque, external magnetic field, angular dependence, gradient field, computer modeling.

Weak magnetic materials are characterized by very small magnetization under the influence of an external magnetic field, and the magnetic dipole model plays an important role in determining their magnetic properties. In a homogeneous magnetic field, such materials do not produce a net force, but a force moment arises due to the angle between the magnetic moment and the direction of the field. In the presence of a magnetic field gradient, an additional net force arises in a weak magnetic medium.

In recent years, the study of the behavior of weakly magnetic materials in angular and spatial magnetic fields using computer modeling methods has become increasingly relevant from a scientific and practical point of view. In this work, the formation and change of the torque under the influence of an external magnetic field at different angles are investigated based on a computational model.

Weak magnet - is a material that shows very small or almost imperceptible magnetization under an external magnetic field. Electron spins of such materials are irregular or their sensitivity to an external field is very low. Weak magnetic materials (such as paramagnetic or diamagnetic materials, or weak magnetic dipoles) respond mainly through induced or existing magnetic moments when exposed to an external uniform magnetic field. This effect often depends on the angle θ between the material's magnetic moment (μ) and the external magnetic field (B). Below are the basic theoretical concepts, formulas, and explanations. This theory is based on classical electromagnetism and describes the behavior of a magnetic dipole in an external field.

Position of a magnetic dipole in an external magnetic field

In the same magnetic field, no net force acts on the magnetic dipole (weak magnet), since the field is the same everywhere. However, a torque acts on the dipole, which forces the dipole to rotate in the direction of the field. This moment tends to make the magnetic moment of the dipole parallel to the field.

Formula: $\tau = \mu \times B$ (in vector form)

In magnitude: $\tau = \mu B \sin \theta$

Here:

τ - torque (Nm),

μ - magnetic dipole moment (Am²),

B - external magnetic field (T),

θ is the angle (degree) between μ and B .

The maximum value of $\sin \theta$ is at 1 ($\theta = 90^\circ$), i.e., the moment is greatest; at $\theta = 0^\circ$ or 180° , the moment is zero.

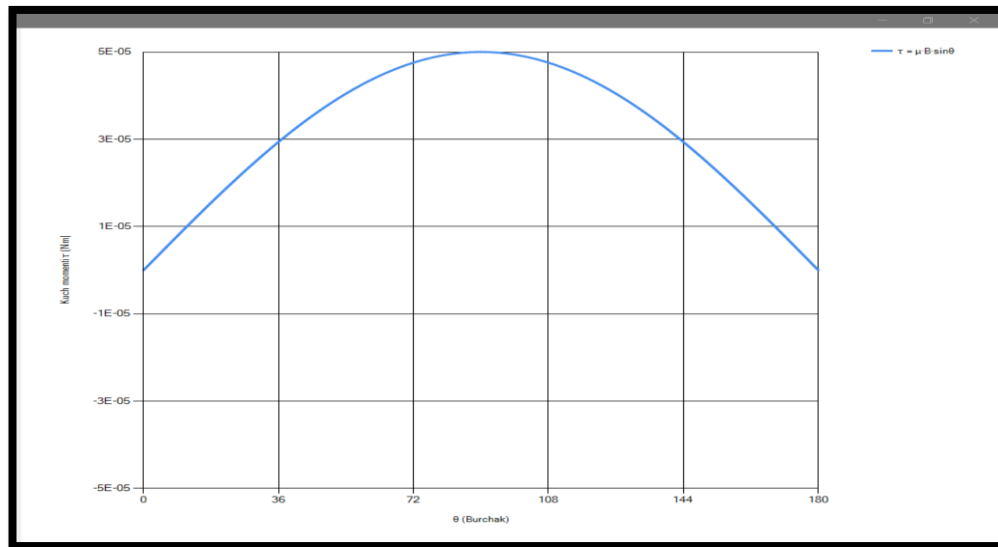


Figure 1. Dipole in a uniform magnetic field | Torque

Correlation of angles and significance of the experiment

When studying the effect at different angles (e.g., 0° , 45° , 90° , 135° , 180°):

$\theta = 0^\circ$: Moment zero, energy minimal - the magnet remains "in place."

$\theta = 90^\circ$: The moment is maximal - the magnet is rotated strongly.

In weak magnetics (small μ), this effect is weak, but measurable. In paramagnetic materials (for example, aluminum), weak attraction is observed, in diamagnetic materials (for example, copper), weak repulsion.

This theory is applied in compass operation, magnetic resonance imaging (MRI), and other devices.

Moment of couple on Magnetic field

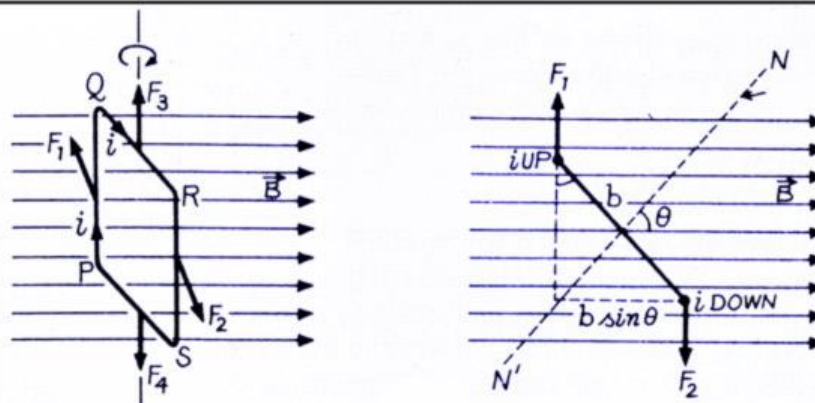


Figure 2. Magnetic dipole: Magnetic dipole moment and properties

Influence of magnetic field gradient

Magnetic field gradient is the spatial change in magnetic field strength (B), i.e., when the field is not uniform. When weakly magnetic materials (such as paramagnetic or diamagnetic

materials) are subjected to an external gradient magnetic field, unlike the previous state of the same field, not only torque but also net force appears. This force pulls or pushes the material toward the strong or weak side of the field. Below are the basic theoretical concepts, formulas, and explanations. This theory is based on classical electromagnetism and describes the motion of a magnetic dipole in a non-uniform field.

Force in a non-uniform field

In a uniform magnetic field, a net force does not act on the magnetic dipole, only a moment. However, in a gradient field (non-uniform), a change in the field ($\beta\beta$) attracts the dipole towards the strong field (for paramagnetics) or repels it towards the weak field (for diamagnetics). This force depends on the magnetic moment (μ) of the dipole and the field gradient.

Formula (in vector form): $F = \beta (\mu \cdot B)$ Or equivalent: $F = (\mu \cdot \beta) B$ (if μ does not depend on the field).

In magnitude (if the gradient is in the same direction, for example, along z): $F_z = \mu_z (\partial B_z / \partial z)$ Here:

F - net force (N),

μ - magnetic dipole moment (Am²),

B - magnetic field (T),

- gradient operator, indicating spatial changes in the field.

The larger the gradient, the stronger the force. For example, paramagnetic materials ($\mu > 0$) are attracted to the strong field, while diamagnetic materials ($\mu < 0$) are attracted to the strong field.

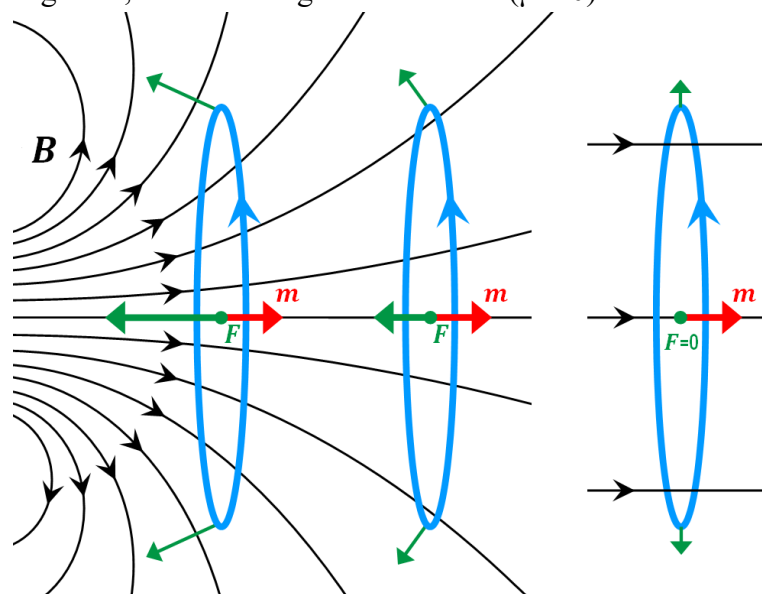


Figure 3. Magnetic dipole moment

Experimental significance and examples

When studying gradient effects:

- Paramagnetic materials (e.g., oxygen, aluminum): They are attracted to a strong field because their induced moment is parallel to the field.
- Diamagnetic materials (such as water, copper): Repelled in the direction of a weak field because the moment is opposite to the field.
- In the experiment: Gradient coils can be used to create a field gradient. Weighing scales or a suspended system are used to measure force.

This theory is applied from gradient fields for imaging in MRI machines, as well as in magnetic separators and nanotechnologies. If the field is the same, then there will be only a moment (as described in the previous section).

In this work, the behavior of weakly magnetic materials under the influence of an external magnetic field was analyzed from the point of view of classical electromagnetism. It has been shown that in a uniform magnetic field, a net force does not act on the magnetic dipole, but a force moment arises, which tends to rotate the magnetic moment in the direction of the field. The dependence of the magnitude of the torque on the magnetic dipole moment, the force of the external field, and the angle between them according to the sine law was substantiated. The movement of paramagnetic and diamagnetic materials in opposite directions in a gradient field was explained by the sign of their magnetic moment.

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