What property does “magnetic field” denote?

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ABSTRACT

When we have at some point the phenomenon we describe, overall, as a “magnetic field”, it has two distinct quantifiable properties.

But we find that often when “magnetic field” is mentioned in the sense of a specific quantifiable property, sometimes it means one of these two properties and sometimes the other. Over the years this has led to innumerable misunderstandings in technical writings.

In this article, I illuminate that ambiguity and make recommendations for usage to avert any misunderstandings.

1 AN EXPLICIT MAGNETIC CIRCUIT

1.1 Introduction

In figure 1 we see an illustrative magnetic circuit with an explicit path trough a “core” composed of a material that is “friendly” to the flow of what we call *magnetic flux* (the “stuff” of magnetism), such as iron (often called a “ferromagnetic” material, since iron is the classical example of such).

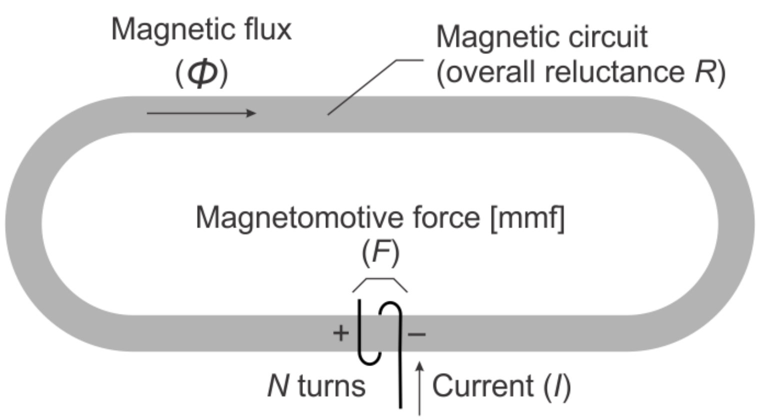

Figure 1. Magnetic circuit

1.2 In a vacuum, or in air

Keep in mind that to have a magnetic phenomenon it is not necessary to have an explicit core of a ferromagnetic material. Such a phenomenon can exist in a vacuum, or in air, or in water.

But in, for example, air, that phenomenon is not essentially confined to a certain path but, in theory, has infinite extent, and thus is mathematically far less tidy. And so the focus here on an explicit "ferromagnetic" magnetic circuit (within which the magnetic phenomenon is almost wholly contained) makes it easier for us to understand what comes next.

1.3 Magnetomotive force

Referring to figure 1, the magnetic circuit is "energized" in the magnetic sense with a certain amount of what is called *magnetomotive force* (mmf for short), with symbol F_m, [1] in this case by means of an electrical coil, having N turns, surrounding the magnetic core, with an electrical current I through it. The + and – signs show the sign of that mmf.

The resulting value of F_m is given (in SI [2] units) by:

$$F_m = NI \qquad (1)$$

Note that it would seem that the unit of NI must be the *ampere-turn*, and it is usually called that in practical technical writing. But since "turn" is dimensionless and unitless (just a "counting number"), mathematically the unit is just the *ampere* (and this is in fact the SI unit).

Magnetomotive force is somewhat parallel to *voltage* in an electrical circuit (whose formal name is in fact *electomotive force*).

1.4 Magnetic flux and reluctance

This magnetomotive force causes a flow of *magnetic flux*, Φ, around the circuit. The value of Φ is given by:

$$\Phi = \frac{F_m}{R} \qquad (2)$$

where R [3] is the *reluctance* of the circuit.

The arrow in figure 1 shows the direction of this flux.

The SI unit for magnetic flux is the Weber (Wb), which is equivalent to the volt-second (yes, it is not easy to see why).

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[1] In some formal writing, $\mathfrak{F}$ ("curly F") is used for *magnetomotive force*.

[2] "SI" refers to the International System of Units (from its French name).

[3] In some formal writing, $\mathfrak{R}$ ("curly R") is used for *reluctance*.

The SI unit of reluctance is the inverse Henry (H^{-1}), where the unit Henry is the same as the SI unit for the inductance of an electrical circuit element.

Magnetic flux is somewhat parallel to *current* in an electrical circuit. Reluctance is somewhat parallel to the *resistance* of an electrical circuit. The equation above is somewhat parallel to *Ohm's law* in an electrical circuit.

2 NORMALIZED UNITS

2.1 Magnetomotive force gradient

It we consider a certain magnetomotive force (mmf), F, applied to a magnetic circuit of length L (in meters), and divide F by L, we get a normalized property that can be aptly thought of as the "mmf gradient".

Its symbol is **H** (shown that way since it is a vector quantity). The SI unit of its magnitude must be the *ampere per meter* (A/m).

In the literature, this quantity is given several names (which is the problem that is the topic of this article), including: [I have emphasized the one that figures in the point of this article.]

- Magnetic field intensity
- Magnetic field strength
- **Magnetic field**
- Magnetizing field [strength]

In the SI it is called *magnetic field strength*.

2.2 Magnetic flux density

If we consider an amount of magnetic flux, Φ, traveling though an explicit circuit of cross-sectional area A (in square meters), and divide Φ by A, we get a normalized property (the amount of magnetic flux per unit of cross-sectional area) that can be aptly called the "magnetic flux density".

Its symbol is **B**. The unit of its magnitude (in SI terms) must be the *weber per meter squared* (Wb/m^2). That unit, however, has is own SI name, the *tesla* (T).

In the literature, this quantity is given several names, including: [Again I have emphasized the one that figures in the point of this article.]

- Magnetic flux density
- Magnetic induction
- **Magnetic field**

In the SI it is called *magnetic flux density*. [Which seems quite reasonable on its own.]

2.3 The B-H relationship

It is quite reasonable to consider that it is the phenomenon whose SI name is *magnetic field strength* (**B**) causes the phenomenon whose SI name is *magnetic flux density* (**H**).

The resulting relationship is this (for SI units):

$$\mathbf{B} = \mu \mathbf{H} \quad (3)$$

where μ (lower-case Greek "mu") represents the parameter *permeability*. It is not a property of a circuit but rather is a "volumetric" property of the material of which the circuit is composed. (For a vacuum, $\mu = 1$.)

It can be thought of as the "receptiveness" of space composed of that material to have **B** create **H** there.

The unit of μ is the *weber per ampere-meter*. That unit does not have its own "simple" name.

3 "FIELDS" IN PHYSICS

3.1 The basic definition

The basic definition, in physics, of a "field" is a physical quantity that has a value for each point in space and time. Thus we could have the "temperature field" of a part in an automotive engine at a specified point in time: a phenomenon that has a at every point of the part.

This definition is actually of little value to the current discussion, but I include it for rigor.

3.2 Fields that exert a force

But in physics we often speak of a "field" as a phenomenon that (at a certain point and time) exerts a force on some sort of particle.

For example, a *gravitational field* exerts a force on a particle with mass. An *electric field* exerts a force on a particle carrying an electrical charge. A "magnetic field" exerts a force on a moving particle carrying an electrical charge.[4] (I put magnetic field in quotes owing to the ambiguity as to what that term describes.)

3.3 The force exerted by a "magnetic field"

The force exerted on a moving particle carrying an electrical charge in a "magnetic field" is proportional to:

- The charge on the particle
- The magnitude of the velocity of the particle
- The magnitude of **B**
- The sine of the angle between the velocity vector and the vector **B**.

Thus it might seem that "magnetic field" should be considered to refer to **B**, even though it is **H** whose formal name includes the term "magnetic field" (as noted in section 2.1).

4 THE AMBIGUITY

4.1 In the literature

In the field of magnetics, over the range of technical literature, both the properties represented by **B** and **H** are sometimes called a "magnetic field" (and we see that in the lists of names in sections 2.1 and 2.2).

So we see that we encounter an ambiguity as to the meaning of "magnetic field". This of course has led to many bedeviling misunderstandings in work in this field.

4.2 One resolution

One way some authors avoid problems from this ambiguity is to refer to these two properties as the "magnetic B field" and the "magnetic H field". This terminology is certainly unambiguous.

But these terms give no hint as to the nature of these two properties, and so this terminology is not very helpful to the reader. And it is a bit cumbersome. In any case, it has not come into widespread use.

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[4] It may be difficult to visualize a charged particle moving through a magnetic circuit made of iron (although that concept is actually valid and plays an important role in the design of certain electrical components), so feel free to think of a "magnetic field" through the air.

5 RECOMMENDATION

5.1 Introduction

In most areas, my recommended practice is to use the formal SI names for quantities. However, in this case I think the choices made for those names are likely to lead to misunderstanding, so I will recommend departures from the SI terminology

5.2 General

If “magnetic field” is used in the sense of a phenomenon, as in, “the Earth has a significant magnetic field”, that usage is probably reasonable.

But when a specific property is meant, perhaps even leading to its quantification (“how strong is the Earth’s magnetic field at the surface of the Earth in Cleveland, Ohio”) we need to be very cautious as to which property is actually meant.[5]

5.3 A temptation

Since in most cases it is the value of **B** that is of interest as to the impact of a “magnetic field”, it is tempting to recommend that the term “magnetic field” be used solely for the phenomenon quantified as **B**.

But this flies fully in the face of the formal SI naming for the two phenomenons: it is **H** whose formal name is *magnetic field strength*.

And adopting that convention would still leave the reader unsure of what was meant (not knowing whose convention was being followed).

So I have not recommended that usage.

5.4 Strategy

Firstly to completely avoid the ambiguity in this matter, I will discourage the use of the phrase “magnetic field” altogether to refer to one of the two phenomenons or the other. (I feel it can be safely used when referring qualitatively to a “magnetic phenomenon”.)

But I have looked for ways to use terms (other then “magnetic field”) that have had some history of use for the two properties, so as to provide some continuity with past practice.

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[5] The property stated for “the strength of the Earth’s magnetic field” is typically denominated in microteslas (μT), and thus must refer to the magnitude of **B**.

5.5 Specific recommendations

a. I recommend that the term “magnetic field” not be used for either of the specific magnetic properties discussed here (those symbolized as **B** and **H**).

b. I recommend that the name “magnetizing field [strength]” be used for the property whose symbol is **H** and its magnitude. (The name *mmf gradient* is also certainly acceptable, and might be more appropriate in a “learned scientific” context)

c. I recommend that the name “magnetic flux density” be used for the property whose symbol is **B** and its magnitude.

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