

Block 16 - Ampère's Law and Magnetomotive Force (MMF)

Student Group

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Table of Contents

Block 16 - Ampère's Law and Magnetomotive Force (MMF)	2
<i>Learning objectives</i>	2
<i>Preparation at Home</i>	2
<i>90-minute plan</i>	2
<i>Conceptual overview</i>	2
<i>Core content</i>	2
<i>Generalization of the Magnetic Field Strength</i>	2
Notice:	3
Notice:	4
<i>Common pitfalls</i>	5
<i>Exercises</i>	5
Worked examples	5
<i>Embedded resources</i>	5

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Learning objectives

After this 90-minute block, you can

- ...

Preparation at Home

Well, again

- read through the present chapter and write down anything you did not understand.
- Also here, there are some clips for more clarification under 'Embedded resources' (check the text above/below, sometimes only part of the clip is interesting).

For checking your understanding please do the following exercises:

- ...

90-minute plan

1. Warm-up (x min):
 1.
2. Core concepts & derivations (x min):
 1. ...
3. Practice (x min): ...
4. Wrap-up (x min): Summary box; common pitfalls checklist.

Conceptual overview

1. ...

Core content

Generalization of the Magnetic Field Strength

So far, only the rotational symmetric problem on a single wire was considered in formula, when the current I and the length s of a magnetic field line around it is given:

$$\begin{align*} \quad H_{\varphi} = \frac{I}{s} = \frac{I}{2 \cdot \pi \cdot r} \quad \Leftrightarrow \end{align*}$$

$$\oint \vec{H} \cdot d\vec{s} = I_{\text{enc}} \quad \text{applies only to the long, straight conductor}$$

Now, this shall be generalized. For this purpose, we will look back at the electric field. For the electric field strength E of a capacitor with two plates at a distance of s and the potential difference U holds:

$$U = E \cdot s \quad \text{applies to capacitor only}$$

In words: The potential difference is given by adding up the field strength along the path of a probe from one plate to the other.

This was extended to the voltage between two points 1 and 2 . Additionally, we know by Kirchhoff's voltage law that the voltage on a closed path is "0".

$$\oint \vec{E} \cdot d\vec{s} = 0$$

We can now try to look for similarities. Also for the magnetic field, the magnitude of the field strength is summed up along a path to arrive at another field-describing quantity.

Because of the similarity the so-called **magnetic potential difference V_m** between point 1 and 2 is introduced:

$$V_m = \int \vec{H} \cdot d\vec{s} \quad \text{applies to rotational symmetric problems only}$$

$$V_m = \int \vec{H} \cdot d\vec{s} = \theta$$

We need to take a closer look here. Any closed path in the static electric field leads to a potential difference of $\oint \vec{E} \cdot d\vec{s} = 0$.

BUT: closed paths in the static magnetic field leads to a magnetic potential difference which is **not mandatorily** 0 ! $V_m = \oint \vec{H} \cdot d\vec{s} = \theta$

Another new quantity is introduced: the **magnetic voltage θ** :

1. The magnetic voltage θ is the magnetic potential difference on a closed path.
2. Since the magnetic voltage θ is valid for exactly one turn along our single wire, θ is also equal to the current through the wire:

$$\theta = \oint \vec{H} \cdot d\vec{s} = I \quad \text{applies only to the long, straight conductor}$$
3. The magnetic potential difference can take a fraction or a multiple of one turn and is therefore **not mandatorily** equal to I .
4. The magnetic voltage is generalized in the following box.

Notice:

The path integral of the magnetic field strength along an arbitrary closed path is equal to the free currents (= current density) through the surface enclosed by the path.

The magnetic voltage θ (and therefore the current) is the cause of the magnetic field strength.

This leads to the **Ampere's Circuital Law**

$$\oint_{\gamma} \vec{H} \cdot d\vec{s} = \theta$$

The magnetic voltage θ can be given as

- $\theta = I$ for a single conductor
- $\theta = N \cdot I$ for a coil
- $\theta = \sum_n I_n$ for multiple conductors
- $\theta = \int_A \vec{S} \cdot d\vec{A}$ for any spatial distribution (see [block15](#))

Notice:

$\oint_{\gamma} \vec{H} \cdot d\vec{s}$ and $\oint_{\gamma} \vec{A} \cdot d\vec{s}$ in $\oint_{\gamma} \vec{H} \cdot d\vec{s} = \theta = \int_A \vec{S} \cdot d\vec{A}$ build a right-hand system.

1. Once the thumb of the right hand is pointing along $\oint_{\gamma} \vec{A} \cdot d\vec{s}$, the fingers of the right hand show the correct direction for $\oint_{\gamma} \vec{H} \cdot d\vec{s}$ for positive $\vec{H}$ and $\vec{S}$
2. Currents into the direction of the right hand's thumb count positive. Currents antiparallel to it count negative.

Fig. 1: Right hand rule



Common pitfalls

- ...

Exercises

Worked examples

...

Embedded resources

Explanation (video): ...

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