

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

Student Group

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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:

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

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

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:

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

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".

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

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:

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

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

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

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

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:

$$\theta = H \cdot s = I \quad | \quad \text{applies only to the long, straight conductor}$$
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**

$\oint_{\mathcal{S}} \vec{H} \cdot d\vec{s} = \theta$	<p>The magnetic voltage θ can be given as</p> <ul style="list-style-type: none"> $\theta = I$ 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)
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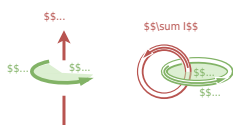
The unit of the magnetic voltage θ is **Ampere** (or **Ampere-turns**).

Notice:

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

1. Once the thumb of the right hand is pointing along $\oint_{\mathcal{S}} \vec{A}$, the fingers of the right hand show the correct direction for $\oint_{\mathcal{S}} \vec{s}$ 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

- ...

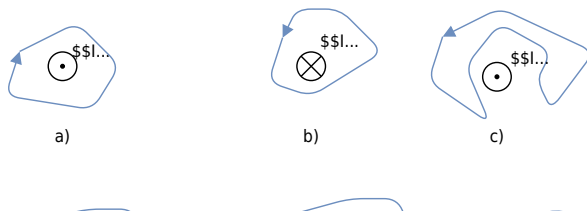
Exercises

Task 3.2.3 Magnetic Potential Difference

Fig. 3: different trajectories around current-carrying conductors

Result **b)**

$$b) \oint_C \mathbf{H} \cdot d\mathbf{l} = 2 \text{ A} = (-2.5 \text{ A}) + (4.5 \text{ A}) \quad I = -2.5 \text{ A}$$



Given are the adjacent closed trajectories in the magnetic field of current-carrying conductors (see figure 3). Let $I_1 = 2 \text{ A}$ and $I_2 = 4.5 \text{ A}$ be valid.

In each case, the magnetic potential difference V_{m} along the drawn path is sought.

Path

- The magnetic potential difference is given as the **sum of the current through the area within a closed path.**
- The direction of the current and the path have to be considered with the righthand rule.

Embedded resources

Explanation (video): ...

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Last update: **2025/11/22 19:01**

