

Block 17 — Magnetic Flux Density and Forces

Student Group

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Block 17 — Magnetic Flux Density and Forces

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

...

Common pitfalls

- ...

Exercises

Exercise E6 Fields of an coax Cable

(written test, approx. 12 % of a 120-minute written test, SS2024)

2. For the graph of the magnitude of the electric field strength E of a coax cable with 0.6 mm inner diameter and 0.55 mm outer diameter, see the diagram. The diagram is a coordinate system with the origin $(0,0)$ in the center of the cable. The dimensions and labels for the diagram appear as follows:

Path

- Inner conductor: $+3.3 \text{ nA}$, $+10 \text{ nC}$ (current into the plane of the path diagram)
- Outer conductor: -3.3 nA , 0 nC (current out of the plane of diagram)
- for $(0.1 \text{ mm} | 0)$: $E_{\text{inner}} = 5.28 \text{ V/m}$
- for $(0.55 \text{ mm} | 0)$: $E_{\text{outer}} = 6.985 \text{ V/m}$

The magnitude of the electric displacement field D can be calculated by: $\int D \cdot dA = Q_{\text{enc}}$.

In general, the E -field is proportional to $\frac{1}{r}$ for the situation between both conductors.

Here, for any position r at the center, the surrounding area is the surface of a cylindrical shape (here for simplicity without the round endings).

For the charges Q on the surface of the inner and outer conductors, this leads to: $D(x) = \frac{Q}{2\pi r A}$ and $E(x) = \frac{Q}{2\pi r A \epsilon_0}$.

This is proportional to the area within this radius. Therefore, the formula $H = \frac{I}{2\pi r}$ is used.

So, we get for E at $r = 0.1 \text{ mm}$ and $r = 0.55 \text{ mm}$.

For x within the outer conductor one also gets a linear proportionality with a similar approach: $E = \frac{Q}{2\pi r A}$ and $E = \frac{10 \cdot 10^{-9} \text{ C}}{2\pi \cdot 0.1 \cdot 10^{-3} \cdot 0.5 \cdot 10^{-3}}$ and $E = \frac{10 \cdot 10^{-9} \text{ C}}{2\pi \cdot 0.55 \cdot 10^{-3} \cdot 0.5 \cdot 10^{-3}}$.

Hint: For the direction, one has to consider the sign of the enclosed charge. By this, we see that the D -field is positive.

But here, again only the magnitude was questioned!

.. What is the magnitude of the magnetic field strength H at $(0.1 \text{ mm} | 0)$ and $(0.55 \text{ mm} | 0)$?

Path

The magnitude of the magnetic field strength H can be calculated by: $H = \frac{I}{2 \pi \cdot r}$
 So, we get for H_{i} at $r_{\text{i}} = 0.1 \text{ mm}$, and H_{o} at $r_{\text{o}} = 0.55 \text{ mm}$:

$$H_{\text{i}} = \frac{I}{2 \pi \cdot r_{\text{i}}} = \frac{+3.3 \text{ A}}{2 \pi \cdot 0.1 \cdot 10^{-3} \text{ m}} \quad H_{\text{o}} = \frac{I}{2 \pi \cdot r_{\text{o}}} = \frac{+3.3 \text{ A}}{2 \pi \cdot 0.55 \cdot 10^{-3} \text{ m}}$$

Hint: For the direction, one has to consider the right-hand rule. By this, we see that the H -field on the right side points downwards.
 Therefore, the sign of the H -field is negative.
 But here, only the magnitude was questioned!

Exercise E2 Magnetic Flux Density (written test, approx. 6 % of a 120-minute written test, SS2021)

A) The electric motor is operated for an experiment in the laboratory. A current $I = 100 \text{ A}$ with a magnitude of $I = 100 \text{ A}$ is operated.
 How stand it to it and the cable about what this value has been? (B points independent) about.
 The figure below shows the top view of the laboratory with the supply line between A and B .
 $B = 0.12 \text{ m}$
 $\mu_0 = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}}$, $\mu_r = 1$

The formula for the magnetic field strength can be rearranged: $H = \frac{I}{2 \pi \cdot r} \quad r = \frac{I}{2 \pi \cdot H}$

Again, the magnetic flux density B is given as: $B = \mu_0 \mu_r H$
 Therefore: $r = \frac{\mu_0 \mu_r I}{2 \pi \cdot B} = \frac{4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 100 \text{ A}}{2 \pi \cdot 100 \cdot 10^{-6} \text{ T}}$

a) What is the highest magnetic flux density through the line in your body? (3 points)

Path

The magnetic field strength for a conducting wire is given as:

$$H = \frac{I}{2\pi \cdot r}$$

The magnetic flux density B is given as: $B = \mu_0 \mu_r H$

Here, the maximum current is $\hat{I} = 100 \text{ A}$ and the distance to the cable is $r = \sqrt{(0.1 \text{ m})^2 + (0.4 \text{ m})^2} = 0.412... \text{ m}$.

$$B = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1 \cdot \frac{100 \text{ A}}{2\pi \cdot 0.412... \text{ m}}$$

Exercise E1 Toroidal Coil**(written test, approx. 5 % of a 120-minute written test, SS2021)**

A magnetic field with a flux density of at least 50 mT is to be achieved in a ring-shaped coil (toroidal coil).

The coil has 60 turns, wound around soft iron with $\mu_r = 1200$.

The average field line length in the coil should be $l = 12 \text{ cm}$.

Result: $I_{\text{min}} = 4 \text{ A}$



What is the minimum current that must flow through a single winding?

Path

The magnetic field strength of a toroidal coil is given as:

$$\begin{aligned} H &= \frac{N \cdot I}{l} \end{aligned}$$

Based on the flux density the magnetic field strength can be derived by $B = \mu_0 \mu_r \cdot H$.

By this, the formula can be rearranged:

$$\begin{aligned} H &= \frac{N \cdot I}{l} \quad \parallel \quad \frac{B}{\mu_0 \mu_r} &= \\ \frac{N \cdot I}{l} &\parallel I &= \frac{B \cdot l}{\mu_0 \mu_r \cdot N} \\ \end{aligned}$$

Putting in the numbers:
$$I = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1'200 \cdot 60} \parallel = 0.6631... \frac{\text{T} \cdot \text{m}}{\frac{\text{Vs}}{\text{Am}}} = 0.6631... \frac{\text{Vs}}{\text{m}^2} \cdot \text{m} \parallel = 0.6631... \text{ A}$$

Exercise E1 Lorentz Force (hard!)

(written test, approx. 10 % of a 120-minute written test, SS2021)

A) ~~300 picture below shows straight high voltage direct wire of the dimensions shown in the picture. A current of $I = 200 \text{ A}$ flows through the wire.~~
 Result: A component of $F = 1'200 \text{ N}$ of the Lorentz force acts? (Independent)

A homogeneous geomagnetic field is assumed. The magnetic field strength has a vertical component of $B_v = 40 \mu\text{T}$ and a horizontal component of $B_h = 20 \mu\text{T}$.

Only a ~~1'500 N~~ force is perpendicular to \vec{B}_v and to \vec{F}_L and points in the right direction by the right-hand rule.

The angle between the transmission line and the horizontal component of the field strength is $\alpha = 20^\circ$.
 The picture on the right shows the line (black), the field strength components, and the angle in front and top view for illustration purposes.

- a) Calculate the force that results from the current flow on the entire conductor.
First, calculate the vertical and horizontal components and combine them accordingly.

Path
Top View

Path

The force on the transmission line can be calculated via the Lorentz force

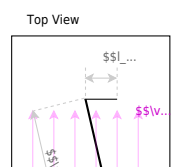
$$\vec{F} = I \cdot (\vec{l} \times \vec{B})$$

- The horizontal component \vec{F}_h of the force is based on the vertical component \vec{B}_v of the magnetic field.
- The vertical component \vec{B}_v of the magnetic field is not shown in the image but is pointing into the ground.
- Considering the right-hand rule (and the cross product), the vertical field \vec{B}_v generates a horizontal force \vec{F}_h and vice versa. The right-hand rule has to be applied.

The **horizontal component** is given by

$$\begin{aligned} F_{\text{h}} &= I \cdot (I \cdot B_{\text{v}}) = 1'200 \text{ A} \cdot 300 \\ &\cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \frac{\text{Vs}}{\text{m}^2} = 14'400 \\ &\frac{\text{VA}}{\text{m}} = 14'400 \frac{\text{Ws}}{\text{m}} = 14'400 \text{ N} \end{aligned}$$

For the **vertical component** the angle α has to be considered.
 For the maximum F_{v} the angle α has to be 90° , therefore the \sin has to be used.



$$\begin{aligned} F_{\text{v}} &= I \cdot I \cdot B_{\text{h}} \cdot \sin\alpha = 1'200 \\ &\text{ A} \cdot 300 \cdot 10^3 \text{ m} \cdot 40 \cdot 10^{-6} \frac{\text{Vs}}{\text{m}^2} \\ &\cdot \sin 20^\circ = 2'462.545... \text{ N} \end{aligned}$$

For the **overall force** F the Pythagorean theorem has to be used:

$$\begin{aligned} F &= \sqrt{F_{\text{v}}^2 + F_{\text{h}}^2} = \sqrt{(14'400 \text{ N})^2 + (2'462.545... \text{ N})^2} \\ &= 14'609.04... \text{ N} \end{aligned}$$

Embedded resources

Explanation (video): ...

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