

# Block 17 — Magnetic Flux Density and Forces

## Student Group

First Name	Surname	Matrikel Nr.

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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 E1 Cylindrical Coil

(written test, approx. 6 % of a 120-minute written test, SS2021)

A) The magnetic flux (2 points) information is given:

Result

- Length  $l = 30 \text{ cm}$ ,

Path Winding diameter  $d = 390 \text{ mm}$ ,

- Number of windings  $N = 240$ ,
- Air-core winding with inductor  $I = 500 \text{ mA}$ ,

- Material inside: Air

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$$

$$\text{The magnetic field strength is } B = \mu_0 \mu_r \cdot H:$$

The proportion of the magnetic voltage outside the coil can be neglected. Determine the following for the inside of the coil:

$$\Phi = B \cdot A = \mu_0 \mu_r \cdot N \cdot I \cdot \pi \cdot r^2$$

a) Determine the magnetic field strength  $H$  and the magnetic flux  $\Phi$ .

$$H = \frac{N \cdot I}{l} = \frac{240 \cdot 0.5 \text{ A}}{0.3 \text{ m}} = 400 \text{ A/m} \quad \Phi = \mu_0 \cdot N \cdot I \cdot \pi \cdot r^2 = 4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 240 \cdot 0.5 \text{ A} \cdot \pi \cdot (0.195 \text{ m})^2 = 0.0005026 \text{ Vs}$$

Path

$$\Phi = B \cdot A = \mu_0 \mu_r \cdot N \cdot I \cdot \pi \cdot r^2$$

Putting in the numbers:  $\Phi = 0.0005026 \text{ Vs}$

$$\Phi = \mu_0 \cdot N \cdot I \cdot \pi \cdot r^2 = 4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 240 \cdot 0.5 \text{ A} \cdot \pi \cdot (0.195 \text{ m})^2 = 0.0005026 \text{ Vs}$$

Putting in the numbers:  $H = \frac{N \cdot I}{l} = \frac{240 \cdot 0.5 \text{ A}}{0.3 \text{ m}} = 400 \text{ A/m}$

## Exercise E2 Magnetic Flux Density

(written test, approx. 6 % of a 120-minute written test, SS2021)

A) The circuit for the experiment is shown in the laboratory. As a result, a current  $I = 100 \text{ mA}$  with an

amplitude of  $\hat{I} = 100 \text{ mA}$  is operated.

How is the distance  $r$  and the current  $I$  related? (3 points, independent)

The figure below shows the top view of the laboratory with the supply line between  $A$  and  $B$ .

$$B = 0.12 \text{ T}$$

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}, \mu_r = 1$$

The formula for the magnetic field strength can be rearranged:  $H = \frac{B}{\mu_0 \mu_r}$

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

Again, the magnetic flux density  $B$  is given as:  $B = \mu_0 \mu_r H$

Therefore: 
$$r = \frac{\mu_0 \mu_r \left\{ \frac{I}{2\pi \cdot B} \right\}}{4\pi \cdot 10^{-7} \left\{ \frac{\text{Vs}}{\text{Am}} \right\} \left\{ \frac{100 \sim \text{A}}{2\pi \cdot 100 \cdot 10^{-6} \sim \text{T}} \right\}}$$

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

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

**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  $50 \text{ mT}$  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:  $I_{\text{min}} = 4 \pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}}$



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. What is the Lorentz force on a  $1 \text{ m}$  long segment of the wire?~~

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  $1 \text{ m}$  long segment is perpendicular to  $\vec{B}_v$  and to  $\vec{B}_h$  and points in the right direction by the right-hand rule.

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  $F_h$  of the force is based on the vertical component  $B_v$  of the magnetic field.
- The vertical component  $F_v$  of the force is based on the horizontal component  $B_h$  of the magnetic field.

Here, we have two components for the current and therefore for the force - to evaluate.

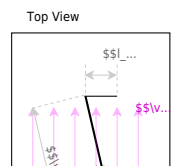
Considering the right-hand rule (and the cross product), the vertical field  $B_v$  generates a horizontal force  $F_h$  and vice versa.

The **horizontal component** is given by



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

For the **vertical component** the angle  $\alpha$  has to be considered.  
 For the maximum  $F_{\text{v}}$  the angle  $\alpha$  has to be  $90^\circ$ , therefore the  $\sin$  has to be used.



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

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

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

## Embedded resources

Explanation (video): ...

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Permanent link:

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