

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 E3 Magnetic Flux Density

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

A) The circuit below is operated for a few days in the laboratory. A current of $I = 100 \text{ A}$ is operated. Result: $\hat{I} = 100 \text{ A}$ is operated.

Now stand next to it and think about what this value means. (3 points, independent)

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

Path B = 0.2 m

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

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

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

Therefore:
$$r = \frac{\mu_0 \mu_r I}{2\pi B} = \frac{4\pi \cdot 10^{-7} \text{ Vs/Am} \cdot 100 \text{ A}}{2\pi \cdot 100 \cdot 10^{-6} \text{ T}} = 0.2 \text{ m}$$

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:

$$\begin{aligned} H &= \frac{I}{2\pi \cdot r} \end{aligned}$$

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

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

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

Exercise E4 Toroidal Coil

(written test, approx. 5 % of a 120-minute written test, SS2021)

A magnetic field with a flux density of at least $50 \text{ ~\rm mT}$ 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 $l = 12 \text{ ~\rm cm}$.

$$B = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1200 \cdot \frac{60}{12 \cdot 10^{-2} \text{ m}}$$



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 $B = \mu_0 \mu_r H$.

By this, the formula can be rearranged:

```
\begin{align*} H &= \left\{ \frac{N \cdot I}{l} \right\} \parallel \left\{ \frac{B}{\mu_0 \mu_r} \right\} &= \\ \left\{ \frac{N \cdot I}{l} \right\} \parallel I &= \left\{ \frac{B \cdot l}{\mu_0 \mu_r \cdot N} \right\} \\ \end{align*}
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Putting in the numbers: \begin{align*} I &= \left\{ \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \cdot \frac{\text{Vs}}{\text{Am}} \cdot 1'200 \cdot 60} \right\} \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} \end{align*}
```

Exercise E12 Lorentz Force (hard!)

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

A) The picture below shows a straight high-voltage line where the transmission line makes the Resultal component of $F = 1'200 \text{ N}$ on the resulting force act? (Independent)

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

Only $1'500 \text{ A}$ 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.

Top View

— — — — —

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

- The horizontal component $\vec{F}_{\text{h}}$ of the force is based on the vertical component $\vec{B}_{\text{v}}$ of the magnetic field.
- The vertical component $\vec{B}_{\text{v}}$ of the magnetic field is not shown in the image but is pointing into the ground.

The force on the transmission line can be calculated via the Lorentz force. The right-hand rule has to be applied.

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

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

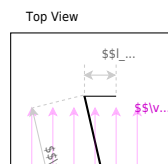
Considering the right-hand rule (and the cross product), the vertical field B_{v} generates a horizontal force F_{h} and vice versa.

The **horizontal component** is given by

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

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.



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

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

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

Embedded resources

Explanation (video): ...

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