

# Block 17 — Magnetic Flux Density and Forces

## Student Group

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# Block xx - xxx

## 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 E9 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  $0.6 \text{ mm}$  inner diameter and  $0.55 \text{ mm}$  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:

Path

- Inner conductor:  $+3.3 \text{ nA}$ ,  $+10 \text{ nC}$  (current into the plane of the path diagram)
- Outer conductor:  $-3.3 \text{ nA}$ ,  $0 \text{ nC}$  (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:  $\int D \cdot dA = Q_{\text{enc}}$ .

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).

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

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  $H_{\text{i}}$  at  $(0.1 \text{ mm} | 0)$ , and  $H_{\text{o}}$  at  $(0.55 \text{ mm} | 0)$ :

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

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 E3 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  $\hat{I} = 100 \text{ A}$  is operated.

Now stand still and think about what this value has to do with the motor's performance.

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

Path  $B = 0.1 \text{ m}$  in  $T$

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

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

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:

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

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 E5 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:

$$H = \frac{N \cdot I}{l}$$

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:

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

Putting in the numbers:  $I = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1200 \cdot 60} = 0.6631... \frac{\text{T} \cdot \text{m}}{\frac{\text{Vs}}{\text{Am}}} = 0.6631... \frac{\text{Vs}}{\text{m}^2} \cdot \text{m} \cdot \frac{\text{Vs}}{\text{Am}}} = 0.6631... \text{ A}$

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

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

$$I = \frac{B \cdot l}{\mu_0 \mu_r \cdot N} = \frac{0.05 \text{ T} \cdot 0.12 \text{ m}}{4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}} \cdot 1200 \cdot 60}$$



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  $B = \mu_0 \mu_{\text{r}} \cdot H$ .

By this, the formula can be rearranged:

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\begin{align*} H &= \frac{N \cdot I}{l} \parallel \frac{B}{\mu_0 \mu_{\text{r}}} &= \\ \frac{N \cdot I}{l} \parallel I &= \frac{B \cdot l}{\mu_0 \mu_{\text{r}} \cdot N} \\ \end{align*}
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Putting in the numbers: \begin{align*} 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} \end{align*}
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## Embedded resources

Explanation (video): ...

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