University Karlsruhe - International Department

Physics Course - Exercises Summer 2009

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Sheet 9
23.9.2009

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1. Exercise: A falling frame

At $t = 0\,\mathrm{s}$ a quadratic metallic frame with length $a = 1\,\mathrm{mm}$ is moving with velocity $v = 1\,\frac{\mathrm{m}}{\mathrm{s}}$ into a coil parallel to its $N = 100$ turns. Through the coil with length $\ell = 12.6\,\mathrm{cm}$ and radius $r = 1\,\mathrm{cm}$ flows a current of $I = 1\,\mathrm{A}$. Consider the radius of the coil is sufficiently large and neglect effects of self induction as well as the magnetic field outside the coil.

(i) Calculate the magnetic field of the coil.

(ii) How would this quantity change when iron ($\mu_r = 1000$) is inserted into the coil? (The relative permeability μ_r describes the relative *increase* of the magnetic field by matter in the same way the relative permittivity ϵ_r does for the relative *decrease* of the electric field.)

(iii) Draw the timedependent magnetic flux $\Phi(t)$ for the empty coil.

(iv) What is the maximal induced voltage $\hat{U}_{\mathrm{ind}}$ for the empty coil?

(v) When can this value be measured?

(vi) In which direction is the current flowing through the frame?

2. Exercise: A train ride

Background: When trains drive along their railways their axles act as conductors which are moving through the magnetic field of the earth. Through induction a current will flow in the rails and the axles which will slow the train.

A metal crossbar is pulled with a constant velocity $v = 30\,\frac{\mathrm{m}}{\mathrm{s}}$ along two conducting rails placed at a distance $\ell = 1\,\mathrm{m}$, which are connected by a resistor $R = 50\,\mathrm{m}\Omega$ as shown on the next page. The crossbar and the rails have negligible resistance. A magnetic field $B = 50\,\mu\mathrm{T}$ is present at an angle of $\alpha = 60°$ to the rails.

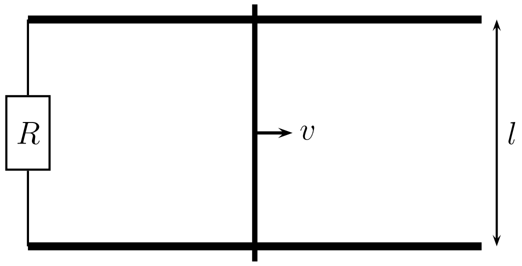
(i) Calculate the magnetic field perpendicular to the plane of the rails.

(ii) Determine the induced voltage U_{ind}.

(iii) Find the induction current I from Ohm's law.

(iv) What force F is needed to keep the metal crossbar at constant velocity v?

(v) Compare the power input by the force to the energy dissipated in the resistor.



3. Exercise: Magnetohydrodynamic generator

Background: Magnetohydrodynamic (MHD) generators are used in some power plants to increase efficiency, sometimes by 25%. Especially in old fossil-fuelled power plants the hot damps are first passed through a MHD generator and later to the usual generators.

A neutral stream, consisting of electrons and positively charged ions, the latter with mass $m_C = 2 \cdot 10^{-26}\,\text{kg}$ and charge $q_C = 12e$, is entering a parallel plane capacitor parallel to its plates with velocity $v = 9 \cdot 10^5\,\frac{\text{m}}{\text{s}}$ on its central axis. Initially the capacitor with area $A = \ell^2 = 100\,\text{m}^2$ and distance $d = 1\,\text{cm}$ is not charged, but inside a homogeneous magnetic field of $B = 1\,\text{mT}$ perpendicular to the moving direction of the stream and parallel to the plates is applied. Neglect scattering within the stream.

(i) What kind of movement are the particles performing inside the capacitor?

(ii) At which two positions x_e, x_C will they hit the plates?

(iii) Which plate becomes negatively charged?

(iv) What voltage U_e should be applied so that all particles would pass the capacitor without been deflected.

Note:

- Mass of an electron: $m_e = 9.1 \cdot 10^{-31}\,\text{kg}$
- Elementary charge: $e = 1.6 \cdot 10^{-19}\,\text{C}$
- Permeability of vacuum: $\mu_0 = 1.26 \cdot 10^{-6}\,\frac{\text{Vs}}{\text{Am}}$