5. Ferromagnetic stripe (12 points) — *Jaan Kalda, Eero Uustalu.*

Tools A caliper, a ruler, graph papers, a resistive magnetic field sensor connected to batteries in a battery holder, a multimeter with two wires, a magnet a stripe made from soft ferromagnetic material of thickness 0.25 mm — **do not bend excessively to avoid damaging**.

i) *(0.5 points)*Connect the banana ends of the wires to the COM port and to the VΩmA-port of the multimeter. Switch on the multimeter in 20 volt (DC) range, and touch the two metallic leads of the battery holder (which are next to the points were the red and black wires come out from the holder) with the crocodile ends of the wires. Record the voltage $\mathcal{E}$ on the output leads of the battery holder. If the voltage is below 3.0 V, you may ask for replacement batteries.

For all your magnetic field measurements, keep in mind that *if the battery voltage were to be exactly* 3 V, *each millivolt in the reading would correspond to 10 microteslas of the magnetic field strength. However, the reading in millivolts is proportional to both the magnetic field and to the battery voltage.*

Connect the crocodiles to the yellow and red wires of the magnetic sensor. Keep in mind that (a) the sensor may have a non-zero offset: even if there is no magnetic field, the multimeter reading V_0 might be non-zero; (b) there is always the magnetic field of Earth. In what follows, avoid measuring magnetic fields which correspond to voltage readings bigger than 500 mV — such strong fields may cause changes in the offset value V_0. If you accidentally expose sensor to such fields, determine and use the new value of V_0.

The magnetic sensor has a small white dot marked on one of its edges. This points to the direction of that magnetic field component which is being measured.

ii) *(1.5 points)*Determine the offset voltage V_0 and the magnitude of the Earth's magnetic field $B_E \equiv |\vec{B}_E|$, and the angle between the vertical direction and the direction of $\vec{B}_E$.

Now, attach the magnet to the ferromagnetic stripe so that its circular face is touching the stripe's surface near one of its ends. Let us use a perpendicular system of coordinates where $x-y$-plane is the plane of the stripe, with the longest symmetry axis of the stripe serving as the x-axis, and $x=0$ being at the position of the centre of the magnet.

The total magnetic field is the superposition of the field of the permanent magnet $\vec{B}_m$, the field of the magnetised ferromagnetic stripe $\vec{B}$, and the Earth's magnetic field $\vec{B}_E$. Below we are interested only in $\vec{B}$. Assume that $\vec{B}_m$ depends only on the distance from the magnet and remains unchanged when the magnet is detached from the stripe.

iii) *(2.5 points)*Measure the vertical field $B_z = B_z(L/2,y)$ caused by the stripe with the magnet, as a function of y, for $-w/2 \le y \le w/2$, at $x = L/2$, where w denotes the width and L — the length of the stripe. Find the ratio $\kappa = \langle B_z \rangle$ to $B_z(L/2,0)$, where the average magnetic field

$$\langle B_z \rangle \equiv \int_{-w/2}^{w/2} B_z(L/2,y)\mathrm{d}y.$$

Assume that κ remains constant along the stripe.

iv) *(3.5 points)* Measure $B_z(x,0)$ near the surface of the stripe, as a function of x, and plot the measurement results.

v) *(2.5 points)* Let J_s denote the saturation magnetisation of the stripe material; estimate the value of $J_s\mu_0$ (this is, roughly speaking, the strongest magnetic B-field which the ferromagnet is able to carry).

vi) *(1.5 points)* Prove experimentally that by small values of x, the magnetisation inside the stripe has reached saturation.