

10. BALL MAGNET (10 points) — *Jaan Kalda.*

Tools: ball-shaped neodymium magnet of diameter $d = 10\text{ mm}$ with remanence $B_r = 1.2\text{ T}$, density $\rho_M \approx 7500\text{ kg} \cdot \text{m}^{-3}$; stand; permanent marker; ruler; measuring tape; flat iron disk; square wooden plate with an iron pin inserted at one side; flat wooden plate with guiding rails and non-slipping surface between them; piece of titanium of diameter 2.4 mm and length 3.4 mm fixed to a string. Density of titanium $\rho_{\text{Ti}} \approx 4500\text{ kg} \cdot \text{m}^{-3}$.

A uniformly magnetised sphere produces an external field identical to that of a point magnetic dipole with a moment $\mu = \frac{4}{3}\pi R^3 B_r / \mu_0$, where R is the sphere's radius. Along the axis of a dipole, $\vec{B} = \mu_0 \vec{\mu} / (2\pi r^3)$, where r is the distance from the dipole. The dipole moment of the Earth is pointing southwards.

Warning: measure as far as possible from iron objects (table frames, chairs), which strongly perturb the geomagnetic field.

i) (2 points) Find the direction of the magnetisation of the magnet: mark on its surface a dot at the point where the straight magnetic field line exits, and a cross where it enters. *Before leaving the room, give the magnet with the markings to the invigilator.*

ii) (4 points) Find the magnitude of the Earth's magnetic field $|\vec{B}_E|$ at the laboratory location.

iii) (4 points) Titanium is a paramagnetic material with magnetic susceptibility $\chi \ll 1$. A small sample of volume V in an inhomogeneous field $\vec{B}(\vec{r})$ experiences a force $\vec{F} = \frac{1}{2}(\chi V / \mu_0) \text{grad } B^2$ ('grad' denotes derivative in the direction of greatest change). Find χ for the supplied titanium wire piece.