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

Tools: ball-shaped neodymium magnet of diameter $d = 10\,\mathrm{mm}$ with remanence $B_\mathrm{r} = 1.2\,\mathrm{T}$, density $\rho_\mathrm{M} \approx 7500\,\mathrm{kg}\cdot\mathrm{m}^{-3}$; 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 $\rho_\mathrm{Ti} \approx 4500\,\mathrm{kg}\cdot\mathrm{m}^{-3}$.

A uniformly magnetised sphere produces an external field identical to that of a point magnetic dipole with a moment $\mu = \frac{4}{3}\pi R^3 B_\mathrm{r}/\mu_0$, 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 $|\vec{B}_\mathrm{E}|$ 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 $\vec{F} = \frac{1}{2}(\chi V/\mu_0)\,\mathrm{grad}\,B^2$ ('grad' denotes derivative in the direction of greatest change). Find χ for the supplied titanium wire piece.