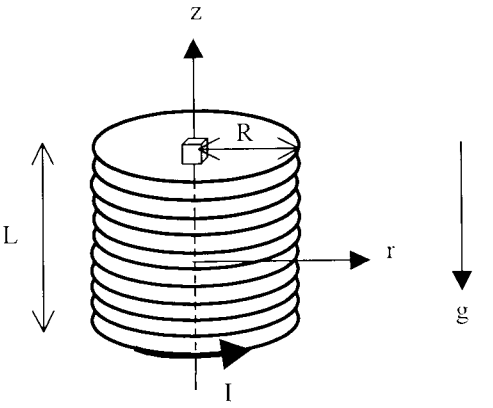
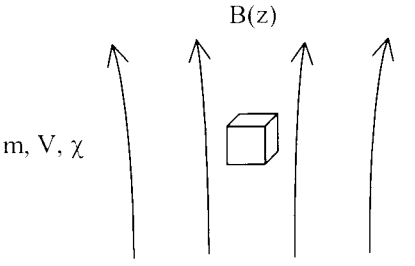
A solenoidal magnet with N turns has radius R and length L. It carries a constant current I. The magnet is oriented with its central axis vertical (along the z-axis). Assume that the number of turns is large (N>>1).



(a) Find the magnitude of the axial magnetic field B_z at the center of the magnet ($z = 0$; $r = 0$), in terms of N, L, R, and I.

(b) Find the ratio of the axial magnetic field at the center of the magnet to that in an infinitely long solenoid with the same number of turns per unit length, the same current, and the same radius, in terms of N, L, and R.

Inhomogeneous magnetic fields can be used to levitate weakly diamagnetic objects (this has recently been done with frogs, as shown). Consider a small, uncharged object of mass m, volume V, and magnetic susceptibility χ, in a spatially-varying vertical magnetic field $B(z)\hat{z}$. Assume that the object is small enough that the transverse components of the magnetic field can be neglected.



(c) Find the magnetic force on the object, in terms of the magnetic field B, its derivative dB/dz, and the parameters V and χ. Compare this to the gravitational force to find an expression for the mass density $\rho = m/V$ of an object that can be levitated in a stable equilibrium position.