1. (**Just for fun**) (2p)

   Assuming the simple $1/R$ dependence for the toroidal magnetic field, calculate the expression for the corresponding gradient-drift velocity (a vector) in terms of the perpendicular speed.

2. (**Magnetic mirror in a tokamak**) (6p)

   Since the magnetic field strength in a tokamak increases towards the symmetry axis and field lines are helical, a particle moving along a field line sees a non-uniform field and, when moving towards a higher field strength, can get reflected if its parallel velocity is not sufficiently high. We say that the particle encounters a magnetic mirror.

   (a) Assuming that the field strength has the simple $1/R$ dependence, find the expression for R_b, the value of major radius at which a particle bounces, i.e., gets reflected, in terms of the magnetic moment μ, the magnetic field strength on the magnetic axis B_0, the major radius of the plasma R_0 and the particle energy E. (3p)

   (b) Show that the condition for a particle to get reflected is given by $\mu B_0/E > 1 - a/R_0$, where a is the minor radius of the plasma. (3p)

   (Hint: Like with the magnetic bottle, use the conservation of energy and magnetic moment.)

3. (**How many bananas in a tokamak?**) (6p)

   Use now the slightly more informative expression for the magnetic field strength, 'derived' during the lecture, $B \approx B_0(1 - \epsilon \cos\theta)$, where $\epsilon = r/R_0$ and θ is the poloidal angle. Assume a large aspect ratio, i.e., that $R_0/r >> 1$.

   (a) Show that for a particle to get reflected somewhere in the plasma it has to satisfy $\frac{v_{\perp,0}^2}{v^2}(1 + 2\epsilon) > 1$, where the sub-index 0 refers to values at the low-field-side equator, i.e., where the magnetic field has its lowest value. (4p)

   (b) Using the result of (a), show that the condition for reflection can also be written as $\frac{v_{\parallel,0}}{v_{\perp,0}} < \sqrt{2\epsilon}$. (2p)

   (Hints: Use the conservation of energy and magnetic moment, and the fact that the last possible point to get reflected is at $\theta = \pi$.)

4. (**Food for thought: Stellarator**)

   During lectures we have discussed only tokamaks when considering toroidal magnetic confinement of plasma. There is an even older concept, called a stellarator, that is making its second coming these days. Find out what a stellarator is, how it differs from a tokamak, why it has been inferior to tokamaks, and why there is suddenly a renewed interest in this concept. Return your short write-up in MyCourses before the next lecture.