Project 3

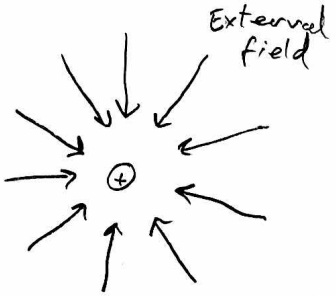
Main topics:

- Ordinary diff. eqs.: initial value problems
  - ↳ One indep. variable. Now: time, t

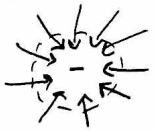
  [So far we've looked at boundary value problems.]
- Main algorithm: Runge-Kutta, 4th order (RK4)
- Object-oriented programming
- Writing a proper report
- Physics case: Simulate a Penning trap [Only classical physics. EM + N2]

Penning trap

- Device for storing charged particles in a vacuum using static $\vec{E}$ and $\vec{B}$ fields.
  - Naive and unphysical idea: Ensure that a positive particle stays put by pushing in from all sides with a static E-field



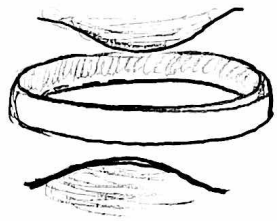
  - This is not possible if we want this to be a vacuum. Because $\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$ ← charge density
    So only way to have this E-field configuration is to have a sink, i.e. a negative charge there
    ⟹ Not a vacuum!



  - Need different solution. ⇒ Penning trap!

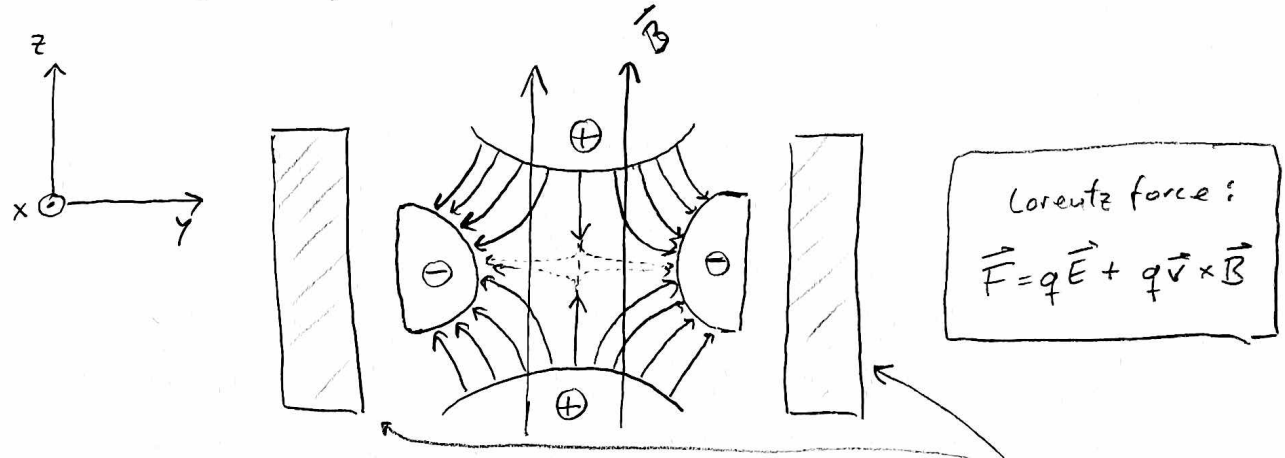
- Used at CERN, e.g. for antimatter research.
  ["Angels & Demons" reference]

- Drawing:



3 electrodes:
2 endcaps
1 ring

At right angles:



- Assume positive particle in trap.
- $\vec{E}$-field confines particle in z-direction, but pushes particles outwards in the x,y direction
- Compensate with $\vec{B}$-field (Put the trap in a magnet.) in z direction
- When a particle moves outwards in xy direction, the $\vec{B}$-field deflects it and puts it into some orbital path
- Penning traps can be used to store / cool down charged particles
- Used in super-precise measurements, e.g. determination of masses of ions (by studying movement), magnetic moments, ...
- Drawback: Lots of material! Difficult to access particles, and difficult to get particles into the trap.

- One approach to filling:
  - Put neutral gas inside
  - Radiate it with ionizing radiation
    atoms → electrons + ions
  - Electrons fly away, positive ions are trapped inside.

- Another approach: Synchronize $\bar{E}, \bar{B}$-fields with beam of particles into trap, so that the fields are off just as the particles enter.

[Go through project description.]