With $\vec{F} = -\operatorname{grad} U(\vec{r})$, the dipole force is

13.15. $$\vec{F}_{dip}(\vec{r}) = -\frac{1}{2\varepsilon_0 c} \operatorname{Re}(\alpha)\, \vec{\nabla} I(\vec{r})$$?

The optical power absorbed by the particle is

$$P_{abs} = \langle \dot{\vec{p}}\, \vec{E} \rangle = 2 \cdot \omega \cdot \operatorname{Im}(p \cdot E^*)$$

13.16. $$= \frac{\omega}{\varepsilon_0 \cdot c} \operatorname{Im}(\alpha) \cdot I \qquad , \omega:$$

and corresponding scattering rate

13.17. $$\Gamma_{sc}(\vec{r}) = \frac{P_{abs}}{\hbar\omega} = \frac{1}{\hbar \varepsilon_0 c} \operatorname{Im}(\alpha)\, I(\vec{r})$$

"quantifies, how often coherent dynamics is interrupted"

- Calculate α using the Lorentz model:

13.18. $$\ddot{x} + \Gamma_\omega \dot{x} + \omega_0^2 x = -\frac{e}{m_e} E(t)$$

result:

13.19. $$\alpha = \frac{e^2}{m_e} \frac{1}{\omega_0^2 - \omega^2 - i\omega\Gamma_\omega}$$

with damping rate

13.20. $$\Gamma_\omega = \frac{e^2 \omega^2}{6\pi \varepsilon_0 m_e c^3}$$ (classical damping rate due to radiative energy loss)

- In the case of large detuning $\delta \equiv \omega - \omega_0 \ll \omega_0$ and after applying the RWA, we obtain the simplified expressions

13.21 $$U_{dip}(\vec{r}) = \frac{3\pi c^2}{2\omega_0^3} \frac{\Gamma}{\delta} I(\vec{r})$$

13.22. $$\Gamma_{sc}(\vec{r}) = \frac{3\pi c^2}{2\hbar \omega_0^3} \left(\frac{\Gamma}{\delta}\right)^2 I(\vec{r})$$

$\longrightarrow$

- same observation as in dressed states treatment:
  - for $\delta < 0$ (red detuning) intensity maxima correspond to potential minima
  - for $\delta > 0$ (blue d.) int. max. corr. to pot. max.

Example: red-det. focussed Gaussian laser beam with intensity

$$I(r,z) = \frac{2P}{\pi w^2(z)} \exp\left(-2\frac{r^2}{w^2(z)}\right), \quad 13.25$$

where

$$w(z) = w_0\sqrt{1+\left(\frac{z}{z_0}\right)^2} \quad 13.26$$

- The optical potential $U(r,z) \sim I(r,z)$ and the depth of the potential is given by $U_0 = |U(r=0, z=0)|$.
- for small temp. of trapped atomic ensembles ($k_B \cdot T \ll U_0$) we have an approx. harmonic potential

$$U(r,z) \simeq -U_0\left[1 - 2\left(\frac{r}{w_0}\right)^2 - \left(\frac{z}{z_0}\right)^2\right] \quad 13.27$$

with oscillation freq.

$$\omega_r = \sqrt{\frac{4U_0}{m w_0^2}}, \quad \omega_z = \sqrt{\frac{2 \cdot U_0}{m \cdot z_0^2}} \quad 13.28$$

- advantages:
  - can be loaded from MOT
  - stores atoms in any (F, m_F) state

other examples:

1D standing wave (conveyor belt, evap. cooling)

2D+3D optical lattice: simulation of solid state physics

evanescent fields: atom mirror and nano fiber-trap

11.5. Magnetic traps

- We know from Stern-Gerlach-Experiment that magnetic fields excert a force

$$\sim \; -\vec{\nabla}\left(-\vec{\mu}\cdot\vec{B}\right)$$

with $\vec{\mu}$ the magnetic dipole moment

- $-\vec{\mu}\cdot\vec{B}$ corresponds to a change of the ground state energy due to the Zeeman effect
- potential is given by

13.29 $$U_{magn}(\vec{r}) = -\vec{\mu}\,\vec{B}(\vec{r}) = g_F\, m_F\, \mu_B\, B(\vec{r})$$

$B(\vec{r}) = |\vec{B}(\vec{r})|$

this assumes that the magnetic moment of the atom adiabatically follows the external magn. field (see later)

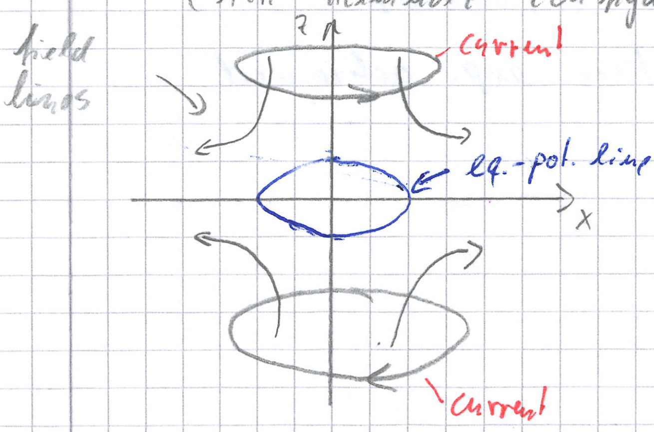
13.30
- $$\vec{F}_{mag} = -\vec{\nabla} U_{mag} = -g_F \cdot m_F \cdot \mu_B \cdot \vec{\nabla} B(\vec{r})$$

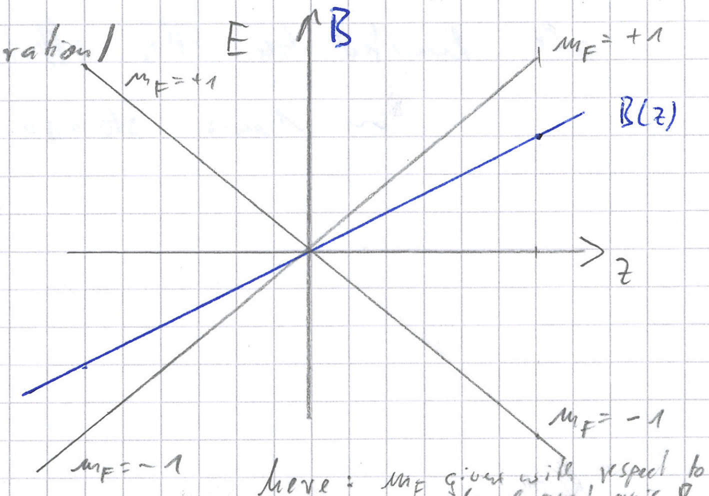
↳ $g_F \cdot m_F > 0$: low-field seeker → req. min. of $|\vec{B}|$

$g_F \cdot m_F < 0$: high-field seeker → req. max. of $|\vec{B}|$ (does not exist in free-space)

simplest configuration : (spherical) quadrupol

- use two parallel coils with currents in opposite directions (Anti-Helmholz-configuration)



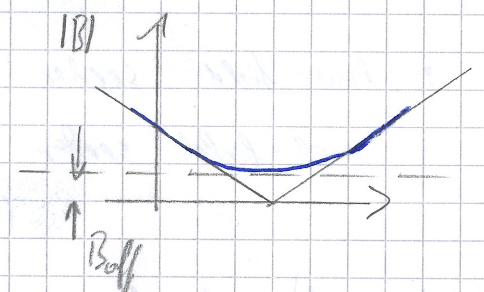


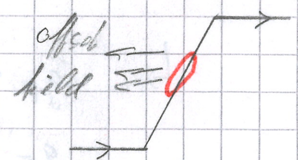
here: m_F given with respect to local quant. axis!

- same config. of magn. fields as for MOT
  ↳ direct loading from one to the other
- magn. field gradients req. in order to hold atoms against gravity: $\approx 10\,g/cm$
- Observation: – for small temp., atoms in the quadropol trap are lost
  – reason: (Majorana) – "Spin flips" become relevant close to $|\vec{B}|=0$, (small temp. → this trajectory more likely)
  ↳ magn. moment cannot adiabatically follow local magn. field anymore
  criterion for adiabaticity:

$$\dot{\omega}_L \ll \omega_L^2 \quad \text{with}$$

  Larmor freq. $\omega_L = g_F \cdot \mu_B |B|/\hbar$
  – after spin flip, atoms might be not in a trapable state anymore
  → solution: avoid $|B|=0$, e.g. Z-trap





- already for $B_{off} \sim 1g$, Spin flips can be supressed for common traps such that the cloud & lifetimes are limited by other effects (pressure)
  ~ 1 min storage time exp. achieved