Describe the basic trapping techniques for ions and neutral atoms

Quantum Engineering II

3rd of June 2021

The Paul Trap

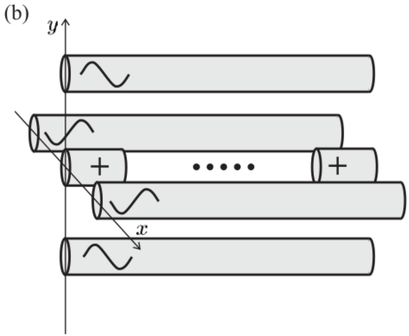
Potential of Quadropole with AC current

$$\phi = \frac{\phi_0}{2r_0}(x^2 - y^2), \quad \text{where} \quad \phi_0 = U + V\cos(\omega t)$$

Ensures that divergence

$$\boldsymbol{\nabla} \cdot \mathbf{E} = \nabla^2 \phi = 0 \quad \text{(No free charges)}$$

Not stable saddle point in the radial direction. Free in z.



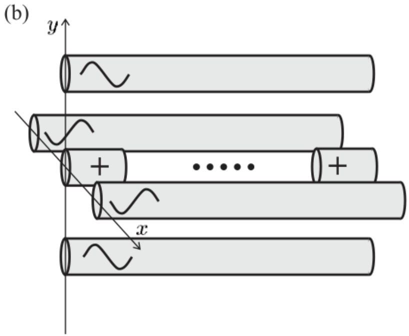
The Paul Trap

The electric field becomes

$$\mathbf{E} = -\boldsymbol{\nabla}\phi, \quad E_x = -\frac{\phi_0}{r_0^2}x$$

Then from Newton

$$m\ddot{x} = +eE_x = \frac{e\phi_0}{r_0^2}x$$



The Paul Trap

Write equations of motion, introduce new variables, τ, a_x and q_x

$$\frac{\mathrm{d}^2 x}{\mathrm{d}\,\tau^2} + (a + 2q\cos(2\tau))x = 0$$
$$\frac{\mathrm{d}^2 y}{\mathrm{d}\,\tau^2} - (a + 2q\cos(2\tau))y = 0$$

where

$$a = \frac{4eU}{mr_0^2\omega^2}, \quad q = \frac{2eV}{mr_0^2\omega^2}, \quad \tau = \frac{\omega t}{2}.$$

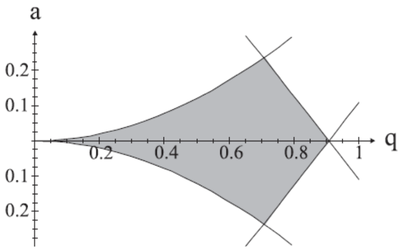


Figure: $a, q \ll 1$

The Paul Trap

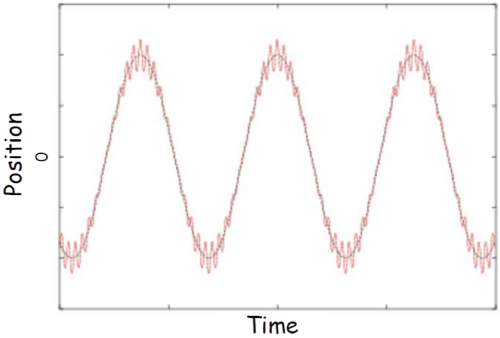
Micromotion and Secular motion

$$x(t) = x_0 \left(1 + \frac{q}{2}\cos(\omega t)\right)\cos(\omega_{\text{sec}} t),$$

$$\omega_{\text{sec}} = \frac{1}{2}\sqrt{a + \frac{q^2}{2}}\omega < \omega$$

Effective Trapping potential

$$\Phi_{\text{pseudo}}(x, y) = \frac{qV}{8}\frac{x^2 + y^2}{r_0^2}$$



Ends

At an extra potential at the ends to trap in z

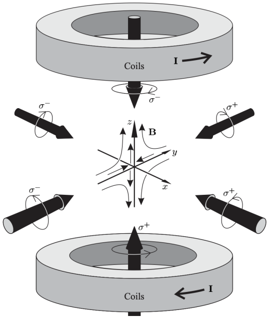
$$\phi(x, y, z) = \phi_{\mathrm{RF}} + \eta U_{\mathrm{end}} \frac{z^2}{z_0} - \frac{1}{2}\eta U_{\mathrm{end}} \frac{x^2 + y^2}{z_0^2} \tag{1}$$

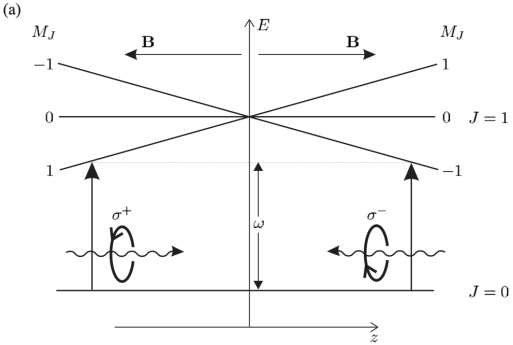
The last term is unstable and comes from

$$\boldsymbol{\nabla} \cdot \mathbf{E} = \nabla^2 \phi = 0 \quad \text{(No free charges)}$$

Must be weaker than the other radial effect.

Magneto-optical traps (MOT)





$$F_{\mathrm{MOT}} = -\alpha v - \beta z$$

Optical Lattice

$$U = -\mathbf{d}\cdot\mathbf{E} = -\frac{\hbar\Gamma}{8}\frac{\Gamma}{\Delta}\frac{I}{I_{\text{sat}}}$$

Red-detuned attracted to high intensity

Walking wave