

# Describe the basic trapping techniques for ions and neutral atoms

## Quantum Engineering II

4th of June 2021

# The Paul Trap

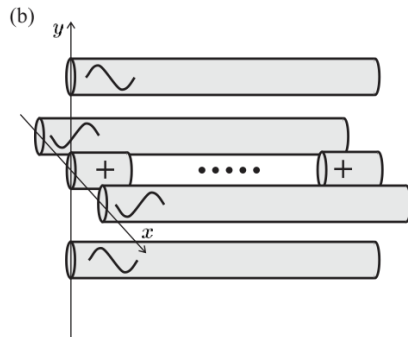
Potential of Quadropole with AC current

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

Ensures that divergence

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

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



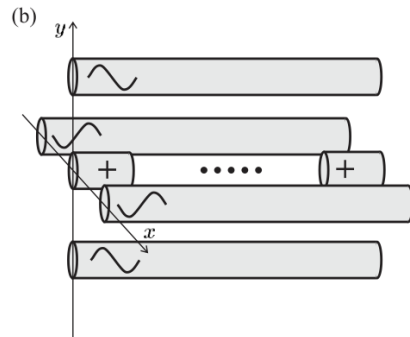
# The Paul Trap

The electric field becomes

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

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,  $\tau$ ,  $a_x$  and  $q_x$

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

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

where

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

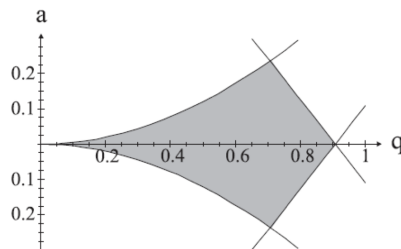


Figure:  $a, q \ll 1$

# The Paul Trap

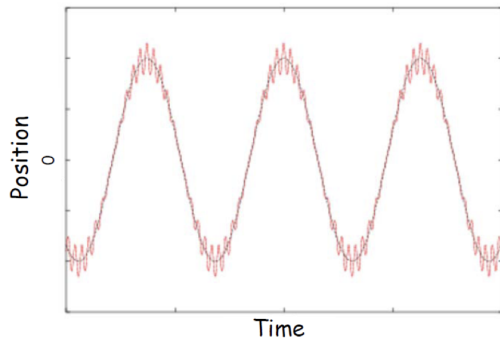
## Micromotion and Secular motion

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

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

## 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  $z$

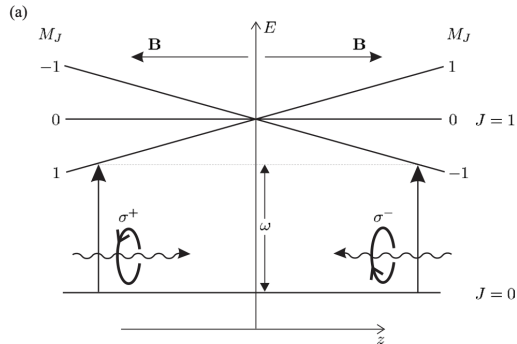
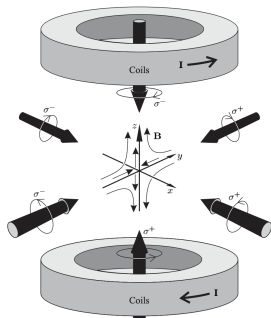
$$\phi(x, y, z) = \phi_{\text{RF}} + \eta U_{\text{end}} \frac{z^2}{z_0^2} - \frac{1}{2} \eta U_{\text{end}} \frac{x^2 + y^2}{z_0^2} \quad (1)$$

The last term is unstable and comes from

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

Must be weaker than the other radial effect.

# Magneto-optical traps (MOT)



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

# 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

