Confinement of Charged Particles in Magnetic Mirrors

Course: MPHYEC-01I Plasma Physics
(M.Sc. IV Sem)

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Lecture 8: Unit-I

Invariance of Magnetic Moment

The components of Lorentz force for a particle moving in magnetic mirrors:

$$\mathbf{F}_r = q(v_\theta B_z - v_z \cancel{B_\theta})$$

$$\mathbf{F}_\theta = q(-v_r B_z + v_z B_r)$$

$$\mathbf{F}_z = q(v_r \cancel{B_\theta} - v_\theta B_r)$$

$$\mathbf{F}_z = -q v_\theta B_r = \frac{q v_\theta r}{2} \frac{\partial B_z}{\partial z}$$

Notably, for a charged particle gyrating along field lines, $v_\theta = \mp v_\perp$ where -ve sign is For +ve charge and -ve sign is for -ve charged particle.

$$\mathbf{F}_z = \mp \frac{q v_\perp r_L}{2} \frac{\partial B_z}{\partial z}$$

Where we have used $r = r_L$ (Larmor radius).

$$\mathbf{F}_z = \mp \frac{1}{2} q \frac{v_\perp^2}{\omega_c} \frac{\partial B_z}{\partial z}$$

$$= -\frac{1}{2} \frac{m v_\perp^2}{B} \frac{\partial B_z}{\partial z}$$

$$\mathbf{F}_z = -\mu \frac{\partial B_z}{\partial z}$$

Where $\mu \equiv \frac{1/2 m v_\perp^2}{B}$ represents magnetic moment associated with the charged particle.

Total energy W= μB_z +1/2($m v_z^2$) where we assume $B \approx B_z$; $v_r << v_z$

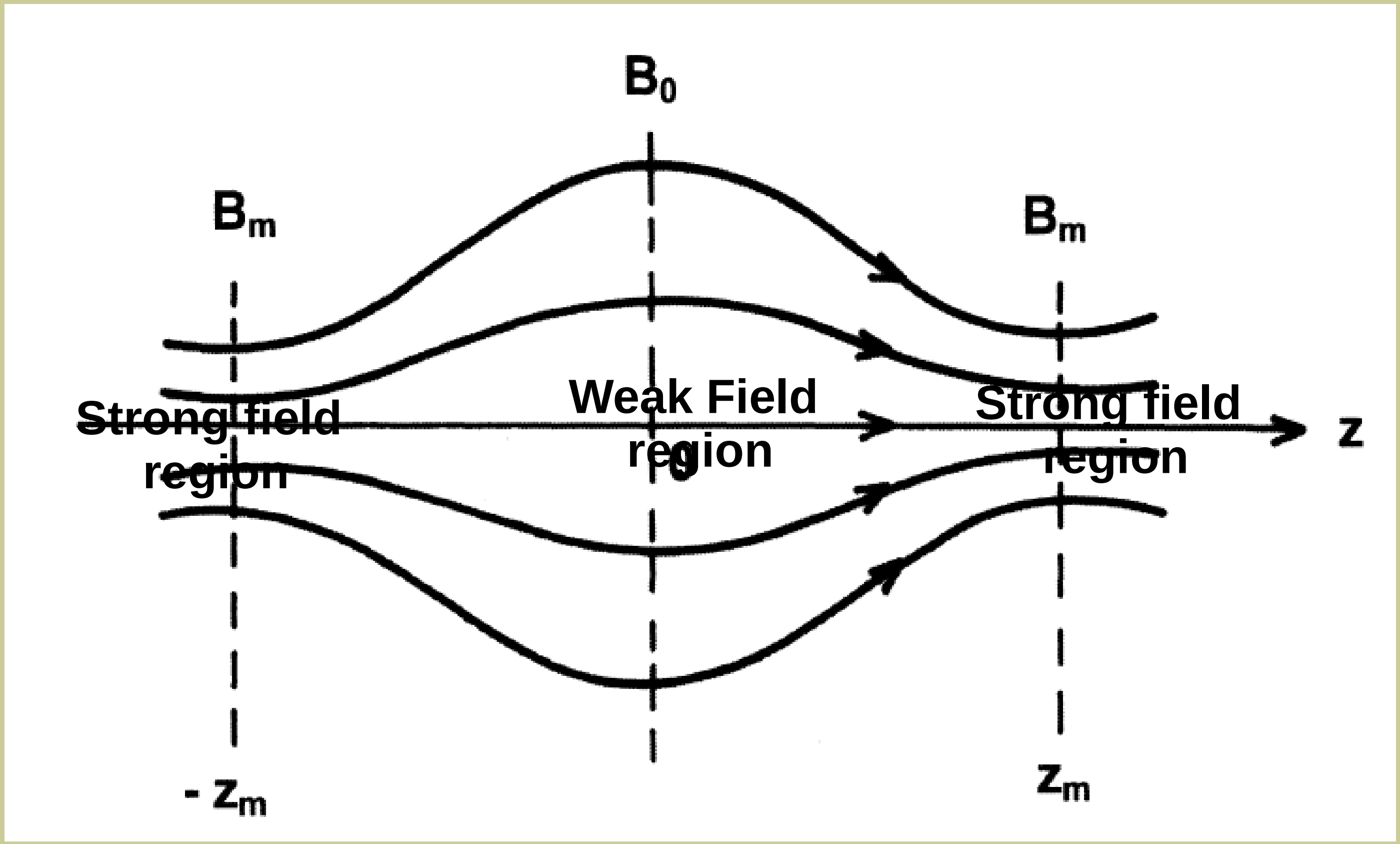
$$\frac{dW}{dt} = \frac{d(\mu B_z)}{dt} + \frac{d(m v_z^2/2)}{dt} = 0$$

$$\frac{d\mu}{dt} = 0$$

Therefore, μ is called **first adiabatic invariant**. Magnetic flux Φ=Kμ is also invariant which called **second adiabatic invariant**. Importantly, although proven for a particular magnetic field configuration, μ and Φ are invariants in non-uniform EM fields which are slowly varying with time (i.e, $\omega_{E/B} << \Omega_c$).

Confinement of Charged Particle

- Invariance of magnetic moment is central to the charged particle confinement in magnetic mirrors.



- When particle moves from a weak field region to strong field region, it experiences an increasing B.

- As a result, v_θ (normal component) increases to keep μ invariant which leads to a decrease in v_z for the constancy of the total energy. Ultimately consiquent into the reflection of particle before reaching to the throats of the coil.

Thanks for the attention!