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Summary of JB lectures

START WITH MICROSCOPIC PHASE SPACE DENSITY

$$\boxed{N(\underline{x},\underline{v},t) = \sum_{i=1}^{N} \delta(\underline{x}-\underline{X}_i(t))\,\delta(\underline{v}-\underline{V}_i(t))}$$ Klimontovitch Density

$\frac{\partial N}{\partial t}$ + ~~[illegible]~~ LORENTZ EQUATIONS $\Rightarrow$ KLIMONTIVICH EQUATION:

$$\boxed{\frac{\partial N}{\partial t} + v\cdot\nabla_x N(\underline{x},\underline{v},t) - \frac{q}{m}(E^m + v\times B^m)\cdot\nabla_v N(\underline{x},\underline{v},t) = 0}$$

or $\boxed{\frac{dN(\underline{x},\underline{v},t)}{dt} = 0}$

Letting $N = f + \delta f$ $\quad f = \langle N\rangle$ $\quad f = \frac{\int N\, d^3x\, d^3v}{\Delta x^3\,\Delta v^3}$

$E^m = E + \delta E$ $\quad E = \langle E_m\rangle$

$B^m = B + \delta B$ $\quad B = \langle B_m\rangle$

$n^{-1/3} \ll \Delta x \ll \lambda$

PERFORMING LOCAL AVERAGES TO OBTAIN SMOOTH & "SLIKEY" QUANTITIES:

$$\boxed{\frac{\partial f}{\partial t} + \dot{\underline{v}}\cdot\frac{\partial f}{\partial \underline{x}} + \frac{d\underline{v}}{dt}\cdot\frac{\partial f}{\partial \underline{v}} = \frac{\partial f}{\partial t_c}} \sim \frac{f}{\tau_c}$$

We estimated $\frac{|\partial f/\partial t_c|}{|\frac{q\underline{E}}{m}\cdot\partial f/\partial \underline{v}|} \sim \frac{1}{16\,\lambda_D^3\, n_0} \ll 1$

$\lambda_D = V_{TH}/\omega_p \qquad V_{TH} \equiv \sqrt{\frac{kT}{m}} \qquad \omega_p \equiv \sqrt{\frac{q^2 n}{\varepsilon_0 m}}$

$$\frac{\partial f}{\partial t} + \underline{v}\cdot\frac{\partial f}{\partial \underline{x}} + \frac{d\underline{p}}{dt}\cdot\frac{\partial f}{\partial \underline{p}} = 0 \quad ; \quad \dot{p} = -\frac{\partial H}{\partial \underline{x}} \; ; \; \dot{x} = \frac{\partial H}{\partial \underline{p}}$$

$\boxed{\frac{df}{dt} = 0}$ LIOUVILLES EQUATION (INCOMPRESSIBILITY OF PHASE VOLUME)

DEFINE NORMALIZED EMITTANCES PROPORTIONAL TO $\Delta p_z \Delta z \propto \Delta E \Delta t$ (CONJUGATE VARIABLES)

$\Delta p_x \Delta x$

$\Delta p_y \Delta y$

SO THAT

$$\varepsilon_{Nx}^2 = \gamma^2\beta^2\left(\langle x^2\rangle\langle x'^2\rangle - \langle x x'\rangle^2\right)$$

$\Rightarrow$ CONSTANT IF FORCES ARE LINEAR IN X & FILAMENTATION IS ABSENT. (LINEAR WITHOUT COUPLING TO Z, OR Y).

WE DERIVED TWO SETS OF PARTICLE EQUATION OF MOTION:

PARAXIAL EQUATION (FOR AXISYMMETRIC SYSTEMS) $\left(\frac{\partial}{\partial\theta} = 0\right)$

STARTING WITH THE LORENTZ FORCE EQUATION $\frac{d\underline{p}}{dt} = q(\underline{E} + \underline{v} \times \underline{B})$ IN CYL. COORD.

$$\underbrace{\frac{d}{dt}(\gamma m \dot{r})}_{\text{INERTIAL}} - \underbrace{\gamma m r \dot{\theta}^2}_{\text{CENTRIFUGAL}} = q\Big(\underbrace{\frac{V''}{2} r}_{E_r \text{ external (DIVERGENCE OF } E = 0)} + \underbrace{r\dot{\theta} B}_{v_\theta B_z}\Big) + q\Big(\underbrace{E_r^{self}}_{\text{SELF-FIELD}} + \underbrace{v_z B_\theta^{self}}_{\text{SELF-FIELD}}\Big)$$

$$\boxed{\dot{r} = \frac{dr}{dt};\ r' = \frac{dr}{ds} = \frac{\dot{r}}{\beta c}}$$

θ-component:

$$p_\theta = \gamma m r^2 \dot{\theta} + \frac{q B(z) r^2}{2} = \text{constant}$$

$$= \gamma m r^2 \beta c \theta' + \frac{q B r^2}{2} = \text{constant}$$

$$\underbrace{r''}_{\text{INERTIAL}} + \underbrace{\frac{\gamma'}{\beta^2\gamma} r'}_{\text{ACCELERATION (INERTIA)}} + \underbrace{\frac{\gamma''}{2\beta^2\gamma} r}_{E_r \text{ (CONVERGENCE OF FIELD LINES)}} + \underbrace{\left(\frac{\omega_c}{2\gamma\beta c}\right)^2 r}_{v_\theta B_z \text{ — CENTRIFUGAL}} - \underbrace{\left(\frac{p_\theta}{\gamma\beta m c}\right)^2 \frac{1}{r}}_{\text{CENTRIFUGAL}} - \underbrace{\frac{q}{\gamma^3 m v_z^2} \frac{\lambda(r)}{2\pi\epsilon_0 r}}_{\text{SELF FIELD}} = 0$$

STATISTICAL AVERAGE OF THIS EQUATION

$$r_b'' + \frac{\gamma'}{\beta^2\gamma} r_b' + \frac{\gamma''}{2\beta^2\gamma} r_b + \left(\frac{\omega_c}{2\gamma\beta c}\right)^2 r_b - \frac{4\langle p_\theta\rangle^2}{(\gamma m\beta c)^2 r_b^3} - \frac{\varepsilon_r^2}{r_b^3} - \frac{Q}{r_b} = 0$$

$$\varepsilon_r^2 \equiv 4\left(\langle r^2\rangle\langle r'^2\rangle - \langle r r'\rangle^2 + \langle r^2\rangle\langle r^2\theta'^2\rangle - \langle r^2\theta'\rangle^2\right); \quad Q = \frac{q\lambda}{2\pi\epsilon_0 \gamma^3 \beta^2 m c^2}$$

$$= \varepsilon_x^2 - 4\langle r^2\theta'\rangle^2 \quad (\text{if } \rho = \rho(r) \text{ only})$$

CARTESIAN EQUATION OF MOTION

J BARNARD

EQUATION OF MOTION

AGAIN STARTING WITH $\frac{d\underline{p}}{dt} = q(\underline{E} + \underline{v} \times \underline{B})$

RETURN TO X, Y COORDINATES

$$x'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z)x' = \frac{-q}{\gamma^3 m v_z^2}\frac{\partial \varphi}{\partial x} \pm \begin{cases} \frac{qB'}{\gamma m v_z} x & \text{for magnetic quads} \\ \frac{qE'}{\gamma m v_z^2} x & \text{for electric quads} \end{cases}$$

Let $\frac{\gamma m v_z}{q} = \frac{p}{q} \equiv [B\rho] \equiv$ RIGIDITY

$$y'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z)y' = \frac{-q}{\gamma^3 m v_z^2}\frac{\partial \varphi}{\partial y} \mp \begin{cases} \frac{B'}{[B\rho]} y & \text{magnetic} \\ \frac{qE'}{\gamma m v_z^2} y & \text{electric} \end{cases}$$

ENVELOPE EQUATION

$$r_x^2 = 4\langle x^2\rangle; \quad r_y^2 = 4\langle y^2\rangle$$

$$r_x' = \frac{4\langle x x'\rangle}{r_x}$$

$$r_x'' = \frac{4\langle x x''\rangle}{r_x} + \frac{\varepsilon_x^2}{r_x^3}; \qquad \varepsilon_x^2 = 16(\langle x^2\rangle\langle x'^2\rangle - \langle x x'\rangle^2)$$

$$r_y'' = \frac{4\langle y y''\rangle}{r_y} + \frac{\varepsilon_y^2}{r_y^3} \qquad \varepsilon_y^2 = 16(\langle y^2\rangle\langle y'^2\rangle - \langle y y'\rangle^2)$$

<u>for magnetic focusing:</u>

$$r_x'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z) r_x' + \frac{4q}{\gamma^3 m v_z^2}\frac{\langle x \frac{\partial \varphi}{\partial x}\rangle}{r_x} \pm \frac{B'}{[B\rho]} r_x - \frac{\varepsilon_x^2}{r_x^3} = 0$$

$$r_y'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z) r_y' + \frac{4q}{\gamma^3 m v_z^2}\frac{\langle y \frac{\partial \varphi}{\partial y}\rangle}{r_y} \pm \frac{B'}{[B\rho]} r_x - \frac{\varepsilon_y^2}{r_y^3} = 0$$

(for electric focusing $\frac{B'}{[B\rho]} \to \frac{qE'}{\gamma m v_z^2}$)

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SPACE CHARGE TERM WITH ELLIPTICAL SYMMETRY

NOW DEFOCUSING IN ONE DIRECTION AND FOCUSING IN THE OTHER $\Rightarrow$ RADIAL SYMMETRY SHOULD BE REPLACED BY ELLIPTICAL SYMMETRY: $\rho = \rho\left(\frac{x^2}{r_x^2} + \frac{y^2}{r_y^2}\right)$

CAN BE SHOWN THAT $\left\langle x \frac{\partial \phi}{\partial x} \right\rangle = \frac{-\lambda}{4\pi\epsilon_0} \frac{r_x}{r_x + r_y}$

$$\left\langle y \frac{\partial \phi}{\partial y} \right\rangle = \frac{-\lambda}{4\pi\epsilon_0} \frac{r_y}{r_x + r_y}$$

USE $\phi(x,y) = \frac{-r_x r_y}{4\epsilon_0} \int_0^\infty \frac{\hat{\rho}(\chi)\, ds}{\sqrt{r_x^2+s}\sqrt{r_y^2+s}}$ to prove, where $\hat{\rho}(\chi) = \frac{d\rho}{d\chi}$

$\rho(x,y) = \hat{\rho}(\chi)\big|_{s=0}$

$\chi = \frac{x^2}{r_x^2+s} + \frac{y^2}{r_y^2+s}$

DEFINING $Q = \frac{2\lambda q}{4\pi\epsilon_0 \gamma^3 m v_z^2}$

$$\Rightarrow \boxed{\begin{aligned} & r_x'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z) r_x' - \frac{2Q}{r_x + r_y} \mp \frac{B'}{[B\rho]} r_x - \frac{\varepsilon_x^2}{r_x^3} = 0 \\ & r_y'' + \frac{1}{\gamma v_z}\frac{d}{ds}(\gamma v_z) r_y' - \frac{2Q}{r_x + r_y} \pm \frac{B'}{[B\rho]} r_y - \frac{\varepsilon_y^2}{r_y^3} \end{aligned}}$$

(for Electric Focusing $\frac{B'}{[B\rho]} \to \frac{qE'}{\gamma m v_z^2}$).

(ANALOGUE TO CIRCULAR BEAM:

$\left\langle r \frac{\partial \phi}{\partial r} \right\rangle = \frac{-\lambda}{4\pi\epsilon_0}$ PROVED IN HOMEWORK)

ENVELOPE EQUATIONS DERIVED

RMS (ENVELOPES DEFINED IN TERMS OF RMS QUANTITIES; EMITTANCE NOT QUANTITIES TO BE CONSERVED).

1. PARAXIAL r_b ; $\rho(r)$
2. ELLIPTICAL r_x, r_y ; $\rho\left(\frac{x^2}{r_x^2}+\frac{y^2}{r_y^2}\right)$
3. LONGITUDINAL r_z FOR $E_z = \frac{-q}{4\pi\varepsilon_0}\frac{\partial\lambda}{\partial z} \propto z$; $[\lambda \propto (1-4z^2/r_z^2)]$ $V \propto (z/r_z)$
4. ELLIPSOIDAL of BUNCHES (ρ CONSTANT) $r_\perp, r_z$ (ALSO r_x, r_y, r_z c.f. Wangler, section 9.9).
5. ELLIPTICAL WITH IMAGES r_x, r_y $\rho\left(\frac{x^2}{r_x^2}+\frac{y^2}{r_y^2}\right)$
6. LARMOR FRAME (PERIODIC SOLENOIDS OR CONTINUOUS FOCUSING) $\tilde{r}_x, \tilde{r}_y$ $\rho(r)$

KINETIC ENVELOPE EQUATIONS (CONSTRAINT EQUATION ON A PARTICULAR DISTRIBUTION FUNCTION; EMITTANCE CONSERVED)

1. KV FOR ELLIPTICAL UNIFORM BEAMS $f(x,x',y,y')$
   [IDENTICAL TO #2 ABOVE]
2. NEUFFER DISTRIBUTION FOR 1D $f(z,z')$
   [IDENTICAL TO #3 ABOVE]

MOMENT EQUATIONS

1. TRANSVERSE WITH CHROMATIC EFFECTS
   $\langle x^2\rangle, \langle x'^2\rangle, \langle xx'\rangle, \langle x^2\delta\rangle, \langle x'^2\delta\rangle, \langle xx'\delta\rangle, \ldots$

Summary of Current Limits From Different Focusing Methods

Einzel Lens

$$Q_{max} \cong \frac{3\pi^2}{8}\left(\frac{q\phi_0}{m v_0^2}\right)^2\left(\frac{r_b}{L}\right)^2$$

Solenoids

$$Q_{max} = \left(\frac{\omega_c r_b}{2\gamma\beta c}\right)^2$$

Quadrupole Focusing

$$Q_{max} \cong \frac{\eta Q_0}{2\pi}\left(\frac{\sin\frac{\eta\pi}{2}}{\frac{\eta\pi}{2}}\right)\left[\frac{B r_b}{[B\rho]}\left[\frac{r_b}{r_p}\right] \quad \frac{2qV_q}{\gamma m v_z^2}\left[\frac{r_b^2}{r_p^2}\right]\right]$$

MAGNETIC

Electric

For Non-Relativistic Beams

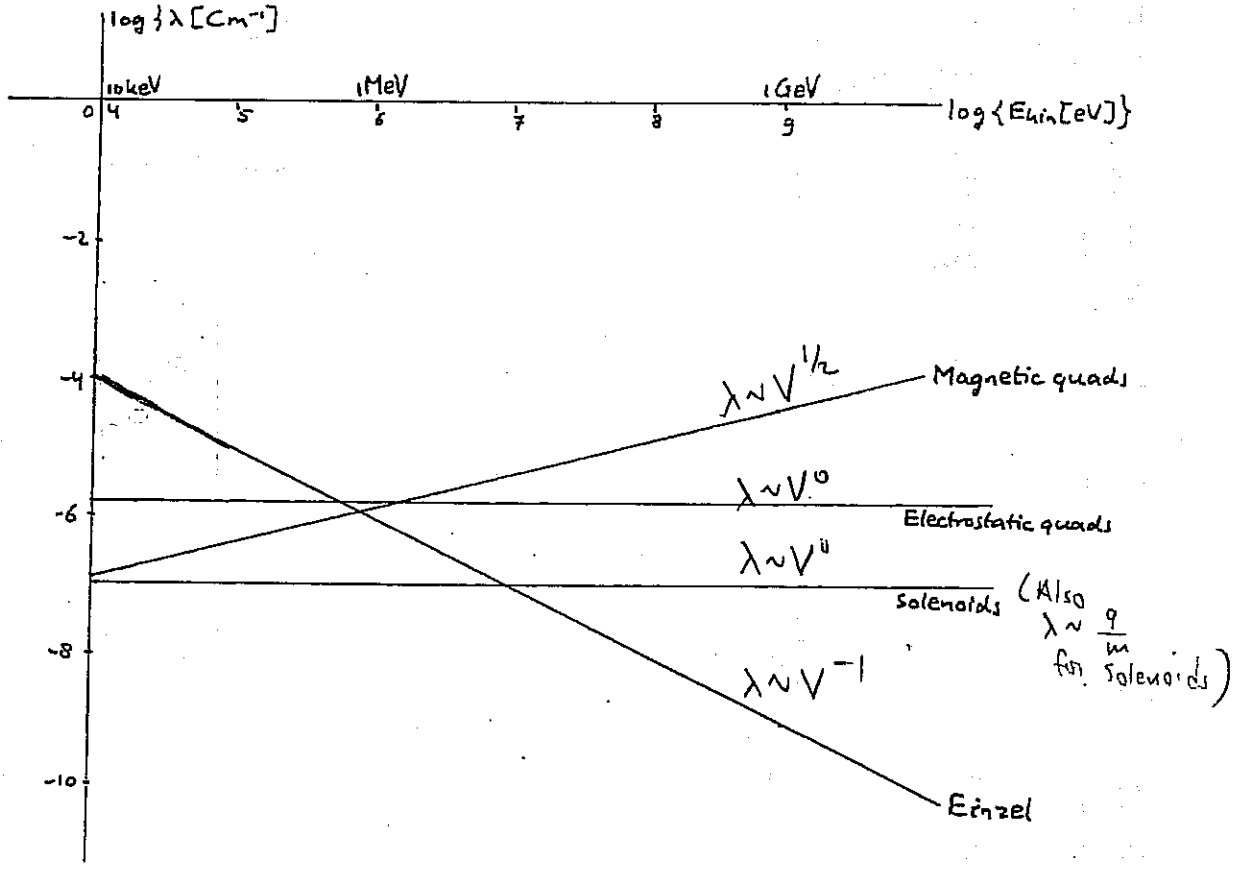
$$\lambda_{max} \propto \frac{Q_0^2}{V}$$

$$\lambda_{max} \propto \frac{q}{m} B^2 r_p^2$$

$$\lambda_{max} \propto \begin{cases} B, V^{1/2} r_p \\ V_q \end{cases}$$

Note
Q_0 = Voltage between Einzel lenses
V_q = Voltage on a quad relative to ground
V = particle energy / q

Solenoids: $\log\{\lambda[Cm^{-1}]\} = -7.0$
Electrostatic quads: $\log\{\lambda[Cm^{-1}]\} = -5.8$
Magnetic quads: $\log\{\lambda[Cm^{-1}]\} = -8.9 + \frac{1}{2}\log\{E_{kin}[eV]\}$
Einzel lenses: $\log\{\lambda[Cm^{-1}]\} = 0.01 - \log\{E_{kin}[eV]\}$



ESTIMATING SPOT SIZE

$$r_x'' + \frac{(\gamma_b \beta_b)'}{\gamma_b \beta_b} r_x + \kappa_x r_x - \frac{2Q}{r_x + r_y} - \frac{\epsilon_x^2}{r_x^3} = 0$$

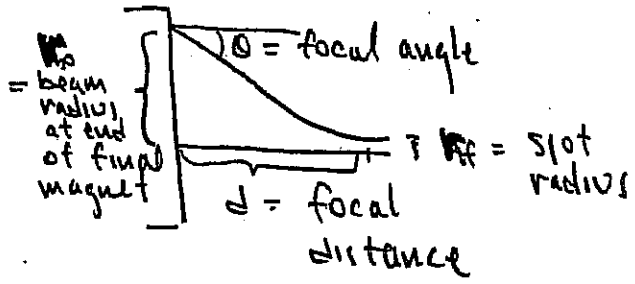
$$r_y'' + \frac{(\gamma_b \beta_b)'}{\gamma_b \beta_b} r_y + \kappa_y r_y - \frac{2Q}{r_x + r_y} - \frac{\epsilon_y^2}{r_y^3} = 0$$

IN CHAMBER: NO EXTERNAL FOCUSING, NO ACCELERATION AND BEAM IS OFTEN CIRCULAR (BY DESIGN)

$$\Rightarrow \quad \kappa_x = \kappa_y = (\gamma_b \beta_b)' = 0 \qquad \& \quad r_x = r_y = r_b$$

$\Rightarrow$ ENVELOPE EQUATION IS:

$$r_b'' = \frac{Q}{r_b} + \frac{\epsilon^2}{r_b^3}$$



MULTIPLYING BY r_b' & INTEGRATING $\Rightarrow$

$$\frac{r_{bf}'^2}{2} - \frac{r_{b0}'^2}{2} = Q \ln \frac{r_{bf}}{r_{b0}} + \frac{\epsilon^2}{2 r_{b0}^2} - \frac{\epsilon^2}{2 r_{bf}^2}$$

Now $r_{b0}' \cong \theta$ $\qquad r_{bf}$ = spot radius $\qquad r_{bf} << r_{b0}$

$r_{bf}' = 0 \qquad r_{b0} \cong d\theta$

$$\Rightarrow \boxed{\theta^2 \cong 2Q \ln\left(\frac{\theta d}{r_{bf}}\right) + \frac{\epsilon^2}{r_{bf}^2}}$$

WHEN $Q = 0$

$$r_{spot}^2 = \frac{\epsilon^2}{\theta^2} + r^2_{\text{CHROMATIC ABERRATION}} + \ldots$$

$$r^2_{\text{CHROMATIC}} = \alpha^2 d^2 \left(\frac{\delta p}{p}\right)^2 \theta^2$$

$\alpha \cong 6$ (system dependent)

LONGITUDINAL DYNAMICS SUMMARY

1D VLASOV EQUATION

$$\frac{\partial \tilde{f}}{\partial s} + z' \frac{\partial \tilde{f}}{\partial z} + z'' \frac{\partial \tilde{f}}{\partial z'} = 0$$

$$E_z = \frac{-g}{4\pi\epsilon_0}\frac{\partial \lambda}{\partial z}$$ "g-factor" model

$$z'' = \frac{q E_z}{m v_0^2} \; ; \qquad \frac{\partial^2 \phi}{\partial z^2} + \frac{1}{r}\frac{\partial}{\partial r}\left(r \frac{\partial \phi}{\partial r}\right) = -\frac{\rho}{\epsilon_0}$$

CHILD-LANGMUIR IN 1-D DIODE

$\boxed{\text{Ellipsoidal Bunch}}$

LEADS TO FLUID EQUATIONS

$\int$(Vlasov Equation) dz'

$$\frac{\partial \lambda}{\partial s} + \frac{\partial}{\partial z}(\lambda \bar{z}') = 0$$

$$\frac{\partial \bar{z}'}{\partial s} + \bar{z}' \frac{\partial \bar{z}'}{\partial z} + \frac{1}{\lambda}\frac{\partial}{\partial z}(\lambda \Delta z'^2) = \frac{q E_z}{m v_0^2}$$

1D E_z: $\Rightarrow$ CHILD LANGMUIR SOLUTION $\leftarrow$ NON-LINEAR SOLUTION TO FLUID EQUATIONS

2D PHASE ELECTRODE

TIME DEPENDENT LAMPEL TIEFENBACK SOLUTION

g-factor: $\Rightarrow$ SPACE-CHARGE WAVES

$\hookrightarrow$ LONGITUDINAL OR RESISTIVE WALL INSTABILITY (IF $E_1 = z^* I_1$)

$\Rightarrow$ SPACE-CHARGE RAREFACTION WAVES $\leftarrow$ NON-LINEAR SOLUTION TO FLUID EQNS.

$\Rightarrow$ PARABOLIC BUNCH COMPRESSION $\leftarrow$ NON-LINEAR SOLUTION TO FLUID EQUATIONS

$\Rightarrow$ "EAR" FIELDS

VLASOV EQUATION ALSO $\Rightarrow$ ENVELOPE EQUATION $\iint$ VLASOV Equation $dz\,dz'$

$$\frac{d^2 r_z}{ds^2} = \frac{\epsilon_z^2}{r_z^3} + \frac{3}{2}\frac{g q Q_c}{4\pi\epsilon_0 m v^2}\frac{1}{r_z^2} - K(r) r_z$$

KINETIC SOLUTION TO VLASOV EQUATION & SATISFYING RMS ENVELOPE EQUATION IS NEUFER DISTRIBUTION

$$f(z,z') = \frac{3N}{2\pi\epsilon_z}\sqrt{1 - \frac{z^2}{r_z^2} - \frac{r_z^2 (z' - r_z' z/r_z)^2}{\epsilon_z^2}}$$

NORMAL MODES

LONGITUDINAL

SPACE-CHARGE WAVES (FLUID)

$\omega = \pm c_s k$ [IN COMOVING BEAM FRAME]

$$c_s = \sqrt{\frac{q g \lambda_0}{4\pi\epsilon_0 m}}$$ = SPACE CHARGE WAVE SPEED

TRANSVERSE

ENVELOPE MODES

CONTINUOUS FOCUSING (LONG BUNCHES)

BREATHING: $k_B^2 = 2k_{\beta 0}^2 + 2k_\beta^2$

QUADRUPOLE $k_Q^2 = k_{\beta 0}^2 + 3k_\beta^2$

(HERE $k_\beta^2 \equiv k_{\beta 0}^2 - \frac{Q}{r_b^2}$)

(ANALOGOUS MODES IN BUNCHED BEAMS)

STEVE LOOKED AT MODES IN PERIODIC SYSTEMS (& CONTINUOUS FOCUSING

+ KINETIC MODES (GLUCKSTERN MODES)
+ FLUID MODES

INSTABILITIES

1. LONGITUDINAL (RESISTIVE WALL) INSTABILITY
   (FLUID INSTABILITY)

2. ELECTRON – ION INSTABILITY
   (CENTROID INSTABILITY)

STEVE TALKED ABOUT:

3. ENVELOPE INSTABILITIES

STEVE TALKED ABOUT:

4. KINETIC INSTABILITIES
   (DISTRIBUTION FUNCTION DEPENDENT)

5. SINGLE PARTICLE RESONANT INSTABILITIES
   - HALO
   - RING RESONANCES

HALO:

CORE TEST PARTICLE MODEL:

$$x'' = \begin{cases} -\left[k_{\beta 0}^2 - \frac{Q}{r_b^2}\right]x & \text{for } r < r_b \\ -\left[k_{\beta 0}^2 - \frac{Q}{r^2}\right]x & \text{for } r > r_b \end{cases}$$

$$r_b = r_{b0} + \delta r_b \cos(k_\beta s + \phi)$$

Gluckstern's phase-amplitude analysis:

$$x'' + \overbrace{\left[k_{\beta 0}^2 - \frac{Q}{r_{b0}^2}\right]}^{k_\beta^2} x = f(x)$$

Non linear + forcing part

$x = A\sin\psi \quad x' = k_\beta A\cos\psi$ ← PHASE/AMPLITUDE

$\psi = k_\beta s + \alpha$ IF $f = 0$ A & α would be constant

$\Rightarrow A' = \frac{1}{k_\beta r_{b0}} f\cos\psi \qquad \alpha' = \frac{-1}{k_\beta r_{b0} A} f\sin\psi$

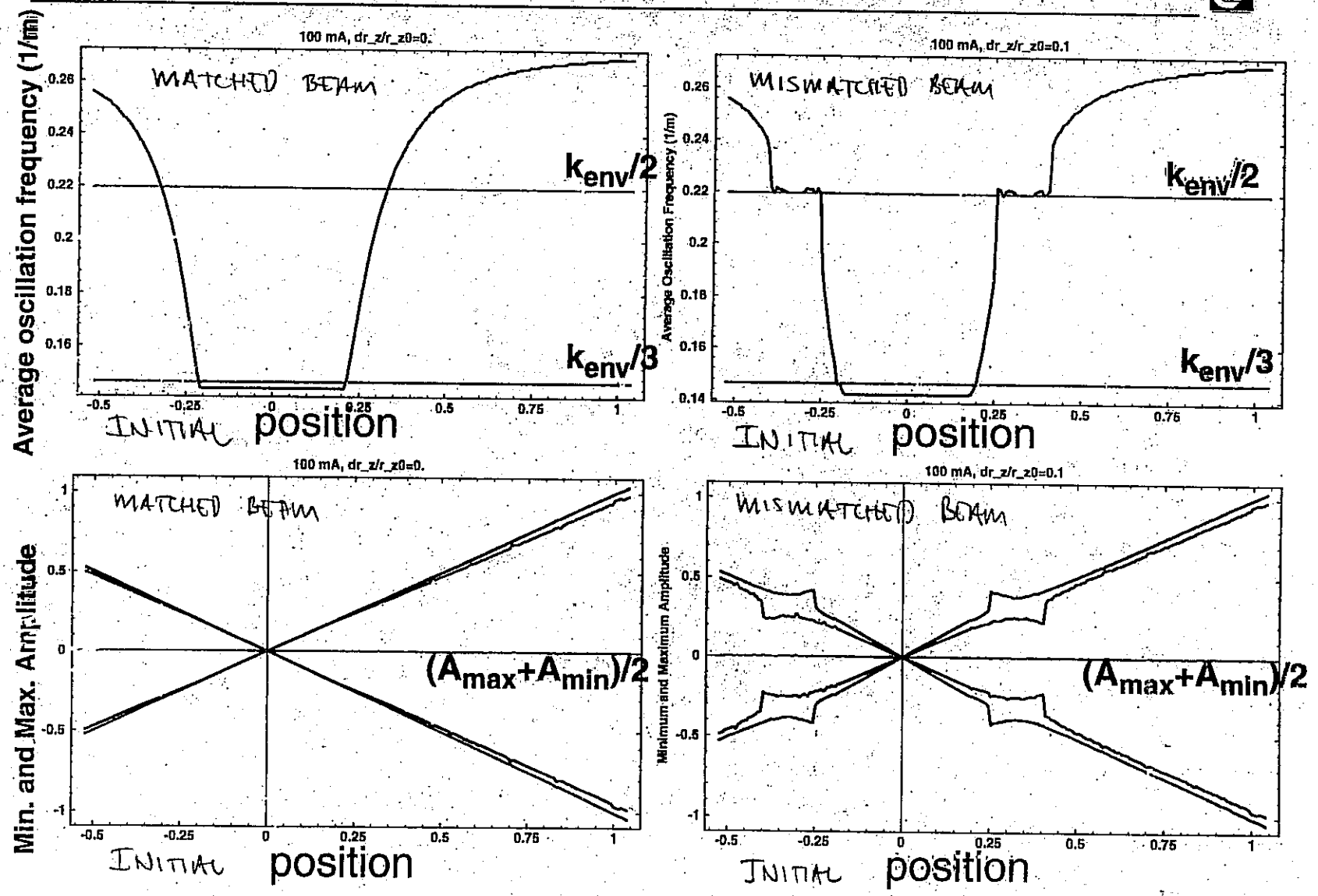
DEFINE RESONANT PHASE $\Psi_r = 2\psi - k_\beta s$

AVERAGE OVER ALL NON-RESONANT FREQUENCIES

$$A_r' = \frac{1}{k_\beta r_{b0}} \int_{-\pi}^{\pi} f\cos\psi \frac{d\psi}{2\pi}; \quad \alpha_r' = \frac{-1}{k_\beta A_r} \int_{-\pi}^{\pi} \frac{d\psi}{2\pi} f\sin\psi$$

$\rightarrow A_r', \Psi_r' \xrightarrow[(\omega = A_r^2)]{} \omega', \Psi_r' \rightarrow H(\omega, \Psi_r) \rightarrow$ GIVE RESONANT PARTICLE TRAJECTORY & SEPARATRIX

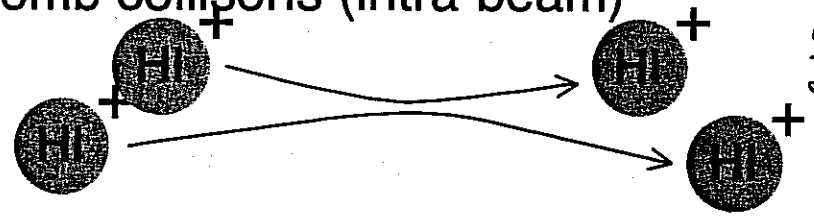
Numerically determined frequency and amplitude of particle oscillations: linear rf focusing



HI+ Heavy ion	Residual gas molecule	e- electron

Processes:

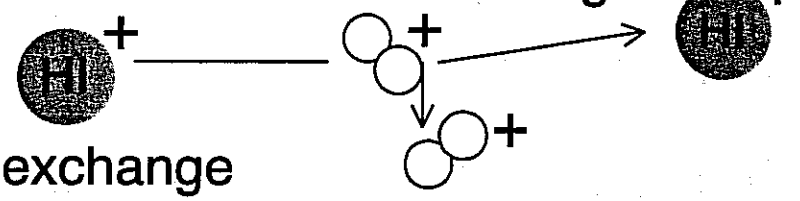
1. Coulomb collisons (intra-beam)



$$\frac{dT_\perp}{dt} = \frac{-1}{2}\frac{dT_\parallel}{dt} = \frac{-(T_\perp - T_\parallel)}{\tau}$$

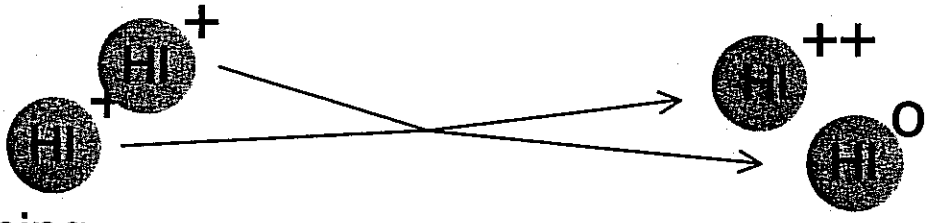
$$\tau \sim \nu_c^{-1}$$

2. Coulomb collisions with residual gas

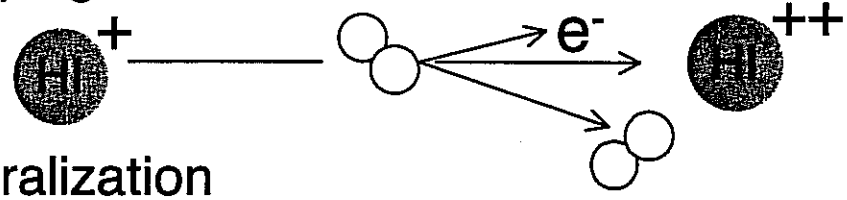


$$\frac{d\epsilon_N}{ds} \sim n_g(\quad)$$

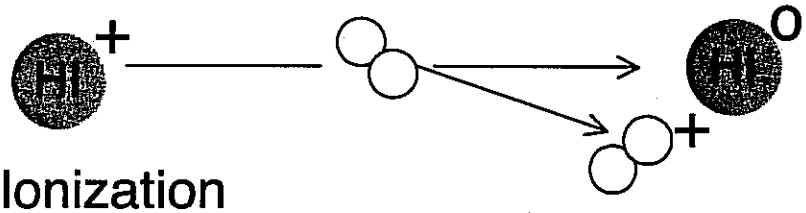
3. Charge exchange



4. Stripping



5. Neutralization



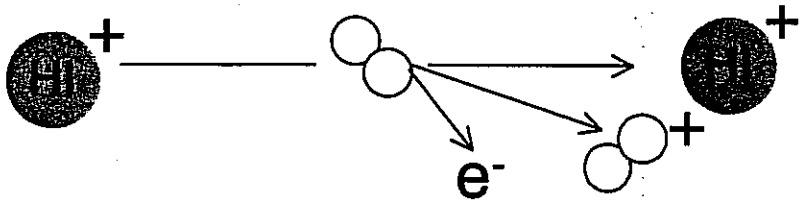
CHARGE CHANGING COLLISIONS

Beam loss

+

n_{HI} molecules

6. Gas Ionization



n_g molecules

SUMMARY OF ELECTRON, GAS, PRESSURE, & SCATTERING EFFECTS

1. COULOMB COLLISIONS WITHIN BEAM CAN TRANSFER ENERGY FROM ⊥ TO ∥ AND PROVIDE LOWER LIMIT ON $T_{\parallel}$, HIGHER THAN FROM ACCELERATIVE COOLING.

2. COULOMB INTERACTIONS WITH RESIDUAL GAS NUCLEI PROVIDE A SOURCE OF EMITTANCE GROWTH (BUT NOT IMPORTANT FOR HIGHER MASS AND LINAC RESIDENCE TIMES).

3. PRESSURE INSTABILITY FROM DESORPTION OF RESIDUAL GAS BY STRIKING BEAM IONS HITTING WALL OR BEAM-IONIZED RESIDUAL GAS ATOMS, FORCED TO WALL BY E-field of BEAM. LIMITS CURRENT IN RINGS OR HIGH REP RATE LINAC.

4. ELECTRONS CAN CASCADE AND REACH A "QUASI" EQUILIBRIUM POPULATION OF SIMILAR LINE CHARGE TO THE ION BEAM. ELECTRON-ION TWO STREAM INSTABILITY IS UNSTABLE, AND CAN LEAD TO TRANSVERSE INSTABILITY, SIMILAR TO WHAT IS OBSERVED IN SOME PROTON RINGS.

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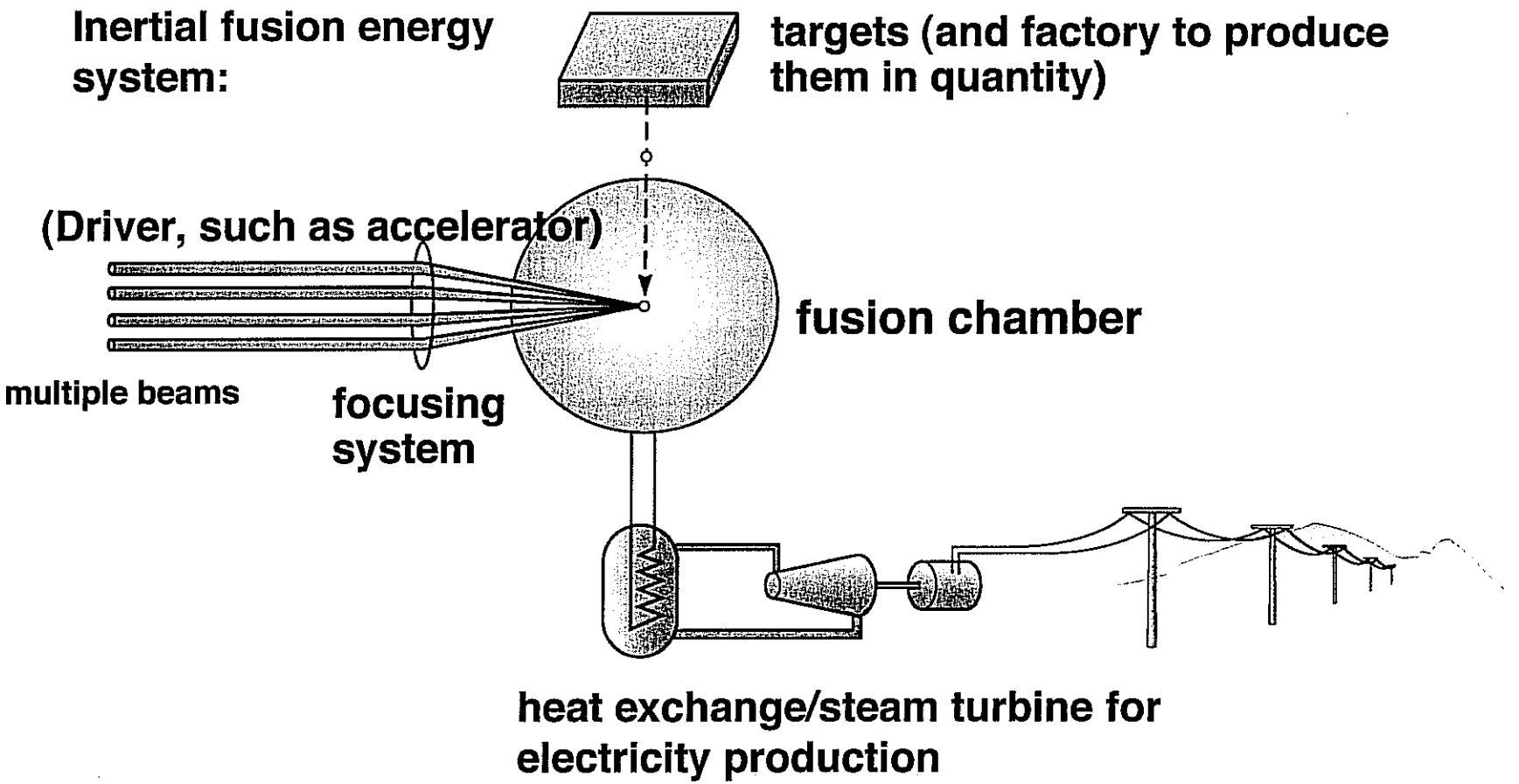
Inertial Fusion Energy (IFE) power plants of the future will consist of four parts