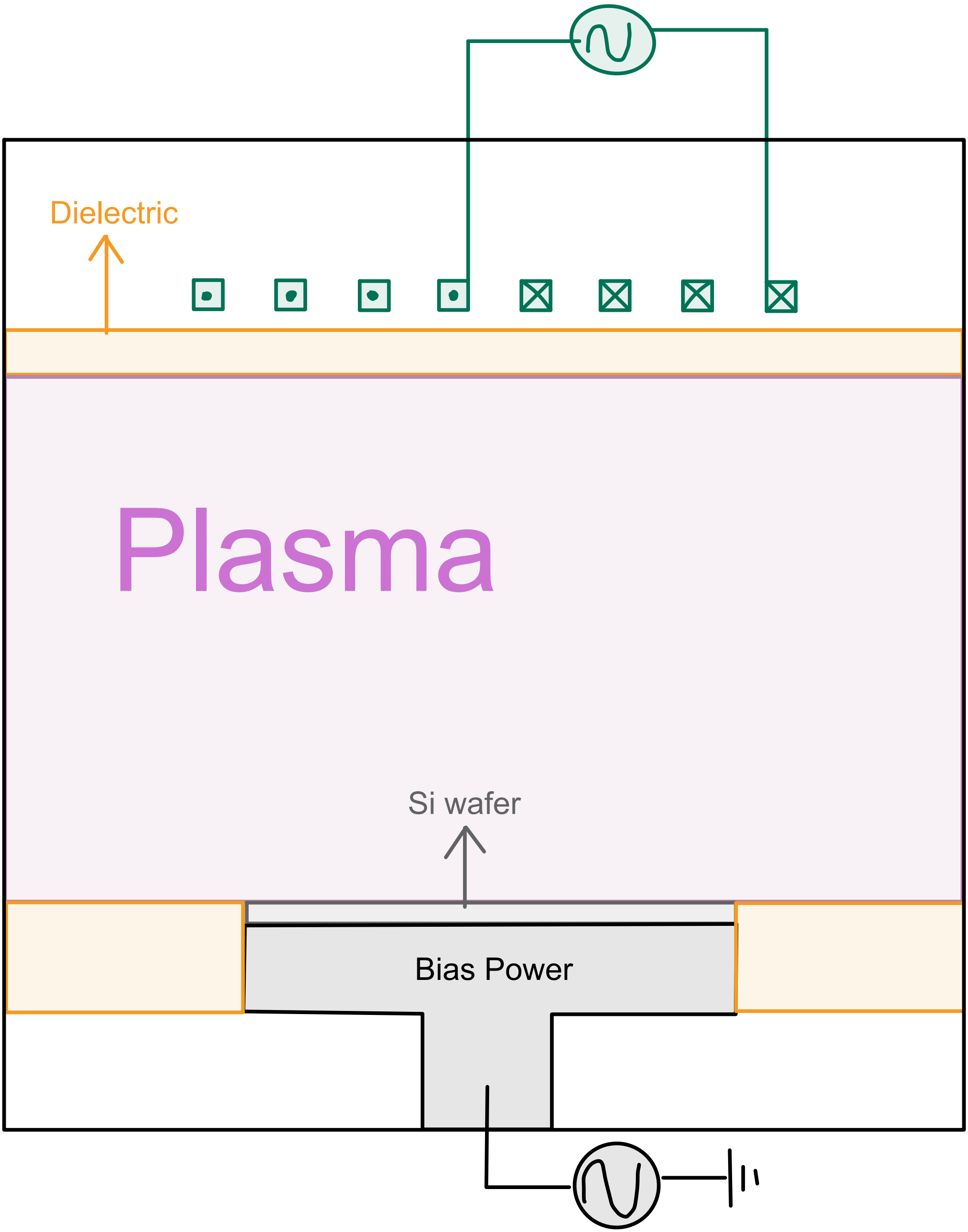
Plasma Fluid Model V1.0



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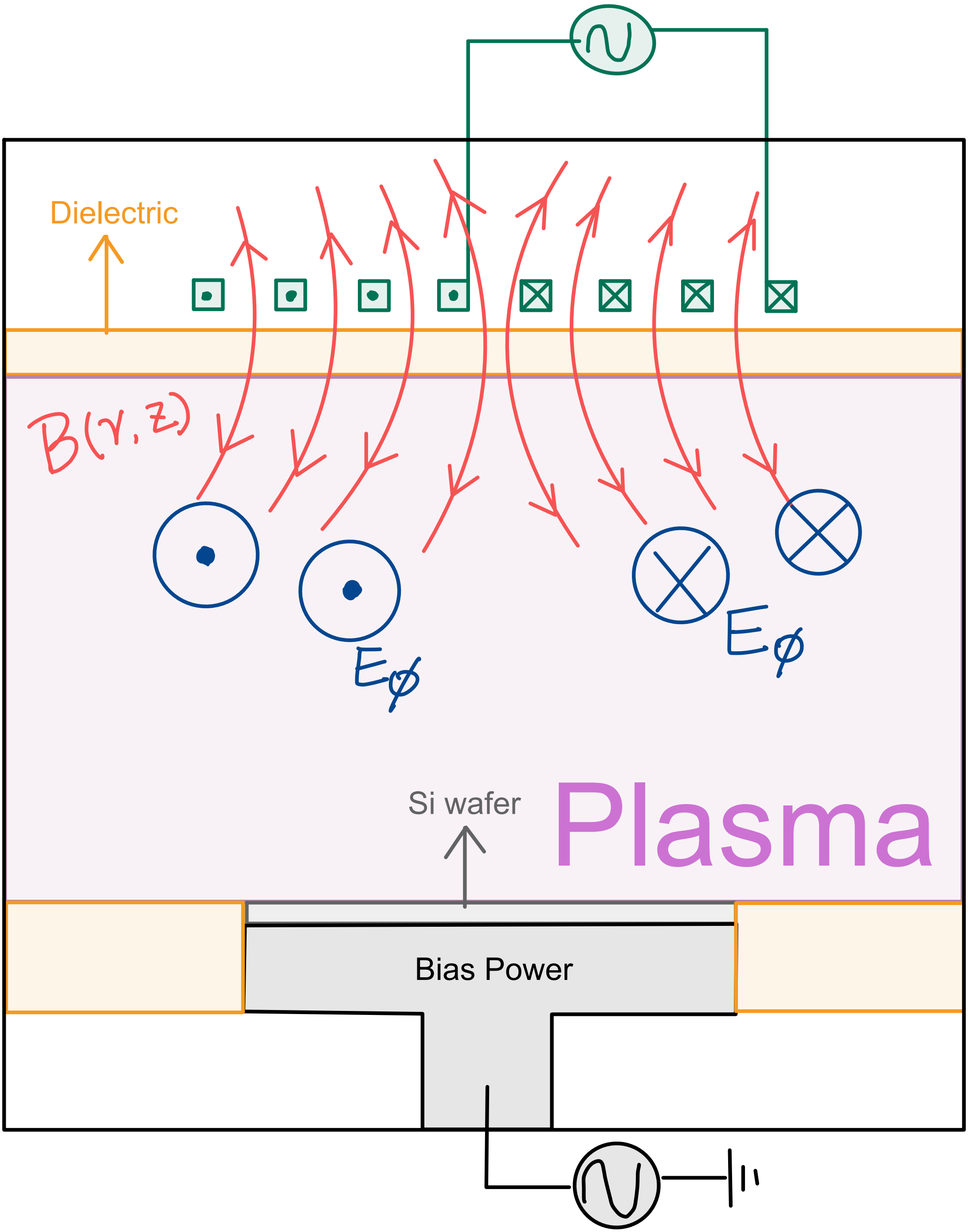
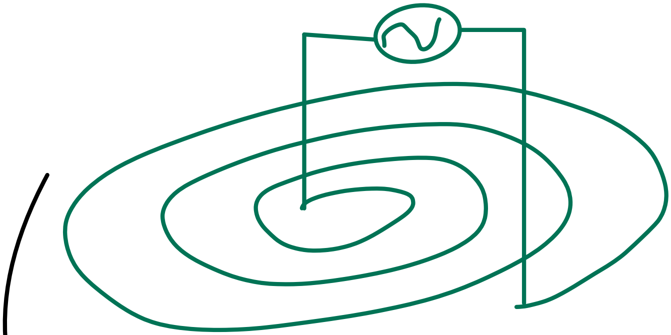


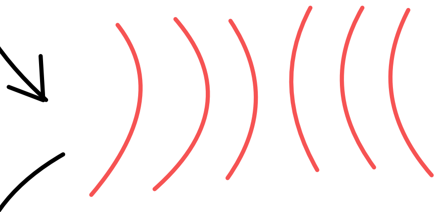


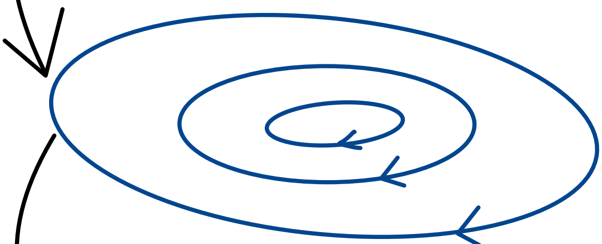
$\vec{J} = J_0 e^{i\omega t}$

Current in coils

$\vec{B} = B_0 e^{i\omega t}$

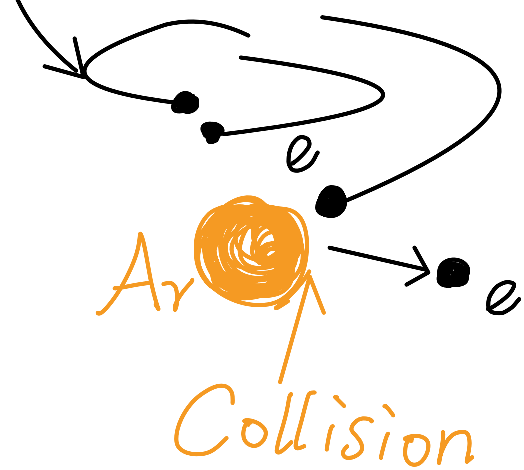
$\vec{B}$ field in chamber





$\vec{E} = E_\phi e^{i\omega t}$

$\vec{E}$ field in plasma



$$a_\phi = \frac{q_e E_\phi e^{i\omega t}}{m_e}$$

steady state,

$$v_\phi = \mu_e E_\phi e^{i\omega t}$$

$\vec{J} \longrightarrow \vec{B} \longrightarrow \vec{E} \longrightarrow \vec{v}$

$J_\phi \longrightarrow B_{r,z} \longrightarrow E_\phi \longrightarrow v_\phi$

All B and E fields are the intermediate steps from current to velocity. As long as velocity is obtained, B and E fields are discarded.

Velocity $\vec{v}$

External J_ϕ

$$v_\phi = \mu_e E_\phi$$

$(n_i - n_e)$ Self induced

$$v_{r,z} = -D_e \frac{\nabla n_e}{n_e} - \mu_e E_{r,z}$$

$$v_\phi \xrightarrow{\text{Collisions}} v_{r,z}$$

Collision Process can be very complicated.
Instead, we solve for electron temperature, Te.

$$D_e, \mu_e = D_e(T_e), \mu_e(T_e)$$

Diffusion coefficient and mobility

$$\Gamma_e = -D_e \nabla n_e - \mu_e n_e \vec{E}$$

$$D_e = \frac{kT_e}{m_e \nu_{coll}} \qquad \mu_e = \frac{|e|}{m_e \nu_{coll}}$$

$$\nu_{coll} = \nu_{coll}(T_e)$$

Continuity Eq. for electron

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \vec{\Gamma}_e = S_e$$

$$S_e = S_e(T_e)$$

1D Maxwellian velocity distribution

$$f(v) = \left(\frac{m}{2\pi kT}\right)^{1/2} \exp\left(-\frac{mv^2}{2kT}\right)$$

m — mass of particle

k — Boltzmann's constant

T — particle temperature, width of the Maxwellian distribution

1D average kinetic energy

$$\mathcal{E}_{mean} = \frac{\int \frac{1}{2} m v^2 f(v)\, dv}{\int f(v)\, dv} = \frac{1}{2} kT$$

3D mean energy $\mathcal{E}_{mean} = \frac{3}{2} kT$

With the assumption of MaxWellian distribution

$\mathcal{E}$ is equivalent to T

In plasma physics, we usually use temperature instead of energy and velocity

Energy equation

Continuity Eq. for electron

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \vec{\Gamma}_e = S_e$$

Energy Eq. for electron

$$\frac{\partial}{\partial t}(n_e \varepsilon_e) + \nabla \cdot \vec{Q}_e = P_{in} - P_{Coll\text{-}Loss}$$

$$n_e \varepsilon_e = \frac{3}{2} n_e k T_e$$ — Electron Energy Density

$$\vec{Q}_e = \frac{5}{2} k T_e \vec{J}_e - k_e \nabla T_e$$ — Energy Flux

$$P_{in} = \boxed{\vec{J}_e \cdot \vec{E}}$$ — Joule/Ohm/collision Heating

$$P_{coll\text{-}loss} = P_{momentum\text{-}Loss} + P_{reaction\text{-}Loss}$$

$$= 3\frac{m_e}{M} n_e k \nu_m (T_e - T_g) + n_e N \sum_j k_j(T_e) \Delta \varepsilon_j$$

Local heating vs. Non-local heating

Local Heating — Fluid Model
collision freq is sufficient high
Energy is balanced Locally

$$P_{in} = \vec{J}_e \cdot \vec{E} = \boxed{J_\phi E_\phi} + \boxed{J_r E_r + J_z E_z}$$

External Field

Induced Field

$$J_{coil} \rightarrow B \rightarrow E_\phi$$

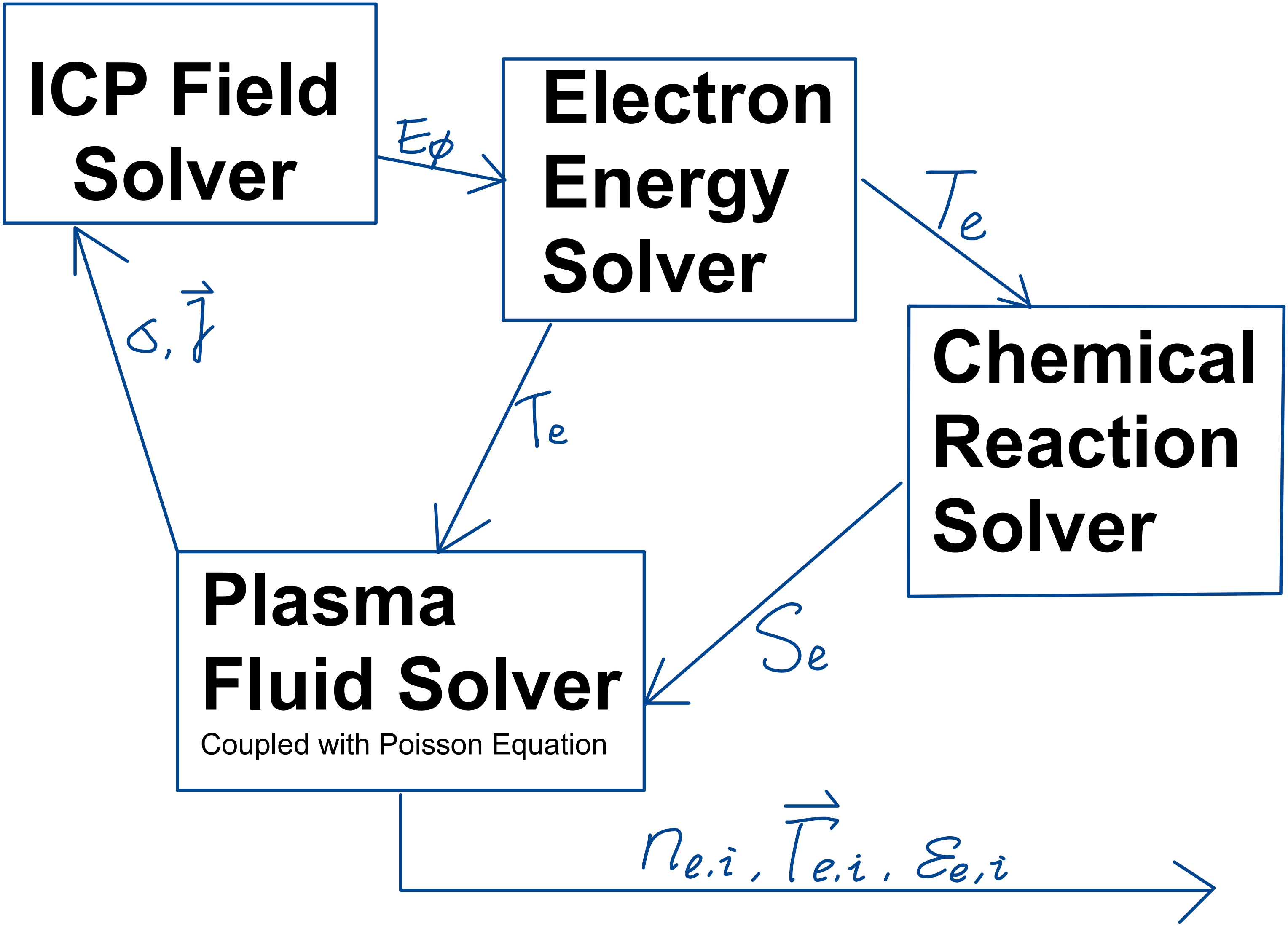
$$\nabla^2 \phi = -\frac{e}{\varepsilon_0}(n_i - n_e)$$

$$J_\phi = \sigma E_\phi$$

$$J_{r,z} = \sigma E_{r,z}$$

Ohm's Law
Assume plasma is homogeneous
σ is same for all directions

$$\sigma = \frac{n_e e^2}{m_e \nu_{coll}} \qquad \nu_{coll} = \nu_{coll}(T_e)$$


ICP Field Solver
E_ϕ
Electron Energy Solver
T_e
Chemical Reaction Solver
T_e
$\sigma, \vec{J}$
S_e
Plasma Fluid Solver
Coupled with Poisson Equation
$n_{e,i}, \vec{\Gamma}_{e,i}, \varepsilon_{e,i}$