1 Equations in r coordinates

$$0 = \frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}\phi + \frac{1}{\epsilon_0}\left(-en_{\mathrm{e}} + Z_{\mathrm{i}}en_{\mathrm{i}} + Z_{\mathrm{b}}en_{\mathrm{b}} + Z_{\mathrm{b}}egn_{\mathrm{b}}^{\mathrm{rp}}\right) \tag{1.1}$$

$$\frac{1}{c^2}\frac{\partial}{\partial t}\dot{A}_\theta = \frac{\partial}{\partial r}\frac{1}{r}\frac{\partial}{\partial r}rA_\theta + \mu_0(-en_{\mathrm{e}}u_{\mathrm{e}\theta} + Z_{\mathrm{i}}en_{\mathrm{i}}u_{\mathrm{i}\theta} + Z_{\mathrm{b}}en_{\mathrm{b}}u_{\mathrm{b}\theta}) \tag{1.2}$$

$$\frac{1}{c^2}\frac{\partial}{\partial t}\dot{A}_\phi = \frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}A_\phi + \mu_0(-en_{\mathrm{e}}u_{\mathrm{e}\phi} + Z_{\mathrm{i}}en_{\mathrm{i}}u_{\mathrm{i}\phi} + Z_{\mathrm{b}}en_{\mathrm{b}}u_{\mathrm{b}\phi}) \tag{1.3}$$

$$\frac{\partial}{\partial t}A_\phi = \dot{A}_\phi \tag{1.4}$$

$$\frac{\partial}{\partial t}A_\theta = \dot{A}_\theta \tag{1.5}$$

$$\frac{\partial}{\partial t}n_{\mathrm{e}} = -\frac{1}{r}\frac{\partial}{\partial r}rn_{\mathrm{e}}u_{\mathrm{e}r} + \nu_{\mathrm{ionize}}\frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}}(n_{01} + n_{02} + n_{03}) - \nu_{\mathrm{L}}(n_{\mathrm{e}} - n_{\mathrm{ediv}})$$

$$+ (1 - f_{\mathrm{CX}})\frac{P_{\mathrm{b}}}{E_{\mathrm{b}}} \tag{1.6}$$

$$\frac{\partial}{\partial t}n_{\mathrm{e}}u_{\mathrm{e}r} = -\frac{1}{r}\frac{\partial}{\partial r}ru_{\mathrm{e}r}n_{\mathrm{e}}u_{\mathrm{e}r} + \frac{1}{r}u_{\mathrm{e}\theta}n_{\mathrm{e}}u_{\mathrm{e}\theta} - \frac{\partial}{\partial r}\frac{n_{\mathrm{e}}T_{\mathrm{e}}}{m_{\mathrm{e}}}$$

$$- \frac{e}{m_{\mathrm{e}}}n_{\mathrm{e}}E_r - \frac{e}{m_{\mathrm{e}}}B_\phi n_{\mathrm{e}}u_{\mathrm{e}\theta} + \frac{e}{m_{\mathrm{e}}}B_\theta n_{\mathrm{e}}u_{\mathrm{e}\phi} \tag{1.7}$$

$$\frac{\partial}{\partial t}n_{\mathrm{e}}u_{\mathrm{e}\theta} = -\frac{1}{r^2}\frac{\partial}{\partial r}r^2 u_{\mathrm{e}r}n_{\mathrm{e}}u_{\mathrm{e}\theta} + \frac{1}{r^2}\frac{\partial}{\partial r}r^3 n_{\mathrm{e}}\mu_{\mathrm{e}}\frac{\partial}{\partial r}\frac{u_{\mathrm{e}\theta}}{r} - \frac{e}{m_{\mathrm{e}}}n_{\mathrm{e}}E_\theta + \frac{e}{m_{\mathrm{e}}}B_\phi n_{\mathrm{e}}u_{\mathrm{e}r}$$

$$- \nu_{\mathrm{NCe}}n_{\mathrm{e}}u_{\mathrm{e}\theta} - \nu_{\mathrm{ei1}}n_{\mathrm{e}}(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \nu_{\mathrm{ei2}}n_{\mathrm{e}}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi})$$

$$- \frac{m_{\mathrm{b}}}{m_{\mathrm{e}}}\nu_{\mathrm{be1}}n_{\mathrm{b}}(u_{\mathrm{e}\theta} - u_{\mathrm{b}\theta}) - \frac{m_{\mathrm{b}}}{m_{\mathrm{e}}}\nu_{\mathrm{be2}}n_{\mathrm{b}}(u_{\mathrm{e}\phi} - u_{\mathrm{b}\phi})$$

$$- \frac{e^2 B_\phi^2 D_{\mathrm{e}}}{m_{\mathrm{e}}T_{\mathrm{e}}}n_{\mathrm{e}}\left[(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{B_\theta}{B_\phi}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + \frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_{\mathrm{e}} r + \frac{1 - \alpha_{\mathrm{e}}}{eB_\phi}\frac{\partial}{\partial r}T_{\mathrm{e}} + \frac{E_r}{B_\phi}\right]$$

$$- 2\nu_{\mathrm{L}}n_{\mathrm{e}}u_{\mathrm{e}\theta} - \nu_{0\mathrm{e}}n_{\mathrm{e}}u_{\mathrm{e}\theta} + \mu_{e2}\frac{B_\phi}{B_\theta^2}\frac{1}{m_{\mathrm{e}}e}\frac{\partial}{\partial r}T_{\mathrm{e}} \tag{1.8}$$

$$\frac{\partial}{\partial t}n_{\mathrm{e}}u_{\mathrm{e}\phi} = -\frac{1}{r}\frac{\partial}{\partial r}ru_{\mathrm{e}r}n_{\mathrm{e}}u_{\mathrm{e}\phi} + \frac{1}{r}\frac{\partial}{\partial r}rn_{\mathrm{e}}\mu_{\mathrm{e}}\frac{\partial}{\partial r}u_{\mathrm{e}\phi} - \frac{e}{m_{\mathrm{e}}}n_{\mathrm{e}}E_\phi - \frac{e}{m_{\mathrm{e}}}B_\theta n_{\mathrm{e}}u_{\mathrm{e}r}$$

$$- \nu_{\mathrm{ei3}}n_{\mathrm{e}}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) - \nu_{\mathrm{ei2}}n_{\mathrm{e}}(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{m_{\mathrm{b}}}{m_{\mathrm{e}}}\nu_{\mathrm{be2}}n_{\mathrm{b}}(u_{\mathrm{e}\theta} - u_{\mathrm{b}\theta}) - \frac{m_{\mathrm{b}}}{m_{\mathrm{e}}}\nu_{\mathrm{be3}}n_{\mathrm{b}}(u_{\mathrm{e}\phi} - u_{\mathrm{b}\phi})$$

$$+ \frac{e^2 B_\phi^2 D_{\mathrm{e}}}{m_{\mathrm{e}}T_{\mathrm{e}}}\frac{B_\theta}{B_\phi}n_{\mathrm{e}}\left[(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{B_\theta}{B_\phi}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + \frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_{\mathrm{e}} r + \frac{1 - \alpha_{\mathrm{e}}}{eB_\phi}\frac{\partial}{\partial r}T_{\mathrm{e}} + \frac{E_r}{B_\phi}\right]$$

$$- 2\nu_{\mathrm{L}} n_{\mathrm{e}} u_{\mathrm{e}\phi} - \nu_{0\mathrm{e}} n_{\mathrm{e}} u_{\mathrm{e}\phi} \tag{1.9}$$

$$\frac{\partial}{\partial t} \frac{3}{2} n_{\mathrm{e}} T_{\mathrm{e}} = -\frac{1}{r} \frac{\partial}{\partial r} r \left(\frac{5}{2} u_{\mathrm{e}r} n_{\mathrm{e}} T_{\mathrm{e}} - n_{\mathrm{e}} \chi_{\mathrm{e}} \frac{\partial}{\partial r} T_{\mathrm{e}} \right) + u_{\mathrm{e}r} \frac{\partial}{\partial r} n_{\mathrm{e}} T_{\mathrm{e}} - e E_{\theta} n_{\mathrm{e}} u_{\mathrm{e}\theta} - e E_{\phi} n_{\mathrm{e}} u_{\mathrm{e}\phi}$$

$$- \frac{3}{2} \nu_{\mathrm{Tei}} n_{\mathrm{e}} (T_{\mathrm{e}} - T_{\mathrm{i}}) - \nu_{\mathrm{L}} T_{\mathrm{e}} (n_{\mathrm{e}} - n_{\mathrm{ediv}}) - \frac{3}{2} \nu_{\mathrm{L}T_{\mathrm{e}}} n_{\mathrm{e}} (T_{\mathrm{e}} - T_{\mathrm{ediv}})$$

$$- E_{\mathrm{H}} \nu_{\mathrm{ionize}} \frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}} (n_{01} + n_{02} + n_{03}) + f_{\mathrm{ei}} P_{\mathrm{b}} + P_{\alpha\mathrm{e}} + P_{\mathrm{RFe}} - P_{\mathrm{Br}} \tag{1.10}$$

$$\frac{\partial}{\partial t} n_{\mathrm{i}} = -\frac{1}{r} \frac{\partial}{\partial r} r n_{\mathrm{i}} u_{\mathrm{i}r} + \frac{\nu_{\mathrm{ionize}}}{Z_{\mathrm{i}}} \frac{n_{\mathrm{e}}}{n_{01} + nnb + n_{03}} (n_{01} + n_{02} + n_{03}) - \frac{\nu_{\mathrm{L}}}{Z_{\mathrm{i}}} (n_{\mathrm{e}} - n_{\mathrm{ediv}})$$

$$+ \nu_{\mathrm{b}} n_{\mathrm{b}} + \nu_{\mathrm{b}} g n_{\mathrm{b}}^{\mathrm{rp}} - f_{\mathrm{CX}} \frac{P_{\mathrm{b}}}{E_{\mathrm{b}}} + \nu_{\mathrm{bL}} n_{\mathrm{b}} + S_{\mathrm{LC}} - \nu_{\mathrm{OL}} n_{\mathrm{i}} \tag{1.11}$$

$$\frac{\partial}{\partial t} n_{\mathrm{i}} u_{\mathrm{i}r} = -\frac{1}{r} \frac{\partial}{\partial r} r u_{\mathrm{i}r} n_{\mathrm{i}} u_{\mathrm{i}r} + \frac{1}{r} u_{\mathrm{i}\theta} n_{\mathrm{i}} u_{\mathrm{i}\theta} - \frac{\partial}{\partial r} \frac{n_{\mathrm{i}} T_{\mathrm{i}}}{m_{\mathrm{i}}}$$

$$+ Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} n_{\mathrm{i}} E_r + Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} B_{\phi} n_{\mathrm{i}} u_{\mathrm{i}\theta} - Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} B_{\theta} n_{\mathrm{i}} u_{\mathrm{i}\phi} \tag{1.12}$$

$$\frac{\partial}{\partial t} n_{\mathrm{i}} u_{\mathrm{i}\theta} = -\frac{1}{r^2} \frac{\partial}{\partial r} r^2 u_{\mathrm{i}r} n_{\mathrm{i}} u_{\mathrm{i}\theta} + \frac{1}{r^2} \frac{\partial}{\partial r} r^3 n_{\mathrm{i}} \mu_{\mathrm{i}} \frac{\partial}{\partial r} \frac{u_{\mathrm{i}\theta}}{r} + Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} n_{\mathrm{i}} E_{\theta} - Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} B_{\phi} n_{\mathrm{i}} u_{\mathrm{i}r}$$

$$- \nu_{\mathrm{NCi}} n_{\mathrm{i}} u_{\mathrm{i}\theta} - \frac{m_{\mathrm{e}}}{m_{\mathrm{i}}} \nu_{\mathrm{ei}1} n_{\mathrm{e}} (u_{\mathrm{i}\theta} - u_{\mathrm{e}\theta}) - \frac{m_{\mathrm{e}}}{m_{\mathrm{i}}} \nu_{\mathrm{ei}2} n_{\mathrm{e}} (u_{\mathrm{i}\phi} - u_{\mathrm{e}\phi}) - \frac{m_{\mathrm{b}}}{m_{\mathrm{i}}} \nu_{\mathrm{bi}} n_{\mathrm{b}} (u_{\mathrm{i}\theta} - u_{\mathrm{b}\theta})$$

$$+ \frac{e^2 B_{\phi}^2 D_{\mathrm{e}}}{m_{\mathrm{i}} T_{\mathrm{e}}} n_{\mathrm{e}} \left[(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{B_{\theta}}{B_{\phi}} (u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + \frac{B}{B_{\phi}} \left\langle \frac{\omega}{m} \right\rangle_{\mathrm{e}} r + \frac{1 - \alpha_{\mathrm{e}}}{e B_{\phi}} \frac{\partial}{\partial r} T_{\mathrm{e}} + \frac{E_r}{B_{\phi}} \right]$$

$$- 2\nu_{\mathrm{L}} n_{\mathrm{i}} u_{\mathrm{i}\theta} - \nu_{0\mathrm{i}} n_{\mathrm{i}} u_{\mathrm{i}\theta} - \nu_{\mathrm{CX}} n_{\mathrm{i}} u_{\mathrm{i}\theta} + S_{\mathrm{LC}\theta} - \nu_{\mathrm{OL}} n_{\mathrm{i}} u_{\mathrm{i}\theta} - \mu_{i2} \frac{B_{\phi}}{B_{\theta}^2} \frac{1}{m_{\mathrm{i}} Z_{\mathrm{i}} e} \frac{\partial}{\partial r} T_{\mathrm{i}} + T_{\theta,\mathrm{i}} \tag{1.13}$$

$$\frac{\partial}{\partial t} n_{\mathrm{i}} u_{\mathrm{i}\phi} = -\frac{1}{r} \frac{\partial}{\partial r} r u_{\mathrm{i}r} n_{\mathrm{i}} u_{\mathrm{i}\phi} + \frac{1}{r} \frac{\partial}{\partial r} r n_{\mathrm{i}} \mu_{\mathrm{i}} \frac{\partial}{\partial r} u_{\mathrm{i}\phi} + Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} n_{\mathrm{i}} E_{\phi} + Z_{\mathrm{i}} \frac{e}{m_{\mathrm{i}}} B_{\theta} n_{\mathrm{i}} u_{\mathrm{i}r}$$

$$- \frac{m_{\mathrm{e}}}{m_{\mathrm{i}}} \nu_{\mathrm{ei}3} n_{\mathrm{e}} (u_{\mathrm{i}\phi} - u_{\mathrm{e}\phi}) - \frac{m_{\mathrm{e}}}{m_{\mathrm{i}}} \nu_{\mathrm{ei}2} n_{\mathrm{e}} (u_{\mathrm{i}\theta} - u_{\mathrm{e}\theta}) - \frac{m_{\mathrm{b}}}{m_{\mathrm{i}}} \nu_{\mathrm{bi}} n_{\mathrm{b}} (u_{\mathrm{i}\phi} - u_{\mathrm{b}\phi})$$

$$- \frac{e^2 B_{\phi}^2 D_{\mathrm{e}}}{m_{\mathrm{i}} T_{\mathrm{e}}} \frac{B_{\theta}}{B_{\phi}} n_{\mathrm{e}} \left[(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{B_{\theta}}{B_{\phi}} (u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + \frac{B}{B_{\phi}} \left\langle \frac{\omega}{m} \right\rangle_{\mathrm{e}} r + \frac{1 - \alpha_{\mathrm{e}}}{e B_{\phi}} \frac{\partial}{\partial r} T_{\mathrm{e}} + \frac{E_r}{B_{\phi}} \right]$$

$$- 2\nu_{\mathrm{L}} n_{\mathrm{i}} u_{\mathrm{i}\phi} - \nu_{0\mathrm{i}} n_{\mathrm{i}} u_{\mathrm{i}\phi} - \nu_{\mathrm{CX}} n_{\mathrm{i}} u_{\mathrm{i}\phi} + S_{\mathrm{LC}\phi} - \nu_{\mathrm{OL}} n_{\mathrm{i}} u_{\mathrm{i}\phi} + T_{\phi,\mathrm{i}} \tag{1.14}$$

$$\frac{\partial}{\partial t} \frac{3}{2} n_{\mathrm{i}} T_{\mathrm{i}} = -\frac{1}{r} \frac{\partial}{\partial r} r \left(\frac{5}{2} u_{\mathrm{i}r} n_{\mathrm{i}} T_{\mathrm{i}} - n_{\mathrm{i}} \chi_{\mathrm{i}} \frac{\partial}{\partial r} T_{\mathrm{i}} \right) + u_{\mathrm{i}r} \frac{\partial}{\partial r} n_{\mathrm{i}} T_{\mathrm{i}} + Z_{\mathrm{i}} e E_{\theta} n_{\mathrm{i}} u_{\mathrm{i}\theta} + Z_{\mathrm{i}} e E_{\phi} n_{\mathrm{i}} u_{\mathrm{i}\phi}$$

$$- \frac{3}{2} \nu_{\mathrm{Tei}} n_{\mathrm{e}} (T_{\mathrm{i}} - T_{\mathrm{e}}) + m_{\mathrm{b}} v_{\mathrm{b}} \frac{B_{\theta} u_{\mathrm{i}\theta} + B_{\phi} u_{\mathrm{i}\phi}}{B} \frac{P_{\mathrm{b}\|}}{E_{\mathrm{b}}} - \frac{\nu_{\mathrm{L}}}{Z_{\mathrm{i}}} T_{\mathrm{i}} (n_{\mathrm{e}} - n_{\mathrm{ediv}})$$

$$- \frac{3}{2} \nu_{\mathrm{L}T_{\mathrm{i}}} n_{\mathrm{i}} (T_{\mathrm{i}} - T_{\mathrm{idiv}}) + \frac{3}{2} \frac{\nu_{\mathrm{ionize}}}{Z_{\mathrm{i}}} \frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}} (n_{01} T_{01} + n_{02} T_{02} + n_{03} T_{03})$$

2

$$-\frac{3}{2}\nu_{\mathrm{CX}}n_{\mathrm{i}}(T_{\mathrm{i}}-T_{01}) + (1-f_{\mathrm{ei}})P_{\mathrm{b}} + P_{\alpha\mathrm{i}} + P_{\mathrm{RFi}} \tag{1.15}$$

$$\frac{\partial}{\partial t}n_{\mathrm{b}} = \frac{P_{\mathrm{b}}}{E_{\mathrm{b}}} - g\frac{P_{\mathrm{b}\perp}}{E_{\mathrm{b}}} - \nu_{\mathrm{b}}n_{\mathrm{b}} - \nu_{\mathrm{bL}}n_{\mathrm{b}} - \nu_{\mathrm{eff}}g(\sqrt{\delta}n_{\mathrm{b}} - n_{\mathrm{b}}^{\mathrm{rp}}) + \frac{1}{r}\frac{\partial}{\partial r}rf_{t}D_{\mathrm{b}}\frac{\partial}{\partial r}n_{\mathrm{b}} \tag{1.16}$$

$$\frac{\partial}{\partial t}n_{\mathrm{b}}u_{\mathrm{b}\theta} = Z_{\mathrm{b}}\frac{e}{m_{\mathrm{b}}}n_{\mathrm{b}}E_{\theta} - \nu_{\mathrm{be1}}n_{\mathrm{b}}(u_{\mathrm{b}\theta} - u_{\mathrm{e}\theta}) - \nu_{\mathrm{be2}}n_{\mathrm{b}}(u_{\mathrm{b}\phi} - u_{\mathrm{e}\phi}) - \nu_{\mathrm{bi}}n_{\mathrm{b}}(u_{\mathrm{b}\theta} - u_{\mathrm{i}\theta})$$

$$-\nu_{0\mathrm{b}}n_{\mathrm{b}}u_{\mathrm{b}\theta} - \nu_{\mathrm{CX}}n_{\mathrm{b}}u_{\mathrm{b}\theta} + v_{\mathrm{b}\theta}\frac{P_{\mathrm{b}\parallel}}{E_{\mathrm{b}}} - \nu_{\mathrm{bL}}n_{\mathrm{b}}u_{\mathrm{b}\theta} - \nu_{\mathrm{eff}}g\sqrt{\delta}n_{\mathrm{b}}u_{\mathrm{b}\theta}$$

$$+\frac{1}{r}\frac{\partial}{\partial r}ru_{\mathrm{b}\theta}f_{t}D_{\mathrm{b}}\frac{\partial}{\partial r}n_{\mathrm{b}} \tag{1.17}$$

$$\frac{\partial}{\partial t}n_{\mathrm{b}}u_{\mathrm{b}\phi} = Z_{\mathrm{b}}\frac{e}{m_{\mathrm{b}}}n_{\mathrm{b}}E_{\phi} - \nu_{\mathrm{be3}}n_{\mathrm{b}}(u_{\mathrm{b}\phi} - u_{\mathrm{e}\phi}) - \nu_{\mathrm{be2}}n_{\mathrm{b}}(u_{\mathrm{b}\theta} - u_{\mathrm{e}\theta}) - \nu_{\mathrm{bi}}n_{\mathrm{b}}(u_{\mathrm{b}\phi} - u_{\mathrm{i}\phi})$$

$$-\nu_{0\mathrm{b}}n_{\mathrm{b}}u_{\mathrm{b}\phi} - \nu_{\mathrm{CX}}n_{\mathrm{b}}u_{\mathrm{b}\phi} + v_{\mathrm{b}\phi}\frac{P_{\mathrm{b}\parallel}}{E_{\mathrm{b}}} - \nu_{\mathrm{bL}}n_{\mathrm{b}}u_{\mathrm{b}\phi} - \nu_{\mathrm{eff}}g\sqrt{\delta}n_{\mathrm{b}}u_{\mathrm{b}\phi}$$

$$+\frac{1}{r}\frac{\partial}{\partial r}ru_{\mathrm{b}\phi}f_{t}D_{\mathrm{b}}\frac{\partial}{\partial r}n_{\mathrm{b}} \tag{1.18}$$

$$\frac{\partial}{\partial t}n_{01} = \frac{1}{r}\frac{\partial}{\partial r}rD_{01}\frac{\partial}{\partial r}n_{01} - \frac{1}{Z_{\mathrm{i}}}\nu_{\mathrm{ionize}}\frac{n_{\mathrm{e}}}{n_{01}+n_{02}+n_{03}}n_{01} - \nu_{\mathrm{CX}}\frac{n_{\mathrm{i}}}{n_{01}+n_{02}}n_{01}$$

$$+\gamma_{0}\frac{\nu_{\mathrm{L}}}{Z_{\mathrm{i}}}(n_{\mathrm{e}} - n_{\mathrm{ediv}}) \tag{1.19}$$

$$\frac{\partial}{\partial t}n_{02} = \frac{1}{r}\frac{\partial}{\partial r}rD_{02}\frac{\partial}{\partial r}n_{02} - \frac{1}{Z_{\mathrm{i}}}\nu_{\mathrm{ionize}}\frac{n_{\mathrm{e}}}{n_{01}+n_{02}+n_{03}}n_{02} + \nu_{\mathrm{CX}}\frac{n_{\mathrm{i}}}{n_{01}+n_{02}}n_{01} \tag{1.20}$$

$$\frac{\partial}{\partial t}n_{03} = \frac{1}{r}\frac{\partial}{\partial r}rD_{03}\frac{\partial}{\partial r}n_{03} - \frac{1}{Z_{\mathrm{i}}}\nu_{\mathrm{ionize}}\frac{n_{\mathrm{e}}}{n_{01}+n_{02}+n_{03}}n_{03} + f_{\mathrm{CX}}\frac{P_{\mathrm{b}}}{E_{\mathrm{b}}} \tag{1.21}$$

$$\frac{\partial}{\partial t}n_{\mathrm{b}}^{\mathrm{rp}} = \frac{P_{\mathrm{b}\perp}}{E_{\mathrm{b}}} + \nu_{\mathrm{eff}}(\sqrt{\delta}n_{\mathrm{b}} - n_{\mathrm{b}}^{\mathrm{rp}}) - \nu_{\mathrm{b}}n_{\mathrm{b}}^{\mathrm{rp}} - \frac{1}{r}\frac{\partial}{\partial r}\left(ru_{\mathrm{b}}^{\mathrm{rp}}n_{\mathrm{b}}^{\mathrm{rp}} - rD_{\mathrm{b}}^{\mathrm{rp}}\frac{\partial}{\partial r}n_{\mathrm{b}}^{\mathrm{rp}}\right) \tag{1.22}$$

2 Relations Between Fields and Potentials

$$E_{r} = -\frac{\partial}{\partial r}\phi \tag{2.1}$$

$$E_{\theta} = -\frac{\partial}{\partial t}A_{\theta} = -\dot{A}_{\theta} \tag{2.2}$$

$$E_{\phi} = -\frac{\partial}{\partial t}A_{\phi} = -\dot{A}_{\phi} \tag{2.3}$$

$$B_\theta = -\frac{\partial}{\partial r} A_\phi \tag{2.4}$$

$$B_\phi = \frac{1}{r}\frac{\partial}{\partial r} r A_\theta \tag{2.5}$$

3 Equations in $s(=r^2)$ coordinates

$$0 = 4\frac{\partial}{\partial s}s\frac{\partial}{\partial s}\phi + \frac{1}{\epsilon_0}\left(-en_\mathrm{e} + Z_\mathrm{i}en_\mathrm{i} + Z_\mathrm{b}en_\mathrm{b} + Z_\mathrm{b}egn_\mathrm{b}^\mathrm{rp}\right) \tag{3.1}$$

$$\frac{1}{c^2}\frac{\partial}{\partial t}r\dot{A}_\theta = \left(4\frac{\partial}{\partial s}s\frac{\partial}{\partial s}rA_\theta - 4\frac{\partial}{\partial s}rA_\theta\right) + \mu_0(-ern_\mathrm{e}u_{\mathrm{e}\theta} + Z_\mathrm{i}ern_\mathrm{i}u_{\mathrm{i}\theta} + Z_\mathrm{b}ern_\mathrm{b}u_{\mathrm{b}\theta}) \tag{3.2}$$

$$\frac{1}{c^2}\frac{\partial}{\partial t}\dot{A}_\phi = 4\frac{\partial}{\partial s}s\frac{\partial}{\partial s}A_\phi + \mu_0(-en_\mathrm{e}u_{\mathrm{e}\phi} + Z_\mathrm{i}en_\mathrm{i}u_{\mathrm{i}\phi} + Z_\mathrm{b}en_\mathrm{b}u_{\mathrm{b}\phi}) \tag{3.3}$$

$$\frac{\partial}{\partial t}A_\phi = \dot{A}_\phi \tag{3.4}$$

$$\frac{\partial}{\partial t}rA_\theta = r\dot{A}_\theta \tag{3.5}$$

$$\frac{\partial}{\partial t}n_\mathrm{e} = -2\frac{\partial}{\partial s}rn_\mathrm{e}u_{\mathrm{e}r} + \nu_\mathrm{ionize}\frac{n_\mathrm{e}}{n_{01}+n_{02}+n_{03}}\left(n_{01}+n_{02}+n_{03}\right) - \nu_\mathrm{L}(n_\mathrm{e}-n_\mathrm{ediv})$$
$$+ (1-f_\mathrm{CX})\frac{P_\mathrm{b}}{E_\mathrm{b}} \tag{3.6}$$

$$\frac{\partial}{\partial t}rn_\mathrm{e}u_{\mathrm{e}r} = -2r\frac{\partial}{\partial s}u_{\mathrm{e}r}rn_\mathrm{e}u_{\mathrm{e}r} + \frac{u_{\mathrm{e}\theta}}{r}rn_\mathrm{e}u_{\mathrm{e}\theta} - 2s\frac{\partial}{\partial s}\frac{n_\mathrm{e}T_\mathrm{e}}{m_\mathrm{e}}$$
$$+ 2\frac{e}{m_\mathrm{e}}sn_\mathrm{e}\frac{\partial}{\partial s}\phi - \frac{e}{m_\mathrm{e}}B_\phi rn_\mathrm{e}u_{\mathrm{e}\theta} - 2\frac{e}{m_\mathrm{e}}s\frac{\partial A_\phi}{\partial s}n_\mathrm{e}u_{\mathrm{e}\phi} \tag{3.7}$$

$$\frac{\partial}{\partial t}rn_\mathrm{e}u_{\mathrm{e}\theta} = -2\frac{\partial}{\partial s}ru_{\mathrm{e}r}rn_\mathrm{e}u_{\mathrm{e}\theta} + \left(4\frac{\partial}{\partial s}s\mu_\mathrm{e}\frac{\partial}{\partial s}rn_\mathrm{e}u_{\mathrm{e}\theta} - 4\frac{\partial}{\partial s}s\mu_\mathrm{e}ru_{\mathrm{e}\theta}\frac{\partial n_\mathrm{e}}{\partial s} - 4\frac{\partial}{\partial s}\mu_\mathrm{e}rn_\mathrm{e}u_{\mathrm{e}\theta}\right)$$
$$+ \frac{e}{m_\mathrm{e}}n_\mathrm{e}r\dot{A}_\theta + \frac{e}{m_\mathrm{e}}B_\phi rn_\mathrm{e}u_{\mathrm{e}r} - \nu_\mathrm{NCe}rn_\mathrm{e}u_{\mathrm{e}\theta} - \nu_\mathrm{ei1}rn_\mathrm{e}(u_{\mathrm{e}\theta}-u_{\mathrm{i}\theta}) + 2s\frac{\partial A_\phi}{\partial s}\frac{\nu_\mathrm{ei2}}{B_\theta}n_\mathrm{e}(u_{\mathrm{e}\phi}-u_{\mathrm{i}\phi})$$
$$- \frac{m_\mathrm{b}}{m_\mathrm{e}}\nu_\mathrm{be1}rn_\mathrm{b}(u_{\mathrm{e}\theta}-u_{\mathrm{b}\theta}) + 2\frac{m_\mathrm{b}}{m_\mathrm{e}}s\frac{\partial A_\phi}{\partial s}\frac{\nu_\mathrm{be2}}{B_\theta}n_\mathrm{e}(u_{\mathrm{e}\phi}-u_{\mathrm{b}\phi})$$
$$- \frac{e^2B_\phi^2D_\mathrm{e}}{m_\mathrm{e}T_\mathrm{e}}n_\mathrm{e}\left[(ru_{\mathrm{e}\theta}-ru_{\mathrm{i}\theta}) + 2\frac{\partial A_\phi}{\partial s}\frac{s}{B_\phi}(u_{\mathrm{e}\phi}-u_{\mathrm{i}\phi}) + s\frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_\mathrm{e}\right.$$
$$\left.+ 2s\frac{1-\alpha_\mathrm{e}}{eB_\phi}\frac{\partial}{\partial s}T_\mathrm{e} - 2s\frac{1}{B_\phi}\frac{\partial}{\partial s}\phi\right] - 2\nu_\mathrm{L}rn_\mathrm{e}u_{\mathrm{e}\theta} - \nu_\mathrm{0e}rn_\mathrm{e}u_{\mathrm{e}\theta}$$

$$+ 2\mu_{e2}\frac{B_\phi}{B_\theta^2}\frac{s}{m_\mathrm{e}en_\mathrm{e}}\frac{\partial}{\partial s}n_\mathrm{e}T_\mathrm{e} - 2\mu_{e2}\frac{B_\phi}{B_\theta^2}\frac{s}{m_\mathrm{e}en_\mathrm{e}^2}\frac{\partial n_\mathrm{e}}{\partial s}n_\mathrm{e}T_\mathrm{e} \tag{3.8}$$

$$\frac{\partial}{\partial t}n_\mathrm{e}u_{\mathrm{e}\phi} = -2\frac{\partial}{\partial s}ru_{\mathrm{e}r}n_\mathrm{e}u_{\mathrm{e}\phi} + \left(4\frac{\partial}{\partial s}s\mu_\mathrm{e}\frac{\partial}{\partial s}n_\mathrm{e}u_{\mathrm{e}\phi} - 4\frac{\partial}{\partial s}s\mu_\mathrm{e}u_{\mathrm{e}\phi}\frac{\partial n_\mathrm{e}}{\partial s}\right)$$

$$+ \frac{e}{m_\mathrm{e}}n_\mathrm{e}\dot{A}_\phi + 2\frac{e}{m_\mathrm{e}}\frac{\partial A_\phi}{\partial s}rn_\mathrm{e}u_{\mathrm{e}r} - \nu_{\mathrm{ei}3}n_\mathrm{e}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + 2\frac{\partial A_\phi}{\partial s}\frac{\nu_{\mathrm{ei}2}}{B_\theta}rn_\mathrm{e}(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta})$$

$$+ 2\frac{m_\mathrm{b}}{m_\mathrm{e}}\frac{\partial A_\phi}{\partial s}\frac{\nu_{\mathrm{be}2}}{B_\theta}rn_\mathrm{e}(u_{\mathrm{e}\theta} - u_{\mathrm{i}\theta}) - \frac{m_\mathrm{b}}{m_\mathrm{e}}\nu_{\mathrm{be}3}n_\mathrm{b}(u_{\mathrm{e}\phi} - u_{\mathrm{b}\phi})$$

$$- 2\frac{e^2 B_\phi D_\mathrm{e}}{m_\mathrm{e}T_\mathrm{e}}\frac{\partial A_\phi}{\partial s}n_\mathrm{e}\left[(ru_{\mathrm{e}\theta} - ru_{\mathrm{i}\theta}) + s\frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_\mathrm{e} + 2s\frac{1-\alpha_\mathrm{e}}{eB_\phi}\frac{\partial}{\partial s}T_\mathrm{e} - 2s\frac{1}{B_\phi}\frac{\partial}{\partial s}\phi\right]$$

$$- \frac{e^2 B_\phi^2 D_\mathrm{e}}{m_\mathrm{e}T_\mathrm{e}}\left(\frac{B_\theta}{B_\phi}\right)^2 n_\mathrm{e}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) - 2\nu_\mathrm{L}n_\mathrm{e}u_{\mathrm{e}\phi} - \nu_{0\mathrm{e}}n_\mathrm{e}u_{\mathrm{e}\phi} \tag{3.9}$$

$$\frac{\partial}{\partial t}\frac{3}{2}n_\mathrm{e}T_\mathrm{e} = -5\frac{\partial}{\partial s}ru_{\mathrm{e}r}n_\mathrm{e}T_\mathrm{e} + \left(4\frac{\partial}{\partial s}s\chi_\mathrm{e}\frac{\partial}{\partial s}n_\mathrm{e}T_\mathrm{e} - 4\frac{\partial}{\partial s}s\chi_\mathrm{e}T_\mathrm{e}\frac{\partial n_\mathrm{e}}{\partial s}\right) + 2ru_{\mathrm{e}r}\frac{\partial}{\partial s}n_\mathrm{e}T_\mathrm{e}$$

$$- e\frac{E_\theta}{r}rn_\mathrm{e}u_{\mathrm{e}\theta} - eE_\phi n_\mathrm{e}u_{\mathrm{e}\phi} - \frac{3}{2}\nu_{\mathrm{Tei}}n_\mathrm{e}(T_\mathrm{e} - T_\mathrm{i})$$

$$- \nu_\mathrm{L}T_\mathrm{e}(n_\mathrm{e} - n_\mathrm{ediv}) - \frac{3}{2}\nu_{\mathrm{L}T_\mathrm{e}}n_\mathrm{e}(T_\mathrm{e} - T_\mathrm{ediv})$$

$$- E_\mathrm{H}\nu_{\mathrm{ionize}}\frac{n_\mathrm{e}}{n_{01} + n_{02} + n_{03}}(n_{01} + n_{02} + n_{03}) + f_{\mathrm{ei}}P_\mathrm{b} + P_{\alpha\mathrm{e}} + P_{\mathrm{RFe}} - P_{\mathrm{Br}} \tag{3.10}$$

$$\frac{\partial}{\partial t}n_\mathrm{i} = -2\frac{\partial}{\partial s}rn_\mathrm{i}u_{\mathrm{i}r} + \frac{\nu_{\mathrm{ionize}}}{Z_\mathrm{i}}\frac{n_\mathrm{e}}{n_{01} + n_{02} + n_{03}}(n_{01} + n_{02} + n_{03}) - \frac{\nu_\mathrm{L}}{Z_\mathrm{i}}(n_\mathrm{e} - n_\mathrm{ediv})$$

$$+ \nu_\mathrm{b}n_\mathrm{b} + \nu_\mathrm{b}gn_\mathrm{b}^{\mathrm{rp}} - f_{\mathrm{CX}}\frac{P_\mathrm{b}}{E_\mathrm{b}} + \nu_{\mathrm{bL}}n_\mathrm{b} + S_{\mathrm{LC}} - \nu_{\mathrm{OL}}n_\mathrm{i} \tag{3.11}$$

$$\frac{\partial}{\partial t}rn_\mathrm{i}u_{\mathrm{i}r} = -2r\frac{\partial}{\partial s}u_{\mathrm{i}r}rn_\mathrm{i}u_{\mathrm{i}r} + \frac{u_{\mathrm{e}\theta}}{r}rn_\mathrm{i}u_{\mathrm{i}\theta} - 2s\frac{\partial}{\partial s}\frac{n_\mathrm{i}T_\mathrm{i}}{m_\mathrm{i}}$$

$$- 2Z_\mathrm{i}\frac{e}{m_\mathrm{i}}sn_\mathrm{i}\frac{\partial}{\partial s}\phi + Z_\mathrm{i}\frac{e}{m_\mathrm{i}}B_\phi rn_\mathrm{i}u_{\mathrm{i}\theta} + 2Z_\mathrm{i}\frac{e}{m_\mathrm{i}}s\frac{\partial A_\phi}{\partial s}n_\mathrm{i}u_{\mathrm{i}\phi} \tag{3.12}$$

$$\frac{\partial}{\partial t}rn_\mathrm{i}u_{\mathrm{i}\theta} = -2\frac{\partial}{\partial s}ru_{\mathrm{i}r}rn_\mathrm{i}u_{\mathrm{i}\theta} + \left(4\frac{\partial}{\partial s}s\mu_\mathrm{i}\frac{\partial}{\partial s}rn_\mathrm{i}u_{\mathrm{i}\theta} - 4\frac{\partial}{\partial s}s\mu_\mathrm{i}ru_{\mathrm{i}\theta}\frac{\partial n_\mathrm{i}}{\partial s} - 4\frac{\partial}{\partial s}\mu_\mathrm{i}rn_\mathrm{i}u_{\mathrm{i}\theta}\right)$$

$$- Z_\mathrm{i}\frac{e}{m_\mathrm{i}}n_\mathrm{i}r\dot{A}_\theta - Z_\mathrm{i}\frac{e}{m_\mathrm{i}}B_\phi rn_\mathrm{i}u_{\mathrm{i}r} - \nu_{\mathrm{NCi}}rn_\mathrm{i}u_{\mathrm{i}\theta} - \frac{m_\mathrm{e}}{m_\mathrm{i}}\nu_{\mathrm{ei}1}rn_\mathrm{e}(u_{\mathrm{i}\theta} - u_{\mathrm{e}\theta})$$

$$+ 2\frac{m_\mathrm{e}}{m_\mathrm{i}}s\frac{\partial A_\phi}{\partial s}\frac{\nu_{\mathrm{ei}2}}{B_\theta}n_\mathrm{e}(u_{\mathrm{i}\phi} - u_{\mathrm{e}\phi}) - \frac{m_\mathrm{b}}{m_\mathrm{i}}\nu_{\mathrm{bi}}rn_\mathrm{b}(u_{\mathrm{i}\theta} - u_{\mathrm{b}\theta})$$

$$+ \frac{e^2 B_\phi^2 D_\mathrm{e}}{m_\mathrm{i}T_\mathrm{e}}n_\mathrm{e}\left[(ru_{\mathrm{e}\theta} - ru_{\mathrm{i}\theta}) + 2\frac{\partial A_\phi}{\partial s}\frac{s}{B_\phi}(u_{\mathrm{e}\phi} - u_{\mathrm{i}\phi}) + s\frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_\mathrm{e}\right.$$

$$+2s\frac{1-\alpha_e}{eB_\phi}\frac{\partial}{\partial s}T_e - 2s\frac{1}{B_\phi}\frac{\partial}{\partial s}\phi\Bigg] - 2\nu_L r n_i u_{i\theta} - \nu_{0i} r n_i u_{i\theta} - \nu_{CX} r n_i u_{i\theta}$$

$$+ rS_{LC\theta} - \nu_{OL} r n_i u_{i\theta} - 2\mu_{i2}\frac{B_\phi}{B_\theta^2}\frac{s}{m_i Z_i e n_i}\frac{\partial}{\partial s}n_i T_i + 2\mu_{i2}\frac{B_\phi}{B_\theta^2}\frac{s}{m_i Z_i e n_i^2}\frac{\partial n_i}{\partial s}n_i T_i + T_{\theta,i} \quad (3.13)$$

$$\frac{\partial}{\partial t}n_i u_{i\phi} = -2\frac{\partial}{\partial s}r u_{ir} n_i u_{i\phi} + \left(4\frac{\partial}{\partial s}s\mu_i\frac{\partial}{\partial s}n_i u_{i\phi} - 4\frac{\partial}{\partial s}s\mu_i u_{i\phi}\frac{\partial n_i}{\partial s}\right) - Z_i\frac{e}{m_i}n_i\dot{A}_\phi - 2Z_i\frac{e}{m_i}\frac{\partial A_\phi}{\partial s}r n_i u_{ir}$$

$$- \frac{m_e}{m_i}\nu_{ei3}n_e(u_{i\phi} - u_{e\phi}) + 2\frac{m_e}{m_i}\frac{\partial A_\phi}{\partial s}\frac{\nu_{ei2}}{B_\theta}r n_e(u_{i\theta} - u_{e\theta}) - \frac{m_b}{m_i}\nu_{bi}n_b(u_{i\phi} - u_{b\phi})$$

$$+ 2\frac{e^2 B_\phi D_e}{m_i T_e}\frac{\partial A_\phi}{\partial s}n_e\left[(r u_{e\theta} - r u_{i\theta}) + s\frac{B}{B_\phi}\left\langle\frac{\omega}{m}\right\rangle_e + 2s\frac{1-\alpha_e}{eB_\phi}\frac{\partial}{\partial s}T_e - 2s\frac{1}{B_\phi}\frac{\partial}{\partial s}\phi\right]$$

$$+ \frac{e^2 B_\phi^2 D_e}{m_i T_e}\left(\frac{B_\theta}{B_\phi}\right)^2 n_e(u_{e\phi} - u_{i\phi}) - 2\nu_L n_i u_{i\phi} - \nu_{0i}n_i u_{i\phi} - \nu_{CX}n_i u_{i\phi}$$

$$+ S_{LC\phi} - \nu_{OL}n_i u_{i\phi} + T_{\phi,i} \quad (3.14)$$

$$\frac{\partial}{\partial t}\frac{3}{2}n_i T_i = -5\frac{\partial}{\partial s}r u_{er} n_e T_e + \left(4\frac{\partial}{\partial s}s\chi_e\frac{\partial}{\partial s}n_i T_i - 4\frac{\partial}{\partial s}s\chi_i T_i\frac{\partial n_i}{\partial s}\right) + 2r u_{ir}\frac{\partial}{\partial s}n_i T_i$$

$$+ Z_i e\frac{E_\theta}{r}r n_i u_{i\theta} + Z_i e E_\phi n_i u_{i\phi} - \frac{3}{2}\nu_{Tei}n_e(T_i - T_e) + m_b v_b\frac{B_\theta u_{i\theta} + B_\phi u_{i\phi}}{B}\frac{P_{b\parallel}}{E_b}$$

$$- \frac{\nu_L}{Z_i}T_i(n_e - n_{ediv}) - \frac{3}{2}\nu_{LT_i}n_i(T_i - T_{idiv})$$

$$+ \frac{3}{2}\frac{\nu_{ionize}}{Z_i}\frac{n_e}{n_{01} + n_{02} + n_{03}}(n_{01}T_{01} + n_{02}T_{02} + n_{03}T_{03}) - \frac{3}{2}\nu_{CX}n_i(T_i - T_{01})$$

$$+ (1 - f_{ei})P_b + P_{\alpha i} + P_{RFi} \quad (3.15)$$

$$\frac{\partial}{\partial t}n_b = \frac{P_b}{E_b} - g\frac{P_{b\perp}}{E_b} - \nu_b n_b - \nu_{bL}n_b - \nu_{eff}g(\sqrt{\delta}n_b - n_b^{rp}) + 4\frac{\partial}{\partial s}s f_t D_b\frac{\partial}{\partial s}n_b \quad (3.16)$$

$$\frac{\partial}{\partial t}r n_b u_{b\theta} = -Z_b\frac{e}{m_b}n_b r\dot{A}_\theta - \nu_{be1}r n_b(u_{b\theta} - u_{e\theta}) + 2s\frac{\partial A_\phi}{\partial s}\frac{\nu_{be2}}{B_\theta}n_b(u_{b\phi} - u_{e\phi}) - \nu_{bi}r n_b(u_{b\theta} - u_{i\theta})$$

$$- \nu_{0b}r n_b u_{b\theta} - \nu_{CX}r n_b u_{b\theta} + r v_{b\theta}\frac{P_{b\parallel}}{E_b} - \nu_{bL}r n_b u_{b\theta} - \nu_{eff}g\sqrt{\delta}r n_b u_{b\theta}$$

$$+ 4\frac{\partial}{\partial s}s f_t D_b\frac{\partial}{\partial s}r n_b u_{b\theta} - 4\frac{\partial}{\partial s}\left(s f_t D_b\frac{\partial r u_{b\theta}}{\partial s}\right)n_b \quad (3.17)$$

$$\frac{\partial}{\partial t}n_b u_{b\phi} = -Z_b\frac{e}{m_b}n_b\dot{A}_\phi - \nu_{be3}n_b(u_{b\phi} - u_{e\phi}) + 2\frac{\partial A_\phi}{\partial s}\frac{\nu_{be2}}{B_\theta}n_b(u_{b\theta} - u_{e\theta}) - \nu_{bi}n_b(u_{b\phi} - u_{i\phi})$$

$$- \nu_{0b}n_b u_{b\phi} - \nu_{CX}n_b u_{b\phi} + v_{b\phi}\frac{P_{b\parallel}}{E_b} - \nu_{bL}n_b u_{b\phi} - \nu_{eff}g\sqrt{\delta}n_b u_{b\phi}$$

$$+ 4\frac{\partial}{\partial s} s f_t D_{\mathrm{b}} \frac{\partial}{\partial s} n_{\mathrm{b}} u_{\mathrm{b}\phi} - 4\frac{\partial}{\partial s}\left(s f_t D_{\mathrm{b}} \frac{\partial u_{\mathrm{b}\phi}}{\partial s}\right) n_{\mathrm{b}} \tag{3.18}$$

$$\frac{\partial}{\partial t} n_{01} = 4\frac{\partial}{\partial s} s D_{01} \frac{\partial}{\partial s} n_{01} - \frac{1}{Z_{\mathrm{i}}} \nu_{\mathrm{ionize}} \frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}} n_{01} - \nu_{\mathrm{CX}} \frac{n_{\mathrm{i}}}{n_{01} + n_{02}} n_{01}$$
$$+ \gamma_0 \frac{\nu_{\mathrm{L}}}{Z_{\mathrm{i}}}\left(n_{\mathrm{e}} - n_{\mathrm{ediv}}\right) \tag{3.19}$$

$$\frac{\partial}{\partial t} n_{02} = 4\frac{\partial}{\partial s} s D_{02} \frac{\partial}{\partial s} n_{02} - \frac{1}{Z_{\mathrm{i}}} \nu_{\mathrm{ionize}} \frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}} n_{02} + \nu_{\mathrm{CX}} \frac{n_{\mathrm{i}}}{n_{01} + n_{02}} n_{01} \tag{3.20}$$

$$\frac{\partial}{\partial t} n_{03} = 4\frac{\partial}{\partial s} s D_{03} \frac{\partial}{\partial s} n_{03} - \frac{1}{Z_{\mathrm{i}}} \nu_{\mathrm{ionize}} \frac{n_{\mathrm{e}}}{n_{01} + n_{02} + n_{03}} n_{03} + f_{\mathrm{CX}} \frac{P_{\mathrm{b}}}{E_{\mathrm{b}}} \tag{3.21}$$

$$\frac{\partial}{\partial t} n_{\mathrm{b}}^{\mathrm{rp}} = \frac{P_{\mathrm{b}\perp}}{E_{\mathrm{b}}} + \nu_{\mathrm{eff}}(\sqrt{\delta} n_{\mathrm{b}} - n_{\mathrm{b}}^{\mathrm{rp}}) - \nu_{\mathrm{b}} n_{\mathrm{b}}^{\mathrm{rp}} - 2\frac{\partial}{\partial s} r u_{\mathrm{b}}^{\mathrm{rp}} n_{\mathrm{b}}^{\mathrm{rp}} + 4\frac{\partial}{\partial s} s D_{\mathrm{b}}^{\mathrm{rp}} \frac{\partial}{\partial s} n_{\mathrm{b}}^{\mathrm{rp}} \tag{3.22}$$

4 Boundary Conditions

num.	name	variable	center	edge
1	LQm1	ϕ	N	0
2	LQm2	$r\dot{A}_\theta$	0	$2s_b B_{\rm V}$
3	LQm3	$\dot{A}_\phi$	N	$-2bB_{\theta{\rm b}}$
4	LQm4	A_ϕ	$\times$	$\times$
5	LQm5	rA_θ	$\times$	$\times$
6	LQe1	$n_{\rm e}$	$\times$	$\times$(N)
7	LQe2	$rn_{\rm e}u_{{\rm e}r}$	0	$0(\times)$
8	LQe3	$rn_{\rm e}u_{{\rm e}\theta}$	0	0
9	LQe4	$n_{\rm e}u_{{\rm e}\phi}$	N	0
10	LQe5	$n_{\rm e}T_{\rm e}$	N	N
11	LQi1	$n_{\rm i}$	$\times$	$\times$(N)
12	LQi2	$rn_{\rm i}u_{{\rm i}r}$	0	$0(\times)$
13	LQi3	$rn_{\rm i}u_{{\rm i}\theta}$	0	0
14	LQi4	$n_{\rm i}u_{{\rm i}\phi}$	N	0
15	LQi5	$n_{\rm i}T_{\rm i}$	N	N
16	LQb1	$n_{\rm b}$	$\times$(N)	$\times$(N)
17	LQb3	$rn_{\rm b}u_{{\rm b}\theta}$	$\times$(0)	$\times$(0)
18	LQb4	$n_{\rm b}u_{{\rm b}\phi}$	$\times$(0)	$\times$(0)
19	LQn1	n_{01}	N	$2bS_{\rm gas}$
20	LQn2	n_{02}	N	0
20	LQn3	n_{03}	N	0
21	LQr1	$n_{\rm b}^{\rm rp}$	N	N

0: Dirichlet condition ($u = 0$)

N: Neumann condition ($u' = 0$)

value: Neumann condition ($u' = $ value)

$\times$: no condition