Chapter 13

Plasma physics

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Plasma physics parameters (Gaussian units)

Z_i = charge on ith ion (units of electronic charge),
N_e, N_i = electron, ion particle densities, respectively (cm^{-3}),
T = temperature (K),
B = magnetic flux density (gauss),
ρ = density ($g\,cm^{-3}$),
A = mass in amu,
g = gravitational acceleration ($cm\,s^{-2}$),
$\omega = 2\pi\nu$ ($rad\,s^{-1}$).

Frequencies (Hz)
plasma oscillation frequency:

$$\nu_{pe} = (N_e e^2/\pi m_e)^{1/2} = 8.978 \times 10^3 N_e^{1/2} \quad \text{Hz},$$

electron gyrofrequency:

$$\nu_{ce} = (e/2\pi m_e c)B = 2.7994 \times 10^6 B,$$

ion gyrofrequency:

$$\nu_{ci} = (Ze/2\pi m_i c)B = 1.535 \times 10^3 Z_i B/A.$$

Velocities ($cm\,s^{-1}$)
electron rms thermal velocity:

$$v_{Te} = (3kT/m_e)^{1/2} = 6.745 \times 10^5 T^{1/2} \quad cm\,s^{-1},$$

atoms, ions rms thermal velocity:

$$v_{Ti} = (3kT/m)^{1/2} = 1.580 \times 10^4 (T/A)^{1/2},$$

ion sound velocity:

$$c_s = (kT/m_i)^{1/2} = 9.12 \times 10^3 (T/A)^{1/2},$$

Alfvén speed:

$$v_A = B/(4\pi\rho)^{1/2} = 0.282 B/\rho^{1/2},$$

electron drift velocity in crossed magnetic and electric field

$$= 3 \times 10^{10} E_\perp (\text{statvolts}\,cm^{-1})/B(\text{gauss}),$$

electron drift velocity in magnetic and gravitational field

$$= m_e gc/eB = 5.686 \times 10^{-8} g/B.$$

Lengths (cm)
Debye length:

$$\lambda_D = (kT/4\pi e^2 N_e)^{1/2} = 6.92 (T/N_e)^{1/2} \quad cm,$$

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electron gyroradius:

$$a_e = m_e v_\perp c/eB = 5.69 \times 10^{-8} v_\perp/B$$
$$\simeq 2.21 \times 10^{-2} T^{1/2}/B,$$

ion gyroradius:

$$a_i = m_i v_\perp c/Z_i eB = 1.036 \times 10^{-4} v_\perp A/Z_i B$$
$$\simeq 0.945 T^{1/2} A^{1/2}/Z_i B.$$

Miscellaneous

electrical resistivity:

$$\eta = 9 \times 10^{-9} (\ln \Lambda) T^{-3/2} \quad \text{s},$$

Coulomb logarithm:

$$\ln \Lambda \approx 9.00 + 3.45 \log T - 1.15 \log N_e,$$

thermal conductivity

$$= 1.0 \times 10^{-6} T^{5/2} \quad \text{erg cm}^{-1}\,\text{s}^{-1}\,\text{K}^{-1},$$

life of magnetic field in a plasma:

$$\tau = 4\pi L^2/\eta c^2$$
$$= 1.5 \times 10^{-12} L^2 (\ln \Lambda)^{-1} T^{3/2} \quad \text{s}$$

(L is the characteristic scale of the field).

Maxwellian velocity distribution:

$$f(v)\,dv = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} e^{-mv^2/(2kT)} v^2\,dv,$$

$$\int_0^\infty f(v)\,dv = 1,$$

$$\bar{v} = (8kT/\pi m)^{1/2} \quad \text{cm s}^{-1},$$

$$v_{\text{rms}} = (3kT/m)^{1/2}$$
$$= 6.7 \times 10^5 T^{1/2} \quad \text{for electrons}$$
$$= 1.57 \times 10^4 T^{1/2} \quad \text{for protons},$$

$$\tfrac{1}{2} m_e v_{\text{rms}}^2 = 3kT/2 = 2.1 \times 10^{-16} T \quad \text{erg}.$$

Classical skin depth:

$$d \equiv c/2\pi v_{pe} = 5.32 \times 10^5 N_e^{-1/2} \quad \text{cm}.$$

Electron–ion collision frequency:

$$\nu_{e-i} \approx 28 N_i T_e^{-3/2} \frac{\ln \Lambda}{20} \quad \text{s}^{-1}.$$

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Approximate parameters for some astrophysical plasmas

Plasma	N_e (cm^{-3})	T_e (K)	B (gauss)	ν_{pe} (Hz)	λ_D (cm)
Ionosphere	10^3–10^6	10^2–10^3	10^{-1}	3×10^5–10^7	7×10^{-2}–7
Interplanetary space	1–10^4	10^2–10^3	10^{-6}–10^{-5}	10^4–10^6	7×10^{-1}–2×10^2
Solar corona	10^8–10^{12} (flare)	10^6–10^7 (flare)	10^{-5}–1	10^8–10^{10}	10^{-2}–2
Solar chromosphere	10^{12}	2–3×10^4	10^3	10^{10}	10^{-3}
Stellar interiors	10^{27}	$10^{7.5}$	—	3×10^{17}	10^{-9}
Planetary nebulae	10^3–10^5	10^3–10^4	10^{-4}–10^{-3}	3×10^5–3×10^6	7×10^{-1}–2×10^1
H II regions	10^2–10^3	10^3–10^4	10^{-6}	10^5–3×10^5	7–7×10^1
H I regions	10^{-3}	10^2	—	3×10^2	2×10^3
White dwarfs	10^{32}	10^7	10^6 (surface)	10^{20}	2×10^{-12}
Pulsars	10^{42} (center)	—	10^{12} (surface)	10^{25}	—
	10^{12} (surface)	—	—	10^{10}	—
Interstellar space	10^{-3}–10	10^2	10^{-6}	3×10^2–3×10^4	2×10^1–2×10^3
Intergalactic space	$\lesssim 10^{-5}$	10^5–10^6	$\lesssim 10^{-8}$	< 30	2×10^6

N_e = electron density; T_e = electron temperature; B = magnetic field; ν_{pe} = plasma frequency; λ_D = Debye length.

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