Questions Related to Chapter 3 of Heliophysics, Vol. IV

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1. (a) The collisional mean free path can be defined as $\ell = (\sigma n)^{-1}$, where σ is a cross section and n is a number density. Assuming $\sigma_{pp} = 4 \times 10^{-12}$ cm^2, $\sigma_{HH} = 9 \times 10^{-17}$ cm^2, and $\sigma_{Hp} = 5 \times 10^{-15}$ cm^2 for proton-proton collisions, H-H collisions, and H-proton charge exchange interactions, respectively, compute mean free paths for these three interactions, assuming densities appropriate for the interstellar medium (ISM) near the Sun.

(b) Comparing these mean free paths with the size scale of the heliosphere, what does this imply about how protons and neutral H interact within our heliosphere?

2. (a) The distance to the termination shock, d_{TS}, in the upwind direction (relative to the ISM flow) can be approximated as the location where the solar wind (SW) ram pressure balances the ISM ram pressure. Considering that ram pressure can be expressed as $P_{ram} = \rho V^2$, derive an expression for d_{TS} in terms of $\rho_{SW\oplus}$, V_{SW}, ρ_{ISM}, and V_{ISM}; where $\rho_{SW\oplus}$ is the solar wind density at Earth's orbit (i.e., at $d_\oplus = 1$ AU).

(b) Based on the results of Question #1, do you think ρ_{ISM} in the d_{TS} equation should include both protons and neutral H, or only protons? Whatever your answer, compute d_{TS} assuming typical values for the solar wind and local ISM (see Vol. I, Sect. 9.4; Vol. IV, Sect. 3.2), and compare with the actual observed value (Vol. IV, Sect. 3.4).

(c) By what multiplicative factor would ρ_{ISM} have to be increased to push the termination shock inside Earth's orbit?

3. (a) The sound and Alfvén speeds can be expressed (in cgs units) as $V_s = \sqrt{kT/m}$ and $V_A = B/\sqrt{4\pi\rho}$, respectively. Based on Fig. 3.5 (from Vol. IV, Ch. 3) showing plasma measurements at the termination shock, what are V_s and V_A for both the pre-shock and post-shock plasmas? The magnetic field is not shown, so just assume $B = 0.5$ μG and $B = 1.2$ μG for the pre-shock and post-shock values, respectively.

(b) Assuming a quasi-perpendicular shock (i.e., magnetic field perpendicular to the shock normal) the Mach number of the plasma can be expressed as $M_A = V_{SW}/\sqrt{V_s^2 + V_A^2}$. What is M_A for the pre-shock and post-shock plasma?

(c) In a normal MHD shock, $M_A > 1$ pre-shock and $M_A < 1$ post-shock. You should have found that this is not the case for the termination shock. Any speculation as to what might be going wrong here?

4. Interstellar absorption lines from singly-ionized Mg (Mg II) and neutral deuterium (D I) have been observed by the *Hubble Space Telescope* towards the nearby star ϵ Eri. Analysis of these lines suggests Doppler width parameters of b(Mg II) $= 2.81$ km s^{-1} and b(D I) $= 8.10$ km s^{-1}, respectively. What is the temperature (T) and nonthermal velocity (ξ) for the ISM towards ϵ Eri (see Vol. IV, Sect. 3.2)?