Solutions to Chen's Plasma Physics

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1-1. Compute the density (in units of m^{-3}) of an ideal gas under the following conditions:

a) At $0^\circ C$ and 760 Torr pressure (1 Torr = 1mm Hg). This is called the Loschmidt number.

b) In a vacuum at 10^{-3} Torr at room temperature ($20^\circ C$). This number is a useful one for the experimentalist to know by heart (10^{-3} Torr = 1 micron).

a) Avogadro's number is $N_A = 6.022 \times 10^{23}$. One mole of gas at STP occupies 22.4 liters. 1 liter is 1×10^{-3} cubic meters. Thus, the number per cubic meter is $N_A/n = 6.022 \times 10^{23}/(22.4 \times 10^{-3}) = 2.66 \times 10^{25} \, m^{-3}$. Thus, the Loschmidt number is 2.66×10^{25} □

b) Using PV=NkT, we obtain (with R= 1.4×10^{-23} J K^{-1} and 1 Torr = 133 Pa):

$$n = \frac{N}{V} = \frac{P}{kT} = \frac{10^{-3} \times 133}{1.4 \times 10^{-23} \times (20 + 273)} = 3.3 \times 10^{19} m^{-3} \quad \square \tag{1}$$

1-2. Derive the constant A for a normalized one-dimensional Maxwellian distribution

$$\hat{f}(u) = Ae^{-mu^2/2kT} \tag{2}$$

such that

$$\int_{-\infty}^{\infty} \hat{f}(u)du = 1 \tag{3}$$

This one is straightforward. Just integrate:

$$1 = \int_{-\infty}^{\infty} Ae^{-mu^2/2kT}du = A\sqrt{\frac{2\pi kT}{m}} \quad \Rightarrow \quad A = \sqrt{\frac{m}{2\pi kT}} \quad \square \tag{4}$$

1-4. Compute the pressure, in atmospheres and in $tons/ft^2$, exerted by a thermonuclear plasma on its container. Assume $kT_e = kT_i = 20keV$, $n = 10^{21}m^{-3}$ and $p = nkT$, where $T = T_i + T_e$.

This is just unit conversion, albeit with units that nobody really ever remembers. For reference, $1 keV = 1.6 \times 10^{-19} J$, so

$$p = 10^{21} \times (20keV + 20keV) = 4 \times 10^{22}m^{-3} \, keV = 4 \times 10^{3}m^{-3} \, J = 4 \times 10^{3}N/m^2 \tag{5}$$

But $1 \, atm = 10^5 N/m^2 = 1 \, ton/ft^2$, so (Note: I think there is a mistake in Chen's solutions here. If I am mistaken, please let me know).

$$p = 0.04 \, atm = 0.04 \, ton/ft^2 \quad \square \tag{6}$$

1-5. In a strictly steady state situation, both the ions and the electrons will follow the Boltzmann relation

$$n_j = n_0 e^{-q_j\phi/kT_j} \tag{7}$$

For the case of an infinite, transparent grid charged to a potential ϕ, show that the shielding distance is given approximately by

$$\lambda_D^{-2} = \frac{ne^2}{\epsilon_0}(\frac{1}{kT_e} + \frac{1}{kT_i}) \tag{8}$$

Show that λ_D is determined by the temperature of the colder species.

We'll use Poisson's equation

$$\nabla^2\phi = \frac{en_e - en_i}{\epsilon_0} = \frac{en_0}{\epsilon_0}(e^{e\phi/kT_e} - e^{-e\phi/kT_i}) \approx \frac{en_0}{\epsilon_0}(1 + \frac{e\phi}{kT_e} - 1 - \frac{-e\phi}{kT_i}) = \frac{e^2 n}{\epsilon_0}(\frac{\phi}{kT_e} + \frac{\phi}{kT_i}) \tag{9}$$

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Lauren Gardner

Chen Plasma Physics Solutions:

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