

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°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°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 $2.66 \times 10^{25} \square$

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

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

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

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

such that

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

This one is straightforward. Just integrate:

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

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

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

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).

$$p = 0.04 atm = 0.04 ton/ft^2 \quad \square \quad (6)$$

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

$$n_j = n_0 e^{-e_j\phi/kT_j} \quad (7)$$

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

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

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

We'll use Poisson's equation

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

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Table of Contents Chen Plasma Physics Solutions

1. Understanding the eBook Chen Plasma Physics Solutions
 - The Rise of Digital Reading Chen Plasma Physics Solutions
 - Advantages of eBooks Over Traditional Books
2. Identifying Chen Plasma Physics Solutions
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Chen Plasma Physics Solutions
 - User-Friendly Interface
4. Exploring eBook Recommendations from Chen Plasma Physics Solutions
 - Personalized Recommendations
 - Chen Plasma Physics Solutions User Reviews and Ratings
 - Chen Plasma Physics Solutions and Bestseller Lists

5. Accessing Chen Plasma Physics Solutions Free and Paid eBooks
 - Chen Plasma Physics Solutions Public Domain eBooks
 - Chen Plasma Physics Solutions eBook Subscription Services
 - Chen Plasma Physics Solutions Budget-Friendly Options
6. Navigating Chen Plasma Physics Solutions eBook Formats
 - ePub, PDF, MOBI, and More
 - Chen Plasma Physics Solutions Compatibility with Devices
 - Chen Plasma Physics Solutions Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Chen Plasma Physics Solutions
 - Highlighting and Note-Taking Chen Plasma Physics Solutions
 - Interactive Elements Chen Plasma Physics Solutions
8. Staying Engaged with Chen Plasma Physics Solutions
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Chen Plasma Physics Solutions
9. Balancing eBooks and Physical Books Chen Plasma Physics Solutions
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Chen Plasma Physics Solutions
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Chen Plasma Physics Solutions
 - Setting Reading Goals Chen Plasma Physics Solutions
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Chen Plasma Physics Solutions
 - Fact-Checking eBook Content of Chen Plasma Physics Solutions
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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