Phys 761

I Introduction

A. The plasma state – basic parameters

Reference: Fitzpatric Introduction

What is a plasma

* Collection of charged particles which interact dominantly through the Coulomb Force

* Examples

Space: Interstellar gas
Gaseous Nebula
Solar Coronna
Plenatary Mangneto spheres

Earth: Gas discharge
Flames
~~Pro~~ Material Processing Reactors
Light Sources
Controlled Fusion Experiments
Charged Particle Beams - Accelerators
Laser Produced Plasmas

Most of the observable universe is ~~a~~ a plasma

* Characteristics

* Typically less dense then solid matter

* Typically hotter than ~~room~~ room temperature

why ?

* necessary to keep plasma "ionized"

~~Vize~~ That is electrons and positive ions separate

— interaction is through "long range" coulomb force.

* Like a gas
* but highly mobile charge carriers

Basic Plasma Parameters Density & Temperature

Density $n_{e,i}$ cm^{-3} e – electrons
i – ions

# of particles / cm^3

(We will use cgs – esu unit system)

CGS - ESU

Charge : stat coulomb

$1 \text{ stat coulomb} = 3 \times 10^{9}$ ~~statcoulomb~~ coul

why?

$$\underset{\text{Newtons}}{|F_{12}|} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2 \sim m} \qquad (SI)$$

$$\epsilon_0 \cong 8.854 \times 10^{-12}$$

$$\underset{\text{dynes}}{|F_{12}|} = \frac{q_1 q_2}{r_{12}^2 \sim cm} \qquad (esu)$$

no funny numbers

charge coul or stat coul.

Potential

$$F = \frac{q V}{L} \quad L \sim \text{length cm}$$

Newtons
or
Dynes

Potential

stat volts

$1 \text{ stat volt} = \frac{1}{3} \times 10^{-2}$ volts

~~fundamental~~

electronic charge 1.6022×10^{-19} C

$= 4.8032 \times 10^{-10}$ Stat Coul

Reference NRL Plasma Formulary

Maxwell's Equations in esu

esu	SI
$\nabla \cdot \underset{\sim}{B} = 0$	$\nabla \cdot \underset{\sim}{B} = 0$
$\nabla \cdot \underset{\sim}{E} = 4\pi\rho$	$\nabla \cdot \underset{\sim}{E} = \frac{\rho}{\epsilon_0}$
$-\frac{1}{c}\frac{\partial \underset{\sim}{B}}{\partial t} = \nabla \times \underset{\sim}{E}$	$-\frac{\partial B}{\partial t} = \nabla \times \underset{\sim}{E}$
$\nabla \times \underset{\sim}{B} = \frac{4\pi}{c}\underset{\sim}{J} + \frac{1}{c}\frac{\partial \underset{\sim}{E}}{\partial t}$	$\nabla \times \underset{\sim}{B} = \mu_0 \underset{\sim}{J} + \epsilon_0\mu_0 \frac{\partial \underset{\sim}{E}}{\partial t}$
<u>comments</u>	<u>comments</u>
$\underset{\sim}{E}$ & $\underset{\sim}{B}$ measured in same units	$\underset{\sim}{E}$ & $\underset{\sim}{B}$ measured in different units
speed of light in vacuum = c	speed of light = $\frac{1}{\sqrt{\epsilon_0\mu_0}}$
no "funny" numbers	$\epsilon_0 = 8.854 \times 10^{-12}$ $\mu_0 = 4\pi \times 10^{-7}$
$\underset{\sim}{F} = q\left(\underset{\sim}{E} + \frac{\underset{\sim}{v} \times \underset{\sim}{B}}{c}\right)$	$\underset{\sim}{F} = q\left(\underset{\sim}{E} + \underset{\sim}{v} \times \underset{\sim}{B}\right)$

~~Electron~~ Particle density: $n_{e,i}$

e = electrons
i = ions

N = # of particles in volume $\mathbb{V}$

$N = n_{e,i}\mathbb{V}$

Temperature

average amount of energy in each degree of freedom in Thermal equilibrium

$U = \frac{1}{2} kT$ — temperature °K

Boltzmann's constant $\frac{\text{ergs}}{°K}$

~~Note we seldom~~
Express temperature in units of energy $kT \rightarrow T_{(\text{ergs})}$

$U = \frac{1}{2} T$

$\boxed{m_e c^2 = 511 \text{ keV}}$

Actually T is measured in electron volts

$1 \text{eV} = 1.6022 \times 10^{-19}$ Joules $= 1.6022 \times 10^{-12}$ ergs
$\approx 1.16 \times 10^{4}$ °K

~~The plasma parameter~~

In thermal equilibrium the average kinetic energy of a particle is

$$\langle K.E. \rangle = \left\langle \frac{1}{2} m \left(V_x^2 + V_y^2 + V_z^2 \right) \right\rangle = \frac{3}{2} T$$

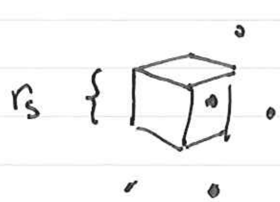
~~The~~ Show-table — what are the other ~~cont~~ columns?

The plasma parameter

How important are individual coulomb forces?

* suppose we have a plasma characterized by density n and temperature T.

* what is the typical interparticle spacing?



There is one particle in a cube of side r_s

$$n r_s^3 = 1$$

$$r_s = n^{-1/3}$$

* what is the energy associated with Coulomb interaction between neighboring particles

$$U \simeq \frac{e^2}{r_s}$$

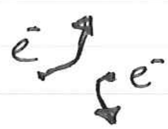
* How does this compare with the typical energy ?

$$\frac{U}{T} = \frac{e^2}{r_s T} = \Gamma \quad \text{the plasma parameter}$$

if $\Gamma > 1$ nearby particles are strongly correlated

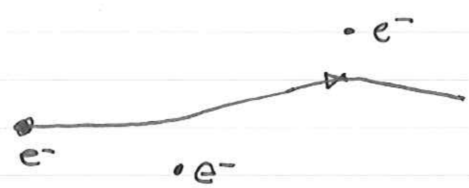
$\Gamma > 2$ gas $\to$ liquid phase transition

$\Gamma > 180$ liquid $\to$ crystal phase transition



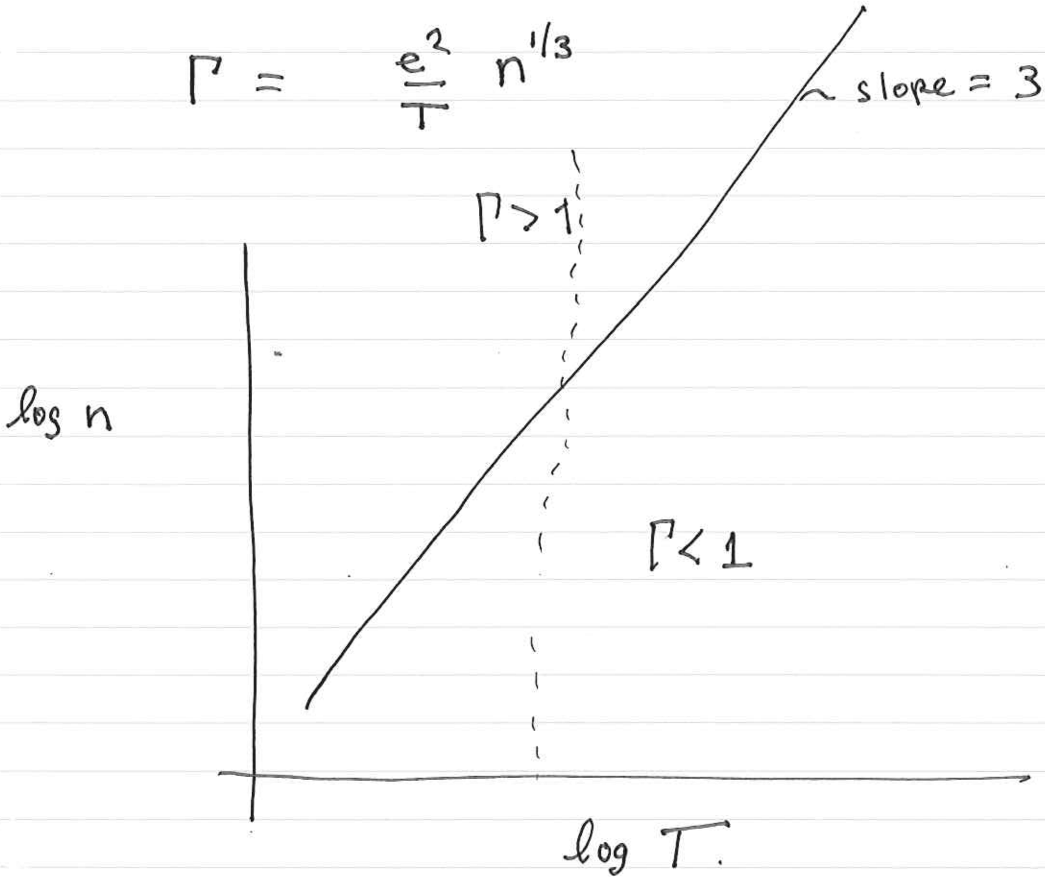
show picture

if $\Gamma < 1$ nearby (all) particles are weakly correlated



charged particles move ballistically suffering only slight deflections due to interactions with individual charged particles

$$\Gamma = \frac{e^2}{T} n^{1/3}$$



Show picture

Introduce Debye length λ_D (I'll define later)

$$\lambda_D^2 = \frac{T}{4\pi n e^2} \qquad T = \lambda_D^2 \, 4\pi n e^2$$

$$\Gamma = \frac{e^2 n^{1/3}}{\lambda_D^2 \, 4\pi n e^2} = \frac{1}{4\pi} \frac{1}{(n \lambda_D^3)^{2/3}}$$

$\Gamma < 1$	$n\lambda_D^3 > 1$
$\Gamma > 1$	$n\lambda_D^3 < 1$