ASTR 5590 - Chapter 11a

Properties of a plasma

★ Why does gravity dominate the evolution of the universe?

All other forces have +/− charges

EM force is $10^{36}\times$ stronger (2 protons)

$m_p \leftrightarrow m_e$

$$F_{EM} = \frac{-e^2}{r^2}, \quad F_g = G\frac{m_p m_e}{r^2}$$

$$\frac{F_{EM}}{F_g} = \frac{e^2}{G m_p m_e} = \frac{(4.8\times10^{-10})^2\, 1836}{6.67\times10^{-8}\,(1.67\times10^{-24})^2} \sim 10^{39}$$

★ What happens when charges get separated?

Universe neutral → not DM

So, some minimum scale where charge is effectively screened — if farther away, plasma looks neutral

Called Debye length λ_D

surface charge density

Imagine a capac[illegible]

$\sigma = e n_e \delta x$ (electrons)

+ charge induced on other side – to discharge plates, need $E = \sigma/\epsilon_0$

Eqn of motion ($F = ma$) is then

mass surface density · accel. = charge surface density · E

$$m_e n_e x \frac{d^2(\delta x)}{dt^2} = -(e n_e x)\frac{e n_e \delta x}{\epsilon_0}$$

charges move as surface, x is const. thickness

$$\frac{d^2(\delta x)}{dt^2} = -\frac{e^2 n_e}{m_e \epsilon_0}\delta x$$

What is this the equation for? SHO

$$\ddot{x} = -\omega^2 x$$

On this scale, charge will oscillate back + forth + be unable to escape, so can't separate further

Plasma freq.

$$\omega_p = \left(\frac{e^2 n_e}{\epsilon_0 m_e}\right)^{1/2}$$

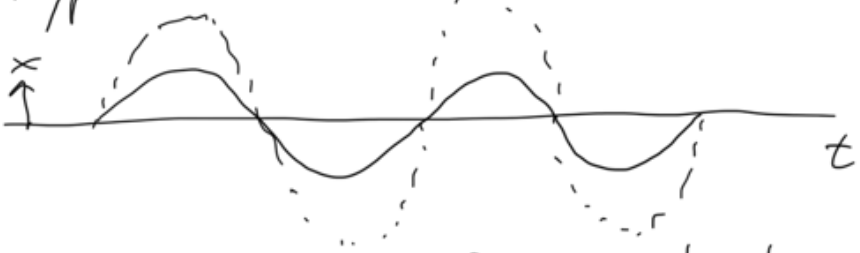
$$\nu_p = \frac{\omega_p}{2\pi} \simeq 9\left(\frac{n_e}{m^{-3}}\right)^{1/2} \text{Hz}$$

$$= 9000\left(\frac{n_e}{cm^{-3}}\right)^{1/2} \text{Hz}$$

★ for e^-, how would freq. change for protons?

$\sqrt{1836} = 46\times$ smaller

Typical distance v_x can travel depends on



oscillate @ same freq., just travel farther

$$\lambda_D = \frac{v_x}{\omega_p} \quad : \text{Debeye length}$$

What is v_x?

Assume thermal, so $\frac{1}{2} m_e \overline{v_x^2} = \frac{1}{2} kT$

(3D, $\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = \frac{3}{2} kT / \frac{1}{2} m_e$)

$$\lambda_D = \left(\frac{kT\,\epsilon_0}{n_e e^2}\right)^{1/2} = 69\left(\frac{T}{n_e}\right)^{1/2} \text{m}$$

$$= 6.9\left(\frac{T}{n_e}\right)^{1/2} \text{cm}$$

No dependence on mass — same for e^- & p^+

$L \gg \lambda_D$, plasma "neutral", behaves collectively

$L \ll \lambda_D$, individual particles behave as particles

When we discuss a "plasma" $L \gg \lambda_D$, $\tau \gg \frac{1}{\omega_p}$

charges effectively shielded