Ion Waves → Ion Sound

Plasma → no neutrals and few collisions

In the absence of collisions → ordinary sound waves would not occur.

Ions can still transmit vibrations to each other because of their charge, acoustic waves can occur through the intermediary of an electric field

Massive ions involved → low-frequency oscillations.

We assume $n_i = n_e = n$ and do not use Poisson's eqn. The ion fluid eqn in the absence of a magnetic field is

$$Mn\left[\frac{\partial v_i}{\partial t} + (v_i \cdot \nabla)v_i\right] = enE - \nabla p$$

$$= -en\nabla\phi - \gamma_i KT_i \nabla n$$

— (6)

assumed $E = -\nabla\phi$ and used eqn of state.

Linearizing and assuming plane waves, we have

$$-i\omega M n_0 v_{i1} = -en_0 ik\phi_1 - \gamma_i kT_i ikn_1$$

— (7)

The balance of forces on electrons, requires

$$n_e = n = n_0 \exp\left(\frac{e\phi_1}{kT_e}\right) = n_0\left(1 + \frac{e\phi_1}{kT_e} + \cdots\right)$$

The perturbation in density of electrons, and, therefore, of ions, is then

$$n_1 = n_0 \frac{e\phi_1}{KT_e} \quad \text{--- (8)}$$

Linearized ion eqⁿ of continuity

$$i\omega n_1 = n_0 i k v_{i1} \quad \text{---(9)}$$

In eqⁿ (7), we may substitute ϕ_1 and n_1 in terms of v_{i1} from eqⁿ (6) & (9)

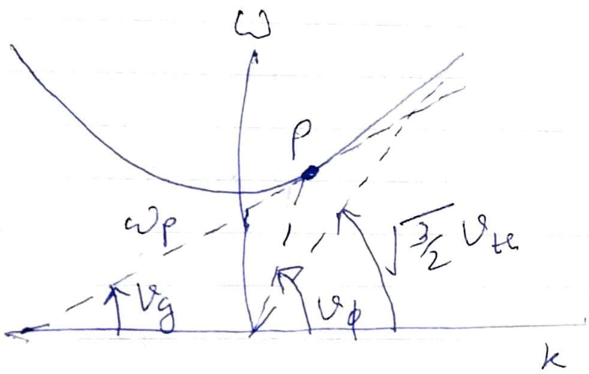
$$i\omega M n_0 v_{i1} = \left(e n_0 i k \frac{KT_e}{e n_0} + \gamma_i K T_i i k \right) \frac{n_0 i k v_{i1}}{i\omega}$$

$$\omega^2 = k^2 \left(\frac{KT_e}{M} + \frac{\gamma_i K T_i}{M} \right)$$

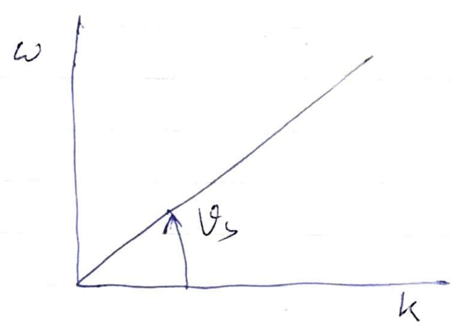
$$\frac{\omega}{k} = \left(\frac{KT_e + \gamma_i K T_i}{M} \right)^{1/2} \equiv v_s \quad \text{---(10)}$$

↓

Sound speed in plasma



Dispersion relation for electron plasma waves (Bohm - Gross Waves)



Dispersion relation for ion acoustic waves in the limit of small Debye length

Plasma oscillations → basically constant - frequency waves with a correction due to thermal motions

Ion waves → constant - velocity waves and exist only when there are thermal motions

For ion waves, group velocity is equal to the phase velocity.

Applications of Plasma Physics

Plasmas → Characterized by the two parameters n and kT_e, applications cover extremely wide range of n and kT_e.

n varies → 28 orders of magnitude from 10^6 to $10^{34}\ m^{-3}$.

KT → can vary over seven orders from 0.1 to 10^6 eV.

- Gas Discharges (Gaseous Electronics)

Earliest work 1920's → Langmuir, Tonks and collaborators.

Vacuum tubes that could carry large currents and therefore had to be filled with ionized gases

Weakly ionized glow discharges and positive columns, $kT_e \simeq 2$ eV and $10^{14} < n < 10^{18}\ m^{-3}$.

Spark gaps, welding arcs, neon and fluore-scent lights, lighting discharges.

Controlled Thermonuclear Plasma

1952 → hydrogen bomb fusion reaction be controlled to make a reactor

The principal reactions involve Deuterium (D) and Tritium (T) atoms

$$D + D \rightarrow {}^{3}He + n + 3.2\ MeV$$

$$D + D \rightarrow T + p + 4.0\ MeV$$

$$D + T \rightarrow {}^{4}He + n + 17.6\ MeV$$

Cross sections for these fusion reactions are appreciable only for incident energies above 5 keV.

Accelerated beams of deuterons bombarding → will not work → deuterons loose energy by scattering → No fusion reaction X

Need of Plasma → Thermal energies in the range of 10 - keV.

↳ Heating & containing such a plasma has rapid growth. ↓ Confinement

Space Physics → Study of the earth's environment in space.

Solar Wind :- Continuous stream of charged particles → impinges on the earth's magnetosphere

↳ $n = 5 \times 10^{6} m^{-3}$, $KT_i = 10\ eV$, $KT_e = 50\ eV$, $B = 5 \times 10^{-9} T$ and drift velocity 300 km/sec.

Ionosphere → from an altitude of 50 km to 10 earth radii → populated by weakly ionized plasma density varying up to $n = 10^{12}\ m^{-3}$. T is only 10^{-1} eV.

Modern Astrophysics :- Stellar interiors and atmospheres are hot enough to be in the plasma state.

Core of the sun → 2 keV (Temp)

Thermonuclear reactions → responsible for the sun's radiation.

Solar Corona → plasma with temp. up to 200 eV

Plasma as a conducting fluid

– Magnetohydrodynamics (MHD)

- Macroscopic Approach :- Plasma is considered to be divided into small volumes

Each of which is large compared to the average spacings of the individual particles it contains

Yet small compared to any distance over which the macroscopic properties vary appreciably.

Associated with this volume

average velocity, magnetic field, density, temperature, pressure, conductivity etc.

→ Behaviour of plasma deduced in terms of the action of these volumes.

Conducting fluid → plasma → subject simultaneously to the laws of electromagnetics and hydrodynamics

→ Magnetohydrodynamics (MHD) or hydromagnetics.

Concept of magnetic pressure

$$p^M = \frac{B^2}{2\mu_0}$$

introduced by Faraday. He thought of tubes of forces as elastic filaments under tension in the direction of the field and compressed in the transverse direction

↓

Maxwell → Stress tensor (mathematical form)

→ Basis for magnetohydrodynamics

Behaviour of conducting fluid in an electromagnetic fluid