Time: ~~Wednesday~~ 2-4 (9:10 ~12:00) P1
Thursday (~~2018~~ 2019) PP.

Office: Composite building 48212

office hour: whenever I am in my office and not in a meeting. You can check my schedule from my lab's calender. Please go to ISAPS webpage to find my calender.

~~Homework:~~

Text book: Introduction to plasma physics and controlled fusion, by Francis F. Chen.

Principles of Plasma Physics for Engineers and Scientists by Umran S. Inan and Marek Golkowski

~~Additional~~

Reference book: - Introduction to Plasma Theory. by Dwight R. Nicholson.

(- Introduction to Plasma Physics. w/ Space Laboratory and Astrophysical Applications) Donald A. Gurnett & Amitava Bhattacharjee

- NRL Plasma Formulary
www.nrl.navy.mil/ppd/content/nrl-plasma-formulary

TA: TBA.

(2018 No Homework) √2019

Homework: Homeworks are expected every other week.

Exam: 2 midterm + 1 final. (10/24, 12/21, 1/9; 11/8)

quizze: 10 mins at the end of each class

Away on 9/19 → reschedule: TBD.

§ 0 Preface:

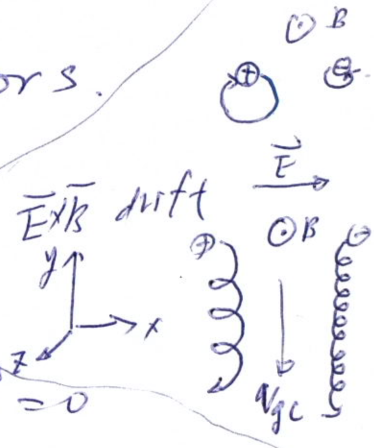
1. Introduction — Definition of plasma will be given.

~~2. Single Particle motions!~~

Plasma

A plasma is a quasineutral gas of charged and neutral particles which exhibits collective behaviors.

2. Single-Particle motions. $\vec{E}\times\vec{B}$ drift



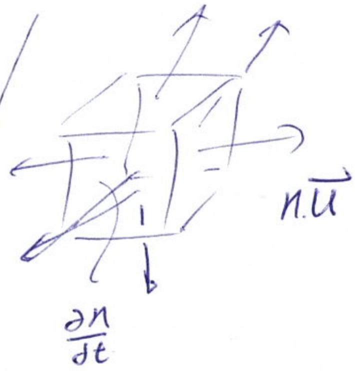
- Uniform $\vec{E}$ & $\vec{B}$
- Nonuniform $\vec{B}$, $\vec{E}=0$
- Nonuniform $\vec{E}$, Uniform $\vec{B}$
- Time-Varying $\vec{E}$, $\vec{E}, \vec{B}$ uniform in space
- Time-Varying $\vec{B}$
- Adiabatic invariants
  - 1st: $\mu = \frac{m v_\perp^2}{2B}$
  - 2nd: $J = \int_a^b v_{\parallel} \, ds$
  - 3rd: $\Phi = \int k \, ds$

* In periodic motion, the action integral $\oint p \, dq = \text{const}$ taken over a period.
* If a slow change is made in the system, so that the motion is not quite periodic, the constant of the motion does not change and is then called an Adiabatic invariant.

3 Plasma as Fluids.

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\vec{u}) = 0$$ Continuity eq.

$$mn\left[\frac{\partial \vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u}\right] = qn(\vec{E} + \vec{v}\times\vec{B}) - \nabla p$$ momentum eq.

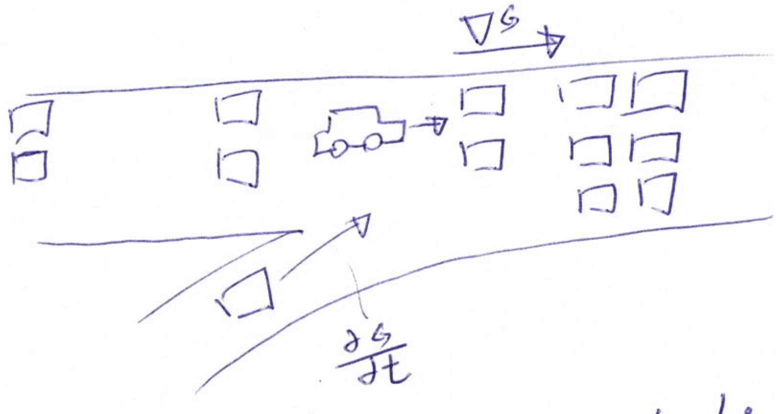


* $G(x,t)$: any property of a fluid in 1D x-space.
* The change of G w/ time in a frame moving w/ the fluid

$$\frac{d\vec{G}(x,t)}{dt} = \frac{\partial \vec{G}}{\partial t} + \frac{\partial \vec{G}}{\partial x}\cdot\frac{dx}{dt} = \frac{\partial \vec{G}}{\partial t} + u_x\frac{\partial \vec{G}}{\partial x}$$

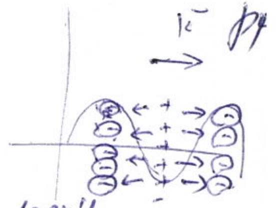
or $$\frac{d\vec{G}(\vec{x},t)}{dt} = \frac{\partial \vec{G}}{\partial t} + (\vec{u}\cdot\nabla)\vec{G}$$

Convective derivative

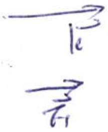


* The time derivative is to be taken at the "position of the particles (elements)". ~~However~~, The position is moving so that the gradient is taken into account.

4. Waves in Fluids.



- Electrostatic wave: $\vec{B}_1 = 0$, $\vec{E}_1 \parallel \vec{k}$
  - Electron waves: ← high frequency, ion doesn't move
    - $\vec{B}_0 = 0$ or $\vec{k} \parallel \vec{B}_0$ — Plasma Oscillation
    - $\vec{k} \perp \vec{B}_0$ — Upper hybrid Oscillation

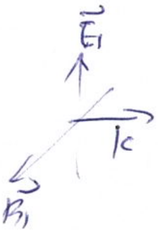


$\omega^2 = \omega_p^2 + \omega_c^2$ (plasma freq ← ω_p, cyclotron freq ← ω_c)

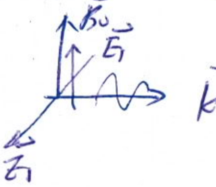
  - Ion waves: ← low frequency, electron moves w/ ions
    - $\vec{B}_0 = 0$ or $\vec{k} \parallel \vec{B}_0$ — Acoustic waves
    - $\vec{k} \perp \vec{B}_0$ — Electrostatic ion cyclotron waves / Lower hybrid oscillations

$\omega = (\Omega_c \omega_c)^{1/2}$ (ion cyclotron freq, e cyclotron freq)

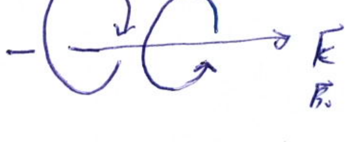
- Electromagnetic waves. $\vec{E}_1 \not\parallel \vec{k}$



  - Electron waves ← high frequency
    - $B_0 = 0$ — Light waves
    - $\vec{k} \perp \vec{B}_0$, $\vec{E}_1 \parallel \vec{B}_0$ — O wave (ordinary wave)

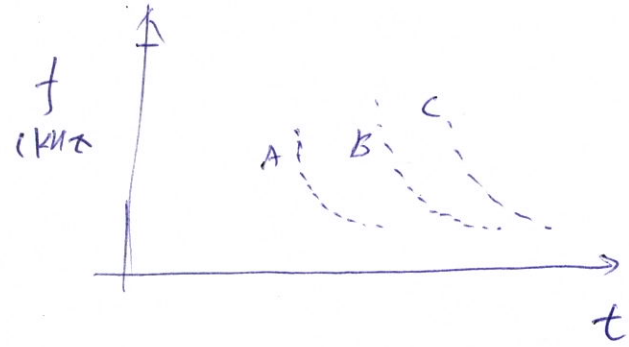


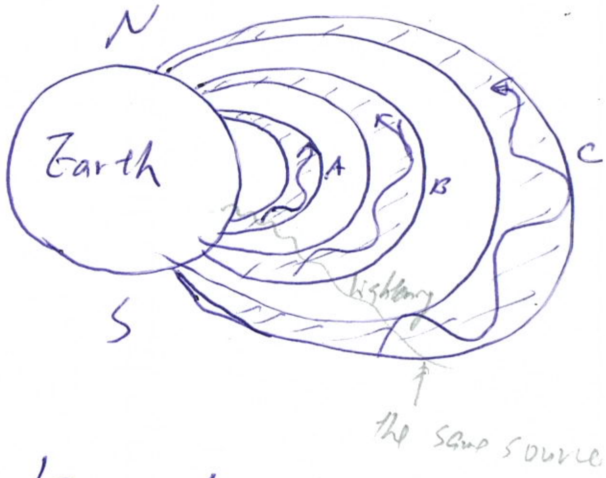
    - $\vec{k} \perp \vec{B}_0$, $\vec{E}_1 \perp \vec{B}_0$ — X wave (extraordinary wave)
    - $\vec{k} \parallel \vec{B}_0$ — R wave (whistler mode), L wave



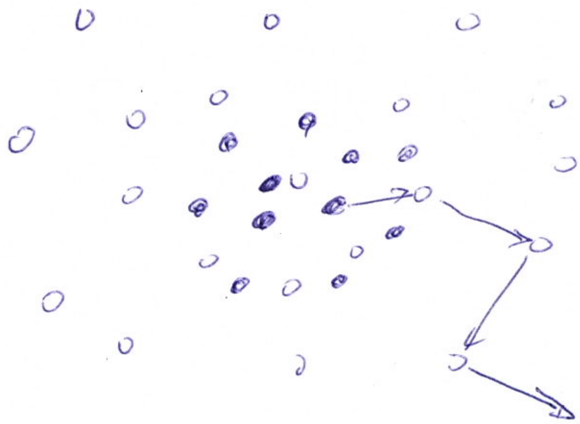
- Example.

Whistler's Mode

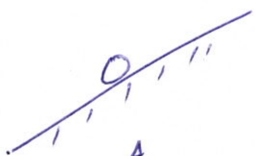




5- Diffusion and Resistivity



6- Equilibrium and Stability.

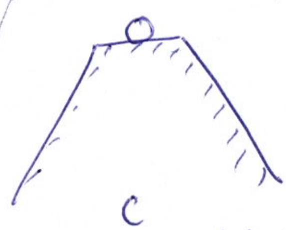


A

No equilibrium

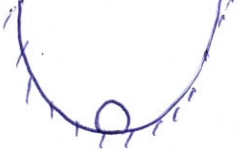
B

neutral stable

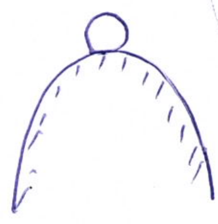


C

(Metastable)
equilibrium

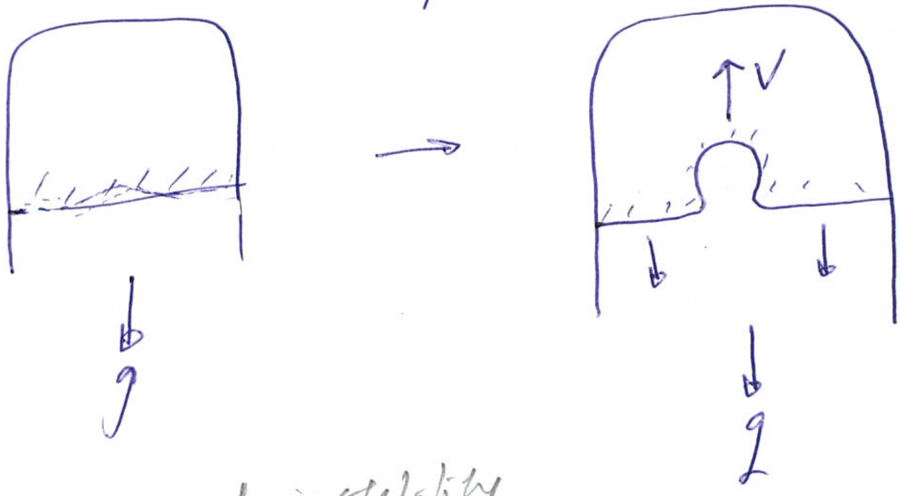


stable equilibrium

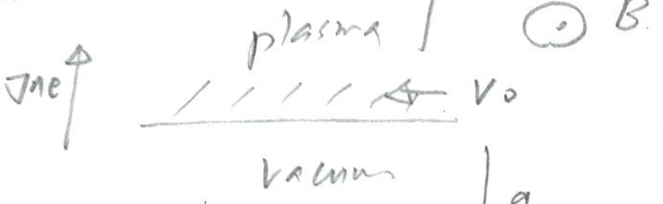


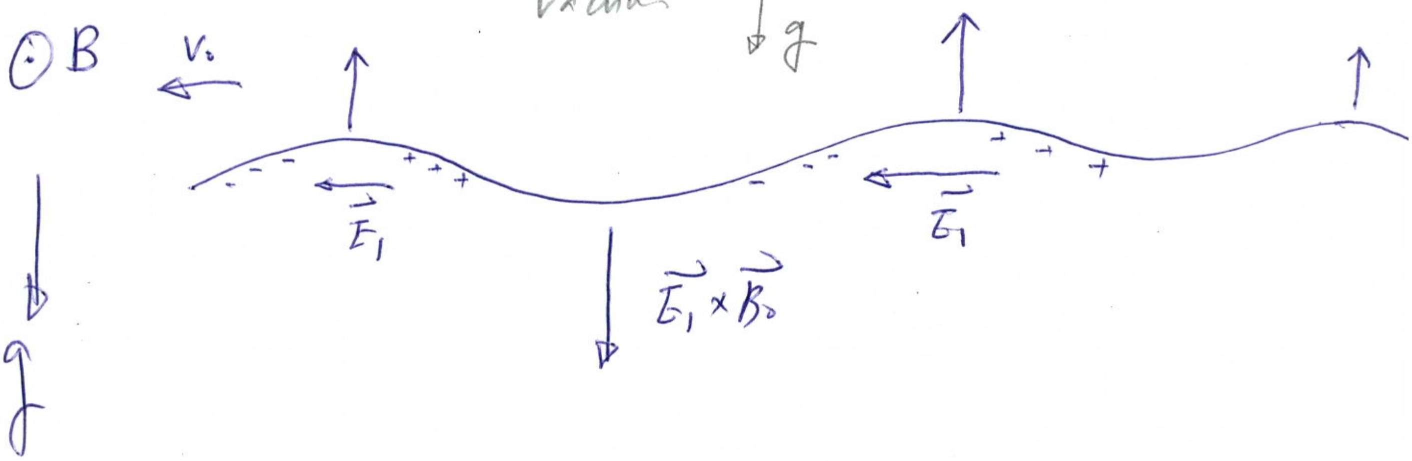
unstable
equilibrium

- Hydrodynamic Rayleigh-Taylor instability

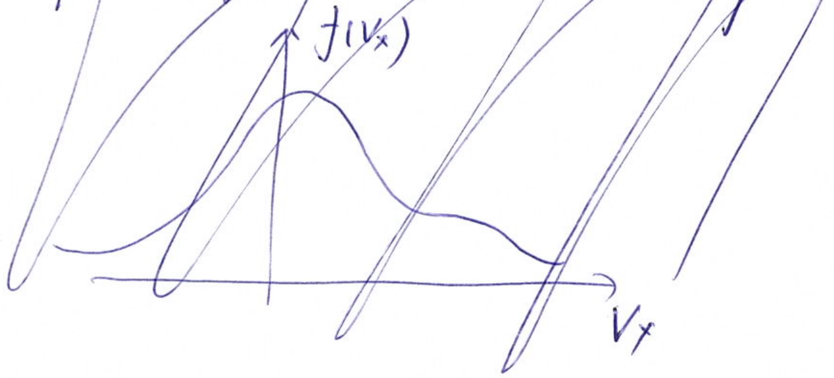


- gravitational instability

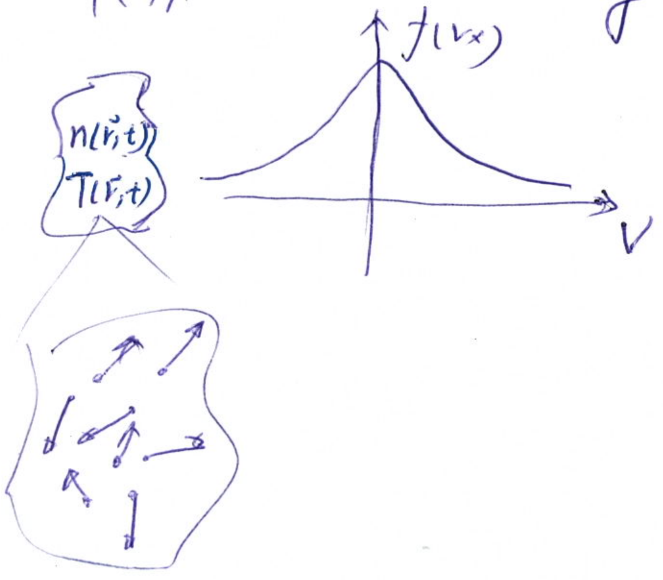




7- Kinetic Theory

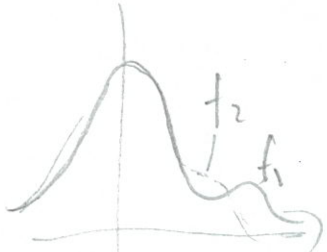


7. Kinetic Theory

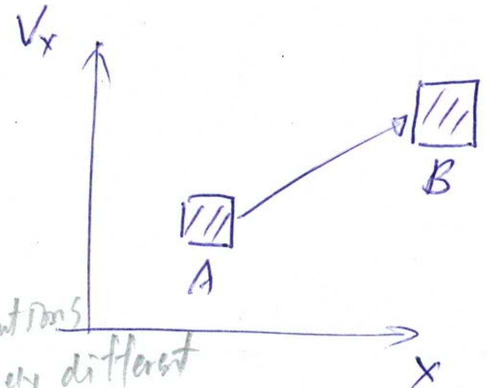


$$f(v_x) = \left(\frac{m}{2\pi KT}\right)^{1/2} \exp\left(-\frac{v_x^2}{v_{th}^2}\right)$$

→ Non kinetic distribution:



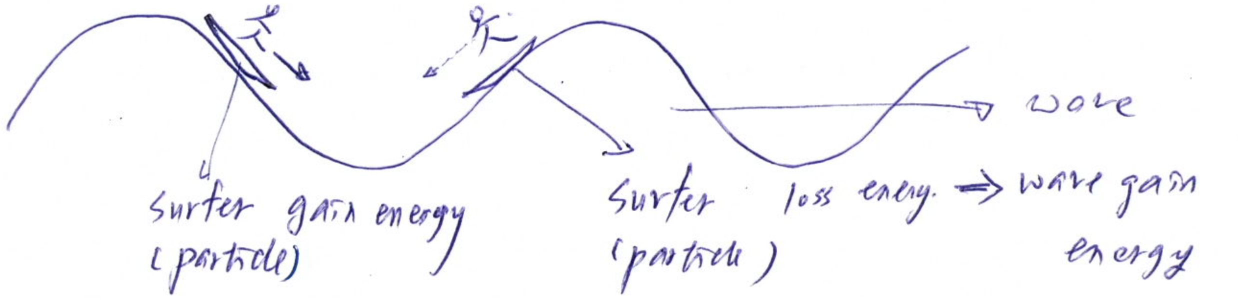
The two distributions will have entirely different behaviors, but as long as the areas under the curves are the same, fluid theory does not distinguish between them.



* use phase space $(\vec{x}, \vec{v})$ to ~~das~~ represent the position and velocity coordinates of a group of particles.

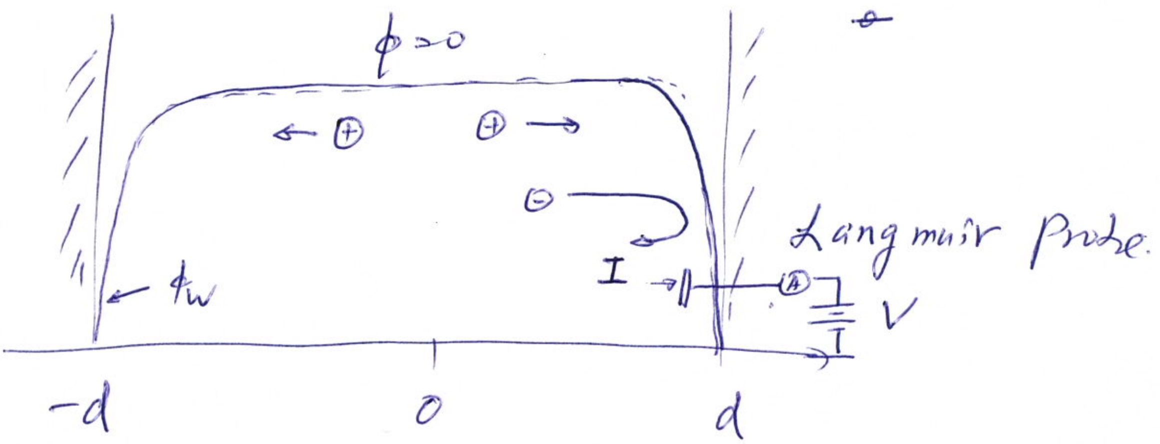
$$\frac{\partial f}{\partial t} + \vec{v}\cdot\nabla f + \frac{\vec{F}}{m}\cdot\frac{\partial f}{\partial \vec{v}} = \left(\frac{\partial f}{\partial t}\right)_c$$

* Landau damping:



8 Nonlinear Effects.

– Sheaths



$$\frac{1}{2}mv^2 \sim kT \implies v \propto \sqrt{\frac{T}{m}}$$

$v_e \gg v_i$ for $T_e = T_i$

* Langmuir probe use the I–V curve of the probe to determine the density and temperature of the plasma.