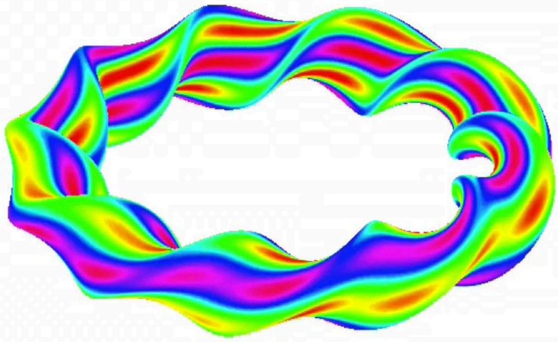
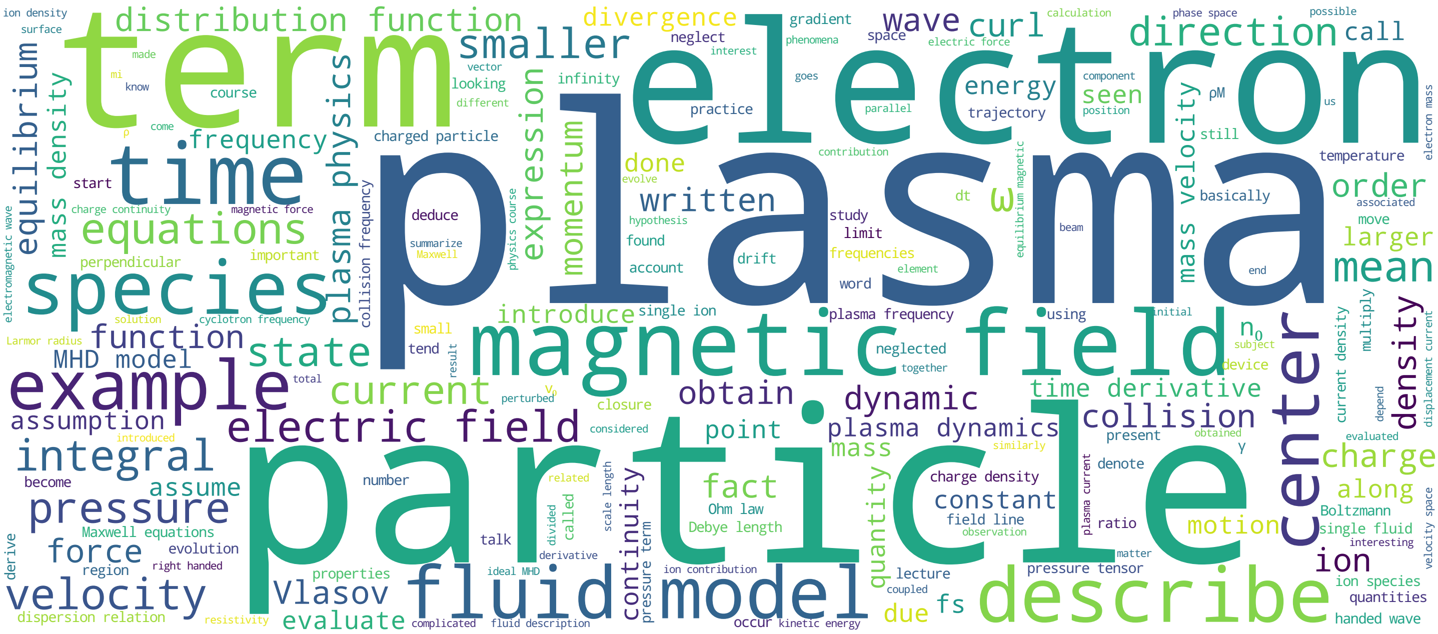


Single fluid equation and MHD model

Plasma Physics and Application to Fusion Energy, Astrophysics and Industry

Lecture 3e

Paolo Ricci



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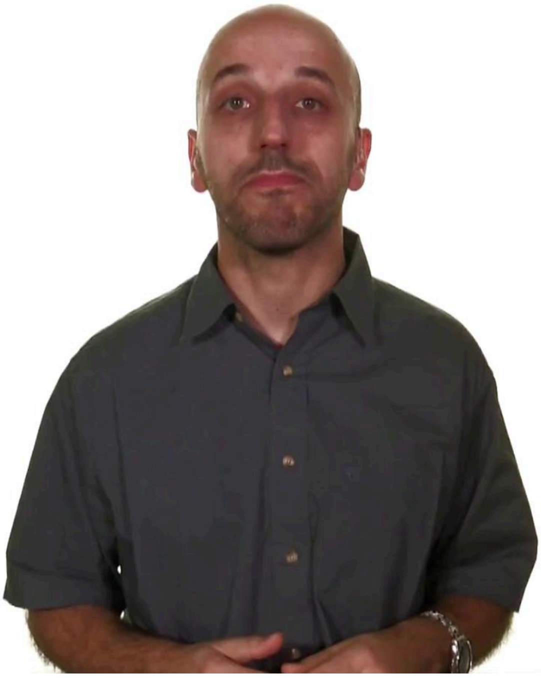
Introduction



- Summary of the two fluid model
- One-fluid variables
- One-fluid model
- The Magneto-hydro dynamics (MHD) model

Plasma

Welcome — welcome to the plasma physics course of EPFL. Today we are going to talk about the single-fluid description of a plasma and the MHD model. In the past lecture, we have seen that it's possible to describe the plasma dynamics with a two-fluid model, basically describing electrons and ions as two different fluids. Today we will provide an even simpler description, one that is able to describe the plasma dynamics as the evolution of one single fluid. As the first thing with you, I will briefly recall the main elements of the two-fluid model. Then I will introduce the variables that are considered by a one-fluid model and I will describe this model, and finally I will describe the typical assumptions that are made in the single-fluid description of a plasma to come up with a magnetohydrodynamic — MHD — model, that is one of the most commonly used models in plasma physics.

Notes

Summary

0m 05s

The two-fluid model

- Continuity equation: $\frac{\partial n_s}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (n_s \vec{u}_s) = 0$
- Momentum equation $m_s n_s \frac{d\vec{u}_s}{dt} = q_s n_s (\vec{E} + \vec{u}_s \times \vec{B}) - \nabla \cdot \overleftrightarrow{P}_s + \vec{R}_s$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \vec{u}_s \cdot \frac{\partial}{\partial \vec{r}} \quad , \quad \vec{R}_s = \int m_s (\vec{v} - \vec{u}_s) \left(\frac{\partial f}{\partial t}\right)_c d\vec{v}$$

- Closure equation

+ Maxwell equations:

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \rho = \sum_s q_s n_s$$

$$\nabla \cdot \vec{B} = 0 \qquad \nabla \times \vec{B} = \mu_0 \left(\vec{j} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right) \qquad \vec{j} = \sum_s q_s n_s \vec{u}_s$$

Plasma

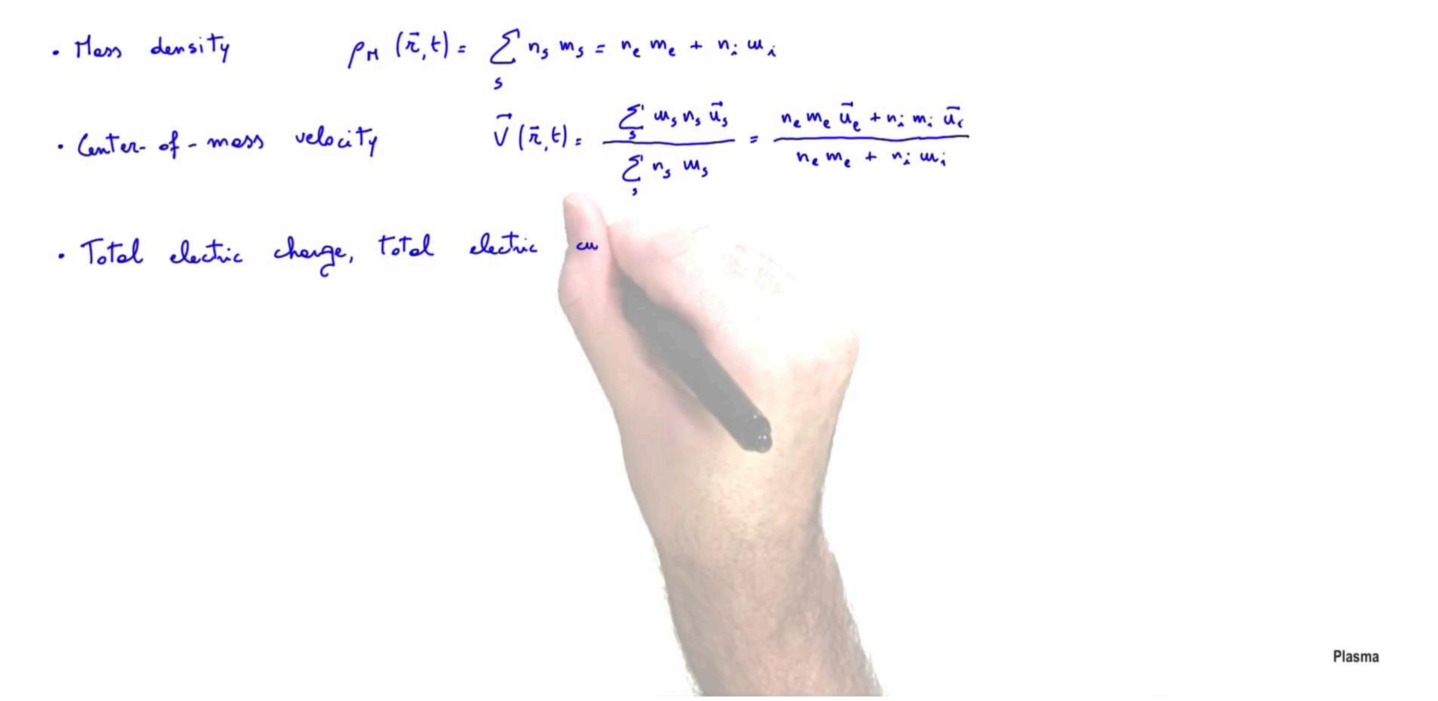
So let's briefly recall the main elements of the two-fluid model. Within the two-fluid model, the dynamics of each fluid is given by a continuity equation — that is, the time derivative of the particle density is due to the particle flux; a momentum equation, which states that the time derivative of the plasma velocity is due to the forces that are acting on this fluid element. That is the electric force, magnetic force, pressure forces and friction force. With d/dt we have made the convective time derivative and the friction forces are given by the integral of the collisions terms of Vlasov into the Boltzmann equation. The pressure term is given by a closure equation that I'm now going to write here. The system has to be coupled to Maxwell's equations that state that ∇·E is equal to ρ/ε0 ∇·B = 0, ∇ × E = -∂B/∂t, and ∇ × B (the curl of B) is given by the current and time derivative of the electric field. The charge density and the current density are related to the two fluid quantitites by the fact that ρ is given by the sum over all species of the charge of each species times ns, the density. The current density is given by the sum, over all species, of qs, ns and us. This the two-fluid model that describes the dynamics of a plasma, taking into account the dynamics of electrons and ions as two different fluids.

Notes

Summary

1m 08s

One-fluid variables



Starting from the quantities such as ns, us, quantities that are relative to each species, we can actually deduce the one-fluid quantites that are evolved by the one-fluid model. The first quantity of interest for the one-fluid description of a plasma is the mass density. We will denote it as ρM. It's a function of space and time and will be given by the sum over all species of the density of each species times the mass. For example, there is one single ion species in our model. This will be given by the sum of the electron contribution plus the ion contribution. Another quantity of interest is the center of mass velocity. We will denote it with a capital V and it's still a function of space and time. It will be given by the ratio between the velocity of all particle species weighted according to their density and their mass, normalized to ρM — that is, ns ms. The sum is over all species. This, for example, for a plasma with a single ion species will be given by the sum of the electron contribution and the ion contribution divided by the total mass. Then there are the quantities related to the total electric charge and total electric current. We have somehow already introduced those in the previous slide.

Notes

Summary

4m 04s

One-fluid variables

- Mass density $\rho_M(\vec{r},t) = \sum_s n_s m_s = n_e m_e + n_i m_i$
- Center-of-mass velocity $\vec{V}(\vec{r},t) = \dfrac{\sum_s m_s n_s \vec{u}_s}{\sum_s n_s m_s} = \dfrac{n_e m_e \vec{u}_e + n_i m_i \vec{u}_i}{n_e m_e + n_i m_i}$
- Total electric charge, total electric current $\rho = \sum_s n_s q_s = e(n_i - n_e)$, $\vec{J} = \sum_s q_s n_s \vec{u}_s$
- Pressure in the center-of-mass frame $\overleftrightarrow{P}_s^{cm} = n_s m_s \int (\vec{v}-\vec{V})(\vec{v}-\vec{V}) f_s \, d\vec{v}$

$$\overleftrightarrow{P}^{cm} = \sum_s \overleftrightarrow{P}_s^{cm} = \overleftrightarrow{P}_e^{cm} + \overleftrightarrow{P}_i^{cm}$$

Plasma

That will still be called ρ, that is the sum over all species of ns qs and for a case of one single ion species that is ionized only once, this will be given by e(ni-ne). For the current we will have, similarly, the sum over all species of the current carried by each species. The last quantity that we want to introduce is the pressure in the center of the mass frame. We first define the pressure in the center of the mass frame for each species. That is a tensor and differs from the standard definition of the pressure because the u(s) has been replaced by V, the center of mass velocity. Starting from the center of mass pressure of each species, we can get the total, the one-fluid variable. It's total pressure in the center of mass that is given by the sum, over all species, of Ps^cm. In the case of one single ion species that will be given by the electron and ion contribution.

Notes

Summary

6m 06s

One-fluid equations

$$\frac{\partial n_e}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (n_e \vec{u}_e) = 0 \qquad \times\, m_e \qquad \times\, -e$$

$$+ \qquad\qquad +$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (n_i \vec{u}_i) = 0 \qquad \times\, m_i \qquad \times\, e$$

$$\frac{\partial \rho_M}{\partial t} + \frac{\partial}{\partial \vec{r}} (\rho_M \vec{V}) = 0 \qquad\qquad \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot \vec{J} = 0$$

$$m_e n_e \frac{d\vec{u}_e}{dt} = -e n_e \left(\vec{E} + \vec{u}_e \times \vec{B}\right)$$

Plasma

We now have all the elements to deduce the one-fluid model of a plasma. Let me just point out that in this derivation we will stop at the level of the momentum equation. For the energy equation, we will use a simple closure. Let's see how we can deduce the one-fluid model that describes the plasma dynamics. To do that we can start from the continuity equation for the electrons and for the ions. We can now multiply the electron continuity equation by me and the ion continuity equation by mi, sum up these two equations, and if we do the calculation, what we obtain is an equation for the mass density where V is the center of mass velocity. Similarly we can multiply the electron continuity equation by -e, the electron charge, and the ion continuity equation by e, the charge of the ion species. Sum them up and what we obtain is an equation for the charge density. We can use a similar approach to deduce the equation that evolves the plasma center of mass velocity and the current. The starting points in this case are the electron and ion momentum equations.

Notes

Summary

7m 49s

$$\frac{\partial n_e}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (n_e \vec{u}_e) = 0 \qquad \times m_e$$

$$+$$

$$\frac{\partial n_i}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (n_i \vec{u}_i) = 0 \qquad \times m_i$$

$$\frac{\partial \rho_M}{\partial t} + \frac{\partial}{\partial \vec{r}} (\rho_M \vec{V}) = 0$$

$$\times\, -e \quad + \quad \times\, e$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot \vec{J} = 0$$

$$m_e n_e \frac{d\vec{u}_e}{dt} = -e n_e (\vec{E} + \vec{u}_e \times \vec{B}) - \frac{\partial}{\partial \vec{r}} \cdot \vec{\vec{P}}_e + \vec{R}_e$$

$$+$$

$$m_i n_i \frac{d\vec{u}_i}{dt} = e n_i (\vec{E} + \vec{u}_i \times \vec{B}) - \frac{\partial}{\partial \vec{r}} \cdot \vec{\vec{P}}_i + \vec{R}_i$$

$$\rho_M \frac{d\vec{V}}{dt} = \rho \vec{E} + \vec{J} \times \vec{B} - \frac{\partial}{\partial \vec{r}} \cdot \vec{\vec{P}}^{cM}$$

$$\times \frac{-1}{e n_e} \quad + \quad \times \frac{1}{e} \frac{m_e}{m_i n_i}$$

in the hypothesis $n_e \simeq n_i = n$, $m_e \ll m_i$, and $\vec{J} \ll e n \vec{u}_i, e n \vec{u}_e$

$$\frac{m_e}{n e^2} \left[\frac{\partial \vec{J}}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\vec{V}\vec{J} + \vec{J}\vec{V}) \right] = \vec{E} + \vec{V} \times \vec{B} - \frac{1}{e n} \frac{\partial}{\partial \vec{r}} \cdot \vec{\vec{P}}_e^{cM} - \eta \vec{J}$$

Plasma

We can sum up these two equations and what we obtain is an equation for the center of mass velocity that takes into account the electric force, the magnetic force and the contribution of the pressure term that is actually written in terms of the center of mass pressure. In order to obtain an equation for the plasma current, we should multiply the electron momentum equation by -1/(e ne) and the ion momentum equation by 1/e me/(mi ni) and sum them up. Within the hypothesis that our plasma is quasi-neutral and we will call that, the electron and ion density, which are very close to n. And also in the hypothesis that me, the electron mass, is much smaller than the ion mass, and that the current is much smaller than the current carried out by each species, we will have an equation for the electron currents that states that this convective time derivative of the electron current is due to the electric field, and the (V × B) term, which represent basically the contribution of the electromagnetic forces, a term that is related to the pressure tensor, and a resistivity term.

Notes

Summary

10m 13s

The one-fluid model

- Mass continuity equation: $\frac{\partial \rho_m}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\rho_m \vec{V}) = 0$

- Charge continuity equation: $\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot \vec{J} = 0$

- Momentum equation : $\rho_m \frac{d\vec{V}}{dt} = \rho \vec{E} + \vec{J} \times \vec{B} - \frac{\partial}{\partial \vec{r}} \cdot \bar{\bar{P}}^{cm}$

- Ohm's law $\frac{m_e}{n e^2} \left[\frac{\partial \vec{J}}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot \left(\vec{V}\vec{J} + \vec{J}\vec{V} \right) \right] = \vec{E} + \vec{V} \times \vec{B} - \frac{1}{en} \frac{\partial}{\partial \vec{r}} \cdot \bar{\bar{P}}_e^{cm} - \eta \vec{J}$

- Closure : if there are sufficient collisions

$$\frac{\partial}{\partial \vec{r}} \cdot \bar{\bar{P}}^{cm} = \frac{\partial}{\partial \vec{r}} P \quad , \quad \frac{d}{dt}\left(P \rho_m^{-\gamma}\right) = 0 \text{ with } \begin{cases} \gamma = 1 & \text{isothermal} \\ \gamma = \frac{c_p}{c_v} & \text{adiabatic} \\ \gamma = +\infty & \text{incompressible} \end{cases}$$

- Maxwell equations

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0 \qquad \nabla \times \vec{B} = \mu_0 \left(\vec{J} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

Plasma

We can now summarize the equations for the one-fluid model. It will be built up by a mass continuity equation, a charge continuity equation, a momentum equation, and an equation that states how the current density evolves. We can call it Ohm's law. This has to be associated with a closure equation. For example, if there are sufficient collisions, then we can assume that the pressure tensor is actually scalar and therefore ∂/∂r [dot] divergence of the pressure tensor becomes the gradient of a scalar that we will call P and P will be given by a state of equation law where γ can be equal to one, for example, and in this case we have isothermal plasma dynamics, or it can be equal to cp/cv for an adiabatic motion, or γ can be equal to infinity in the case of an incompressible flow. The system is then completed by Maxwell's equations that as usual read as divergence of E is equal to ρ (divided by ε0), divergence of B = 0, ∇×E (curl of E) is equal to -∂B/∂t and ∇×B (curl of B) is equal to the contribution of the current. What we have just written here is a closed system of equations that describes the dynamics of a plasma as the evolution of one single fluid.

Notes

Summary

12m 16s

The one-fluid model

- Mass continuity equation: $\frac{\partial \rho_M}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\rho_M \vec{V}) = 0$

- Charge continuity equation: $\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot \vec{J} = 0$

- Momentum equation : $\rho_M \frac{d\vec{V}}{dt} = \rho \vec{E} + \vec{J} \times \vec{B} - \frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}^{CM}$

- Ohm's law $\cancel{\frac{m_e}{ne^2}\left[\frac{\partial \vec{J}}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\vec{V}\vec{J} + \vec{J}\vec{V})\right]} = \vec{E} + \vec{V} \times \vec{B} - \frac{1}{en} \frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}_e^{CM} - \eta \vec{J}$

- Closure : if there are sufficient collisions

$$\frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}^{CM} = \frac{\partial}{\partial \vec{r}} P \quad , \quad \frac{d}{dt}\left(P \rho_M^{-\gamma}\right) \quad \text{with} \quad \begin{cases} \gamma = 1 & \text{isothermal} \\ \gamma = \frac{c_p}{c_v} & \text{adiabatic} \\ \gamma = +\infty & \text{incompressible} \end{cases}$$

- Maxwell equations

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0 \qquad \nabla \times \vec{B} = \mu_0 \left(\vec{J} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right)$$

Typical assumptions

1) Electron inertia negligible, $m_e \to 0$

2) Quasi neutrality ($\frac{L}{\lambda_D} \gg 1$, $\omega \ll \omega_{pe}$, $\omega \ll \omega_{ci}$), $\frac{\rho}{ne} = \frac{n_e - n_i}{n_e} \ll 1$

Plasma

Even if the model that we have just described represents a substantial simplification with respect to the kinetic model and the two-fluid model, sometimes it's too complicated and it's not possible to treat it analytically, numerically. Therefore some assumptions are done (made) in order to make the problem more tractable. Let's see together — what are the typical assumptions that are done? There are actually four assumptions that are done [made]. The first assumption that is typically made is the one of negligible electron inertia. This means in practice to take the limit of the electron mass that goes to zero. In other words, what one does is neglecting this term here. The second assumption is to assume that the plasma is quasi-neutral, which means to consider phenomena that occur on scale length that are much larger than the Debye length, phenomena that have typical frequencies much smaller than the plasma frequency and that have a frequency much smaller than the ion cyclotron frequency. Under this assumption, one can impose that the charge density with respect to the density of the electrons is equal to the ratio of the difference between the electron and the ion density divided by the electron density has to be much smaller than one.

Notes

Summary

14m 42s

The one-fluid model

- Mass continuity equation: $\frac{\partial \rho_M}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\rho_M \vec{V}) = 0$
- Charge continuity equation: $\cancel{\frac{\partial \rho}{\partial t}} + \cancel{\frac{\partial}{\partial \vec{r}} \cdot \vec{J}} = 0$
- Momentum equation : $\rho_M \frac{d\vec{V}}{dt} = \cancel{\rho \vec{E}} + \vec{J} \times \vec{B} - \frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}^{cM}$
- Ohm's law $\cancel{\frac{m_e}{ne^2}\left[\frac{\partial \vec{J}}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\vec{V}\vec{J} + \vec{J}\vec{V})\right]} = \vec{E} + \vec{V} \times \vec{B} - \cancel{\frac{1}{en}\frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}_e^{cM}} - \eta \vec{J}$
- Closure : if there are sufficient collisions

$$\frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}^{cM} = \frac{\partial}{\partial \vec{r}} P \quad , \quad \frac{d}{dt}\left(P \rho_M^{-\gamma}\right) \quad \text{with} \begin{cases} \gamma = 1 & \text{isothermal} \\ \gamma = \frac{c_p}{c_v} & \text{adiabatic} \\ \gamma = +\infty & \text{incompressible} \end{cases}$$

- Maxwell equations

$$\cancel{\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}} \qquad \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0 \qquad \nabla \times \vec{B} = \mu_0 \left(\vec{J} + \cancel{\varepsilon_0 \frac{\partial \vec{E}}{\partial t}}\right)$$

Typical assumptions

1) Electron inertia negligible, $m_e \to 0$
2) Quasi neutrality ($\frac{L}{\lambda_D} \gg 1$, $\omega \ll \omega_{pe}$, $\omega \ll \omega_{ci}$), $\frac{\rho}{ne} = \frac{n_e - n_i}{n_e} \ll 1$
3) Neglect E.M. waves: $\left|\varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right| \ll |\vec{J}|$

$$\Rightarrow \frac{\partial}{\partial \vec{r}} \cdot \vec{J} = 0$$

4) Small Larmor radius ($\frac{L}{\rho_i} \gg 1$); $|\vec{V} \times \vec{B}| \gg \left|\frac{1}{en}\frac{\partial}{\partial \vec{r}} \cdot \overleftrightarrow{P}_e\right|$

Plasma

In practice, what this means is that we can neglect the ρE term in the momentum equation, the ∂ρ/∂t term in the charge continuity equation, and also the Gauss's law becomes an equation that we can not use anymore to evaluate the electric field. The third hypothesis that is done is to neglect electromagnetic waves — that is, to assume that the displacement current is much smaller than the plasma current. This means in practice that we can neglect in the Maxwell's equation, the displacement current. If you look here, what we will have is that the divergence of j will be equal to zero all the time, as the divergence of the curl of B is equal to zero all the time. Therefore, this means that the divergence of j is equal to zero, which in practice tells us that also this term in the charge continuity equation can be neglected. The last hypothesis we'll do is to assume that the phenomena that we consider occur on scale lengths that are much larger than the Larmor radius. This, in other terms, means that the (V × B) term is much larger than the term due to the pressure. Therefore, in Ohm's law we can neglect the pressure term.

Notes

Summary

16m 45s

The Magneto-hydro dynamics (MHD) model

- Continuity: $\frac{\partial \rho_m}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\rho_m \vec{v}) = 0$
- Momentum equation: $\rho_m \frac{d\vec{V}}{dt} = \vec{j} \times \vec{B} - \frac{\partial}{\partial \vec{r}} p$
- Ohm's law: $\vec{E} + \vec{V} \times \vec{B} = \eta \vec{j}$
- Closure equation: $\frac{d}{dt}\left(p \rho_m^{-\gamma}\right) = 0$
- Maxwell equations: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

$\nabla \times \vec{B} = \mu_0 \vec{j}$

$\nabla \cdot \vec{B} = 0$ | initial condition

Plasma

What you have just obtained is the so-called magnetohydrodynamics model, MHD for short. It is one of the most widely used models to describe the dynamics of a plasma. You will use it throughout the rest of the course. So, it's important that we write together all the equations that constitute the MHD model. The first equation is the continuity equation for the mass density. The mass density varies in time according to the particle flux. The second equation is the momentum equation, which states that the center of mass velocity changes because of the (j × B) force and also the gradient of the pressure. Then we have Ohm's law, that with the simplification we have done got reduced to E + V × B is equal to the resistive term. Then there is a closure equation, which in the simplest form can be written as d/dt of the pressure times the mass density to the power of -γ, where γ is the index of the polytropic, equal to zero. All this has to be coupled to Maxwell's equations, that in the simplified form we are looking at can be reduced to curl of E = -∂B/∂t, curl of B = μ0 j, we have neglected the displacement current and divergence of B is equal to zero, which as Maxwell's equation always [says], is to be considered an initial condition of our problem.

Notes

Summary

18m 38s

The Magneto-hydro dynamics (MHD) model

- Continuity: $\frac{\partial \rho_M}{\partial t} + \frac{\partial}{\partial \vec{r}} \cdot (\rho_M \vec{V}) = 0$
- Momentum equation: $\rho_M \frac{d\vec{V}}{dt} = \vec{j} \times \vec{B} - \frac{\partial}{\partial \vec{r}} p$
- Ohm's law: $\vec{E} + \vec{V} \times \vec{B} = \eta \vec{j}$
- Closure equation: $\frac{d}{dt}\left(p \rho_M^{-\gamma}\right) = 0$
- Maxwell equations: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

$\nabla \times \vec{B} = \mu_0 \vec{j}$

$\nabla \cdot \vec{B} = 0$ (initial condition for $\vec{B}$)

ρ_M
$\vec{V}$
$\vec{j}$
$\vec{B}$
p
$\vec{E}$

$\Rightarrow$ 14 unknowns, 14 equations

If $\eta = 0$: ideal MHD model, otherwise: resistive MHD model

Plasma

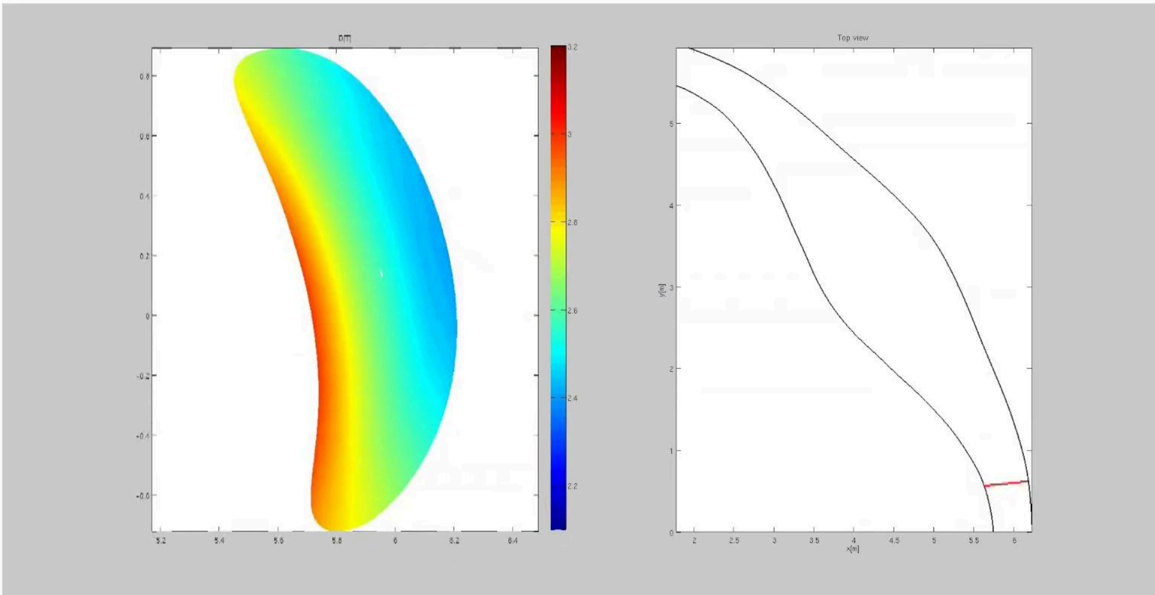
So how many equations and how many unknowns do we have? Let's try to summarize this. The unknowns are ρM, V, j, B, pressure, and the electric field — then, if we count, 14 unknowns — 1 + 3 + 3 + 3 + 1 +3 — 14 unknowns, and how many equations? We have 1+ 3 + 3 + 1 +3 + 3 — 14 equations. What we have obtained here is actually a self-consistent model that is able to describe the plasma dynamics. Let me point out that if the plasma is sufficiently hot, the resistivity can be very small and can be neglected. In this case we will talk about [an] ideal MHD model. Otherwise we will talk about [a] resistive MHD model.

Notes

Summary

21m 04s

Example of MHD simulation



Equilibrium magnetic field in the W7-X experiment

Plasma

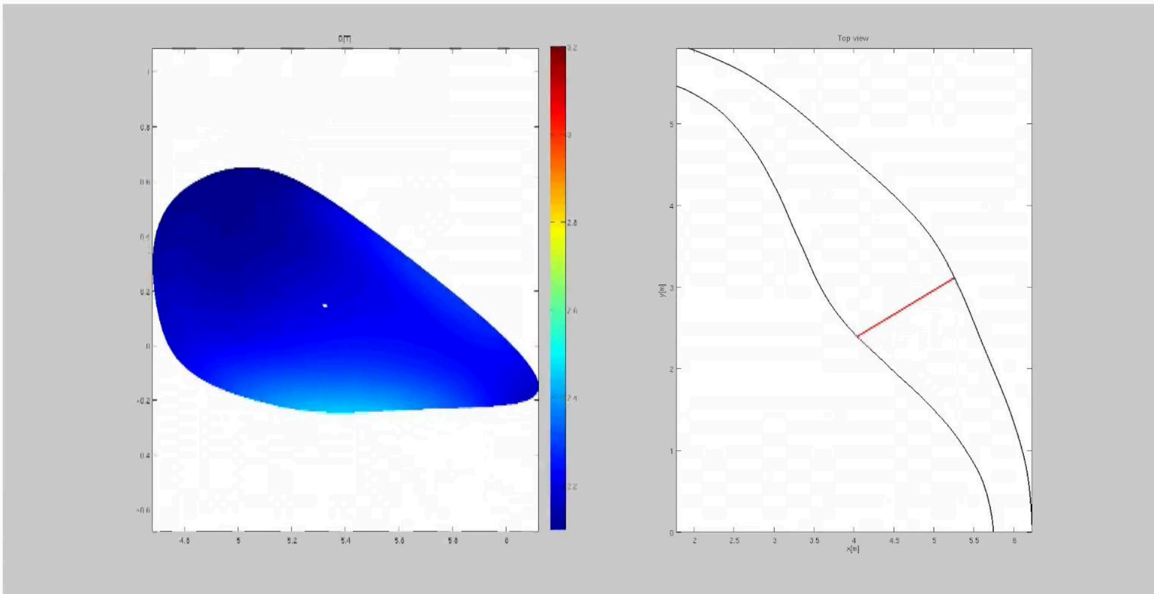
The MHD model is particularly suited to describe the global dynamics of a plasma. For example, it's widely used to describe the dynamics of a plasma in devices that are used to confine plasma for fusion purposes. Here is the result of one MHD simulation that has been run by our group here in Lausanne to study the equilibrium magnetic field in the W7-X experiment.

Notes

Summary

22m 28s

Example of MHD simulation



Equilibrium magnetic field in the W7-X experiment

Plasma

This machine in Germany is one of the largest experiments on Earth and uses a complex three-dimensional configuration to confine plasma for fusion purposes.

Notes

Summary

22m 57s

Summary

- Introduced the one-fluid variables
- One-fluid model deduced to evolve the one-fluid variables
- Neglecting EM waves, Larmor radius effects, electron inertia, and assuming a quasi neutrality, the Magneto-hydro dynamics (MHD) model derived

Plasma

Here we've gotten to the end of this lecture. What we have done today was to derive one single-fluid model to describe the plasma dynamics. More particularly, what we have done was to introduce the one-fluid variables in the equation that evolves them. Then we have seen that by making a number of assumptions, particularly by neglecting electromagnetic waves, Larmor radius effects, electron inertia and assuming quasi-neutrality, a model, the so-called MHD — magnetohydrodynamics model — can be deduced, and this is one of the most fundamental models used in plasma physics.

Notes

Summary

23m 11s