

Fields of active research

1- Plasma theory

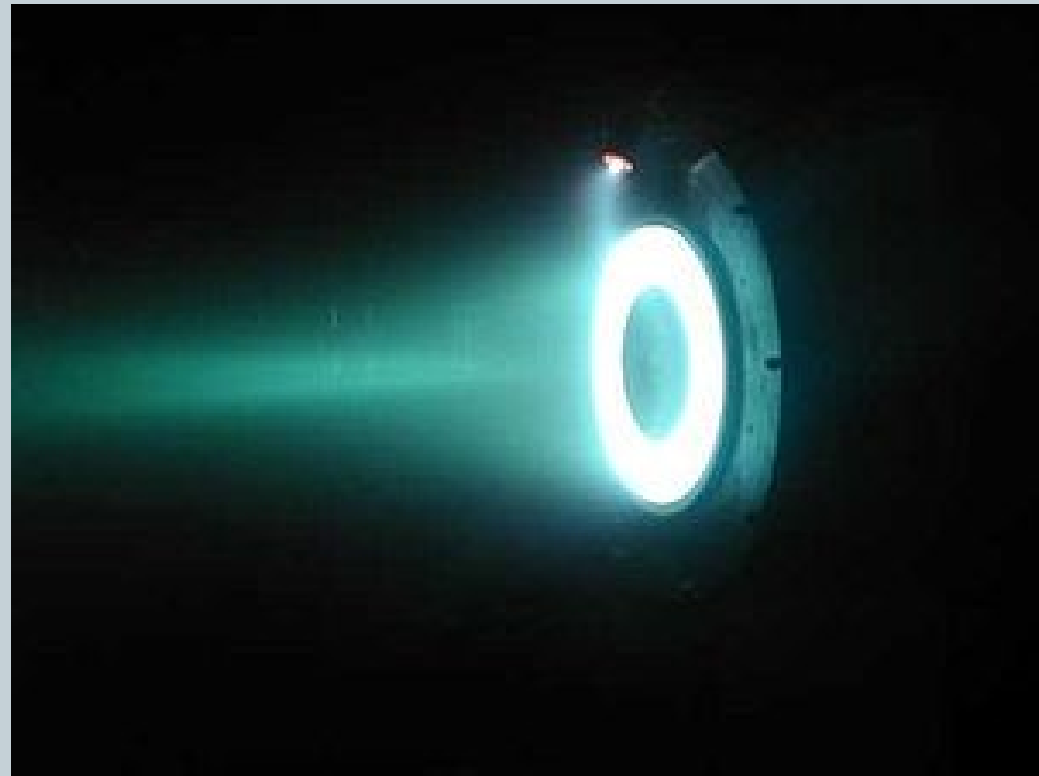
- ✓ Plasma equilibria and stability
- ✓ Plasma interactions with waves and beams
- ✓ Guiding center
- ✓ Adiabatic invariant
- ✓ Debye sheath
- ✓ Coulomb collision

2- Dusty plasmas

3- Plasma sources

4- Plasma diagnostics

- ✓ Thomson scattering
- ✓ Langmuir probe
- ✓ Spectroscopy
- ✓ Interferometry
- ✓ Ionospheric heating
- ✓ Incoherent scatter radar



5 -Plasmas in nature

- ✓ The Earth's ionosphere
- ✓ Space plasmas, e.g. Earth's plasmasphere (an inner portion of the magnetosphere dense with plasma)
- ✓ Astrophysical plasma
- ✓ Industrial plasmas
 - ❖ Plasma chemistry
 - ❖ Plasma processing
 - ❖ Plasma spray
 - ❖ Plasma display



6- Plasma applications

- ✓ Fusion power
 - ❖ Magnetic fusion energy (MFE) – tokamak, stellarator, reversed field pinch, magnetic mirror, dense plasma focus
 - ❖ Inertial fusion energy (IFE) (also Inertial confinement fusion – ICF)
 - ❖ Plasma-based weaponry
- ✓ Ion implantation
- ✓ Plasma ashing
- ✓ Food processing (nonthermal plasma, aka "cold plasma")
- ✓ Plasma arc waste disposal, convert waste into reusable material with plasma.
- ✓ Plasma acceleration

1- Plasma theory

Plasma stability

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An important field of plasma physics is the stability of the plasma.

It usually only makes sense to analyze the stability of a plasma once it has been established that the plasma is in equilibrium.

"Equilibrium" asks whether there are net forces that will accelerate any part of the plasma.

If there are not, then "stability" asks whether a small perturbation will grow, oscillate, or be damped out.

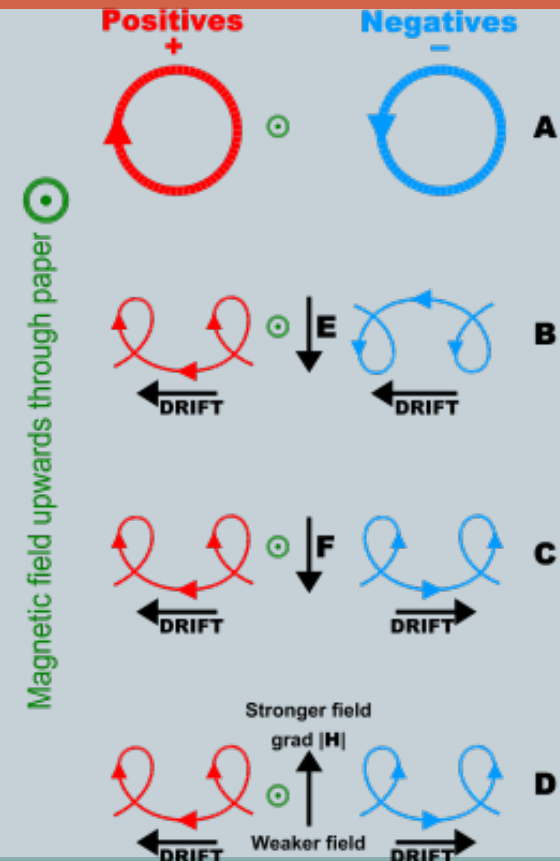
1-Plasma theory

Guiding center

In many cases of practical interest, the motion in a magnetic field of an electrically charged particle (such as an electron or ion in a plasma) can be treated as the superposition of a relatively fast circular motion around a point called the guiding center and a relatively slow drift of this point.

The drift speeds may differ for various species depending on their charge states, masses, or temperatures, possibly resulting in electric currents or chemical separation.

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1-Plasma theory

Adiabatic Invariant

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An adiabatic invariant is a property of a physical system which stays constant when changes are made slowly.

1) **In thermodynamics**, an adiabatic process is a change that occurs without heat flow and slowly compared to the time to reach equilibrium. **In an adiabatic process, the system is in equilibrium at all stages. Under these conditions the entropy is constant.**

2) **In mechanics**, an adiabatic change is a slow deformation of the Hamiltonian where the fractional rate of change of the energy is much slower than the orbital frequency. **The area enclosed by the different motions in phase space are then the adiabatic invariants.**

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3- In quantum mechanics, an adiabatic change is one that occurs at a rate much slower than the difference in frequency between energy eigenstates. In this case, the energy states of the system do not make transitions, so that the quantum number is an adiabatic invariant.

4- The old quantum theory was formulated by equating the quantum number of a system with its classical adiabatic invariant.

This determined the form of the Bohr-Sommerfeld quantization rule: the quantum number is the area in phase space of the classical orbit.

1-Plasma theory

Adiabatic Invariant

Thermodynamics

In thermodynamics, adiabatic changes are those which do not increase the entropy. They occur slowly, and allow heat flow only between objects at the same temperature. For isolated systems, an adiabatic change allows no heat to flow in or out.

Adiabatic Expansion of an Ideal Gas

If a container with an ideal gas is expanded instantaneously, the temperature of the gas doesn't change at all, because none of the molecules slow down. The molecules keep their kinetic energy, but now the gas occupies a bigger volume.

$$PV = N K_B T$$

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But if the container is expanded slowly, so that the ideal gas pressure law holds at any time, the gas molecules lose energy at the rate that they do work on the expanding wall.

The amount of work they do is the pressure times the area of the wall times the outward displacement, which is the pressure times the change in the volume of the gas:

$$dW = PdV = \frac{Nk_B T}{V} dV$$

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If no heat enters the gas, the energy in the gas molecules is decreasing by the same amount.

By definition, a gas is ideal when its temperature is only a function of the internal energy per particle, not the volume. So

$$dT = \frac{1}{NC_v} dE$$

Where C_v is the specific heat at constant volume.

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When the change in energy is entirely due to work done on the wall, the change in temperature is given by:

$$NC_v dT = -dW = -\frac{Nk_B T}{V} dV$$

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This gives a differential relationship between the changes in temperature and volume which can be integrated to find the invariant. The constant k_B is just a unit conversion factor, which can be set equal to one:

$$d(C_v N \log T) = -d(N \log V)$$

An expression for the adiabatic invariant is

$$S = C_v N \log T + N \log V$$

although any function of S is also invariant.

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Adiabatic Expansion of an Ideal Gas

This form is preferred because it is the entropy. In a molecular interpretation, it is the logarithm of the phase space volume of all gas states with energy $E(T)$ and volume V .

$$S = N \log (T^{C_v} V)$$

This is the available volume in phase space at energies E , as can be seen by writing down the energy.

$$E = \frac{1}{2m} \sum_k p_{k1}^2 + p_{k2}^2 + p_{k3}^2$$

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The different internal motions of the gas with total energy E define a sphere in $3N$ dimensions, with radius. Whose surface is a $3N-1$ dimensional and the number of states scales as $(2mE)^{3N/2} - 1$.

The total volume in phase space occupied by the different possible gas motions with energy E is then (ignoring factors which disappear in the logarithm after taking N large):

$$E^{\frac{3N}{2}} V^N$$

?? deduza!!

identifying $T = E^{2/3}$ gives the thermodynamic form.

The specific heat is $3/2$, or $3 / 2k_B$ in units where .

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Classical Mechanics— Action Variables

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For a harmonic oscillator, the area in phase space of an orbit at energy E is the area of the ellipse of constant energy,

$$E = \frac{p^2}{2m} + \frac{m\omega^2 x^2}{2}$$

The x-radius of this ellipse is $\sqrt{2E/\omega^2 m}$, while the p-radius of the ellipse is $\sqrt{2mE}$

Multiplying, the area is $2\pi E / \omega$. So if a pendulum is slowly drawn in, so that the frequency changes, the energy changes by a proportional amount

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Old Quantum Theory

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After Planck identified that Wien's law can be extended to all frequencies, even very low ones, by interpolating with the classical equipartition law for radiation, physicists wanted to understand the quantum behavior of other systems.

The Planck radiation law quantized the motion of the field oscillators in units of energy proportional to the frequency:

$$E = hf = \hbar\omega$$

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This is the only sensible quantization. The quantum can only depend on the **energy/frequency** by adiabatic invariance, and since the energy must be additive when putting boxes end to end, the levels must be equally spaced.

Einstein, followed by Debye, extended the domain of quantum mechanics by considering the sound modes in a solid as quantized oscillators.

This model explained why the specific heat of solids approached zero at low temperatures, instead of staying fixed at $3k_B$ as predicted by classical equipartition.

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At the Solvay conference, the question of quantizing other motions was raised, and Lorentz pointed out a problem.

If you consider a quantum pendulum whose string is shortened very slowly, the quantum number of the pendulum cannot change because at no point is there a high enough frequency to cause a transition between the states. But the frequency of the pendulum changes when the string is shorter, so the quantum states change energy.

Einstein responded that for slow pulling, the frequency and energy of the pendulum both change but the ratio stays fixed. This is analogous to Wien's observation that under slow motion of the wall the energy to frequency ratio of reflected waves is constant. **The conclusion was that the quantities to quantize must be adiabatic invariants.**

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This line of argument was extended by Sommerfeld into a general theory: the quantum number of an arbitrary mechanical system is given by the adiabatic action variable. Since the action variable in the harmonic oscillator is an integer, the general condition is:

$$\int pdq = nh$$

Planck's cte = 6.63×10^{-27} erg.sec

This condition was the foundation of the old quantum theory, which was able to predict the qualitative behavior of atomic systems.

The theory is inexact for small quantum numbers, since it mixes classical and quantum concepts. But it was a useful half-way step to the new quantum theory.

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Plasma Physics

In plasma physics there are three adiabatic invariants of charged particle motion.

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The first adiabatic invariant, μ

The magnetic moment of a gyrating particle,

is a constant of the motion (as long as q / m does not change).

In fact, it is invariant to all orders in an expansion in ω/ω_c , so the magnetic moment remains nearly constant even for changes at rates approaching the gyro-frequency.

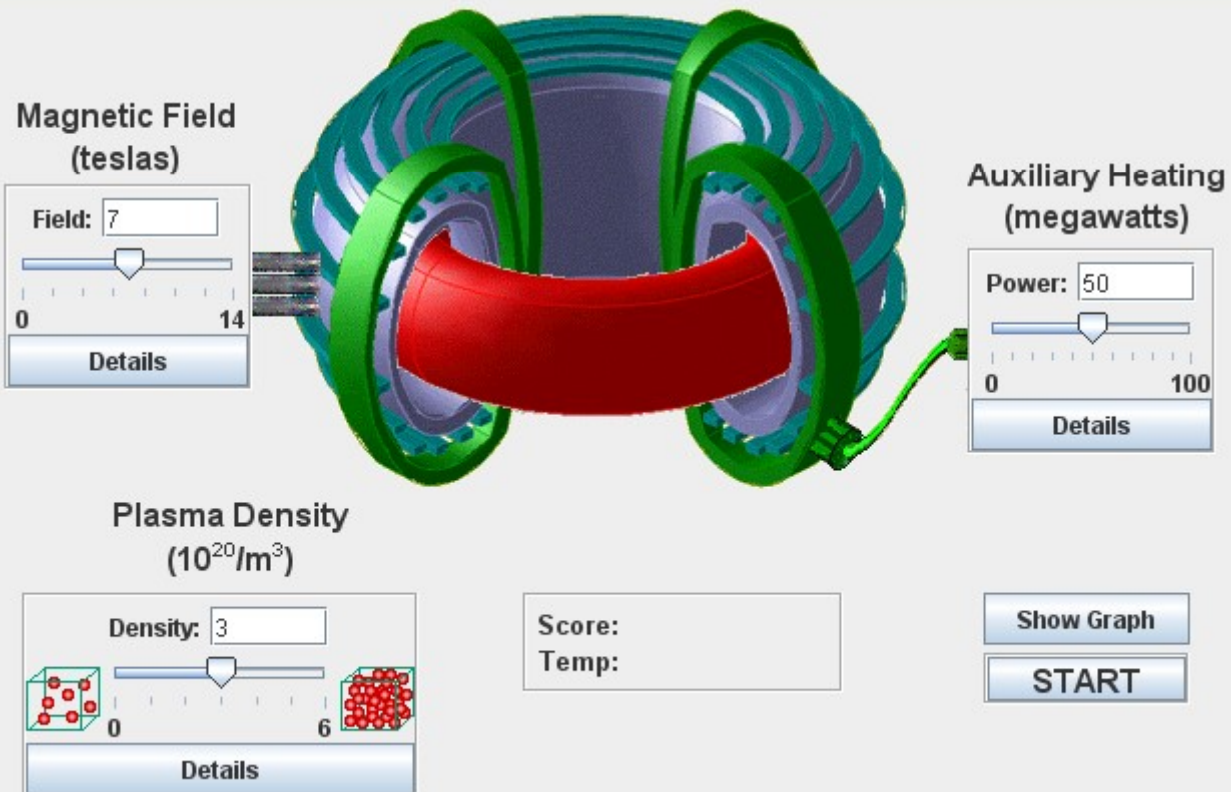
$$\mu = \frac{\frac{1}{2} m v_{\perp}^2}{B}$$

The Interactive Plasma Physics Education Experience!

<http://ippex.pppl.gov/>

<http://ippex.pppl.gov/tokamak/fusion/indexv2.html>

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The interface features a central 3D model of a tokamak reactor. The toroidal chamber is shown in a cutaway view, revealing a red plasma ring. It is surrounded by a complex arrangement of green and blue magnetic coils. The interface includes several control panels:

- Magnetic Field (teslas):** A slider control with a numerical input field showing '7'. The scale ranges from 0 to 14. A 'Details' button is located below the slider.
- Auxiliary Heating (megawatts):** A slider control with a numerical input field showing '50'. The scale ranges from 0 to 100. A 'Details' button is located below the slider.
- Plasma Density ($10^{20}/m^3$):** A slider control with a numerical input field showing '3'. The scale ranges from 0 to 6. Small 3D molecular models are shown at the ends of the slider. A 'Details' button is located below the slider.
- Score:** A text input field.
- Temp:** A text input field.
- Show Graph:** A button.
- START:** A large button.