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Magnetohydrodynamics



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Keywords

Magnetic field · Magnetohydrodynamics

Synonyms

[Hydromagnetics](#); [Magneto-fluid dynamics](#)

Acronyms

MHD Magnetohydrodynamics

Definition

Magnetohydrodynamics (MHD) is a physical paradigm pertinent to describe the dynamics of electrically conducting fluids, such as plasmas, electrolytes, and liquid metals. MHD couples fluids dynamics with electromagnetism.

History

The first recorded use of the word *magnetohydrodynamics* (MHD) can be found in Alfvén (1942), who initiated this field. Hannes Alfvén received the Nobel Prize in Physics in 1970 for his work on MHD

Overview

Magnetohydrodynamics (MHD) is a set of postulates and theories that enables a synthetic description of the behavior of electrically conducting fluids subject to electromagnetic fields. Plasmas, liquid metals, electrolytes are example of electrofluids. Since plasma is by far the most abundant form of ordinary matter, MHD is a key paradigm in astrophysics, applying to stars and the Sun (formation, dynamo mechanism, atmospheric dynamics, eruptions, jets), star-planet interactions and in particular the stellar/solar winds, planetary magnetospheres, as well as protoplanetary disks, interstellar and intracluster media, active galactic nuclei, and possibly to the intergalactic regions.

The standard MHD description relies on several core hypothesis. First, MHD assumes a fluid description of matter, focusing on the macroscopic scales and relying on the continuous assumption, i.e., neglecting the specific behavior and properties of the particles that constitutes the fluid. Under the continuum assumption, macroscopic properties such as density, pressure,

temperature, and bulk velocity are taken to be well-defined at “infinitesimal” volume elements – small in comparison to the characteristic length scale of the system, but large in comparison to the particles length scales. As a fluid theory, MHD also relies on the conservation of mass, momentum, and energy. A second key hypothesis of MHD is the electric neutrality. At valid MHD scales, there shall be no free electric charge. MHD thus applies at a length scale that significantly exceeds the Debye length of the medium as well as at a temporal scale that is markedly larger than any specific particular timescale (e.g., frequency smaller than the plasma frequency).

The set of equations that describe MHD is a combination of the Navier–Stokes equations of fluid dynamics and Maxwell’s equations of electromagnetism. A key concept behind MHD is that the magnetic field that permeates the medium induces electric currents in the moving conductive fluid, currents that in turn affect the dynamic of the fluid, which retroactively modify the magnetic field itself. The Ohm’s law for conductive fluid links the electric field, with the magnetic field and the fluid velocity. The interplay between the magnetic field and the fluid dynamics is marked by the central role of the Lorentz force, through which the magnetic field affects the dynamics of the conductive fluid.

Several models of MHD can be used depending on the degree of complexity necessary to describe the studied system. One can cite: ideal MHD, resistive MHD, incompressible MHD, Hall MHD, multi-fluid MHD, Hartmann MHD, collisionless MHD, electron MHD, relativistic MHD, etc.

In ideal MHD, the fluid is treated as a perfect conductor (e.g., the electric resistivity is infinitely small). In such conditions, the Alfvén’s theorem states the fluid and the magnetic field are tied together, and have to move altogether: the so-called “frozen-in” condition. The magnetic flux through a co-moving surface is conserved in ideal MHD. Magnetic linkage is thus preserved which makes it possible to store magnetic energy

by moving the fluid or the magnetic field. The stored energy can become available if the ideal condition breaks down, e.g., during magnetic reconnection: the magnetic field can then be rearranged and magnetic energy is converted to kinetic energy, thermal energy, and particle acceleration. While magnetic reconnection is by essence an MHD concept, its complete description lies beyond the MHD approximation

MHD waves are another major concept that derives from MHD. There are three main MHD wave modes: pure Alfvén wave, slow (shear) and fast (compressional) MHD waves. Alfvén waves are incompressible waves and do not appear in pure hydrodynamics. All the MHD waves have constant phase velocities for all frequencies and are thus dispersionless. Their role is heavily discussed in link with the heating of stellar corona and the acceleration mechanisms of stellar winds.

Cross-References

- ▶ [Activity, Magnetic](#)
- ▶ [Magnetic Field](#)
- ▶ [Magnetic Field, Planetary](#)
- ▶ [Magnetic Fields and Planetary Systems Formation](#)
- ▶ [Magnetic Fields and Star Formation](#)

References and Further Reading

- Alfvén H (1942) On the cosmogony of the solar system III. *Stockh Observatoriums Ann* 14:9.1–9.29. Bibcode:1942StoAn..14....9A
- Biskamp D (1993) *Nonlinear magnetohydrodynamics*. Cambridge monographs on plasma physics. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9780511599965>
- Galtier S (2016) *Introduction to modern magnetohydrodynamics*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9781316665961>
- Priest E (2014) *Magnetohydrodynamics of the Sun*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9781139020732>