

PhysBio '05



Influence of time-dependent flows on the dynamo onset



Alberto de la Torre and Javier Burguete

Departamento de Física y Matemática Aplicada
Universidad de Navarra
Spain

Magneto-hydrodynamic

Magnetohydrodynamics (MHD) (*magnetofluidynamics* or *hydromagnetics*), is the academic discipline which studies the dynamics of electrically conducting fluids in the presence of a magnetic field.

Wikipedia.org

Magneto-hydrodynamic

Equations:

- Eq. Navier-Stokes + Lorentz force

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla) \vec{v} = -\frac{1}{\rho} \nabla P + \nu \nabla^2 \vec{v} + \frac{1}{\rho \mu_0} (\nabla \times \vec{B}) \times \vec{B}$$

- Eq. MHD

$$\frac{\partial \vec{B}}{\partial t} + (\vec{v} \cdot \nabla) \vec{B} = (\vec{B} \cdot \nabla) \vec{v} + \frac{1}{\mu_0 \sigma} \nabla^2 \vec{B}$$

- Eq. Continuity

$$\nabla \cdot \vec{B} = 0, \nabla \cdot \vec{v} = 0$$

Magneto-hydrodynamic

Parameters

→ $Rm = UL \mu_o \sigma$ Reynolds Magnetic number

→ $Re = UL/\nu$ Reynolds Hydrodynamic number

→ $Pr_m = Rm/Re$ Magnetic Prandtl number

Dynamo effect

- Self-excitation of \vec{B} in a moving conductive fluid.
- Dynamo threshold typically at $Rm \sim 100$
 - Dynamic dynamo: $Pr_m = 1 \Rightarrow Re \sim 100$ Laminar flow
 - Real World: Sodium at 150° , $Pr_m = 10^{-5} \Rightarrow Re \sim 10^7$

Fully-developed turbulence

Kinematic dynamo

- Abording the problem

1. Measure \vec{v} .

2. Simulate de MHD equation with that \vec{v} .

$$\frac{\partial \vec{B}}{\partial t} + (\vec{v} \cdot \nabla) \vec{B} = Rm (\vec{B} \cdot \nabla) \vec{v} + \nabla^2 \vec{B}$$

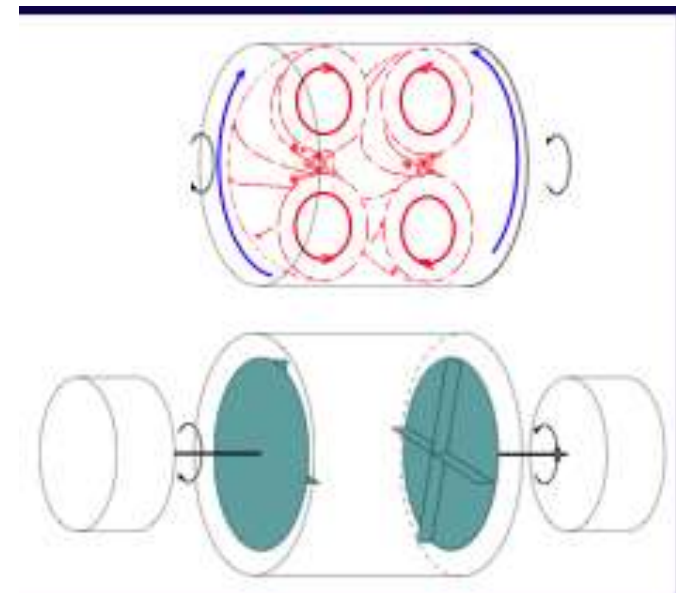
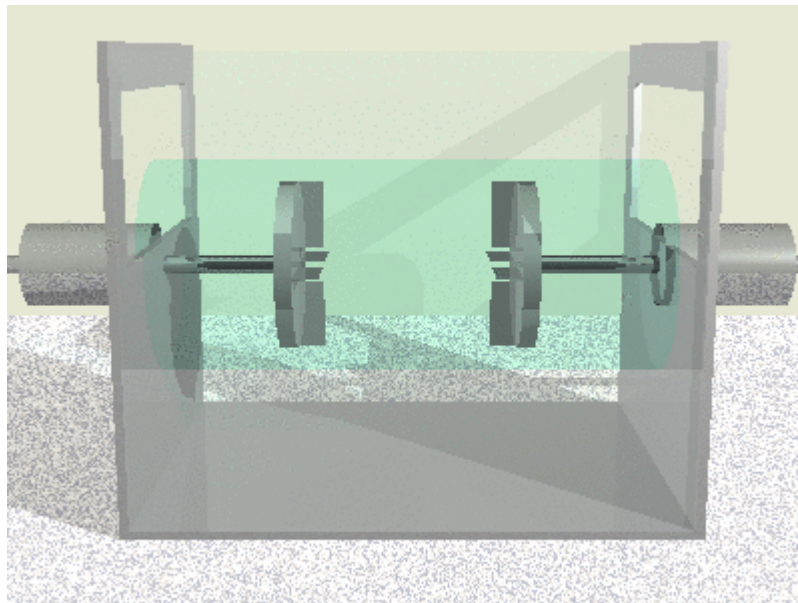
- Aproximations

- Below the threshold \vec{v} is not affected by \vec{B} , so \vec{v} can be taken as a parameter in the MHD equation

- $\tau_B \ll \tau_v$ so we can promediate \vec{v}

Experimental setup

Hydrodynamic of time-dependent von Kármán flows



Marié et al, "Numerical study of homogeneous dynamo based on experimental von Karman type flows", Eur. Phys. Journal B 33 (2003) pp. 469-485

Kinematic dynamo

- Not-so-good agreement with the experiments

Marié et al. “Open questions about homogeneous fluid dynamos: The VKS experiment”
, *Magnetohydrodynamics*, Vol. 38, No. 1-2, pp. 163-176

- Aim of this study: The effects of slow time scales on the dynamo threshold.

Experimental setup

Hydrodynamic of time-dependent von Kármán flows

a) Complementary Measurements

→ PIV (Particle Image Velocimetry)

- Slow time scale
- Small space scale

→ LDV (Laser-Doppler velocimetry)

- Fast time scale
- Large space scale

b) Natural & Forced time-dependence of \vec{v}

Experimental setup

Experimental settings:

- 150 l. experiment cell
- Cylinder: horizontal 10-50 cm, diameter 20-50 cm
- Power: 2 x 1.5 kW
- Freq: 0-15 Hz
- Propellers with or without blades
- Other geometries are possible: Sphere,...

Experimental setup

Are we going to work with sodium at 150°C?

150 g of Na

Experimental setup

Are we going to work with sodium at 150°C? **NO**

Only interested in the velocity field \Rightarrow Hydrodynamic

	ν	ρ
Na at 150°C	0.6 cp	0.86 gr/cm ³

Experimental setup

Are we going to work with sodium at 150°C? **NO**

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	ν	ρ
Na at 150°C	0.6 cp	0.86 gr/cm ³
H ₂ O	1 cp	1 gr/cm ³

Numerical simulations

➔ To reproduce the MHD behaviour for the measured $\vec{v}(t)$

➔ Pseudo-spectral code:

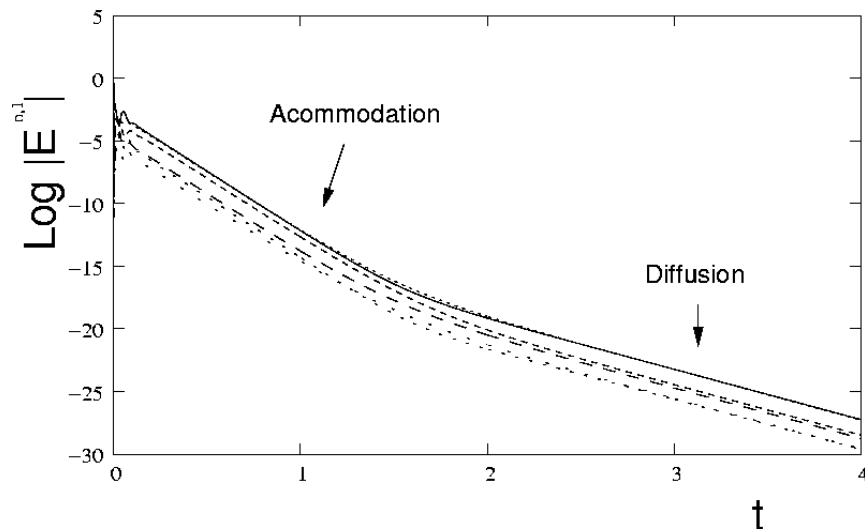
	<u>Scheme</u>	<u>BC</u>
• r-axis:	Finite differences	Isolant at $r=R$
• z-axis:	Spectral	Periodic at $z=0,L$
• q-axis:	Spectral	Periodic

➔ We obtain $\vec{B}(\vec{r}, t) = \sum_{n,m} \vec{B}_{n,m}(r, t) e^{i(nz+n\theta)}$ and $E^{n,m} \sim \int |B_{n,m}|^2 dV \sim e^{\sigma_{n,m}t}$

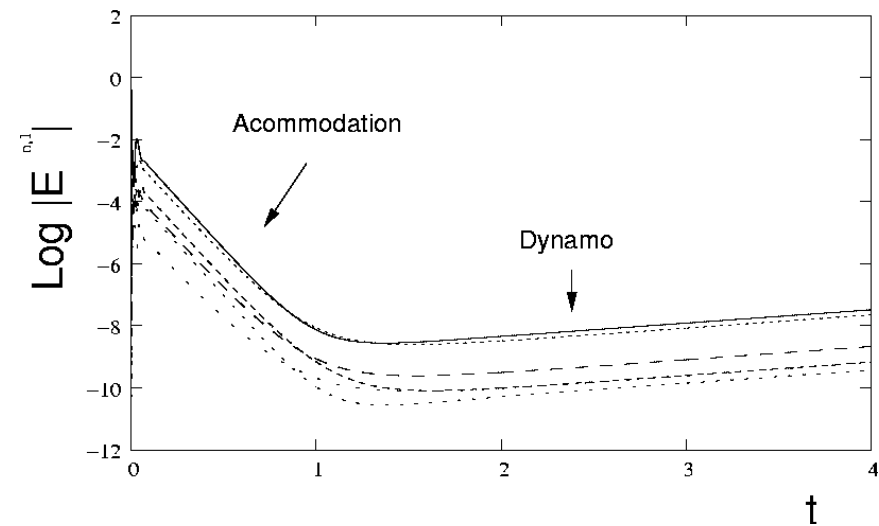
➔ There is dynamo effect when $\exists \sigma_{m,n} > 0$

Numerical simulations

➔ There is dynamo effect when $\exists \sigma_{m,n} > 0$



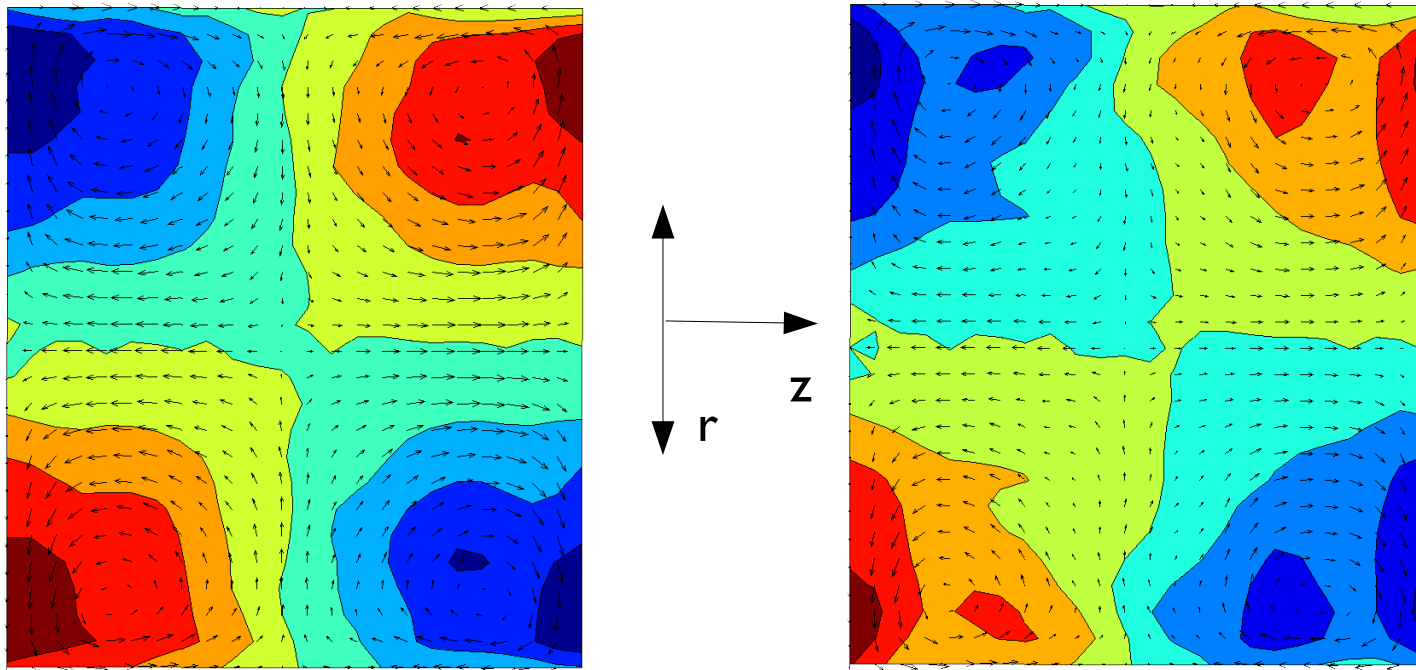
$Rm=60$



$Rm=140$

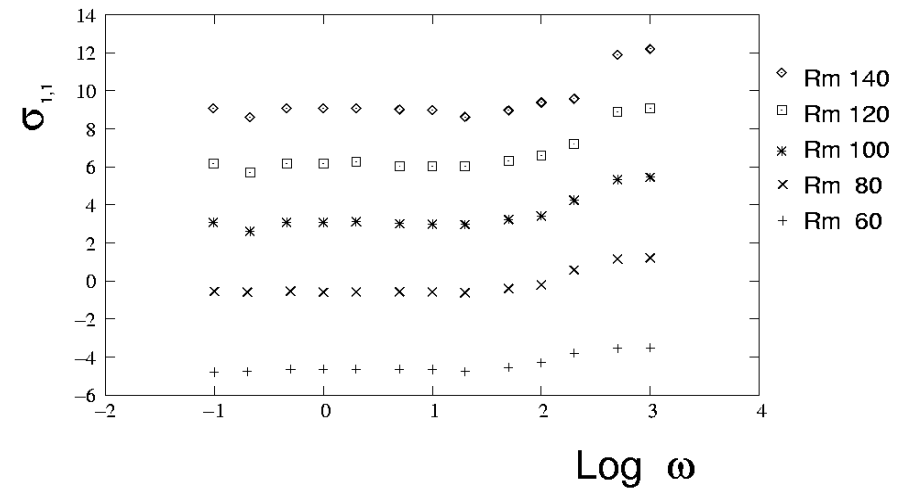
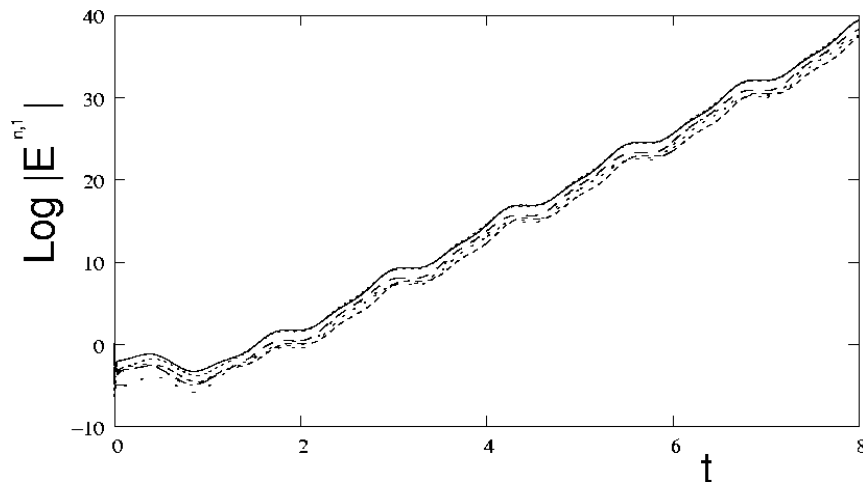
Preliminary results

- Simulations with $\vec{v}(t) = \vec{v}_m + \vec{v}_d \cdot \cos(\omega t)$ being \vec{v}_m, \vec{v}_d time-averaged experimental fields, dynamo or non-dynamo producers.



Preliminary results

- We demonstrate that growth rate and activation R_m varies when the mean-flow is time dependent.



Summarization

- The dynamo effect appears when a magnetic field is self-generated.
- For liquid “free” sodium, the flow is turbulent.
- Kinematic dynamo: Consider \vec{v} promediated and simulate the MHD eq., with some agreement with the experiments.
- We demonstrate that growth rate and activation R_m varies when the mean-flow is time dependent.
- We will study the hydrodynamic of the von Kármán flow to obtain $\vec{v}(t)$ and simulate the MHD behaviour.

Marié, Burguete, Daviaud and Leorat, “Numerical study of homogeneous dynamo based on experimental von Karman type flows”, Eur. Phys. Journal B 33 (2003) pp. 469-485

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<http://fisica.unav.es/mhd/>

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