Dynamo theory and its experimental validation

Karl-Heinz Rädler

Astrophysical Institute Potsdam

Outline

- The idea of the self-exciting dynamo and elements of dynamo theory
- The Riga experiment
- The Karlsruhe experiment
- The Cadarache experiment
- Experiments under preparation
- What did we learn from dynamo experiments and what can we learn in future?

Effects of the geomagnetic field known for long ...

- Evidence for a simple compass in Mexico about 3000 years ago
- Compass in China in the first century BC
- Petrus Peregrinus 1269: ''Epistola de magnete''
- William Gilbert 1600: ''De magnete“ -- The Earth is a big loadstone!
- Gellibrand 1635: Westward drift of the declination
- Carl Friedrich Gauss 1836: ''Allgemeine Theorie des Erdmagnetismus''
- David and Brunhes 1904/05: Reversals of the geomagnetic field
- ....

In 1908 G. E. Hale discovered strong magnetic fields (~ 0.1 T) in sunspots

- There is also a (weaker) general solar magnetic field.

- The 2 x 11 years sunspot cycle coincides
  with the cycle of the general oscillatory solar magnetic field.

The cosmic dynamo

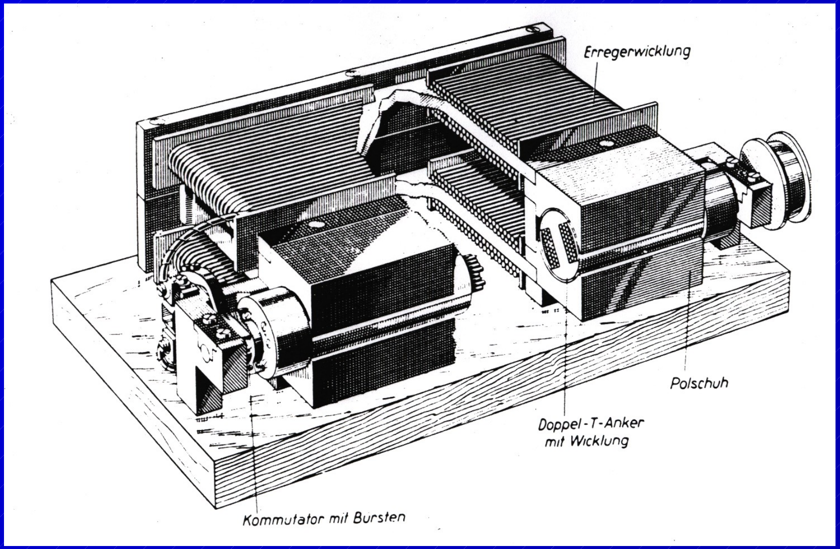
Sir Joseph Larmor 1919

How could a rotating body such as the Sun
become a magnet?

Magnetic field due to electric currents
generated and maintained after the pattern
of a self-exciting dynamo !

The self-exciting dynamo

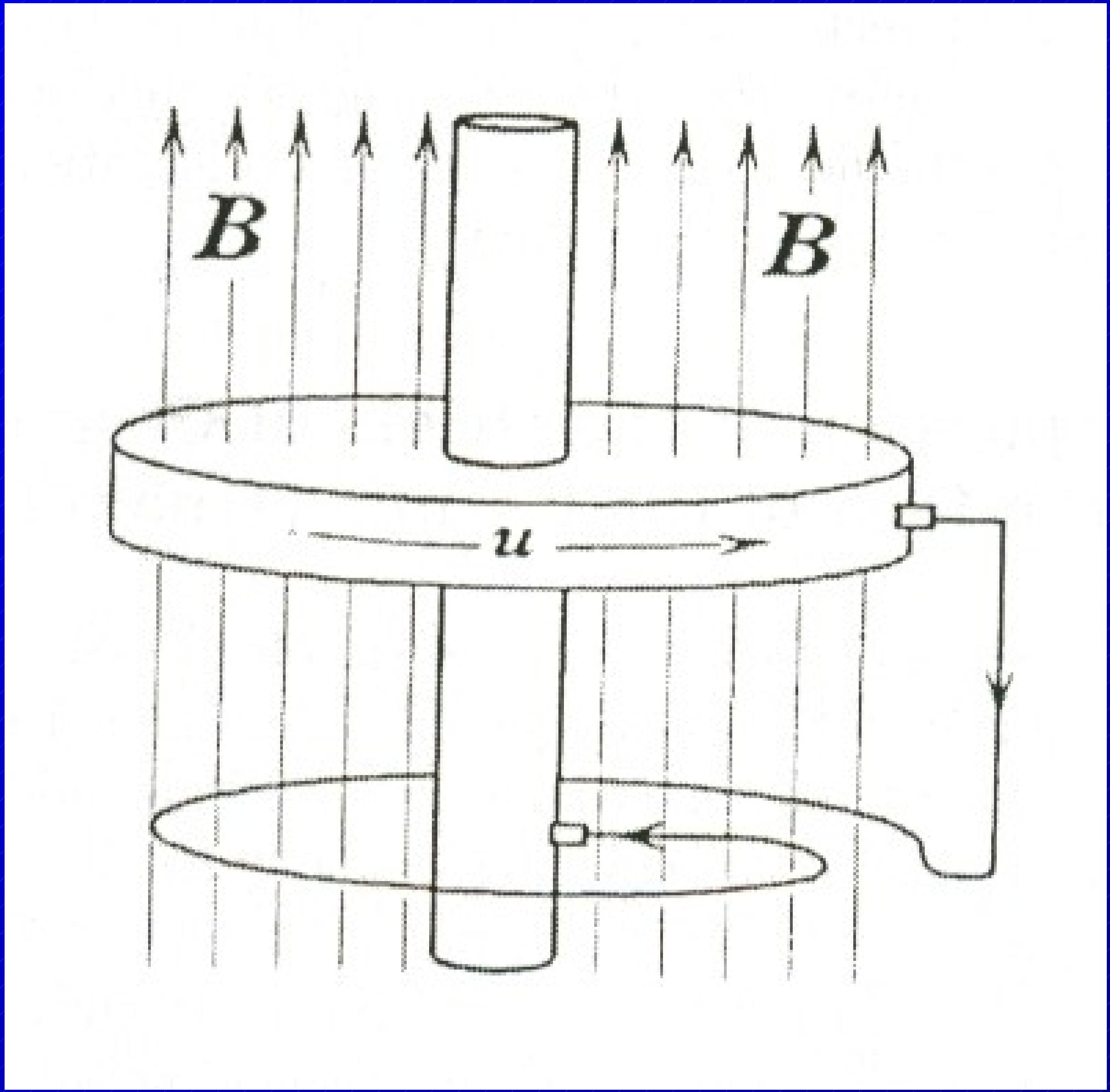
Werner von Siemens 1867



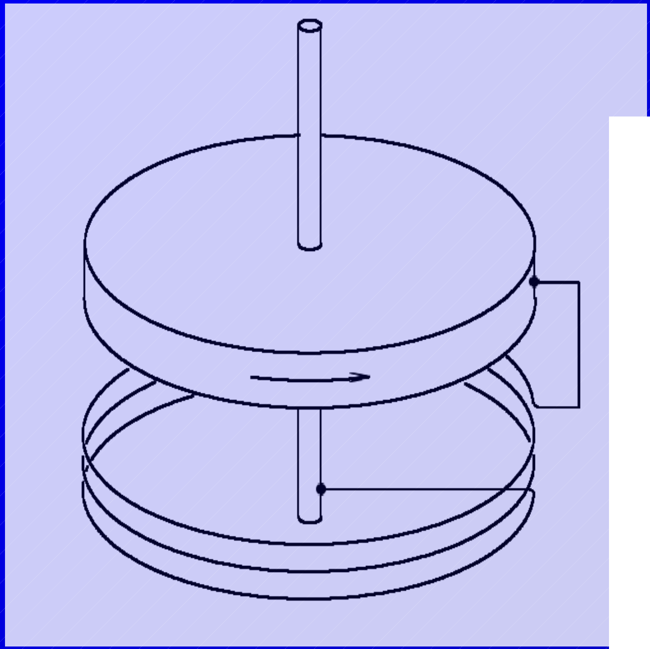
Charles Wheatstone 1867

Anianus Jedlick 1851/53
Sören Hjorth 1854
Samuel Alfred Varley 1866

Disc dynamo



Disc dynamo



$$L\,\frac{\mathrm{d}I}{\mathrm{d}t} + R\,I = \frac{\omega}{2\pi}\,\phi\,, \qquad \phi = L'\,I$$

$$L\,\frac{\mathrm{d}I}{\mathrm{d}t} + (R - \Omega^*)\,I = 0\,, \qquad \Omega^* = \frac{\omega}{2\pi}\,L'$$

$$\Rightarrow \qquad I(t) = I(0)\,\exp\left(-\,\frac{R - \Omega^*}{L}\,t\right)$$

$R > \Omega^*$ decay

$R \leq \Omega^*$ dynamo

$$\omega_{\mathrm{crit}} = 2\pi\frac{R}{L'}$$

Kinematic dynamo theory

The magnetic field B has to satisfy the induction equation

$$\partial_t \boldsymbol{B} - \boldsymbol{\nabla} \times (\boldsymbol{U} \times \boldsymbol{B}) - \eta \boldsymbol{\nabla}^2 \boldsymbol{B} = \mathbf{0}\,, \qquad \boldsymbol{\nabla} \cdot \boldsymbol{B} = 0$$

$$\eta = 1/\mu\sigma$$

inside the fluid body

and proper initial and boundary conditions.

$$R_\mathrm{m} = \frac{U\,L}{\eta}$$

magnetic Reynolds number

Dynamo

$$\boldsymbol{B} \not\to \mathbf{0} \quad \text{as} \quad t \to \infty$$

Necessary for dynamo

$$R_\mathrm{m} \geq R_\mathrm{m\,crit} = O(1)$$

(Anti-)Dynamo theorems

- *Concerning the geometry of the magnetic field*

There is no dynamo
with an axisymmetric magnetic field.

Cowling 1934, ...

- *Concerning the geometry of the fluid motion*

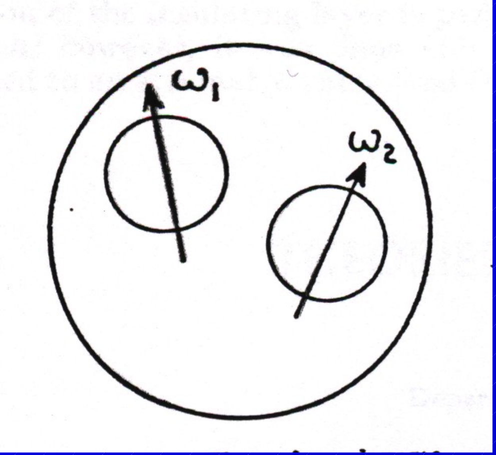
There is no (spherical) dynamo
with a completely toroidal fluid motion
(if the conductivity is constant or depends on radius only).

Elsasser 1946, Bullard and Gellman 1954, ...

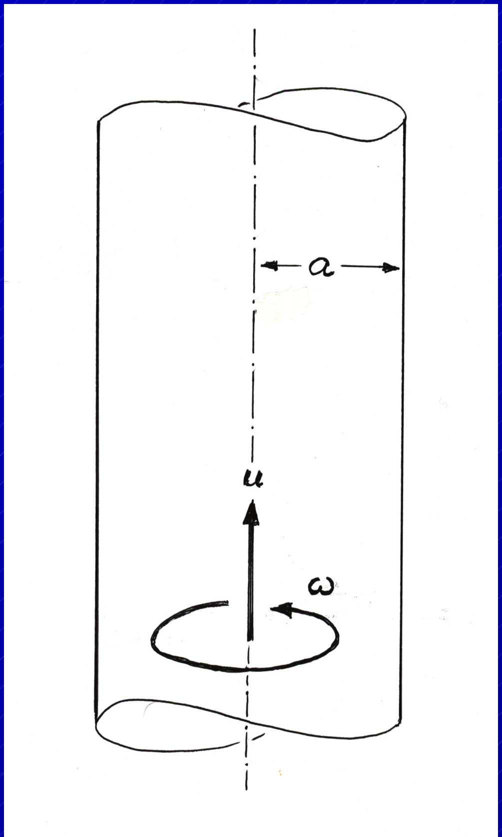
- *Various related theorems ...*

Examples of working dynamos

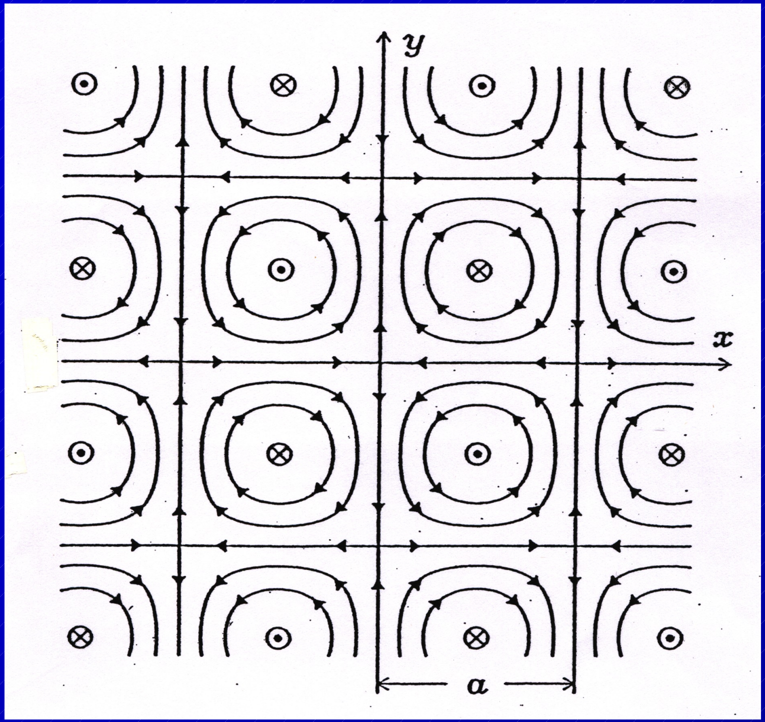
Herzenberg 1958



Ponomarenko 1973



Roberts 1972



Mean-field dynamo theory

Situations with complex behaviors
of the fluid motion und magnetic field
with respect to space and/or time.

Split velocity and magnetic fields into mean and „fluctuating“ parts,

$$U = \overline{U} + u\,, \qquad B = \overline{B} + b\,,$$

with means fields defined by some averaging procedure
that satisfies the Reynolds averaging rules.

Mean-field induction equation

$$\partial_t \overline{B} - \nabla \times (\overline{U} \times \overline{B} + \mathcal{E}) - \eta \nabla^2 \overline{B} = 0\,, \qquad \nabla \cdot \overline{B} = 0\,,$$

contains the mean electromotive force $\mathcal{E} = \overline{u \times b}\,.$

Mean-field dynamo theory

$$\partial_t \overline{\boldsymbol{B}} - \nabla \times (\overline{\boldsymbol{U}} \times \overline{\boldsymbol{B}} + \mathcal{E}) - \eta \nabla^2 \overline{\boldsymbol{B}} = 0\,, \quad \nabla \cdot \overline{\boldsymbol{B}} = 0\,,$$

In the case of helical fluctuating motions $\mathcal{E} = \overline{\boldsymbol{u} \times \boldsymbol{b}}$

has a part parallel or antiparallel to the mean magnetic field --

the **α**-effect,

$$\mathcal{E} = \alpha \overline{\boldsymbol{B}} + \cdots\,.$$

The **α**-effect allows mean-field dynamo models which reflect essential features of real dynamos.

The dynamo is one of the basic phenomenae in the universe.

Mean-field dynamo theory

$$\partial_t \overline{B} - \nabla \times (\overline{U} \times \overline{B} + \mathcal{E}) - \eta \nabla^2 \overline{B} = 0\,, \quad \nabla \cdot \overline{B} = 0\,,$$

In the case of helical fluctuating motions

$$\mathcal{E} = \overline{u \times b}$$

has a part parallel or antiparallel to the mean magnetic field --

the α-effect,

$$\mathcal{E} = \alpha \overline{B} + \cdots\,.$$

Homogeneous isotropic non-mirrorsymmetric (helical) turbulence

$$\alpha = \int_0^\infty \int_\infty G(\boldsymbol{\xi}, \tau) \langle \boldsymbol{u}(\boldsymbol{x}, t) \cdot (\nabla \times \boldsymbol{u}(\boldsymbol{x} - \boldsymbol{\xi}, t - \tau)) \rangle \, \mathrm{d}^3 \xi \, \mathrm{d}\tau$$

In the last six decades ....

- magnetic fields at A and other stars (~ 0.1 T)
- magnetic fields at most of the solar planets
- strong magnetic fields at some white dwarfs (~ 10^2 T)
- magnetic cycles at sun-like stars
- large-scale galactic and intergalactic magnetic fields (~ 10^{-9} T)
- extremely strong magnetic fields at neutron stars (~ 10^{11} T)

The full dynamo problem

E.g., geodynamo

$$\partial_t \boldsymbol{U} + (\boldsymbol{U}\cdot\boldsymbol{\nabla})\boldsymbol{U} = -\frac{1}{\varrho}\boldsymbol{\nabla}P + \nu\boldsymbol{\nabla}^2\boldsymbol{U} + 2\boldsymbol{\Omega}\times\boldsymbol{U} + \frac{1}{\mu\varrho}(\boldsymbol{\nabla}\times\boldsymbol{B})\times\boldsymbol{B} - \alpha_T\boldsymbol{g}\theta$$

$$\partial_t \boldsymbol{B} - \boldsymbol{\nabla}\times(\boldsymbol{U}\times\boldsymbol{B}) - \eta\boldsymbol{\nabla}^2\boldsymbol{B} = \boldsymbol{0}$$

$$\partial_t\theta + \boldsymbol{U}\cdot\boldsymbol{\nabla}\theta - \kappa\Delta\theta = -\boldsymbol{U}\cdot\boldsymbol{\nabla}T_0$$

$$\boldsymbol{\nabla}\cdot\boldsymbol{U} = \boldsymbol{\nabla}\cdot\boldsymbol{B} = 0$$

Dimensionless parameters

$E = \nu/\Omega D^2$	Ekman number
$Ra = \alpha_T g\Delta T D/\nu\Omega$	Rayleigh number
$Pr = \nu/\kappa$	Prandtl number
$Pm = \nu/\eta$	magnetic Prandtl number

The full dynamo problem

E.g., geodynamo

$$\partial_t \boldsymbol{U} + (\boldsymbol{U}\cdot\boldsymbol{\nabla})\boldsymbol{U} = -\frac{1}{\varrho}\boldsymbol{\nabla} P + \nu\boldsymbol{\nabla}^2\boldsymbol{U} + 2\boldsymbol{\Omega}\times\boldsymbol{U} + \frac{1}{\mu\varrho}(\boldsymbol{\nabla}\times\boldsymbol{B})\times\boldsymbol{B} - \alpha_T \boldsymbol{g}\theta$$

$$\partial_t \boldsymbol{B} - \boldsymbol{\nabla}\times(\boldsymbol{U}\times\boldsymbol{B}) - \eta\boldsymbol{\nabla}^2\boldsymbol{B} = \boldsymbol{0}$$

$$\partial_t \theta + \boldsymbol{U}\cdot\boldsymbol{\nabla}\theta - \kappa\Delta\theta = -\boldsymbol{U}\cdot\boldsymbol{\nabla}T_0$$

$$\boldsymbol{\nabla}\cdot\boldsymbol{U} = \boldsymbol{\nabla}\cdot\boldsymbol{B} = 0$$

Earth's core

$$E = \nu/\Omega D^2 = O(10^{-15})$$

$$Ra = \alpha_T g \Delta T D/\nu\Omega = O(10^2)$$

$$Pr = \nu/\kappa = O(1)$$

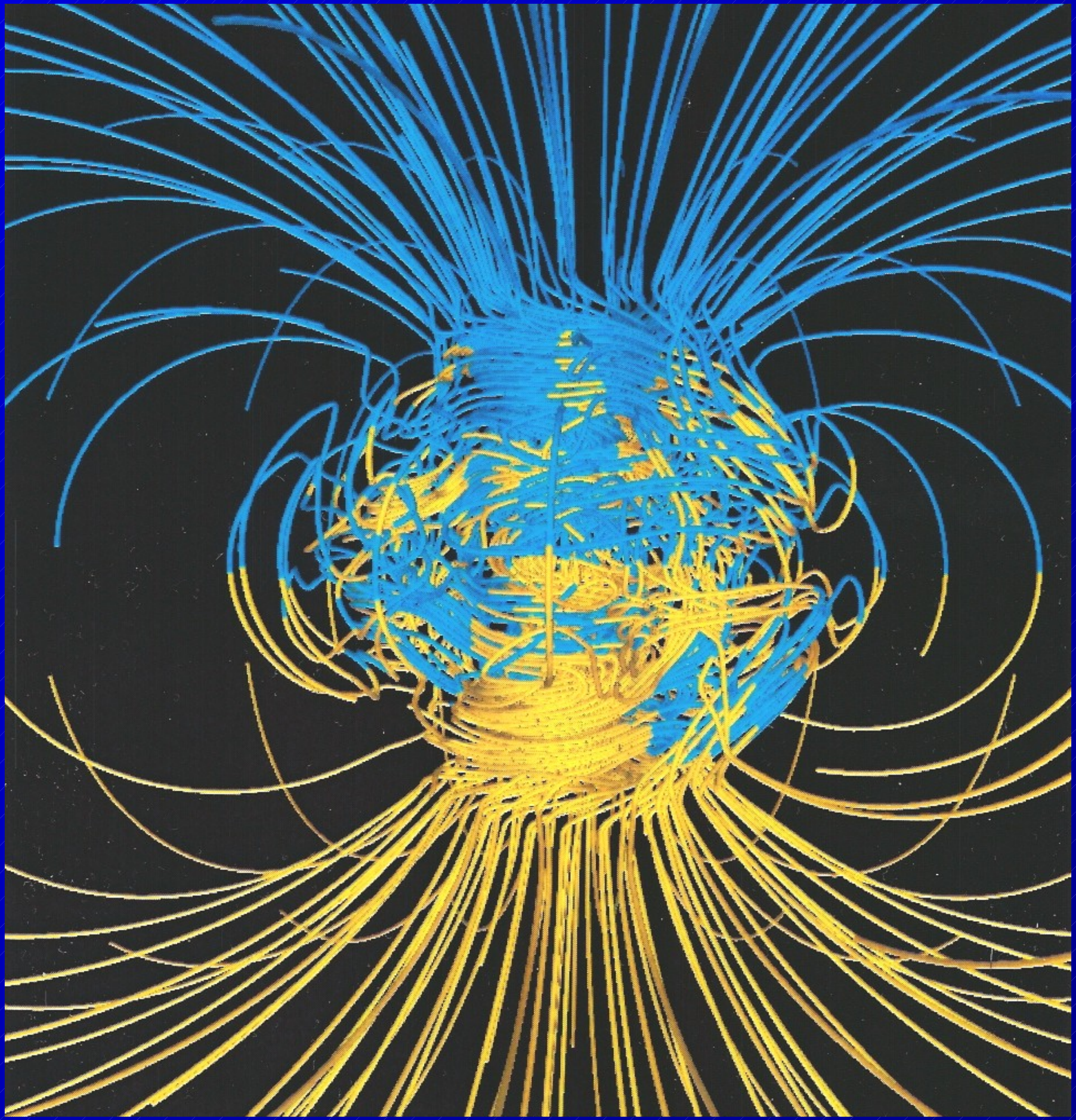
$$Pm = \nu/\eta = O(10^{-6})$$

Note that $Re = Rm/Pm$

Direct numerical simulations

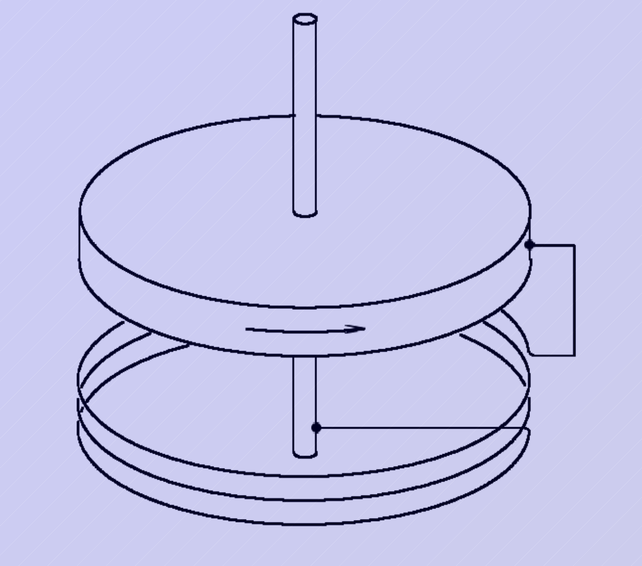
Parameters
far away from
realistic ones
for the Earth's core

Glatzmaier
and Roberts 1995



Disc dynamo

considering the back-reaction
of the magnetic field
on the rotation rate
(„eddy current braking")



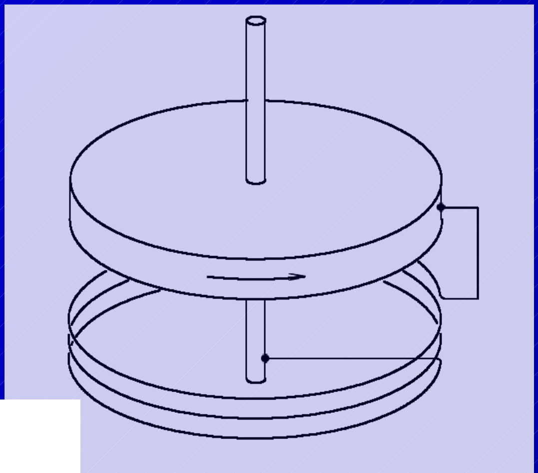
$$L\,\frac{\mathrm{d}I}{\mathrm{d}t} + R\,I = \frac{\omega}{2\pi}\,\phi\,, \qquad \phi = L'\,I$$

$$\frac{1}{2}\frac{\mathrm{d}}{\mathrm{d}t}(\Theta\,\omega^2 + L\,I^2) = D\,\omega - \frac{\Theta\,\omega^2}{\tau^*} - I^2\,R$$

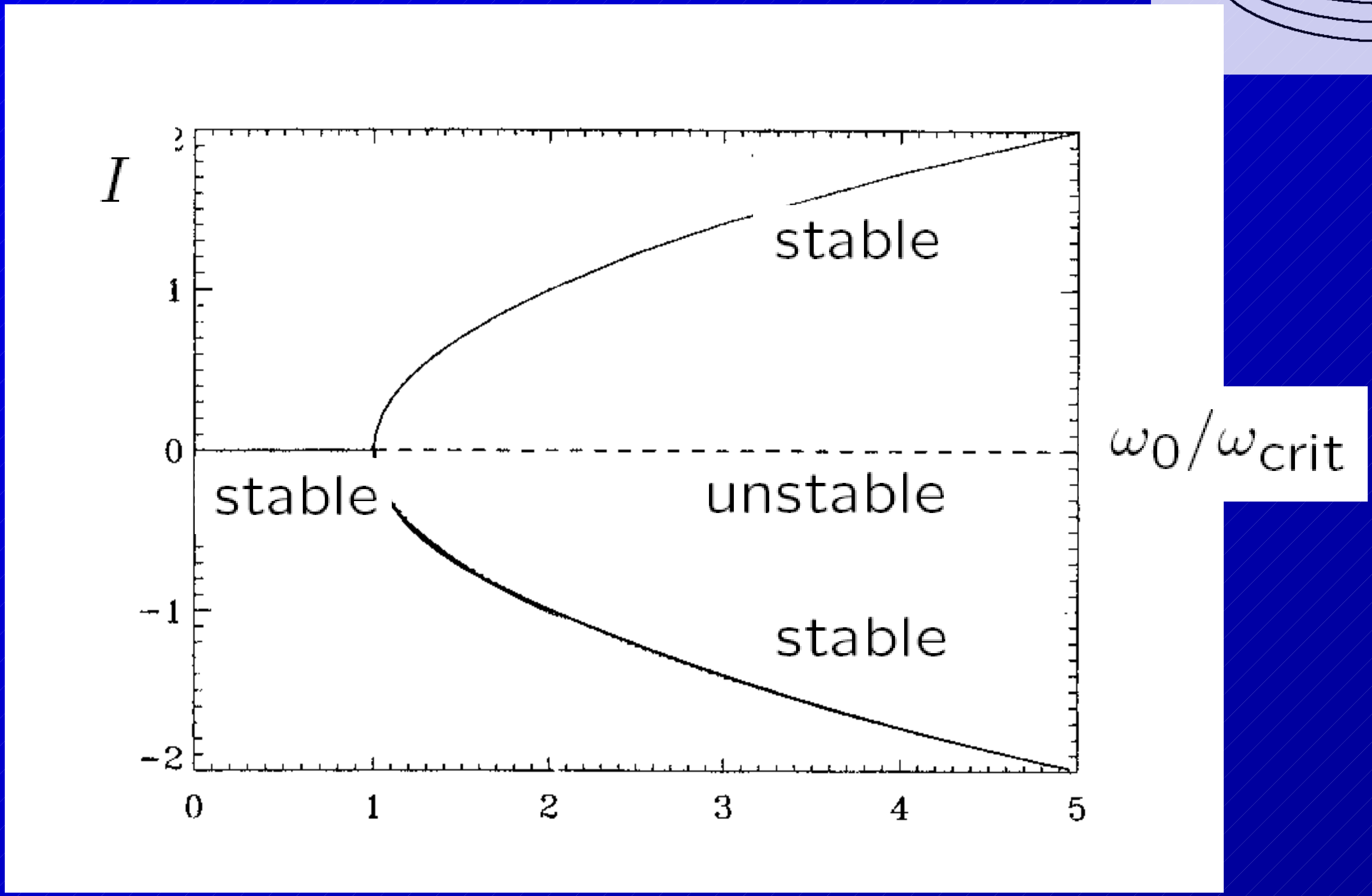
$$I = 0,\ \omega \text{ steady: } \omega = \omega_0 = \frac{D\,\tau^*}{\Theta}$$

Disc dynamo

Back-reaction of the magnetic field on the rotation rate

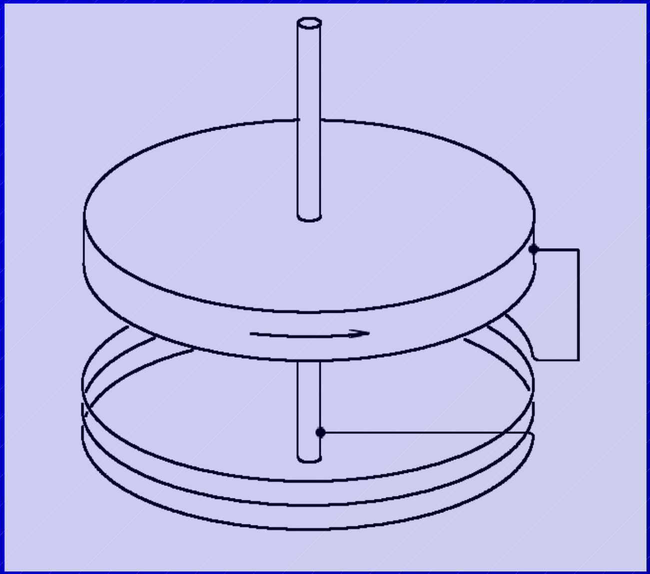


Steady case



Disc dynamo

considering the back-reaction
of the magnetic field
on the rotation rate
and an imposed magnetic field



$$L\,\frac{\mathrm{d}I}{\mathrm{d}t} + R\,I = \frac{\omega}{2\pi}\,\phi\,, \qquad \phi = \phi_0 + L'I$$

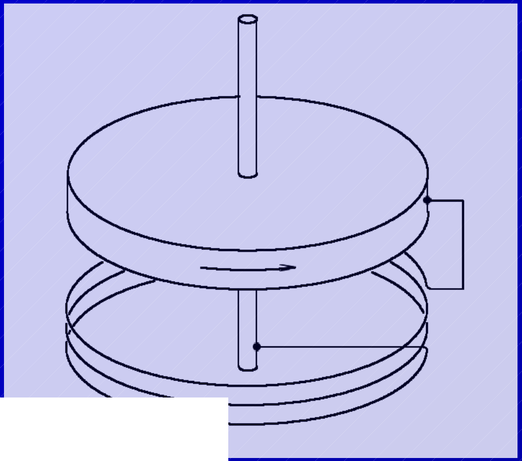
$$\frac{1}{2}\frac{\mathrm{d}}{\mathrm{d}t}(\Theta\,\omega^2 + L\,I^2) = D\,\omega - \frac{\Theta\,\omega^2}{\tau^*} - I^2\,R$$

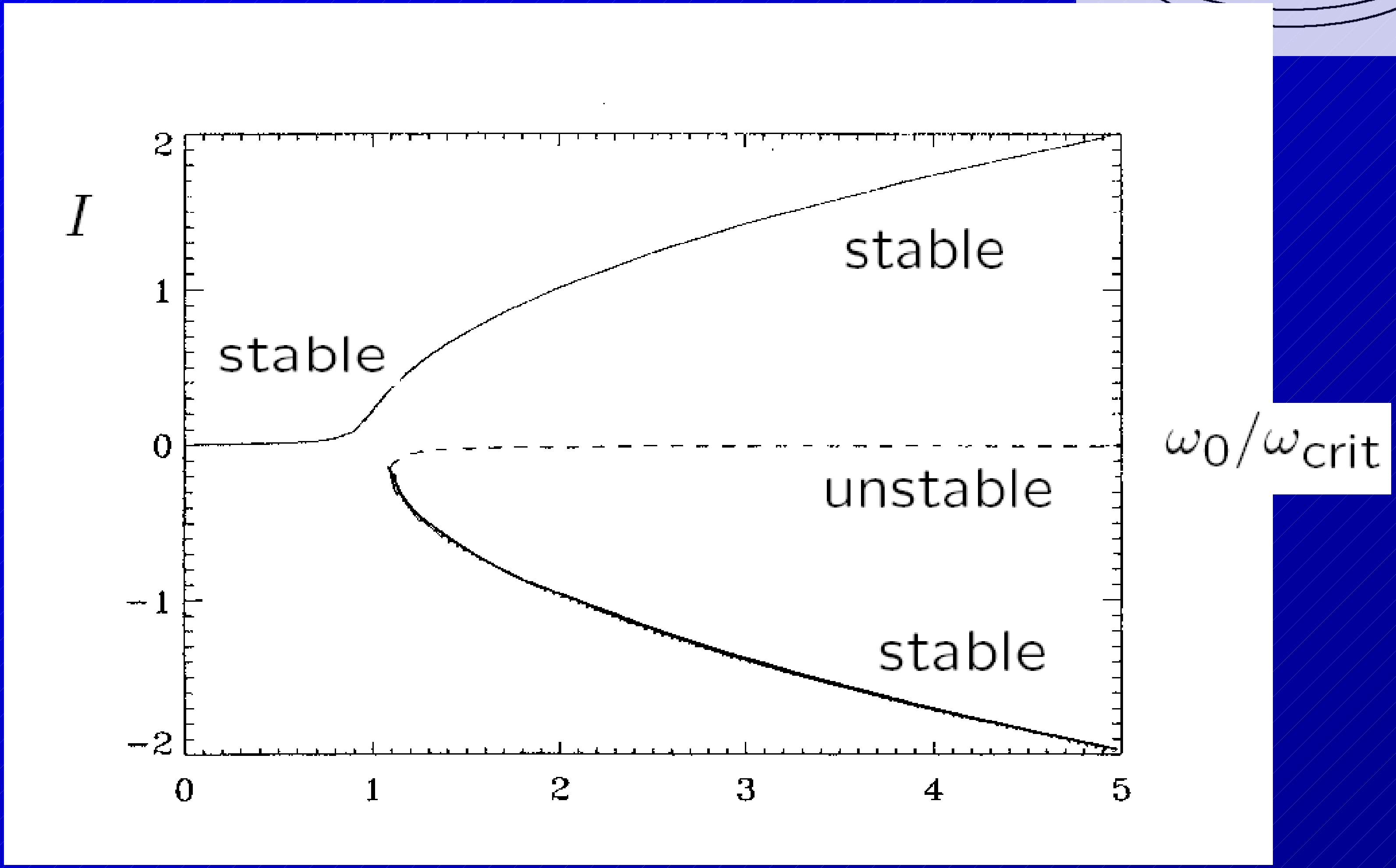
$$\omega_0 = \frac{D\,\tau^*}{\Theta}$$

Disc dynamo

Back-reaction
of the magnetic field
plus imposed magnetic field

Steady case





Dynamos under laboratory or similar conditions

$$R_\mathrm{m} = \frac{U\,L}{\eta}$$

Dynamo requires $R_\mathrm{m} \geq R_{\mathrm{m\,crit}} = O(1)$

E.g., $U = 1\,\mathrm{m/s}$ and $L = 1\,\mathrm{m}$

Earth's core	$\eta = 3\,\mathrm{m^2/s}$	$R_\mathrm{m} = 0.33$
Mercury	$\eta = 0.8\,\mathrm{m^2/s}$	$R_\mathrm{m} = 1.25$
Liquid sodium	$\eta = 0.08\,\mathrm{m^2/s}$	$R_\mathrm{m} = 12.5$

No Bonsai version of a cosmic dynamo !

Self-excitation of magnetic fields in fast-breeder reactors?

The danger of self-excitation of magnetic fields
in large liquid-metal circuits of reactors
has been pointed out in a memorandum of Max Steenbeck 1971
to the Soviet Academy of Sciences

→ Meeting in Obninsk near Moscow 1974

This possibility has been independently considered
by Bevir 1973 and Pierson 1975

Measurements at the Belojarsk BN-600 reactor by Kirko 1985 ...

Investigations related to the French Super Phoenix
by Plunian et al. 1995 / 99

Self-excitation of magnetic fields in fast-breeder reactors?

The danger of self-excitation of magnetic fields
in large liquid metal circuits of reactors
has been pointed out in a memorandum of Max Steenbeck 1971

→ Meeting in Obninsk near Moscow 1974

Steenbeck 1974
in a letter to the president of the Academy of Sciences of the GDR
and several Soviet scientists:

Dynamo experiment
with about 10 m^3 Na
and volumetric flow rates of more than 10 m^3/s

The need for experimental investigations

In magnetohydrodynamics one should not believe
the product of a long and complicated piece of mathematics
if unsupported by observation.

Fermi (reported by Roberts 1993)

Laboratory experiments with dynamos are more than demonstrating or checking an important principle.

Natural dynamos
with complex interactions of motion and magnetic field
are hardly accessible to direct numerical simulations,
e.g., because of the smallness of realistic values of Pm
and the complex turbulence phenomenae.
Experiments should improve our knowledge in this field.

The interaction of theory and experiment
pushes the understanding of dynamo processes forward.

Past dynamo-related MHD experiments

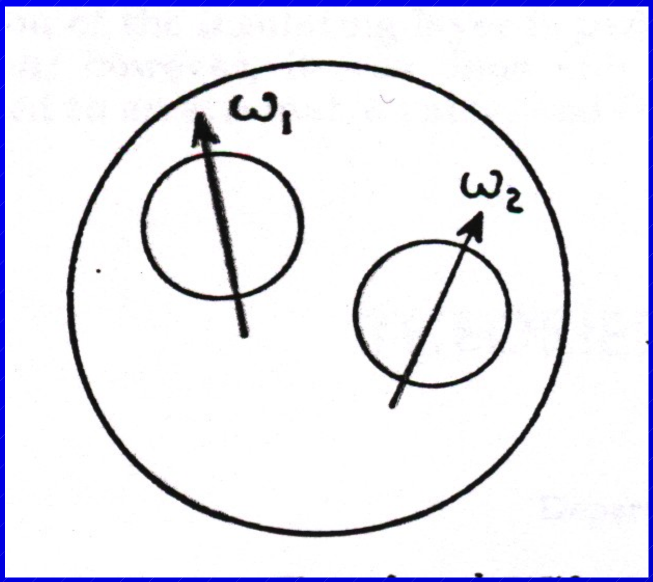
Lehnert 1958

Cylindrical vessel with 58 l sodium

Differential rotation due to a rotating plate

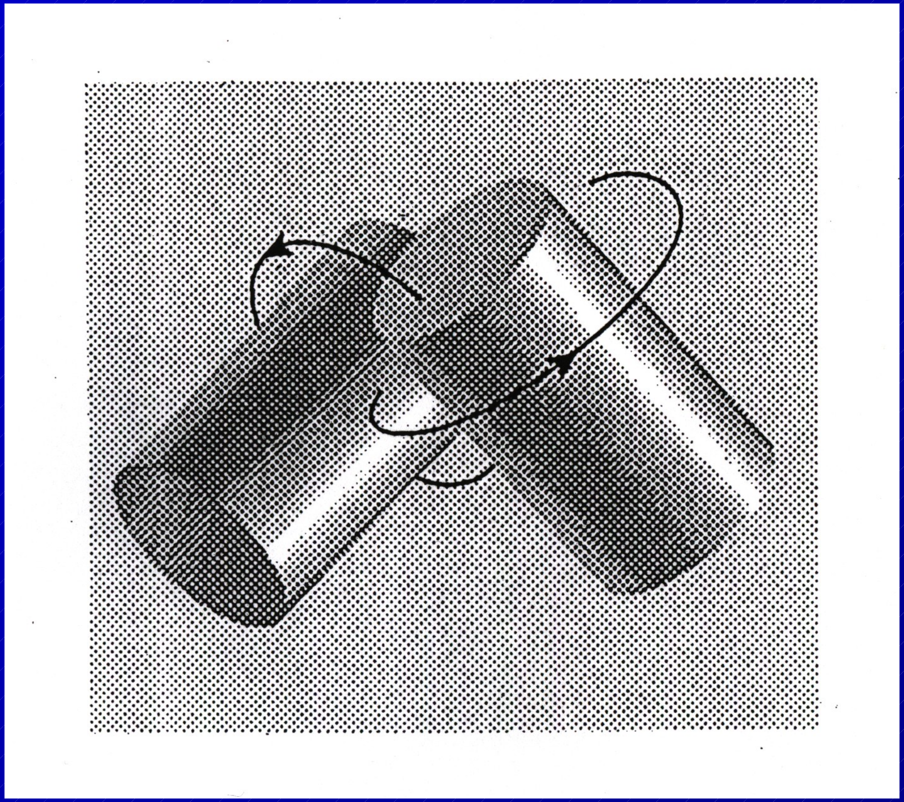
Poloidal → toroidal magnetic field

Past dynamo-related MHD experiments

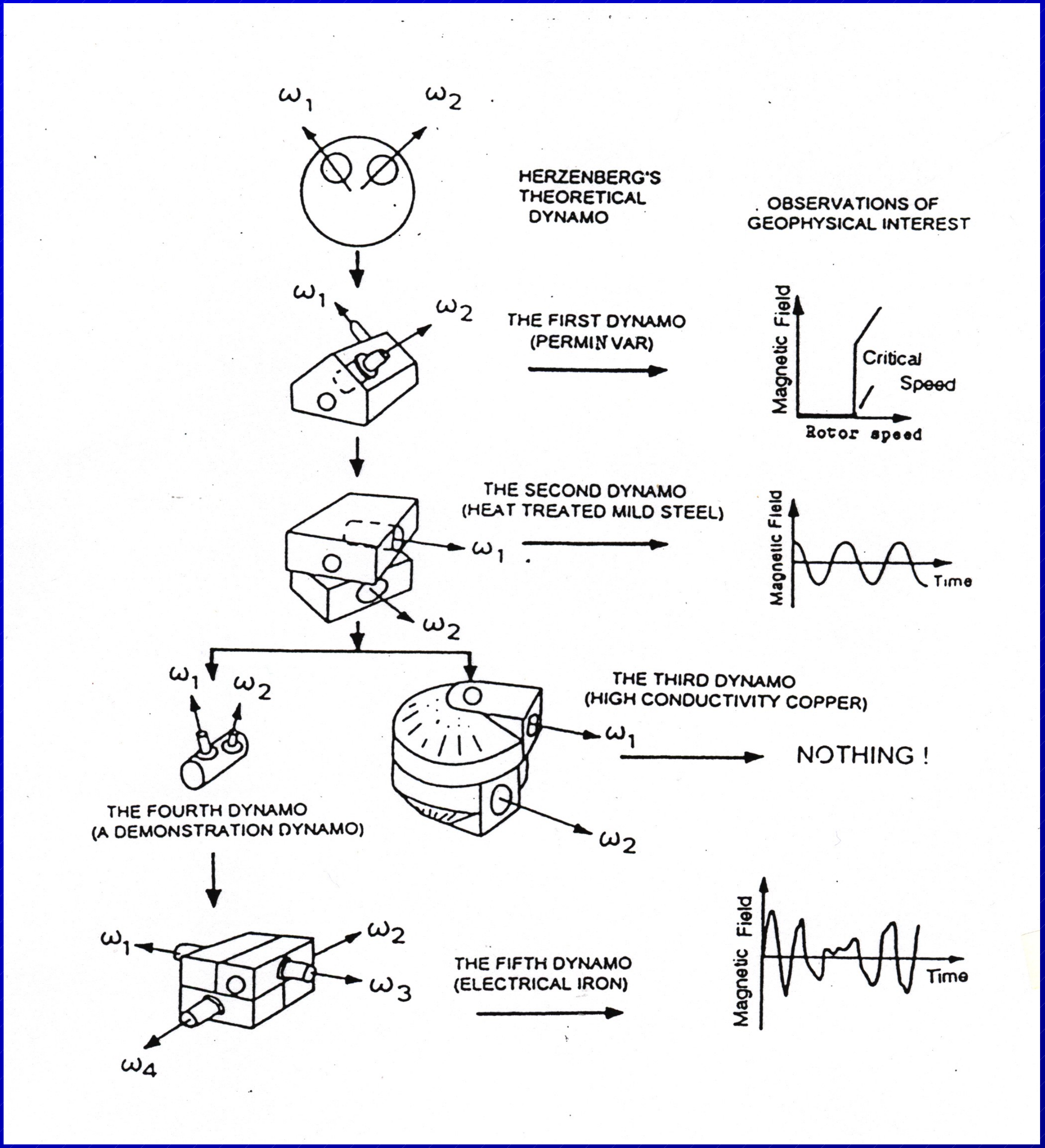


Herzenberg 1958

Lowes and Wilkinson 1963/68



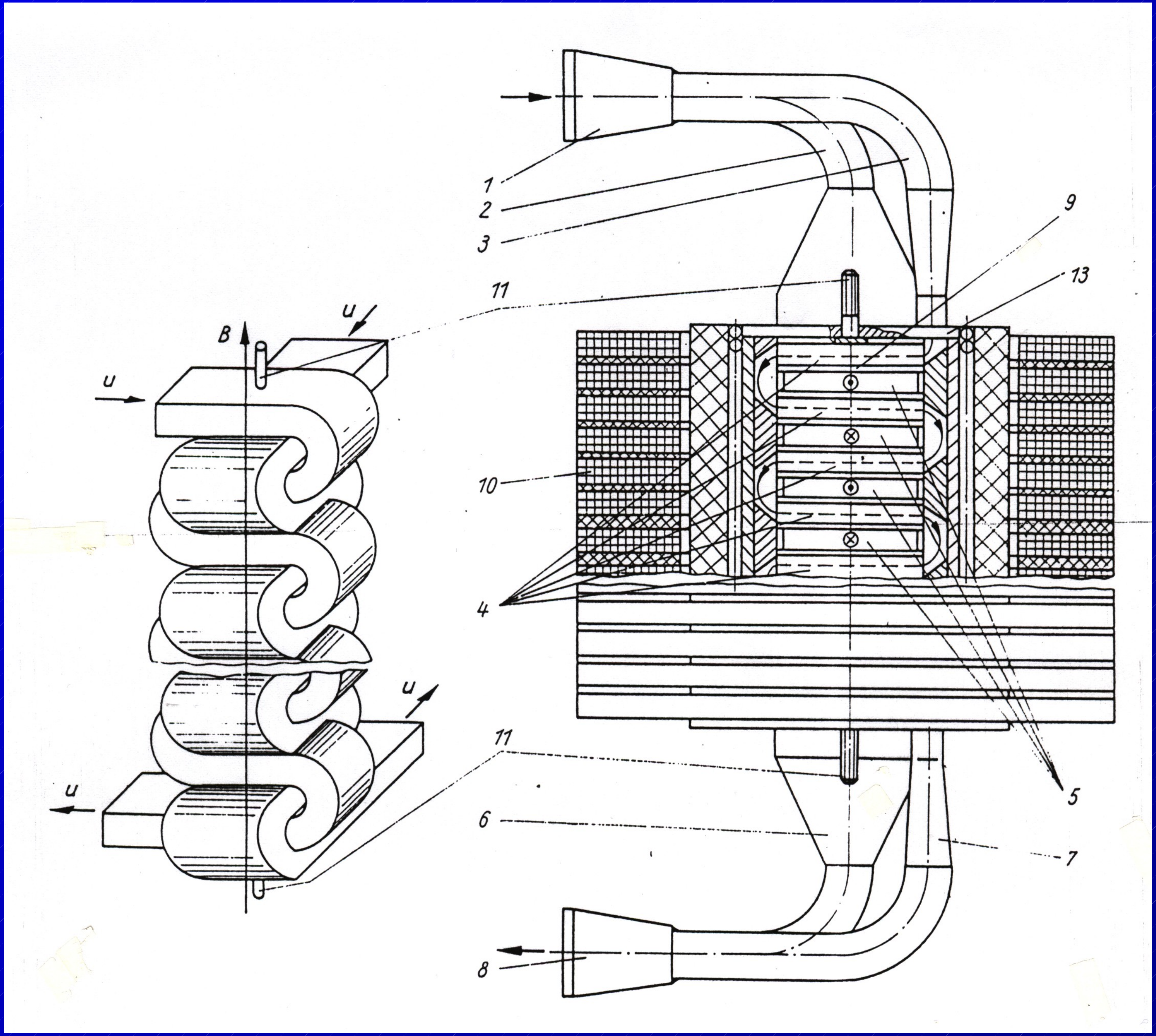
Past dynamo-related MHD experiments



Lowes and Wilkinson
1963/68

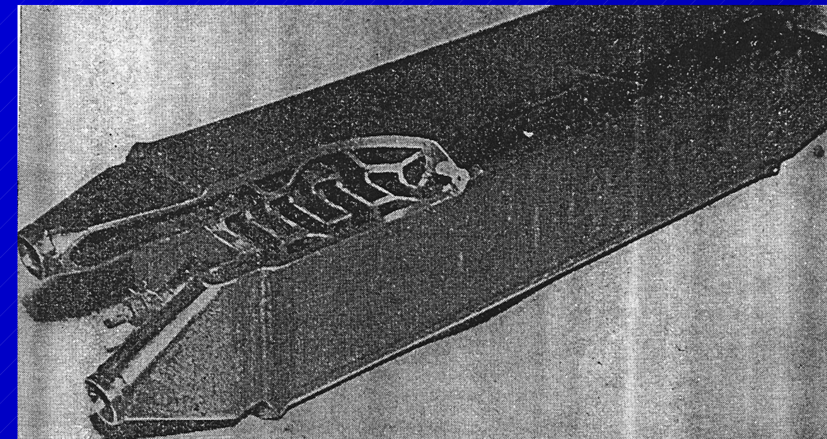
Past dynamo-related MHD experiments

Riga α-box

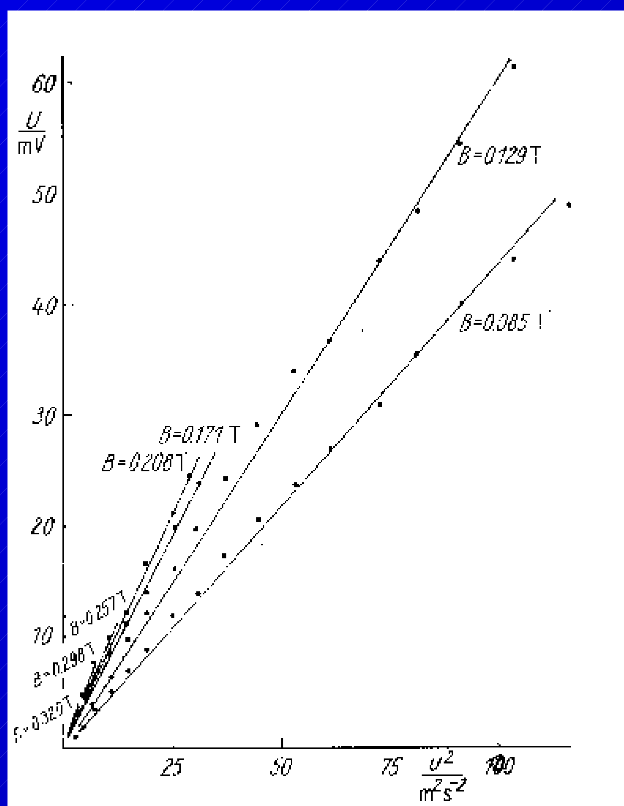


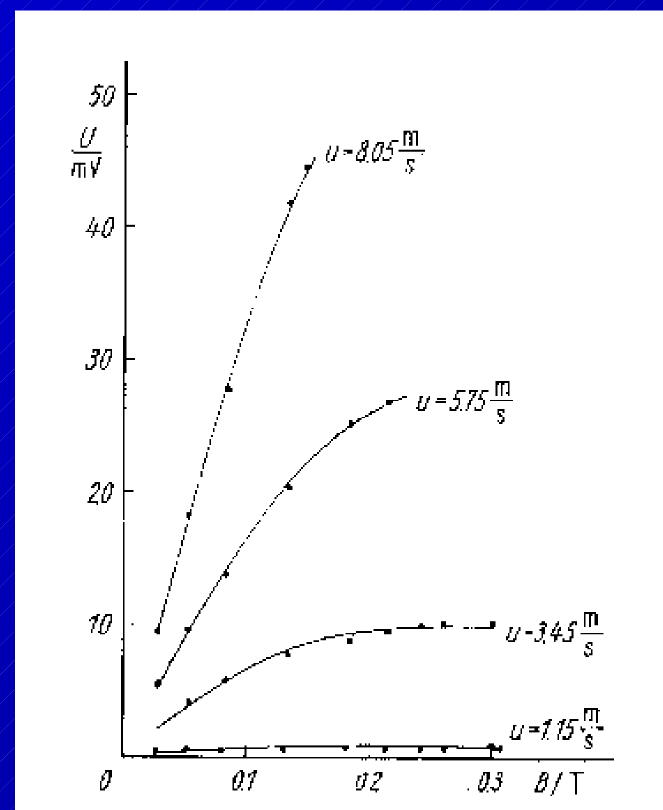
Steenbeck, Kirko, Gailitis, Klawinia, Krause, Laumanis, Lielausis 1967

Past dynamo-related MHD experiments



Riga α-box



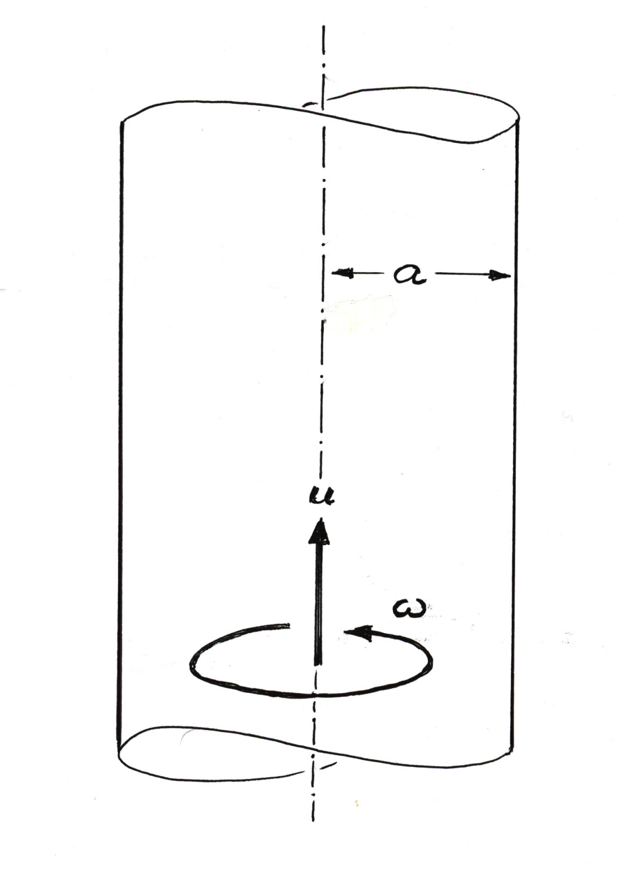


The Riga dynamo experiment

The motivation: low excitation threshold

→ Ponomarenko dynamo

Ponomarenko 1973



$$\boldsymbol{B} = \Re(\hat{\boldsymbol{B}}(r)\,\mathrm{exp}(\mathrm{i}(m\varphi + kz) + \lambda t))$$

$$Rm_\perp = \frac{|\omega| a^2}{\eta}, \qquad Rm_\parallel = \frac{|u| a}{\eta}$$

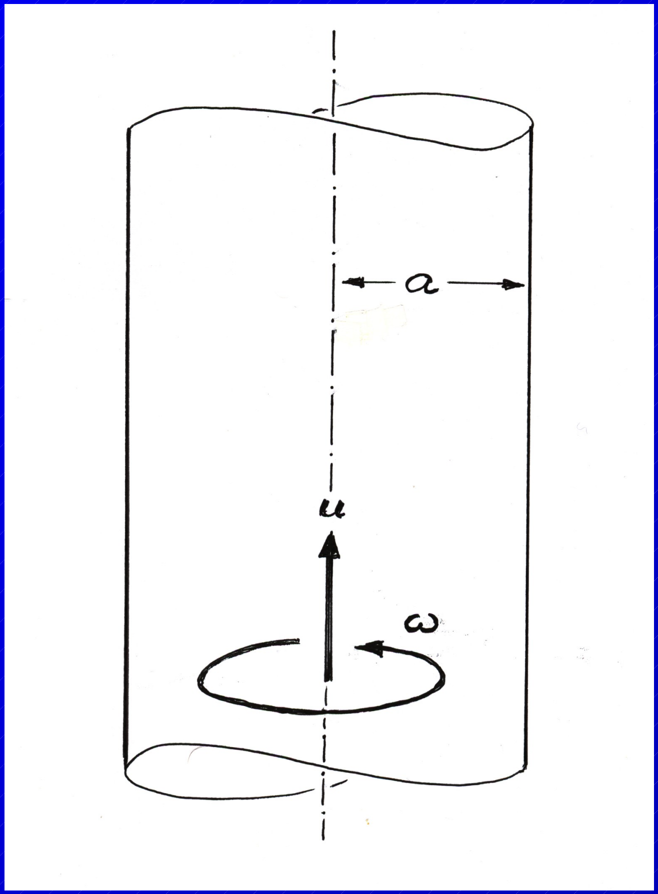
$$Rm = \sqrt{Rm_\perp^2 + Rm_\parallel^2}$$

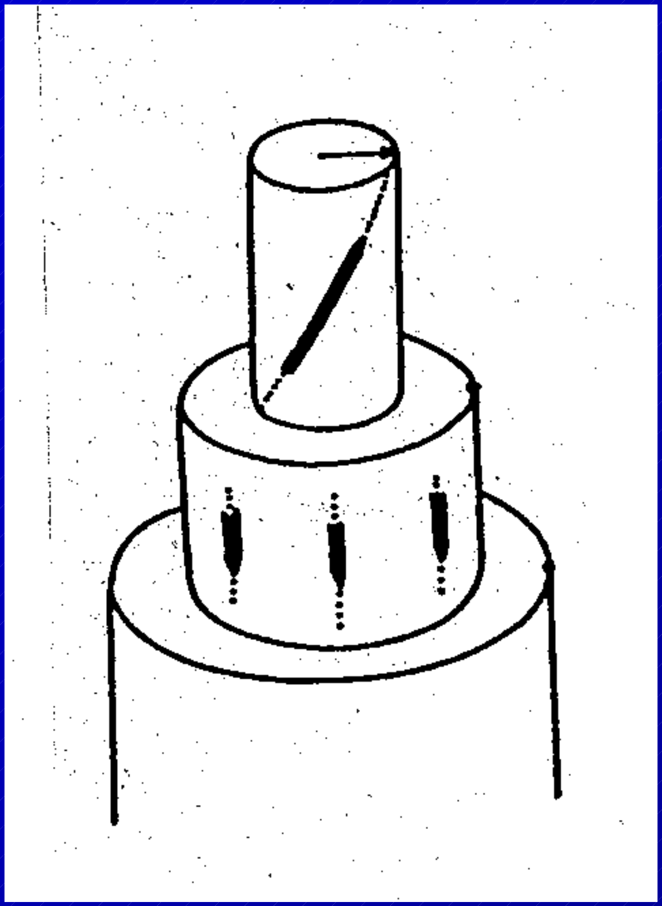
Marginal mode ($\lambda = 0$) with lowest Rm

$$Rm = 17.722, \qquad Rm_\perp / Rm_\parallel = 0.7625$$

$$m = 1, \qquad k/a = -0.3875$$

Riga dynamo experiment

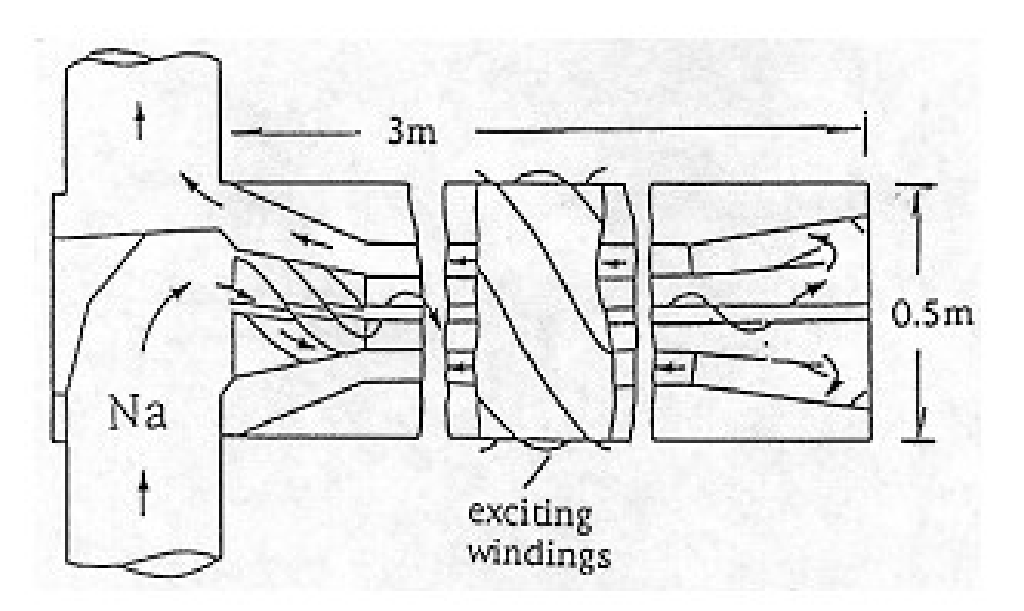


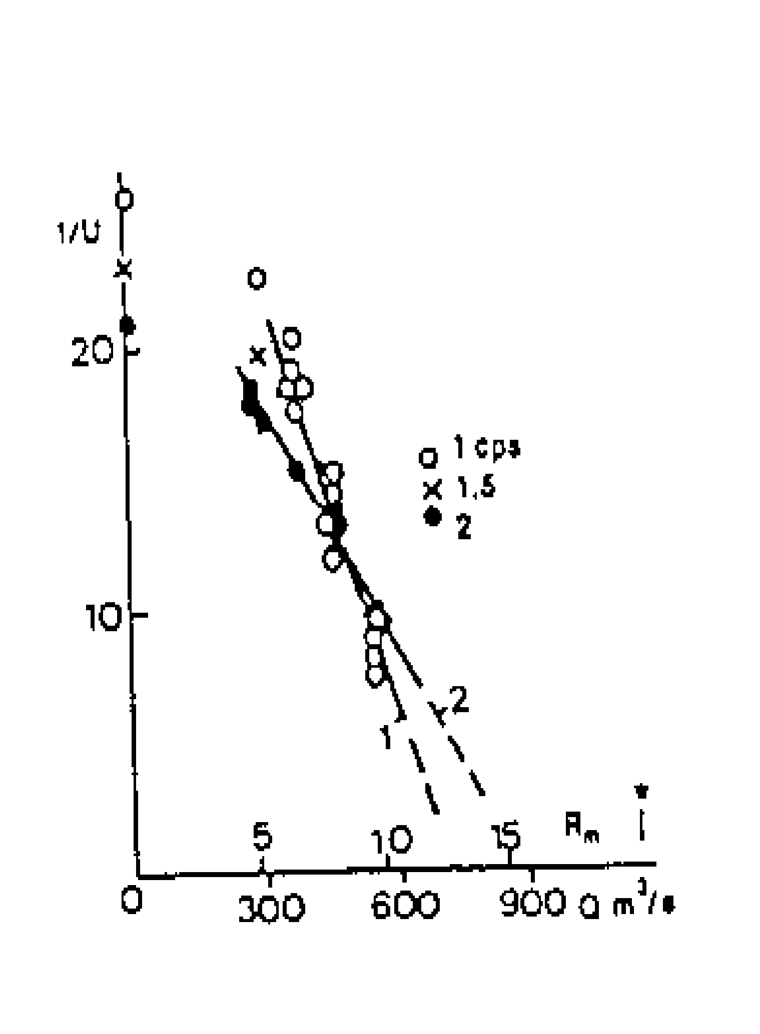


Riga dynamo experiment

The 1987 experiment

Gailitis, Lielausis, ...





Riga dynamo experiment

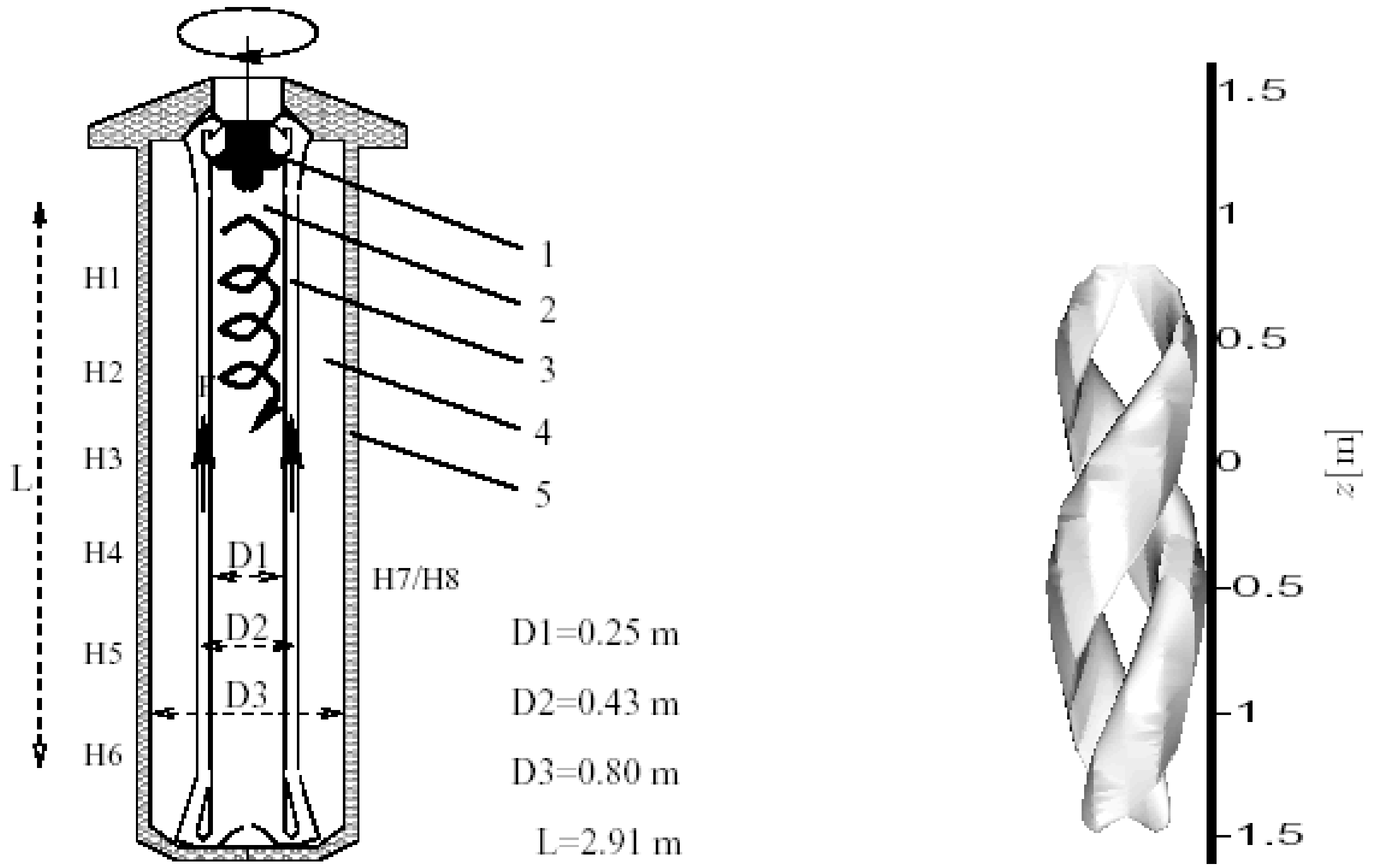


Fig. 1. Left hand side: the main parts of the Riga dynamo facility: *1* – propeller, *2* – helical flow region , *3* – back-flow region, *4* – sodium at rest, *5* – thermal insulation, F – Position of the flux-gate sensor and the induction coil, H1...H6 – positions of six aligned Hall sensors, H7/H8 – two Hall sensors at different azimuths. Right hand side: computed magnetic field energy iso-surface for the kinematic dynamo model.

Riga dynamo experiment

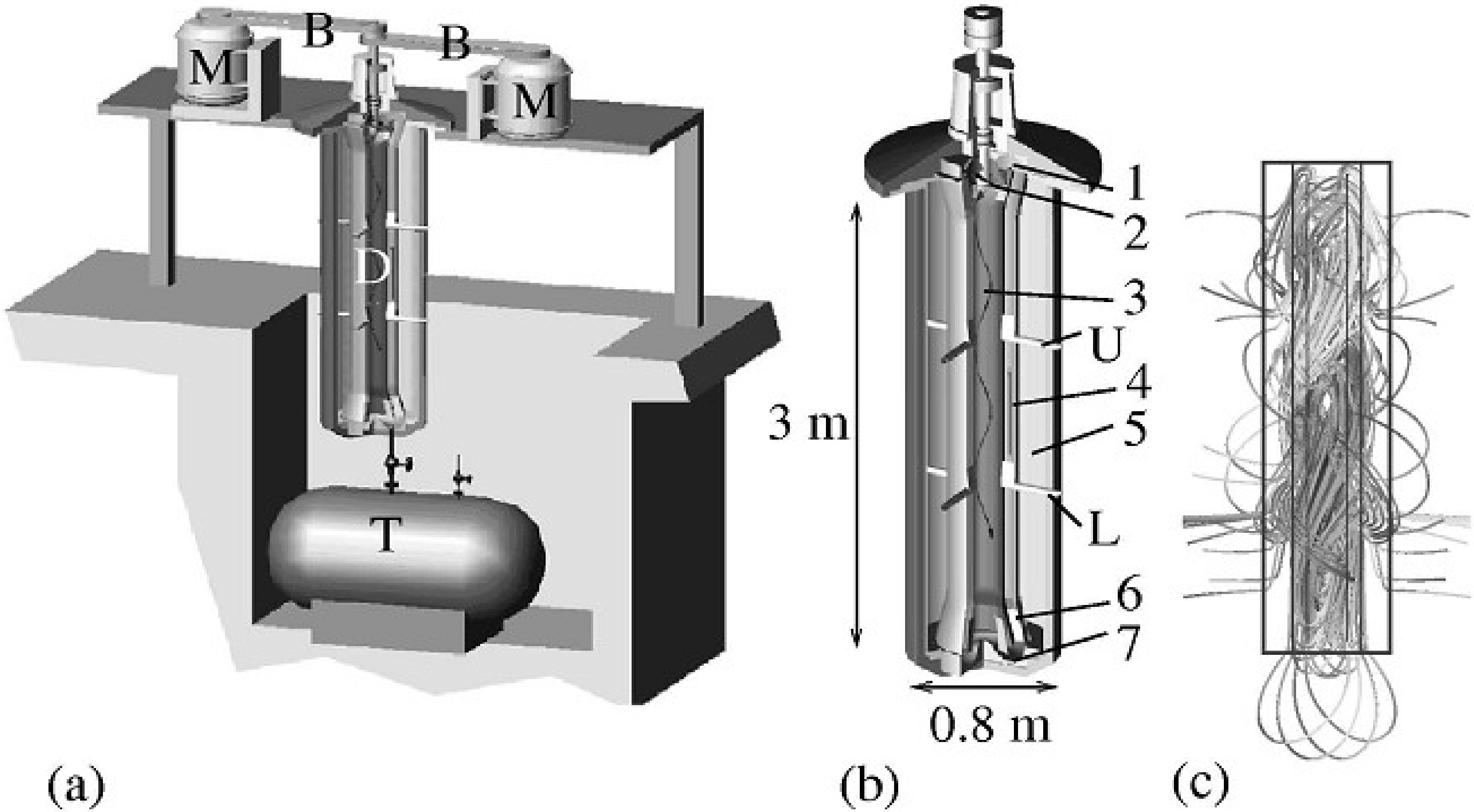


Fig. 5 The Riga dynamo experiment and its eigenfield. (a) Sketch of the facility. M - Motors. B - Belts. D - Central dynamo module. T- Sodium tank. (b) Sketch of the central module. 1 - Guiding blades. 2 - Propeller. 3 - Helical flow region without any flow-guides, flow rotation is maintained by inertia only. 4 - Back-flow region. 5 - Sodium at rest. 6 - Guiding blades. 7 - Flow bending region. (c) Simulated magnetic eigenfield. The gray scale indicates the vertical components of the field.

Riga dynamo experiment

November 10/11, 1999

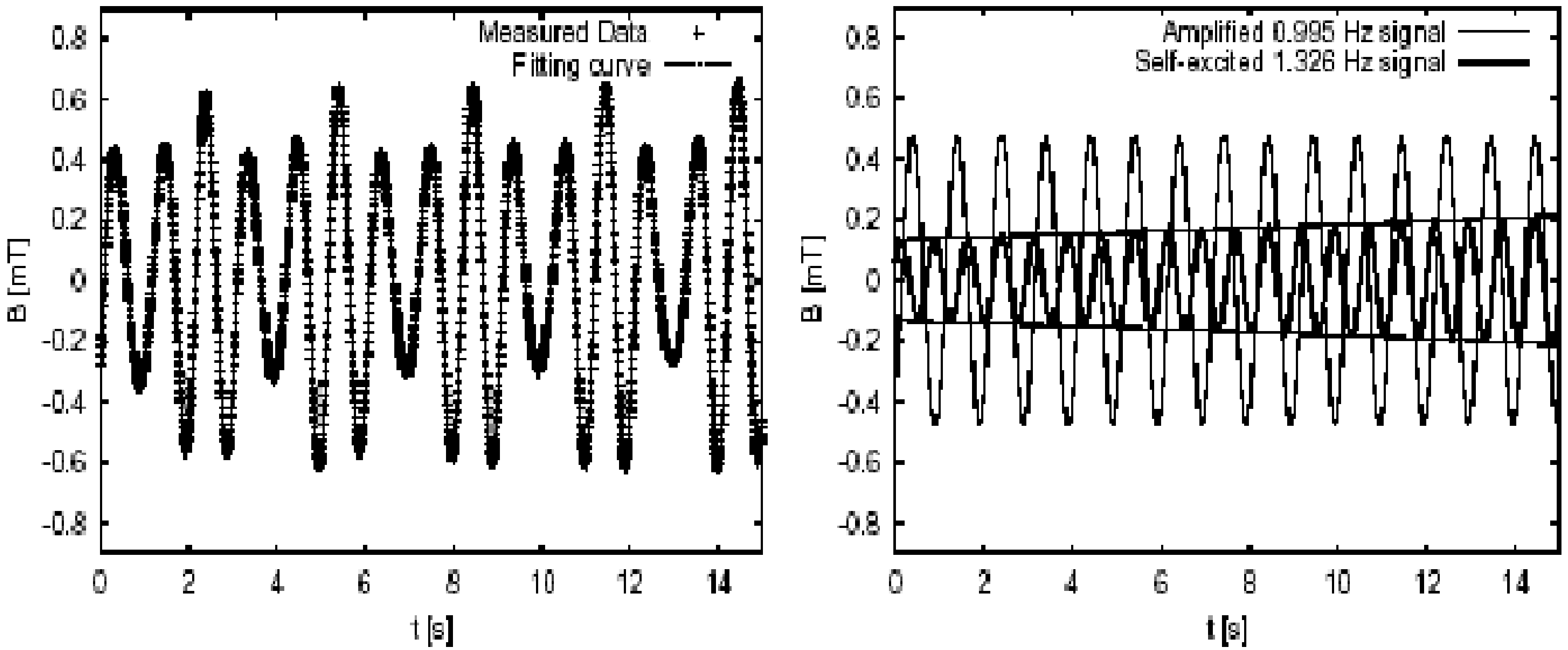
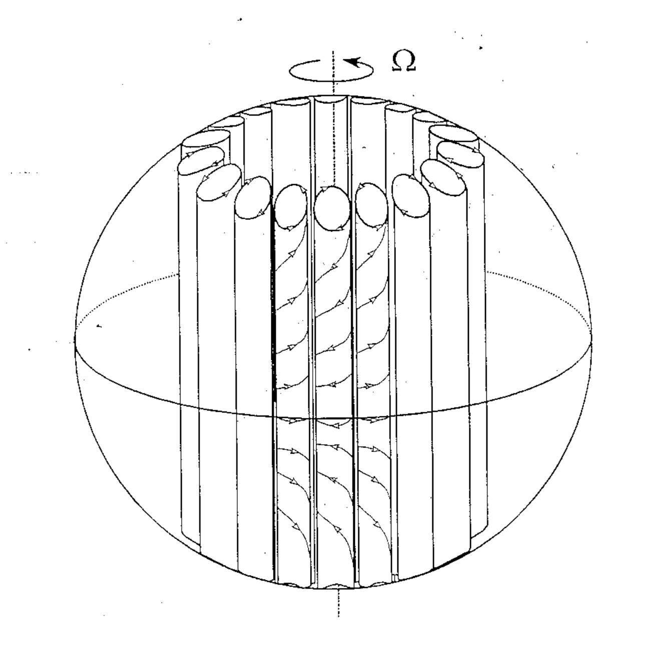


Fig. 5. Magnetic field signal measured at 2150 rpm at the flux gate sensor F and fitting curve (left). Decomposition of the fitting curve into two curves with different frequencies (right). The growth rate of the 1.326 Hz signal was $p = +0.03s^{-1}$.

The Karlsruhe dynamo experiment

The motivation

Müller, Stieglitz, ... 1999

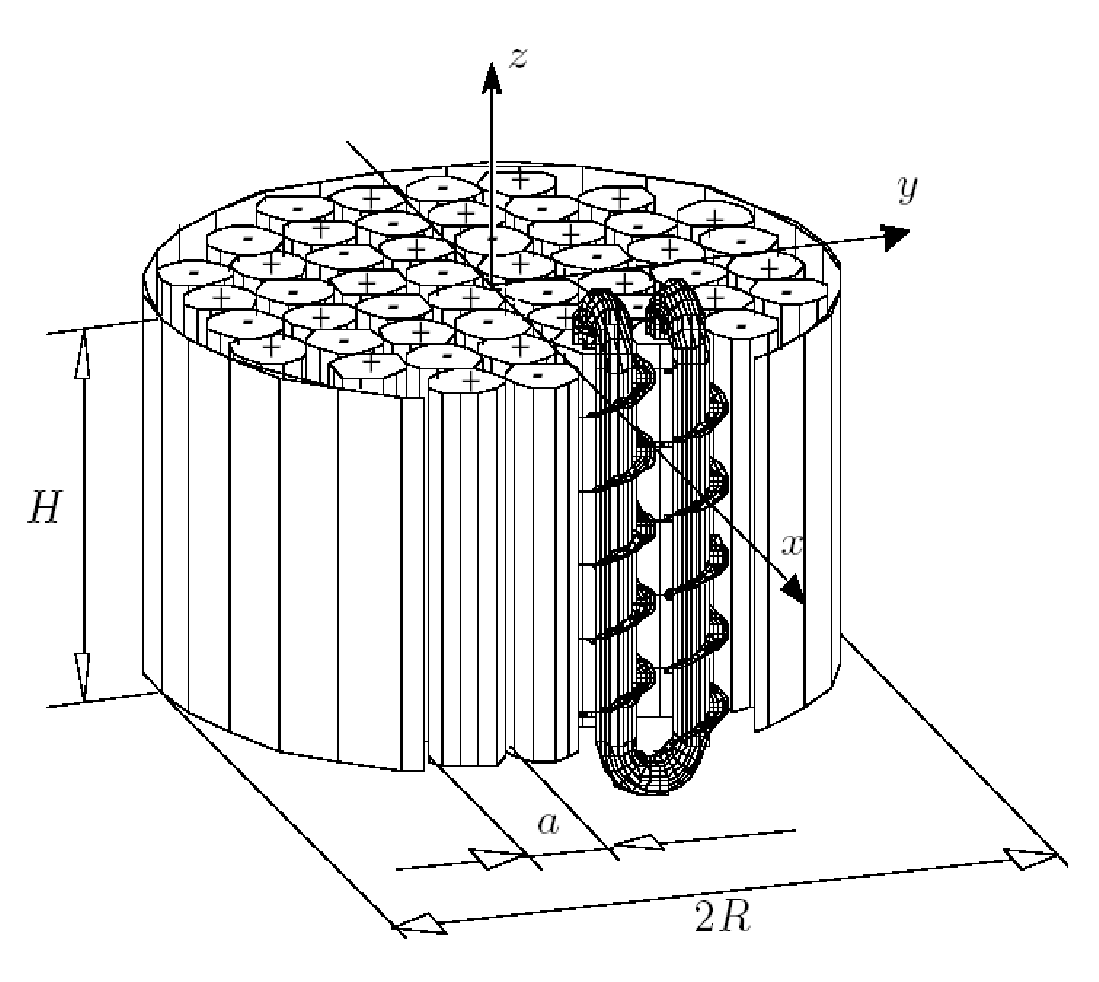


Earth's core

Busse 1970, ...

→

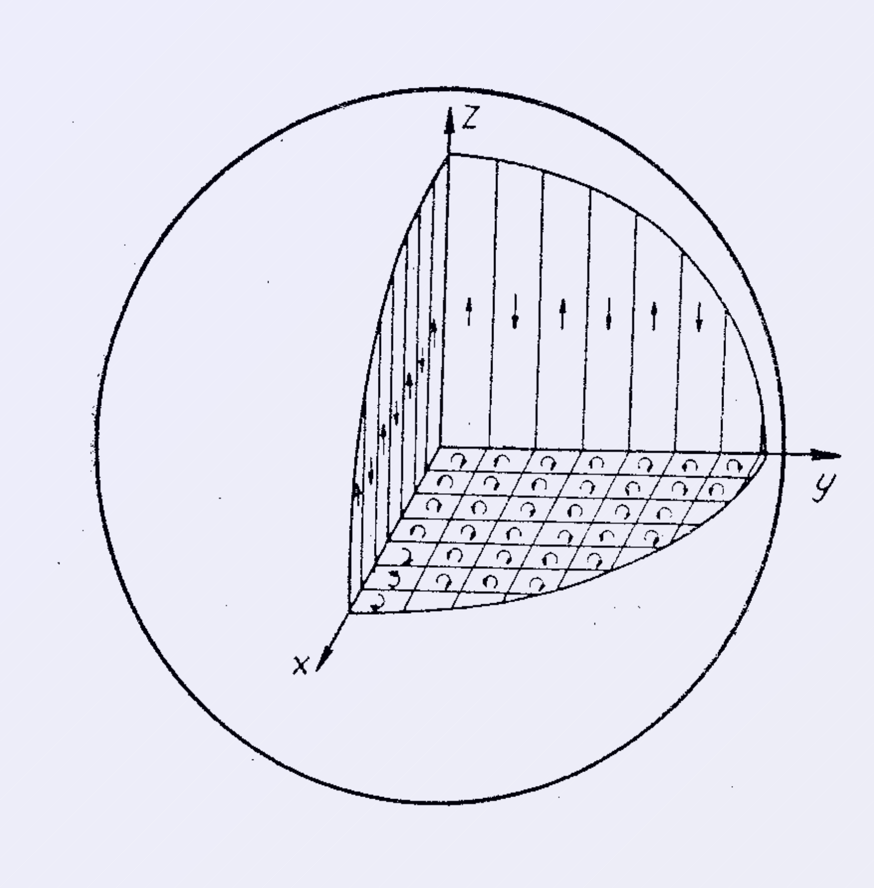
Experiment



Karlsruhe dynamo experiment

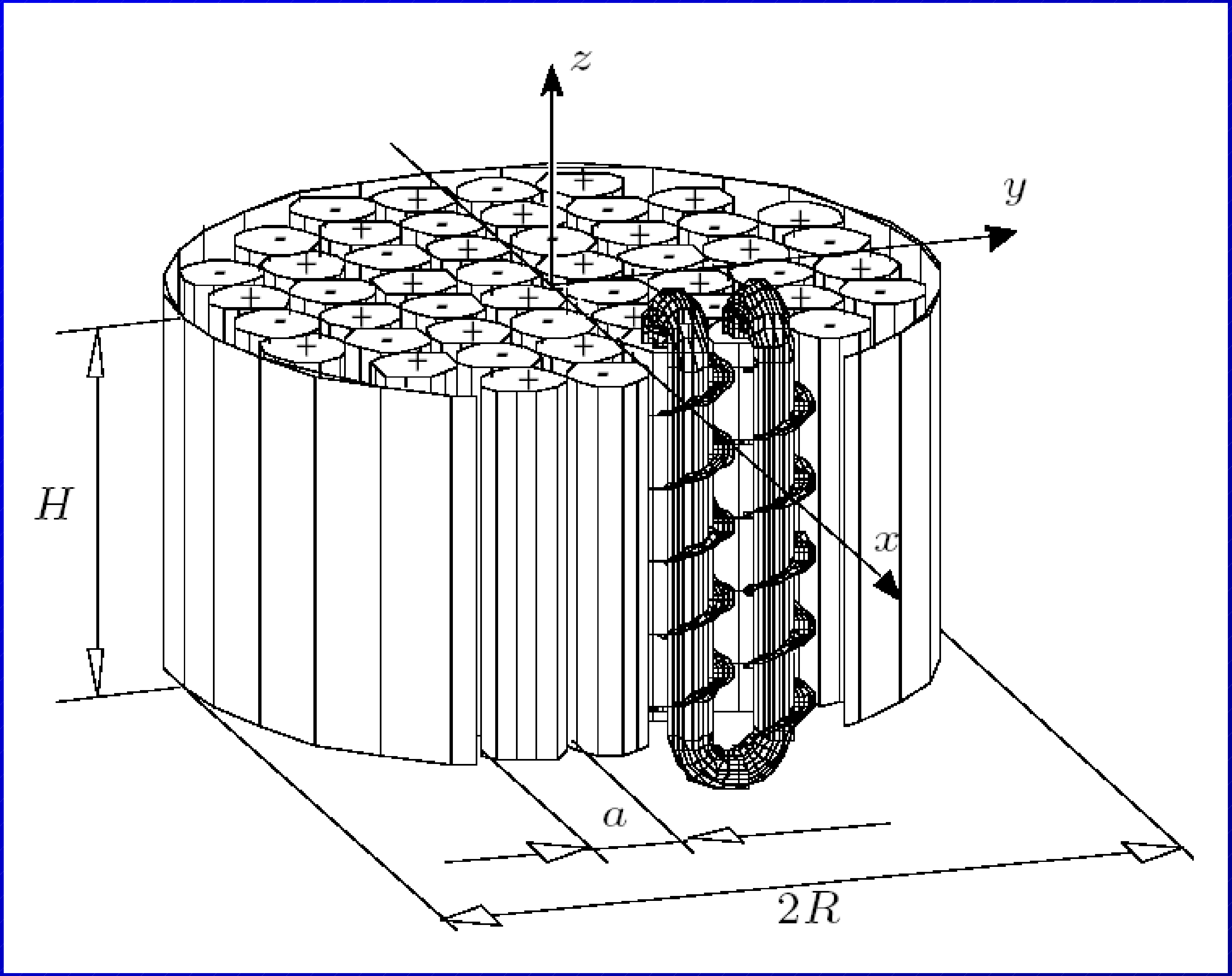
An experiment as later carried out in Karlsruhe has been prosed by Busse 1975

Gailitis' idea 1967



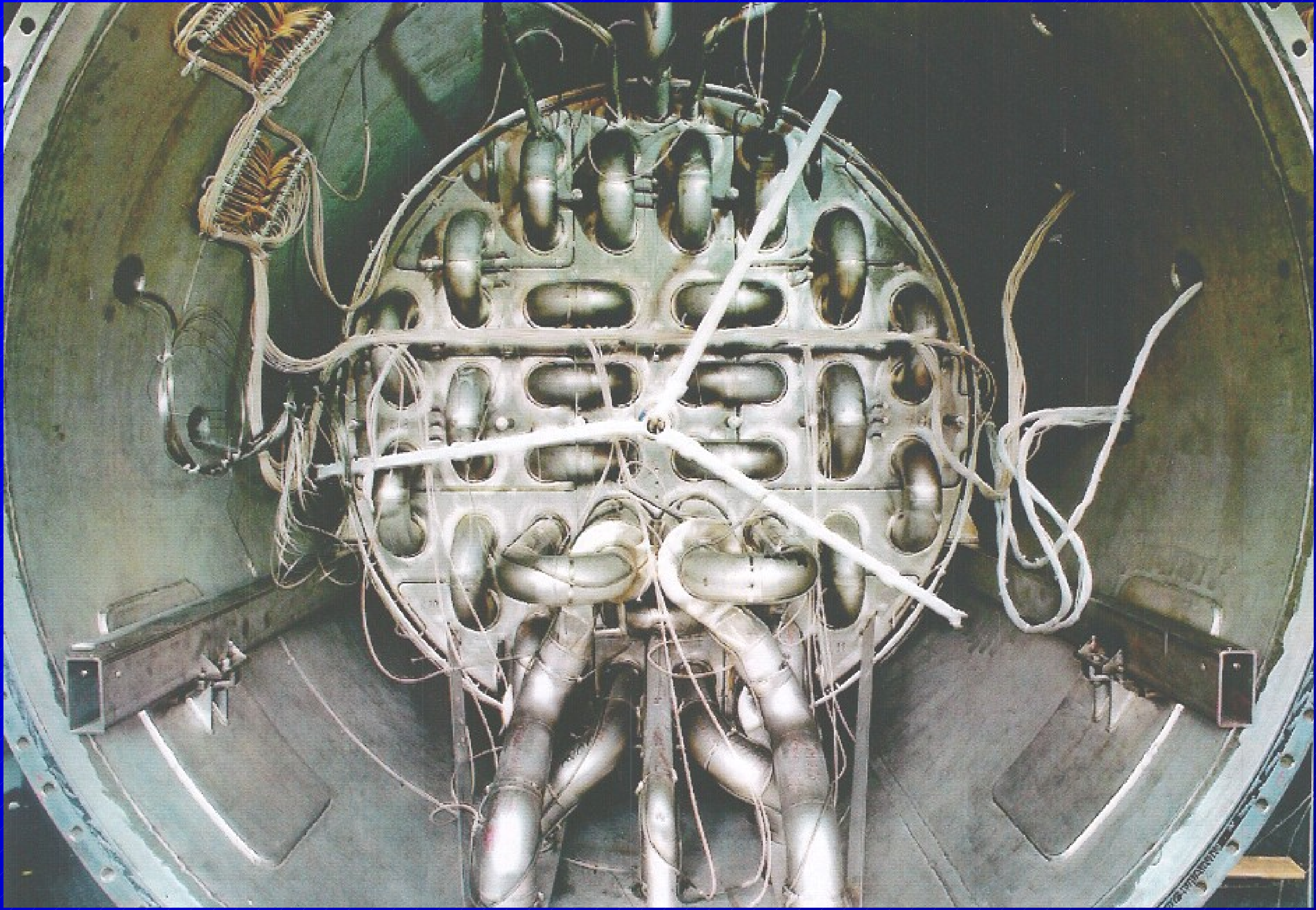
Karlsruhe dynamo experiment

$H = 0.70$ m

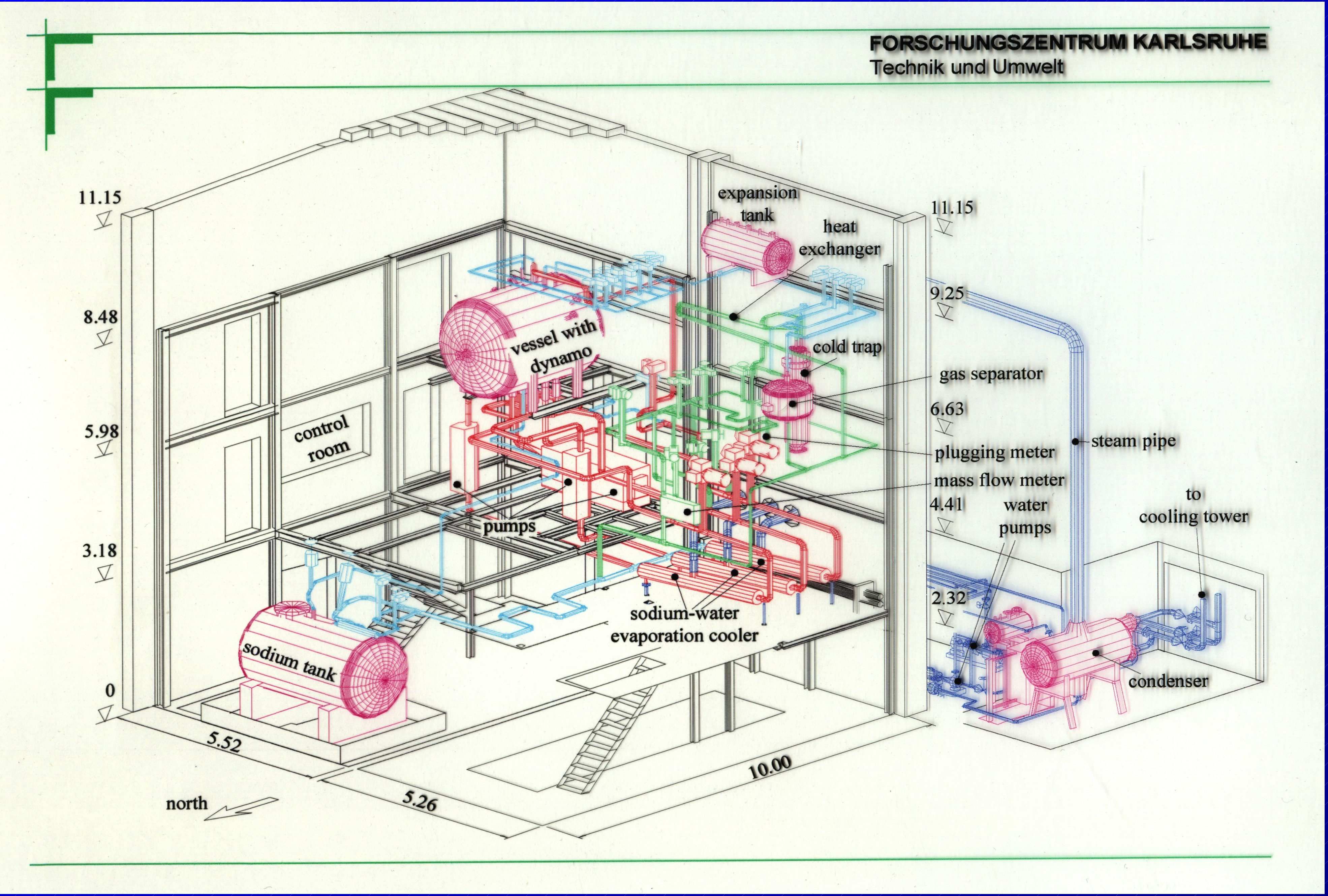


$R = 0.85$ m $a = 0.21$ m

Karlsruhe dynamo experiment



Karlsruhe dynamo experiment



Karlsruhe dynamo experiment

Roberts dynamo

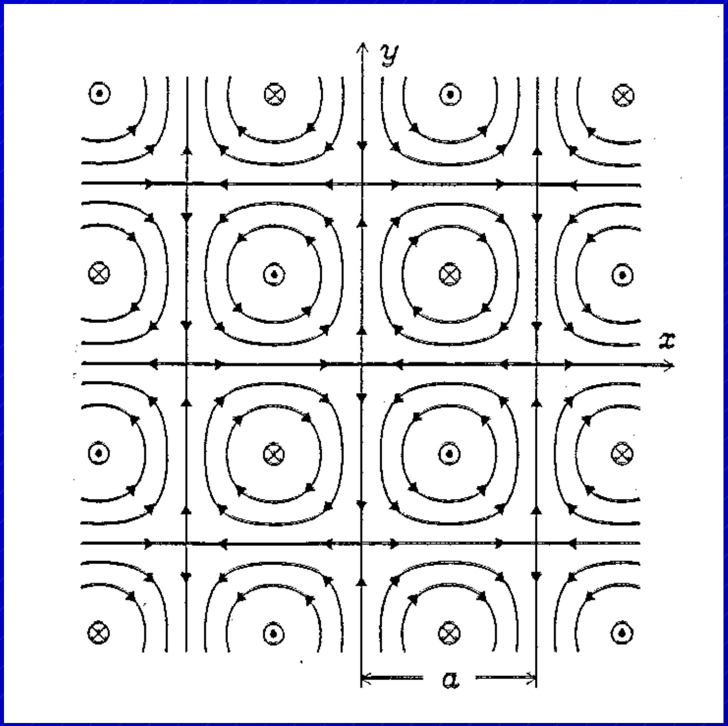
G. O. Roberts 1972

Fluid velocity, e.g.,

$$u_x = -u_\perp \frac{\pi}{2} \sin\left(\frac{\pi}{a} x\right) \cos\left(\frac{\pi}{a} y\right)$$

$$u_y = u_\perp \frac{\pi}{2} \cos\left(\frac{\pi}{a} x\right) \sin\left(\frac{\pi}{a} y\right)$$

$$u_z = -u_\parallel \frac{\pi}{2} \sin\left(\frac{\pi}{a} x\right) \sin\left(\frac{\pi}{a} y\right)$$



Non-decaying magnetic fields

$$\boldsymbol{B} = \Re(\hat{\boldsymbol{B}}(x,y)\exp(\mathrm{i}kz + pt))$$

if

$$Rm_\perp Rm_\parallel \phi(Rm_\perp, k) \geq \frac{16}{\pi^2} a\, k$$

$$Rm_\perp = u_\perp a/2\eta\,, \quad Rm_\parallel = u_\parallel a/\eta\,.$$

Karlsruhe dynamo experiment

Roberts dynamo

Non-decaying magnetic fields

$$\boldsymbol{B} = \Re(\hat{\boldsymbol{B}}(x,y)\,\mathrm{exp}(\mathrm{i}kz + pt))$$

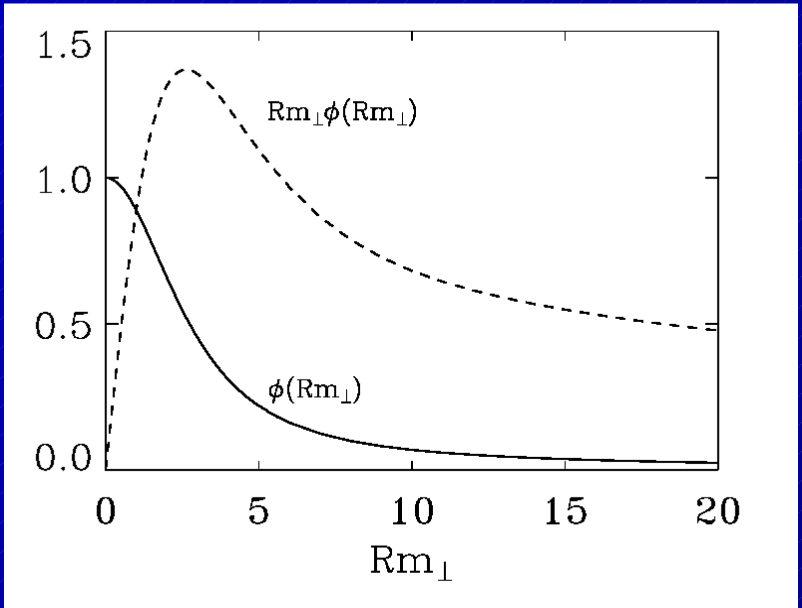
if

$$Rm_\perp\, Rm_\parallel\, \phi(Rm_\perp, k) \geq \frac{16}{\pi^2}\, a\, k$$

$$Rm_\perp = u_\perp a/2\eta\,, \qquad Rm_\parallel = u_\parallel a/\eta\,.$$

Most easily excitable *B* modes contain parts independent of x and y.

(limit of small k)



Karlsruhe dynamo experiment

Roberts dynamo allows mean-field description:

$$\partial_t \overline{B} - \nabla \times (\overline{U} \times \overline{B} + \mathcal{E}) - \eta \nabla^2 \overline{B} = 0 \,, \quad \nabla \cdot \overline{B} = 0 \,,$$

with mean fields defined by averaging over x and y.

$$\mathcal{E} = \boldsymbol{\alpha} \cdot \overline{B} + \cdots$$

$$\boldsymbol{\alpha} = \begin{pmatrix} \alpha_\perp & 0 & 0 \\ 0 & \alpha_\perp & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

anisotropic alpha-effect

(limit of small k)

$$\alpha_\perp = \frac{\pi^2}{16} \frac{\eta}{a} Rm_\perp \, Rm_\parallel \, \phi(Rm_\perp)$$

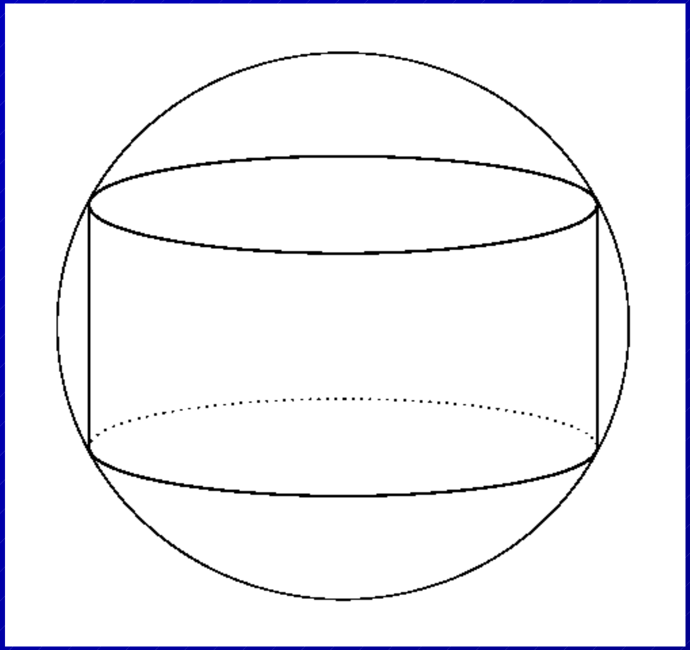
Two branches in the theory of the experiment

- Direct numerical simulations

  Busse, Tilgner 1996...2004

- Mean-field theory

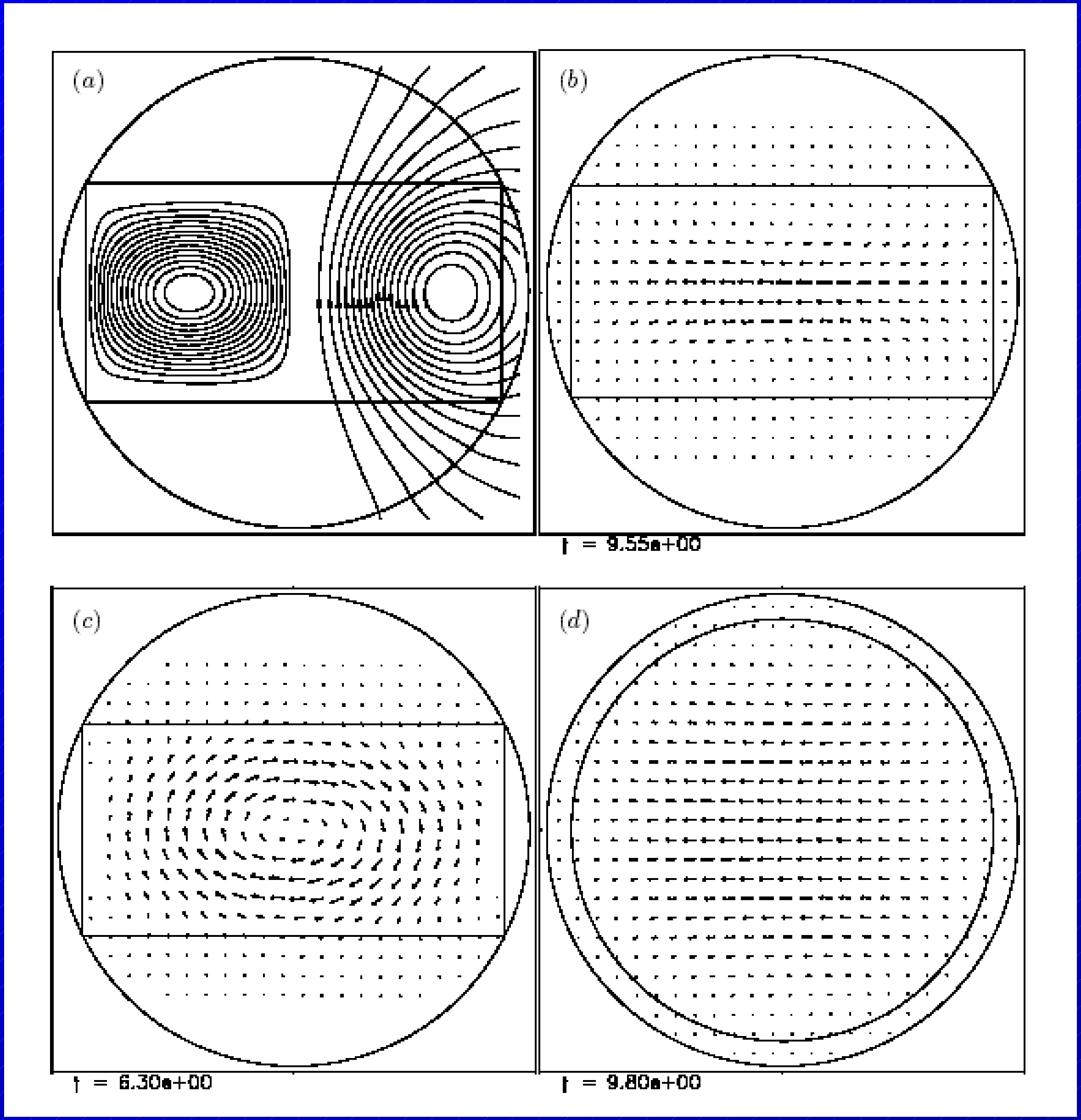
  Apstein, Brandenburg, Fuchs, Schüler,
  Rädler, Rheinhardt 1996...2002



Karlsruhe dynamo experiment

m=0

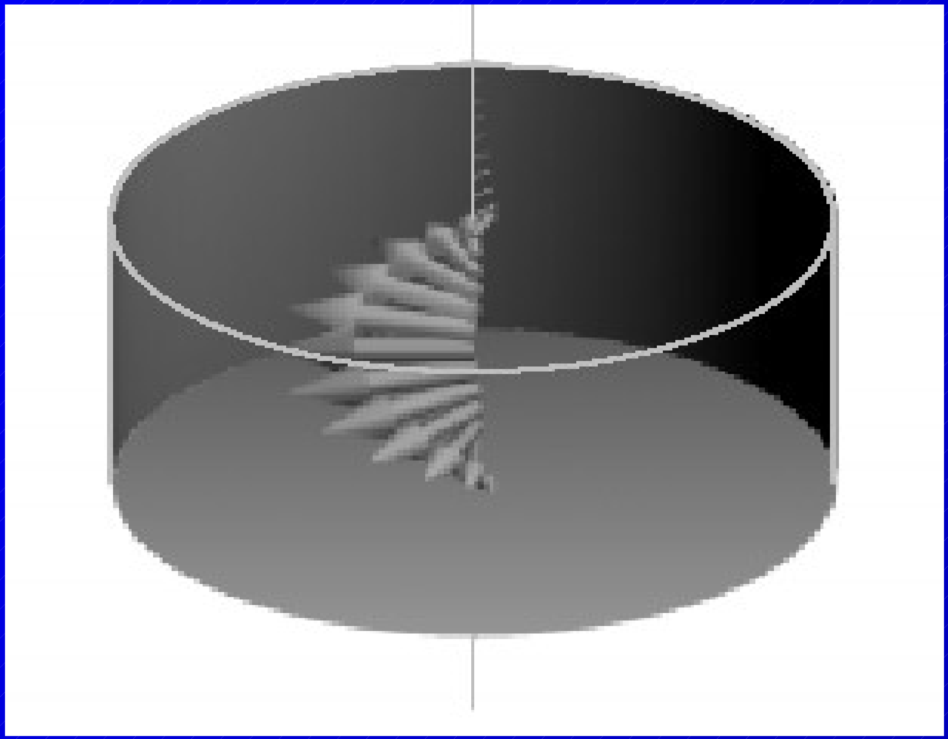
m=1

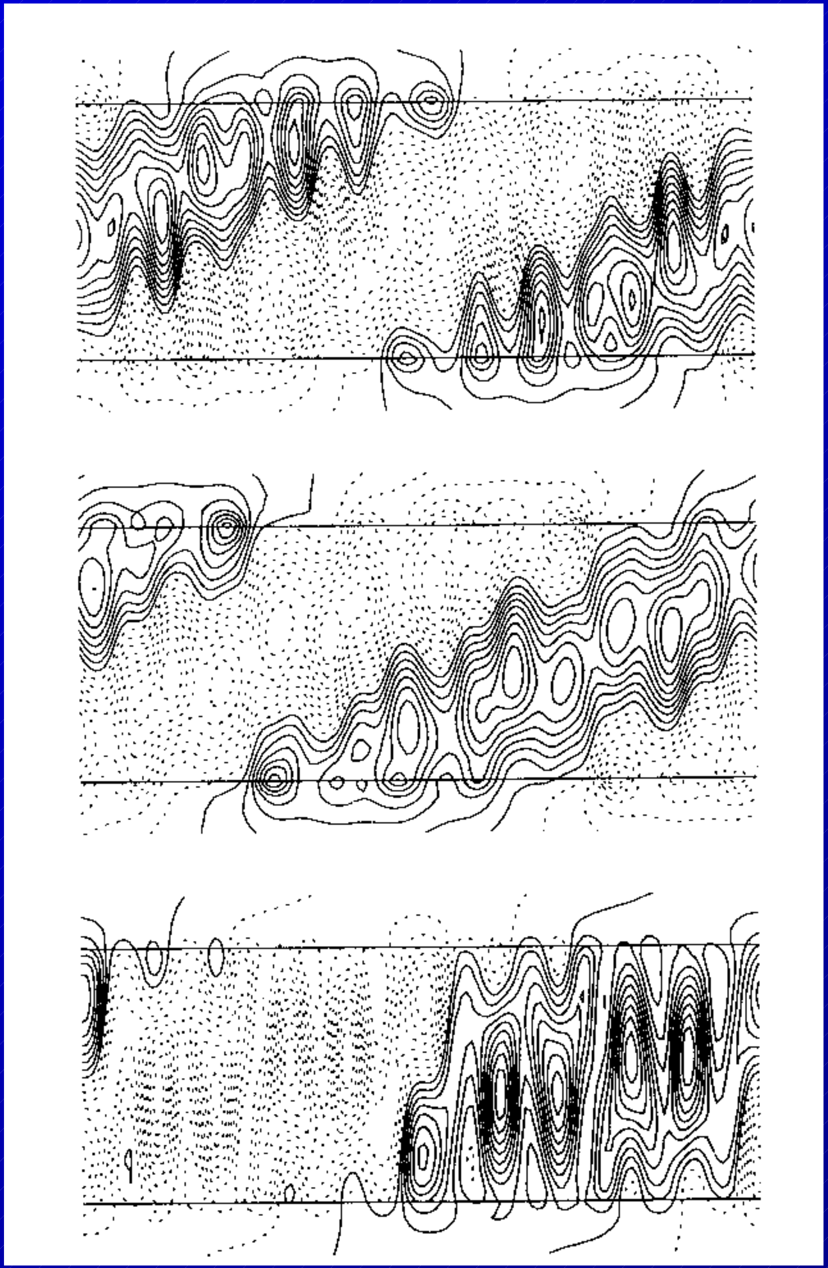


m=1

m=1

Karlsruhe dynamo experiment





m=1

Karlsruhe dynamo experiment

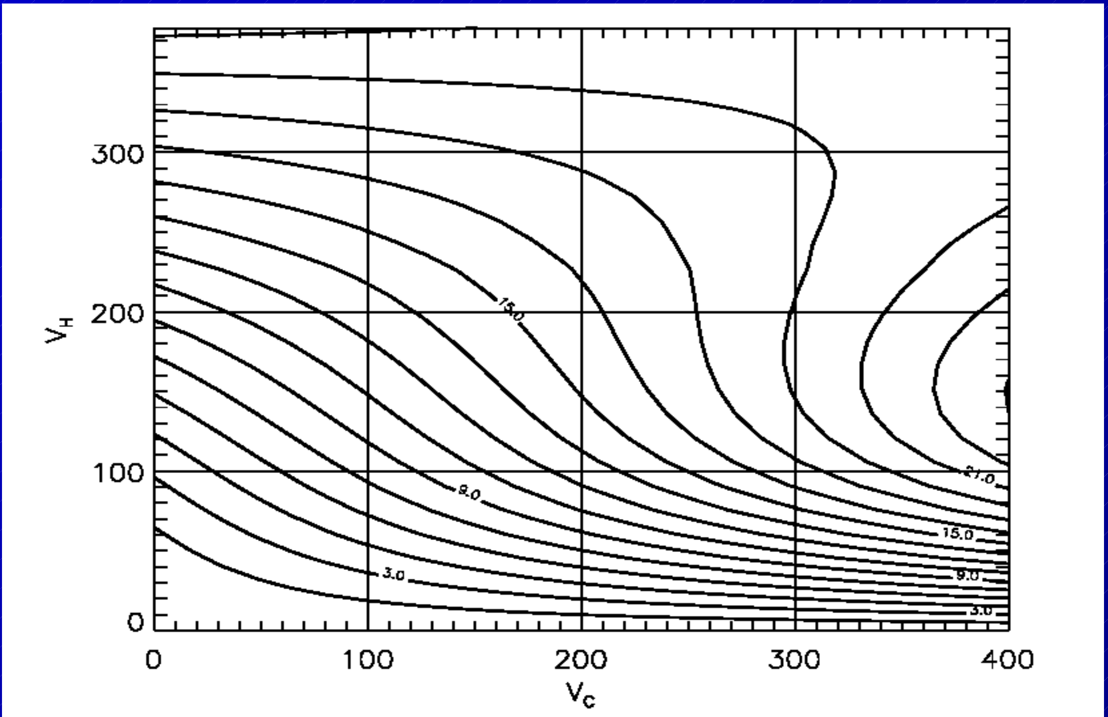
Self-excitation if

$$C_\alpha = \frac{\alpha_\perp R}{\eta} = F(V_C, V_H)$$

exceeds a critical value.

V_C volumetric flow rate through central channel

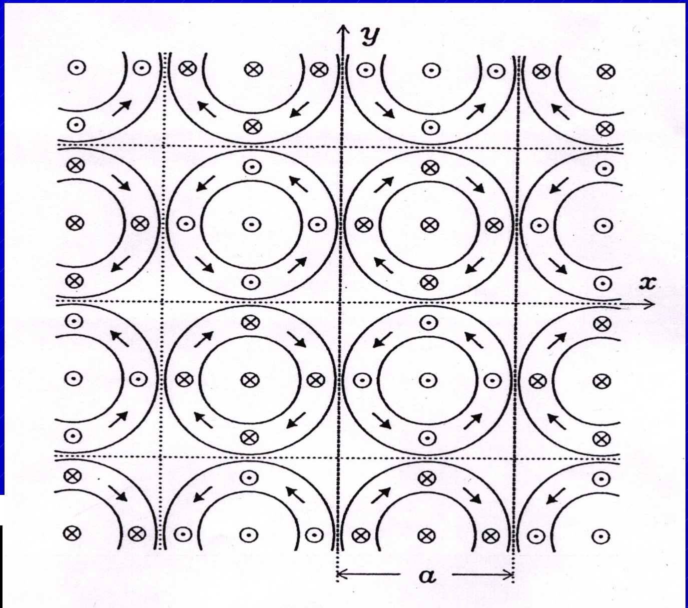
V_H ... through helical channel of a spin generator

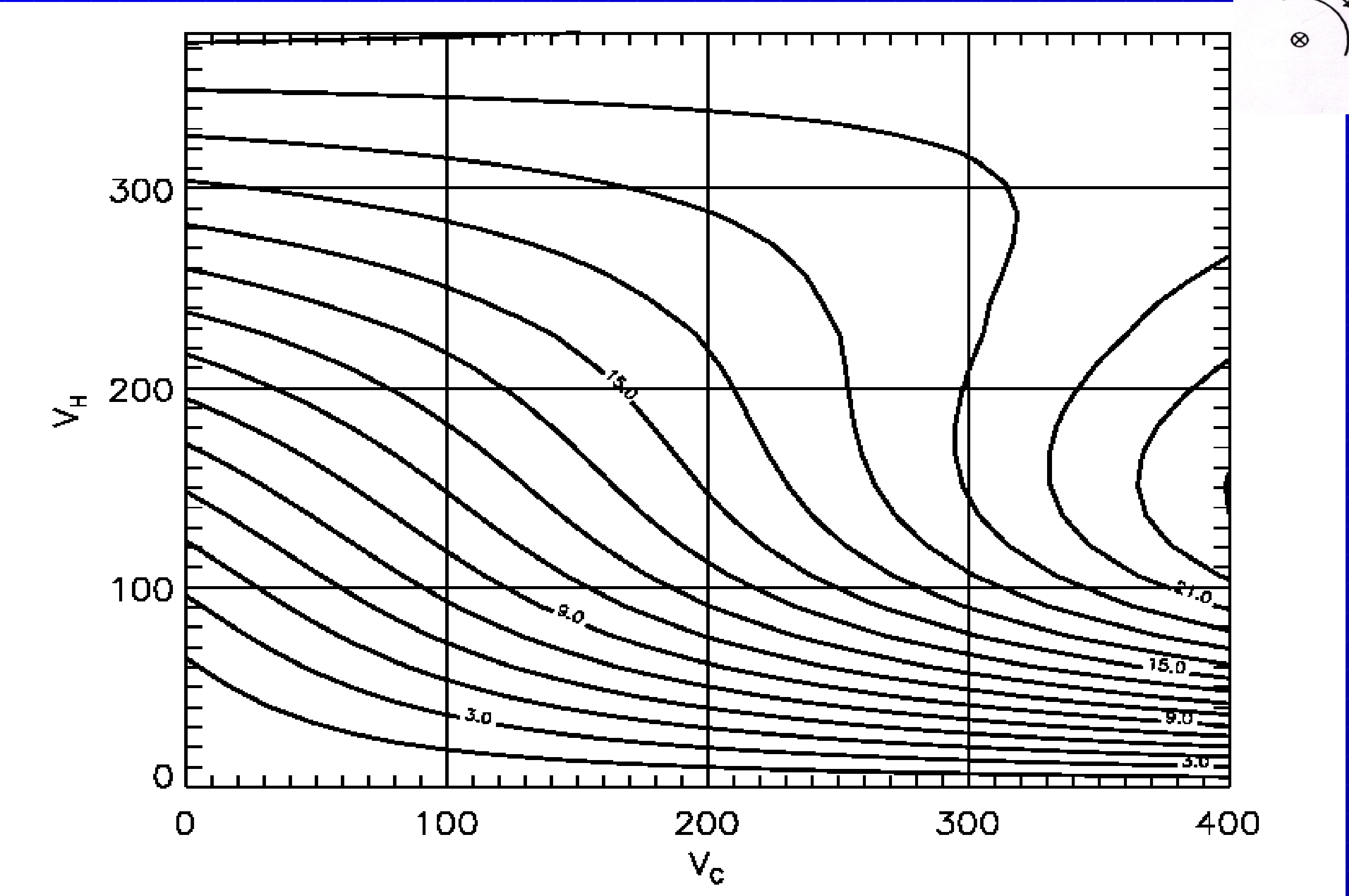


Isolines of $C\alpha$

Karlsruhe dynamo experiment

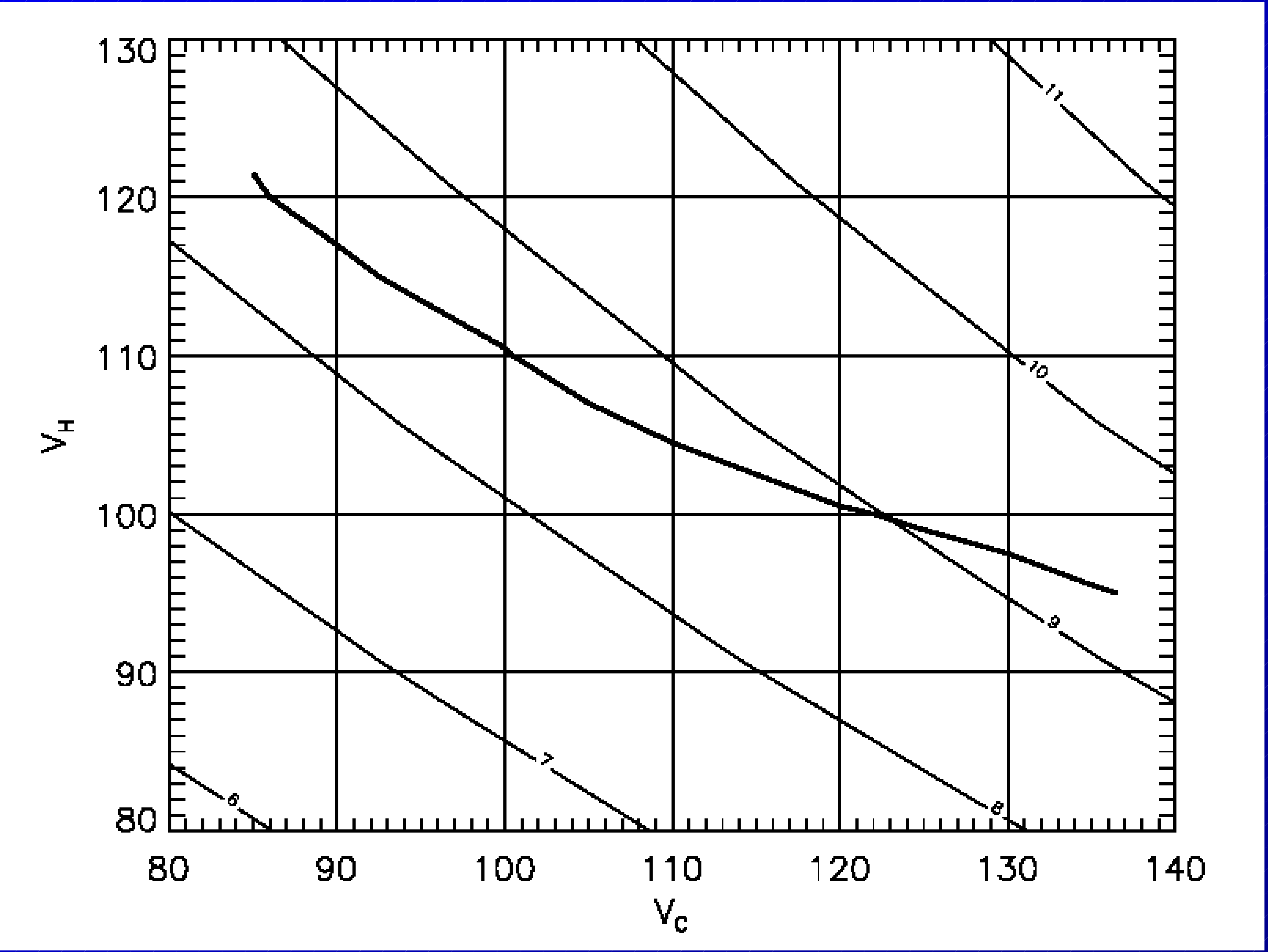
Spingenerator flow





Isolines of $C\alpha$

Karlsruhe dynamo experiment



Karlsruhe dynamo experiment

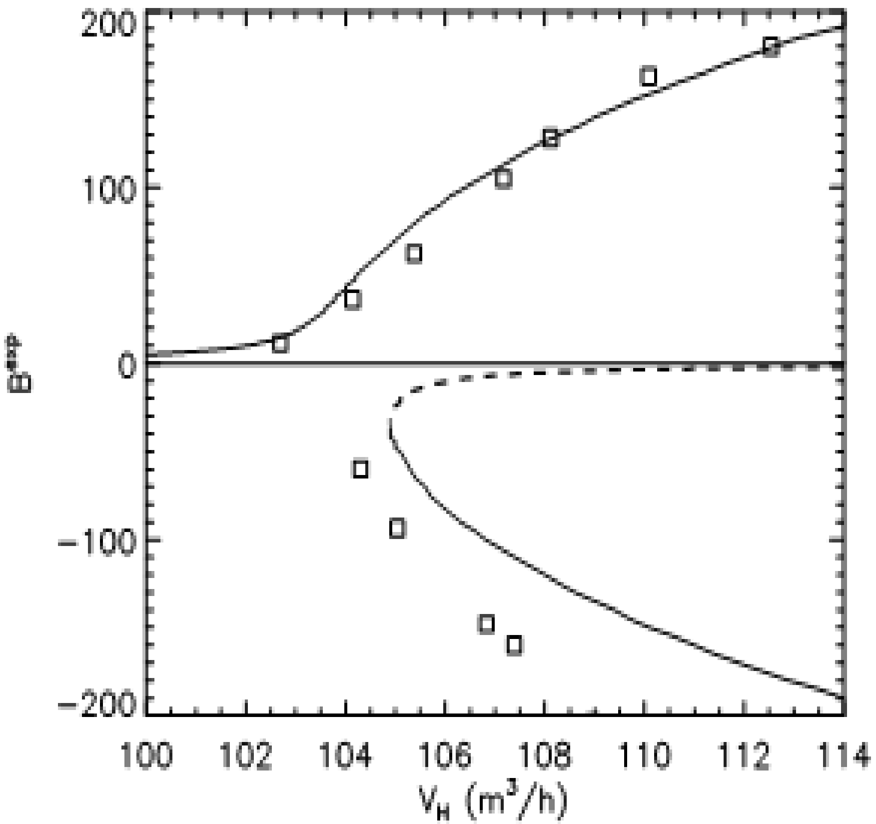
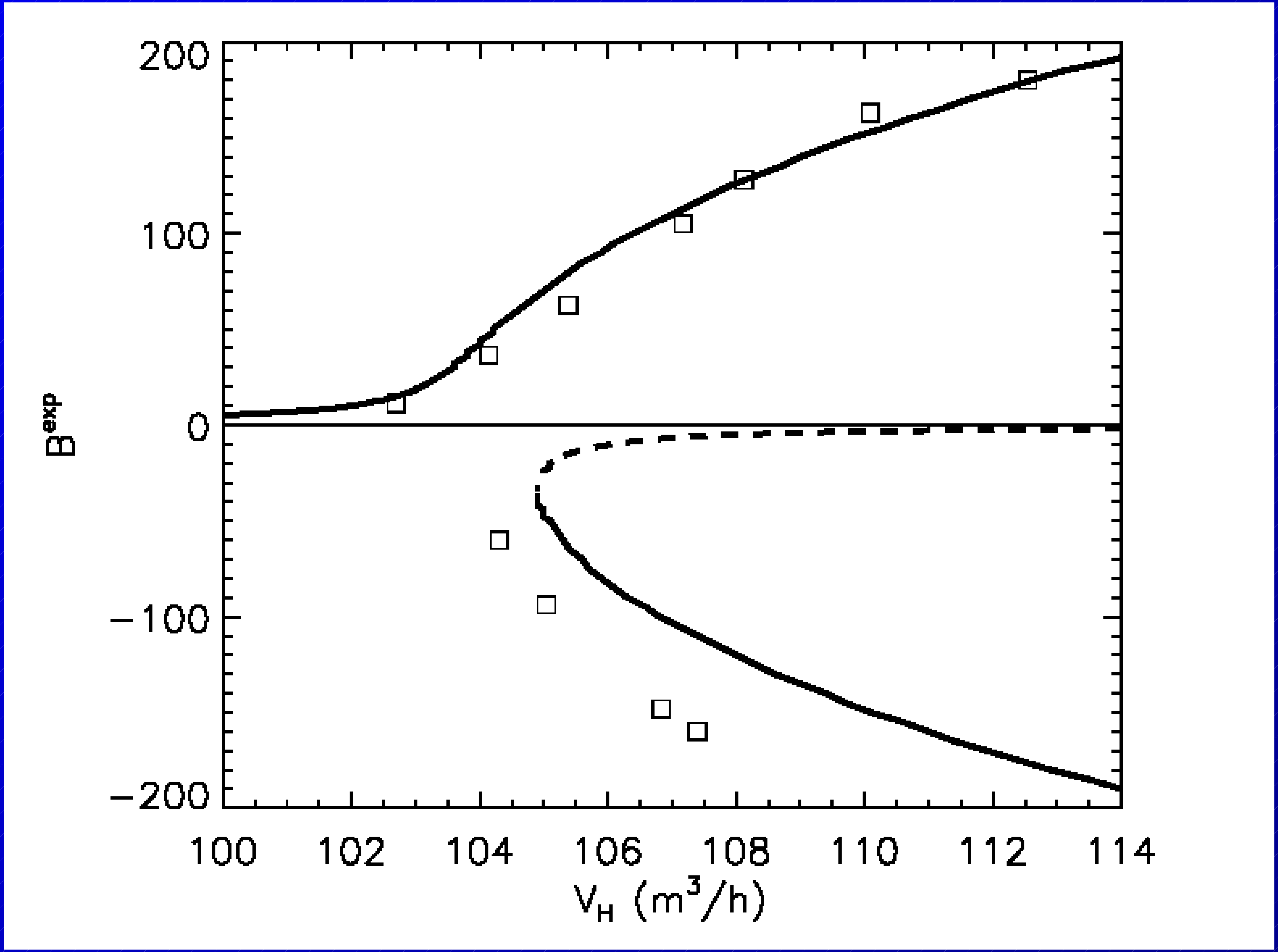


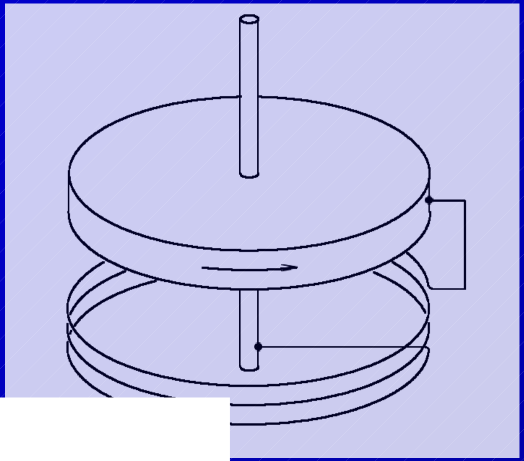
Fig. 8. A bifurcation diagram (solid and dashed lines, used as in Fig. 5) for B^{exp} with $C^* = 9.189$, $V_C = 112.5\,\mathrm{m^3/h}$, $B_c = 0.285$ G and $\epsilon' = 1.47 \times 10^{-7}$ that reproduces in some approximation a set of measured data (squares).

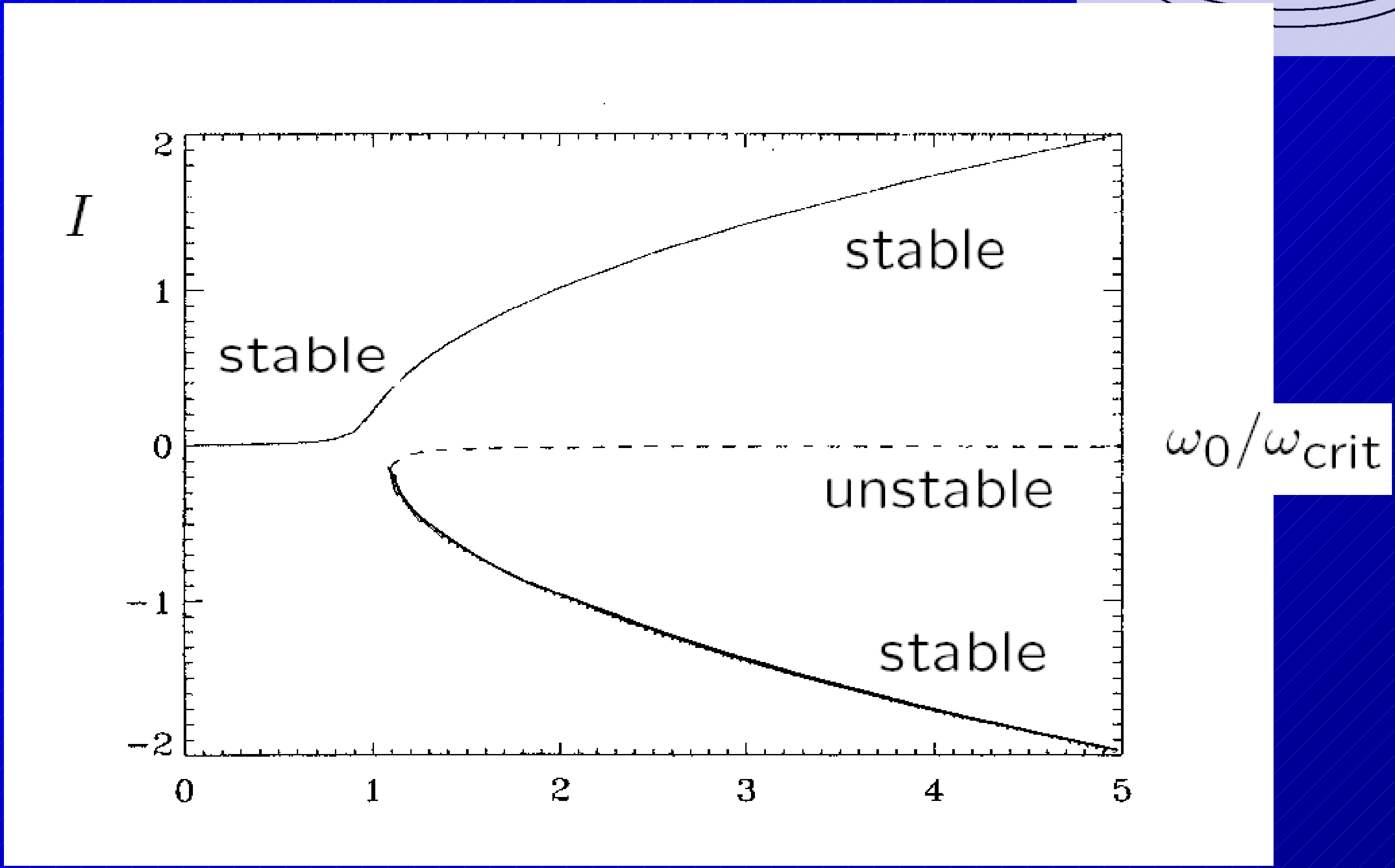
Karlsruhe dynamo experiment



Disc dynamo

Back-reaction
of the magnetic field
plus imposed magnetic field





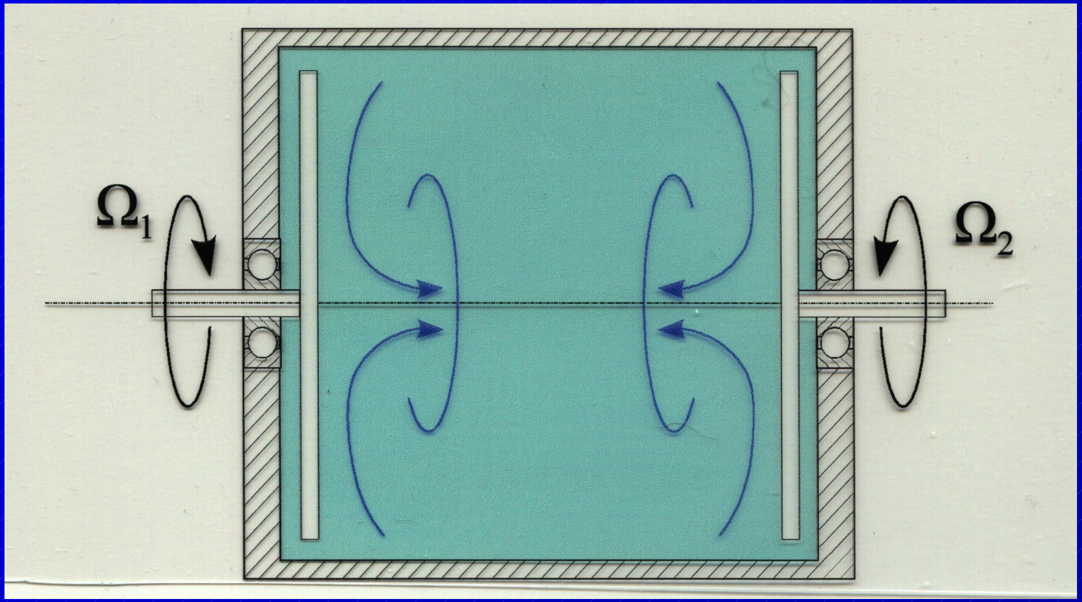
Karlsruhe dynamo experiment

The saturation of the dynamo
is accompanied by developing a piston-like flow profile.

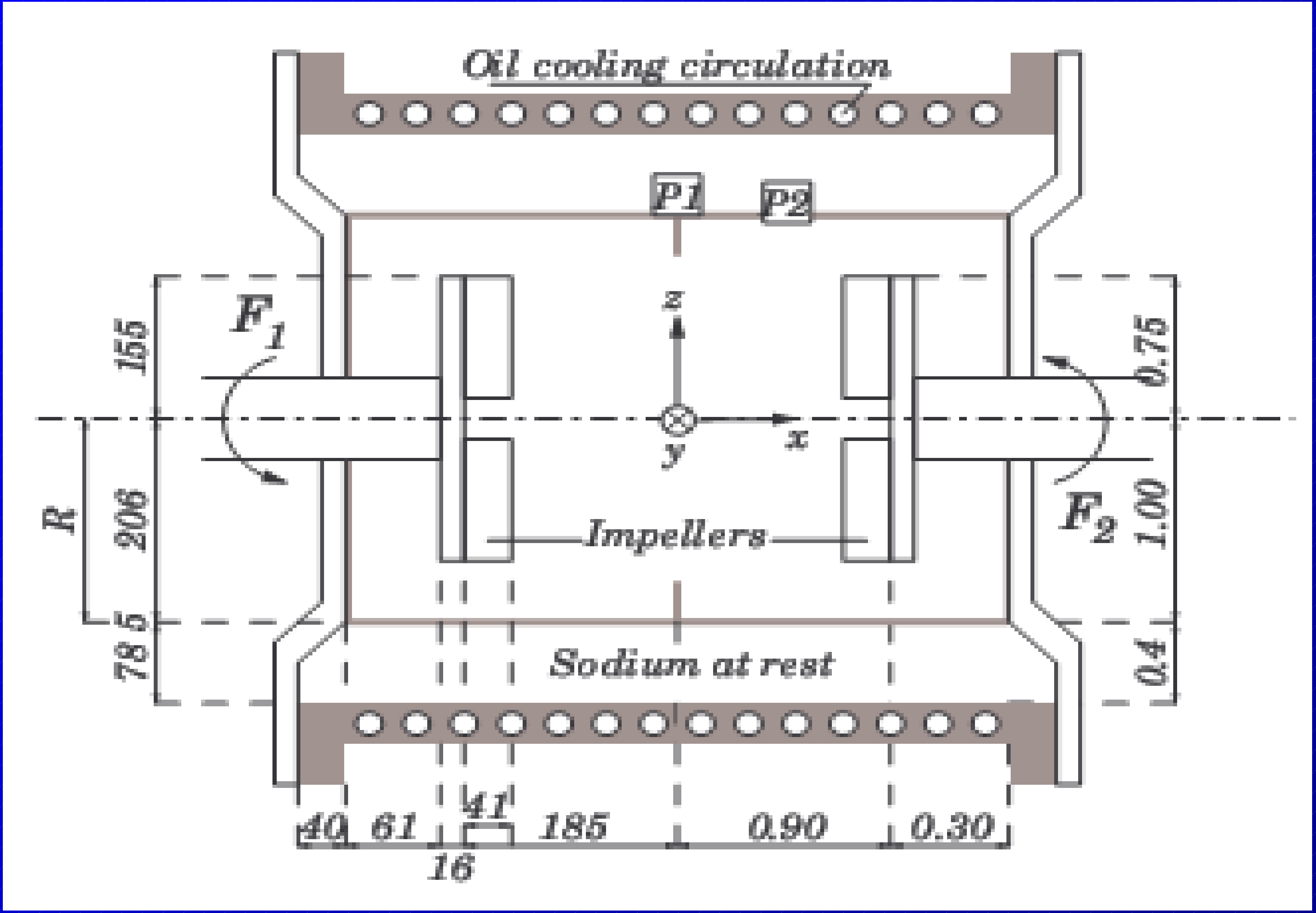
The temperature dependence of the excitation condition
is mainly due to the temperature dependence
of the electric conductivity.

The onset of dynamo action is shifted to lower mean axial flow rates
if this flow varies periodically in time
with periods of the order of the magnetic diffusion time.

The Cadarache (VKS) dynamo experiment



Pinton et al.



Oil cooling circulation
P1
P2
z
x
y
F1
F2
155
206
78.5
R
0.75
1.00
0.4
Impellers
Sodium at rest
40
61
41
185
0.90
0.30
16

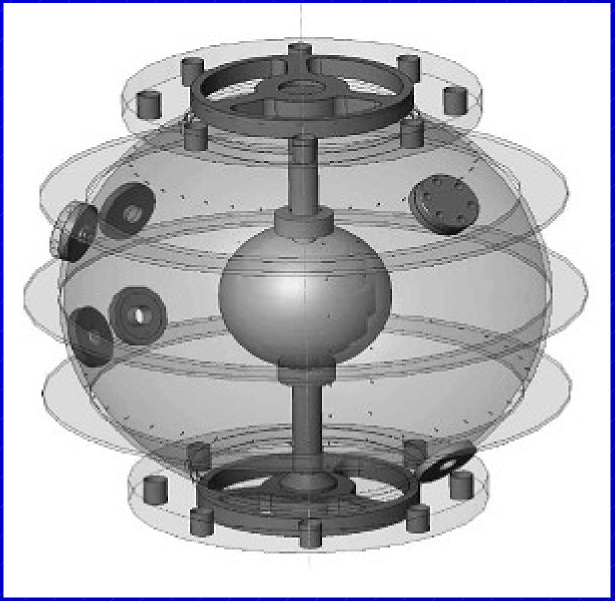
Experiments under preparation

- Grenoble
- Paris
- Madison
- Maryland
- New-Mexico
- Perm

Experiments under preparation

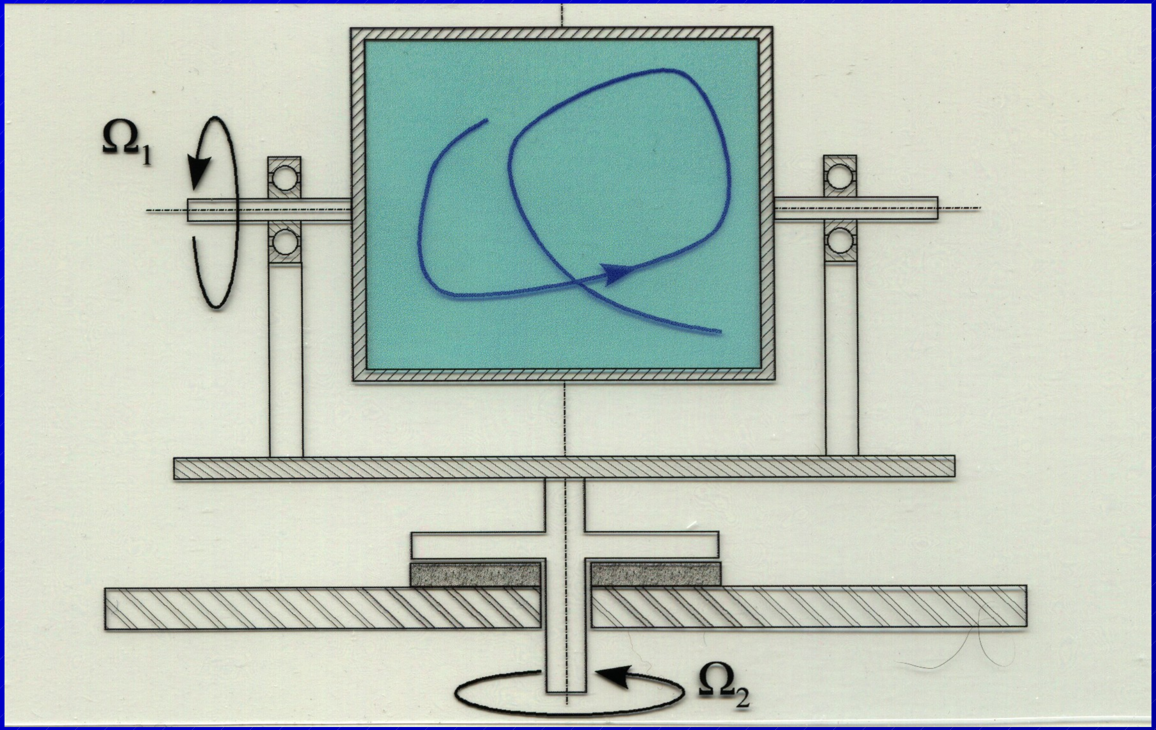
- Grenoble --- Magnetostrophic motions in a differentially rotating spherical shell under the influence of an imposed magnetic field

  Nataf, Schaeffer, ...
- Paris
- Madison
- Maryland
- New-Mexico
- Perm



Experiments under preparation

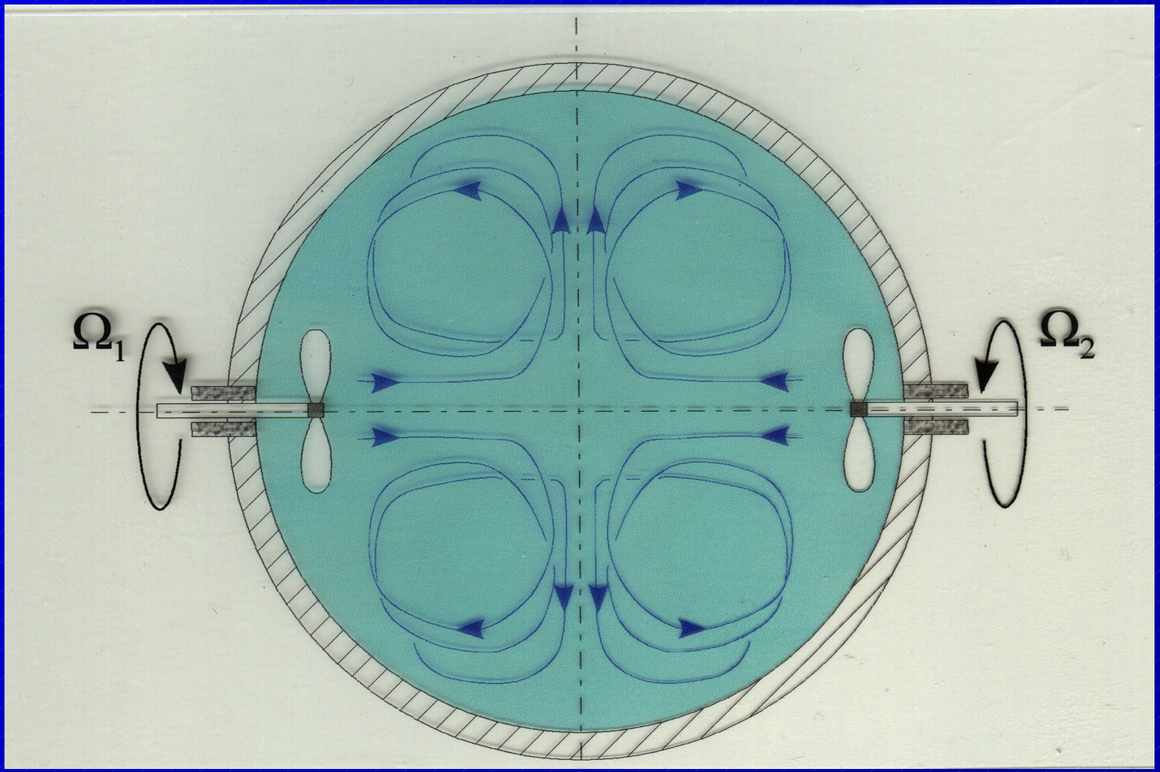
- Grenoble
- Paris -----------
- Madison
- Maryland
- New-Mexico
- Perm



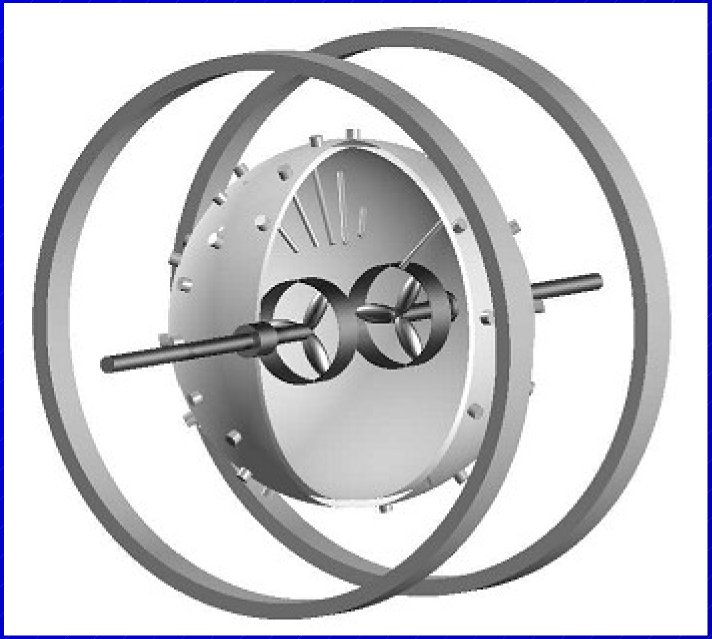
Leorat et al.

Experiments under preparation

- Grenoble
- Paris
- Madison ---------
- Maryland
- New-Mexico
- Perm

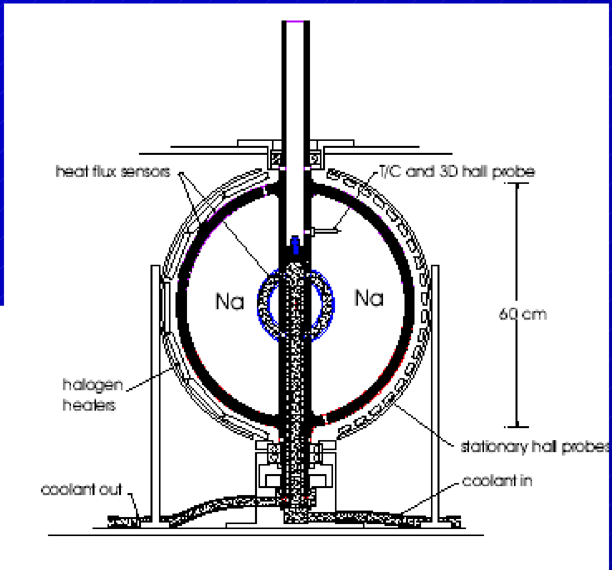


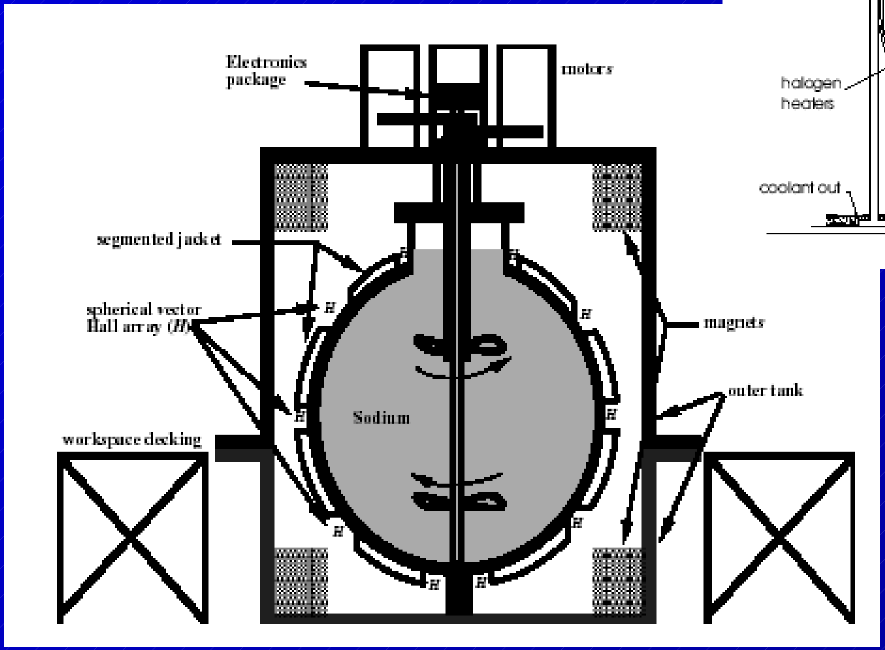
Forest, ...



Experiments under preparation

- Grenoble
- Paris
- Madison
- Maryland ---
- New-Mexico
- Perm

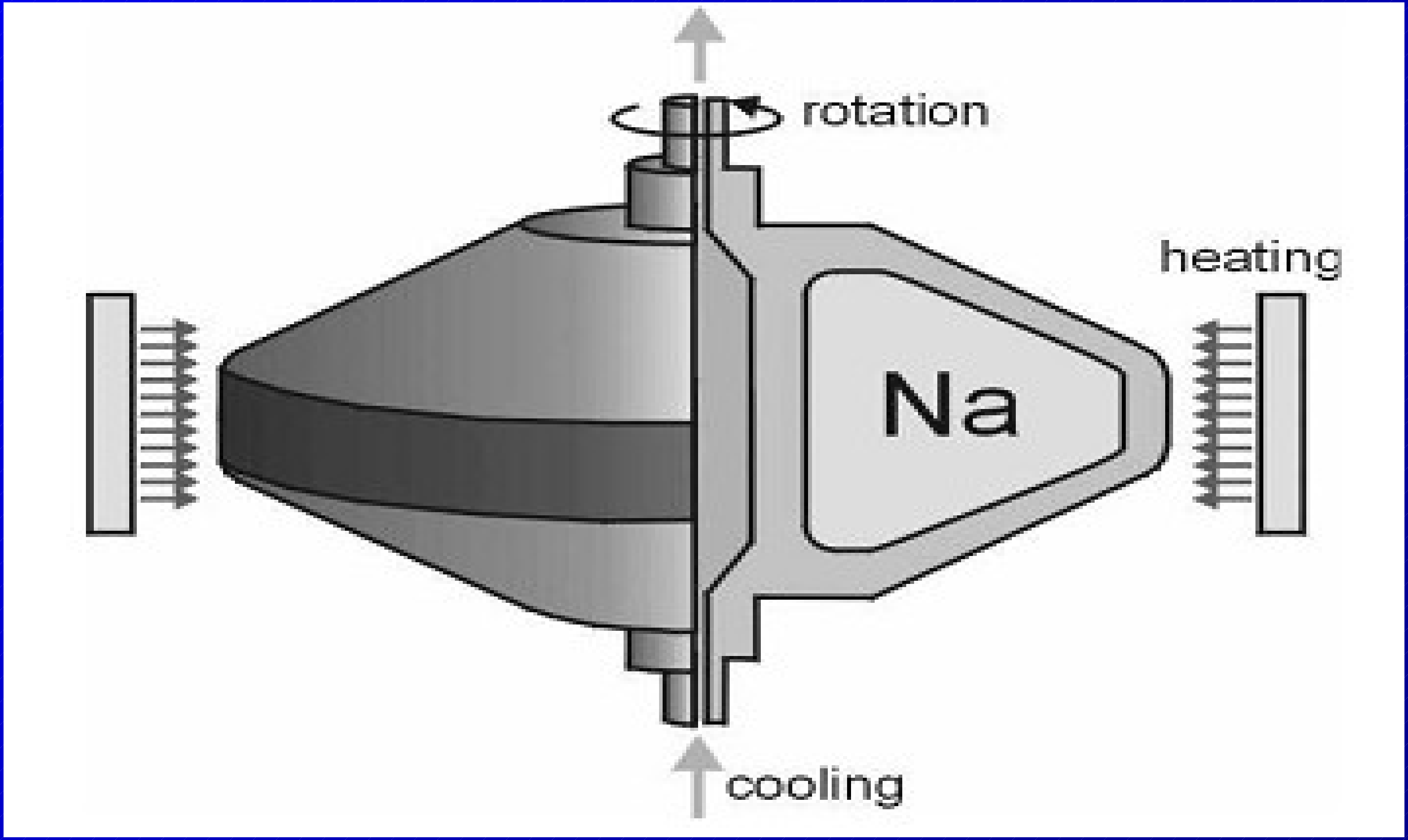




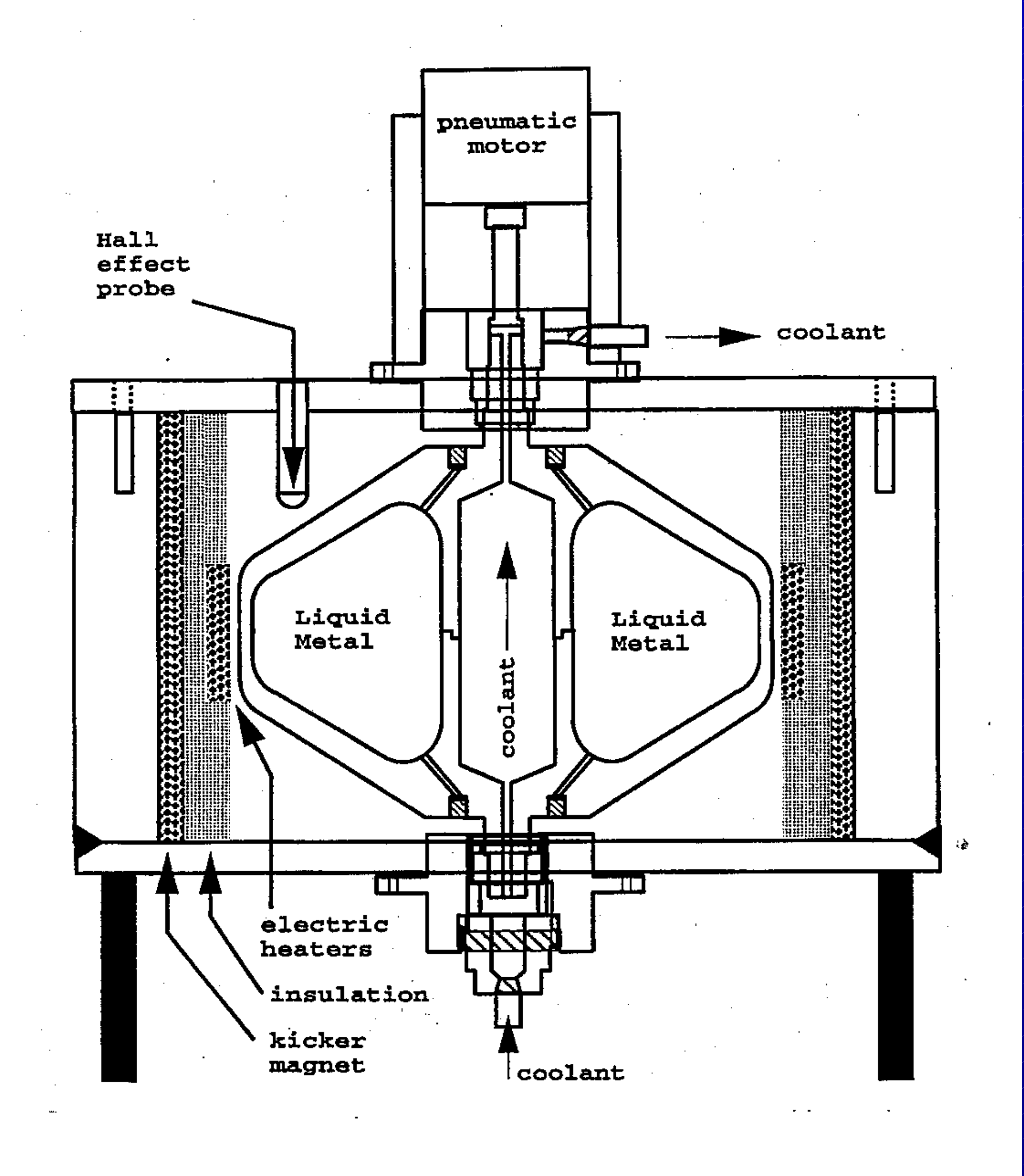
Lathrop, ...

First Maryland experiment

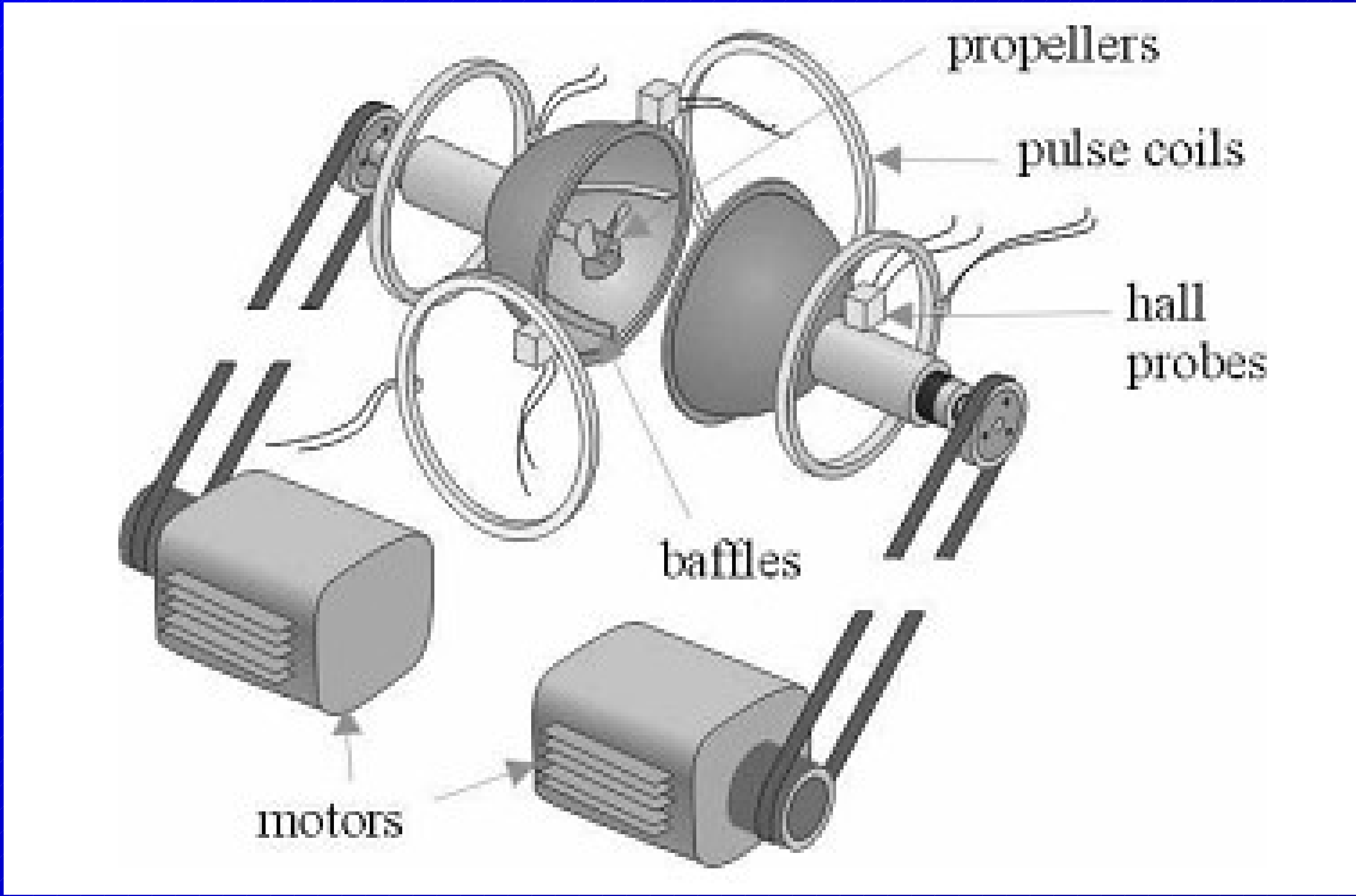
Lathrop and coworkers 2000



Lathrop and coworkers
2000



Maryland

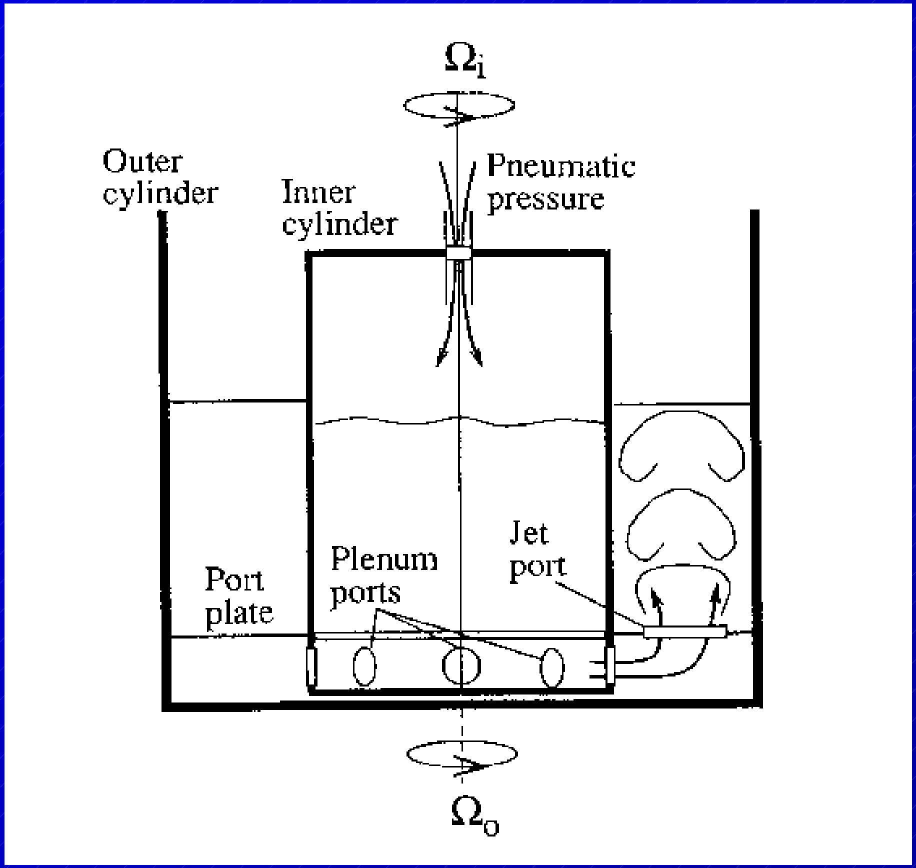


Maryland

3 m diameter sphere

Experiments under preparation

- Grenoble
- Madison
- Maryland
- New-Mexico -------
- Perm

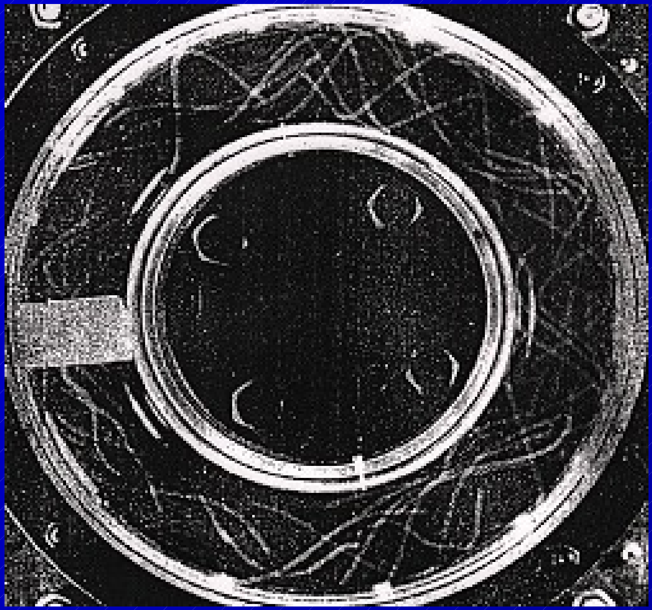


$\alpha\omega$ dynamo similar to such in astrophysical objects

Colgate, ...

Experiments under preparation

- Grenoble
- Madison
- Maryland
- New-Mexico
- Perm ------------------------------



non-stationary dynamo

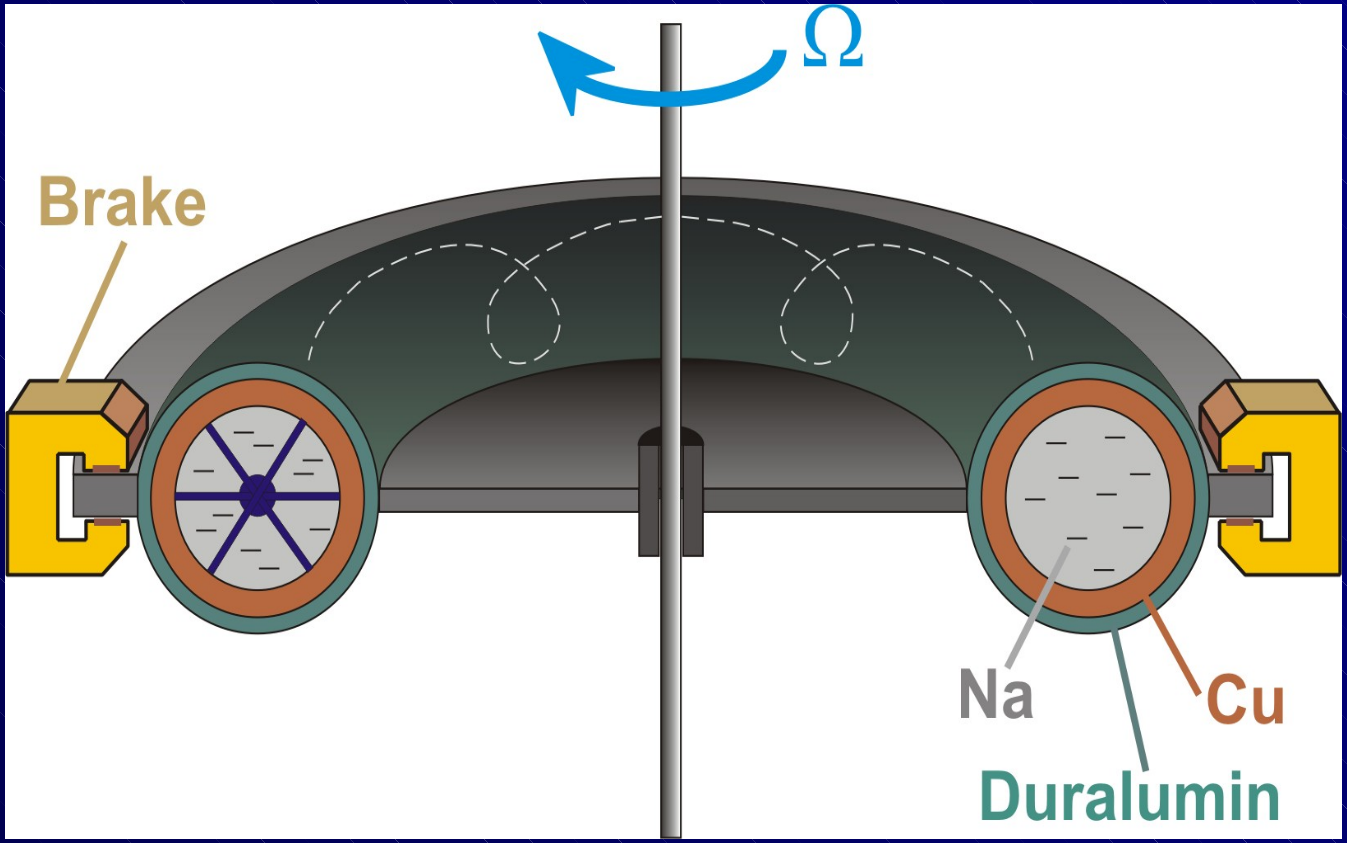
Frick et al.

The Perm dynamo experiment

(under preparation)

Proposed by Denisov, Noskov, Sokoloff, Frick, Khripchenko 1999

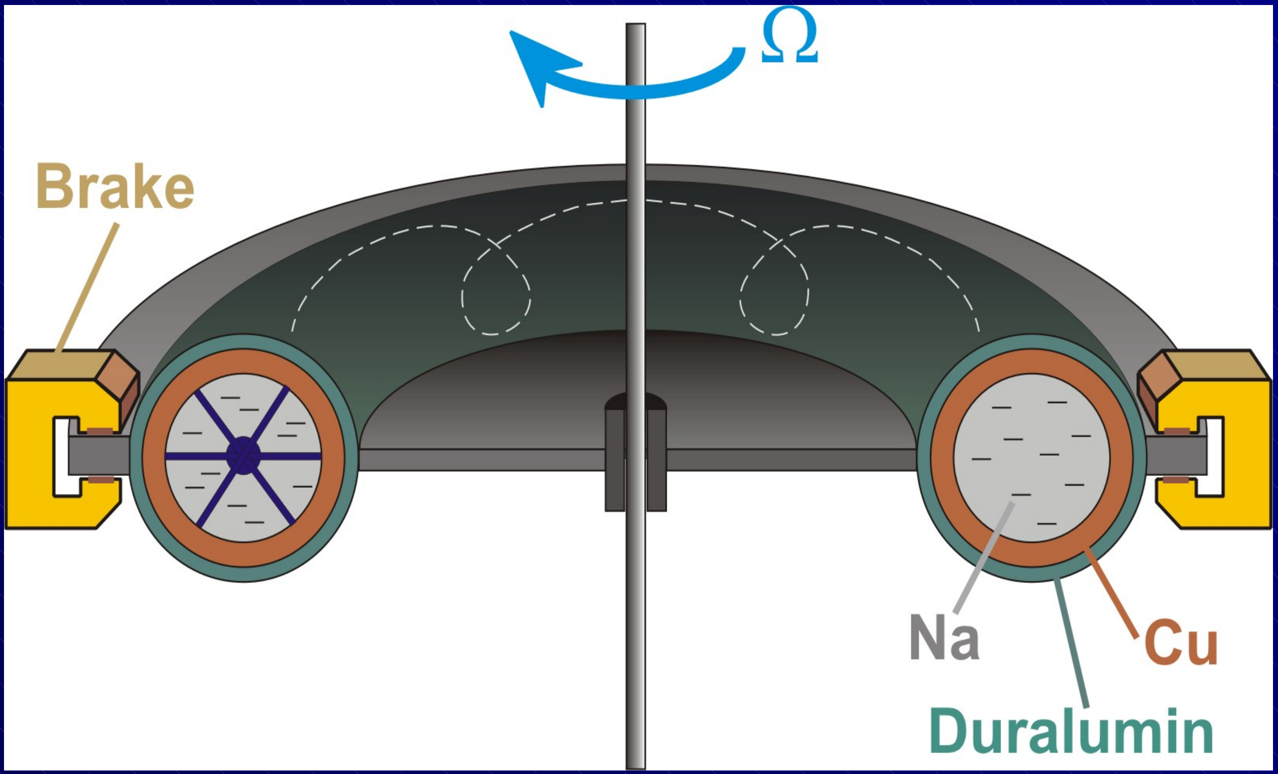
Background: Ponomarenko 1973



non-stationary dynamo

divertor

The Perm dynamo experiment



Large radius 0.40 m
small radius 0.12 m

115 kg Na
50 rps
140 m/s
braking time
0.1 s

Dynamo action if

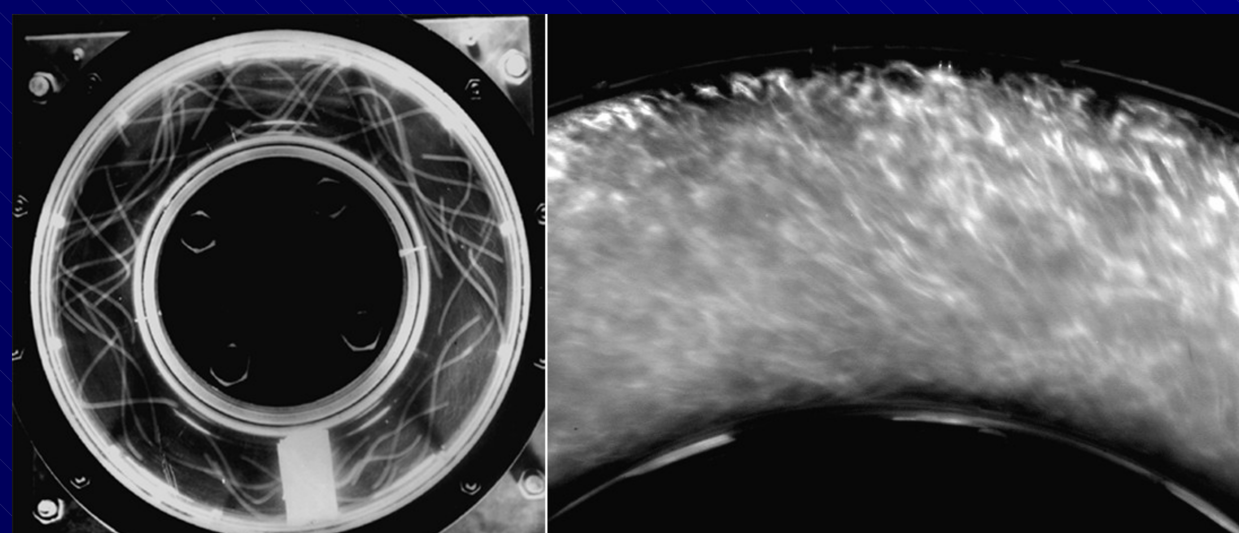
$$Rm > 40$$

$$\longrightarrow \quad Re > 4 \cdot 10^6 \quad \longrightarrow \text{turbulence}$$

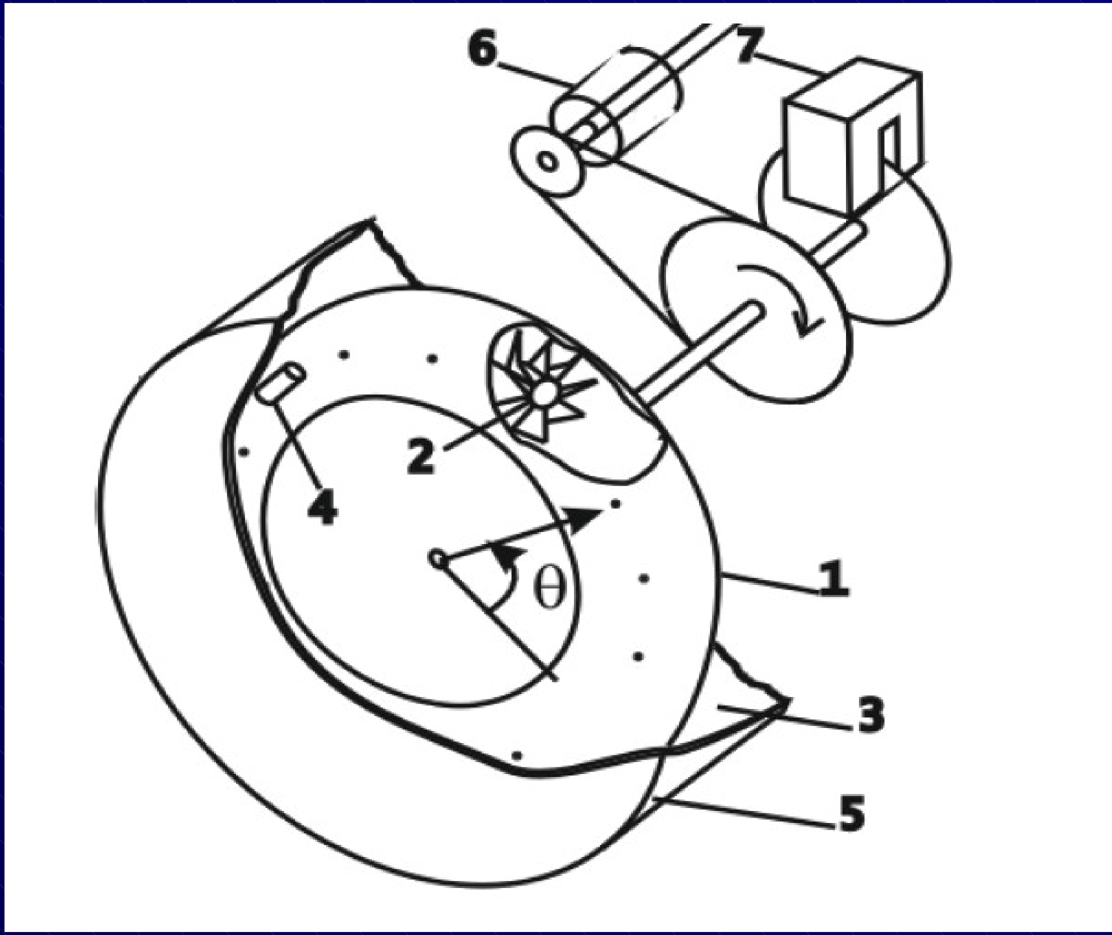
Water experiments

Large radii 0.103 m
and 0.154 m

Helical features
in large
and small scales



The gallium experiment



Large radius of the torus 88 mm
small radius 23 mm

Noskov, Denisov, Frick, Khripchenko, Sokoloff and Stepanov
Magnetic field rotation in the screw gallium flow
EPJ 2004

What did we learn from the experiments ?

- The dynamo is a robust phenomenon
- The kinematic dynamo theory describes the onset of dynamos well
- Mean-field theory of the Karlsruhe dynamo experiment works well
- In both the Riga and the Karlsruhe cases the dynamos saturate due to deformation of the flow profiles by the magnetic field. Turbulence plays a subordinate role.
- In other cases (in particular Cadarache und Madison) fluid motions on small scales seem to be important.

Which problems could be addressed by future experiments ?

- The role of smaller scales of motion in less constrained flows
- Saturation mechanisms
- Dynamos due to magneto-rotational instability
- Reversals of magnetic fields