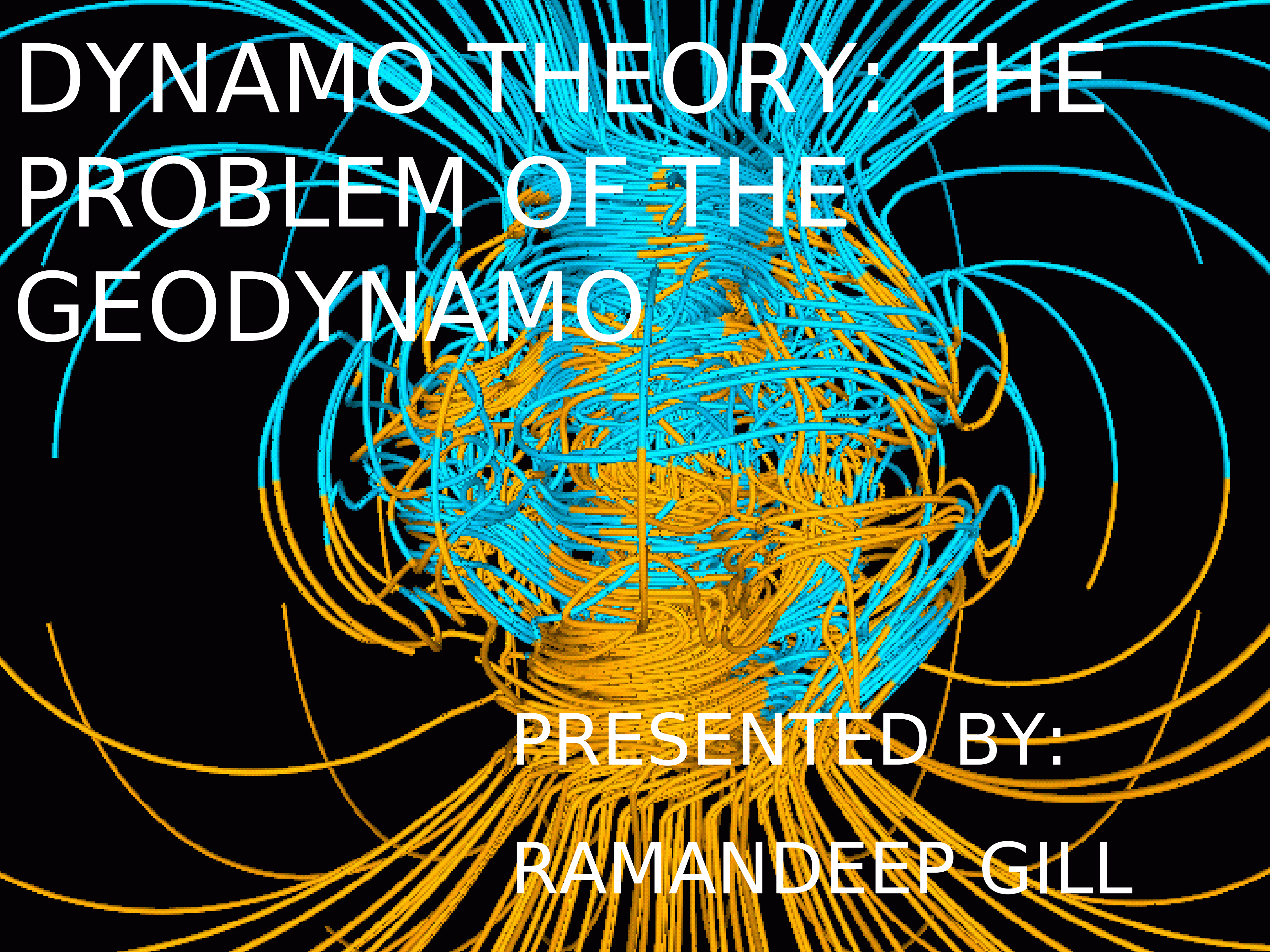


DYNAMO THEORY: THE PROBLEM OF THE GEODYNAMO

PRESENTED BY:

RAMANDEEP GILL

MAGNETIC FIELD OF THE EARTH

- DIPOLE Field Structure

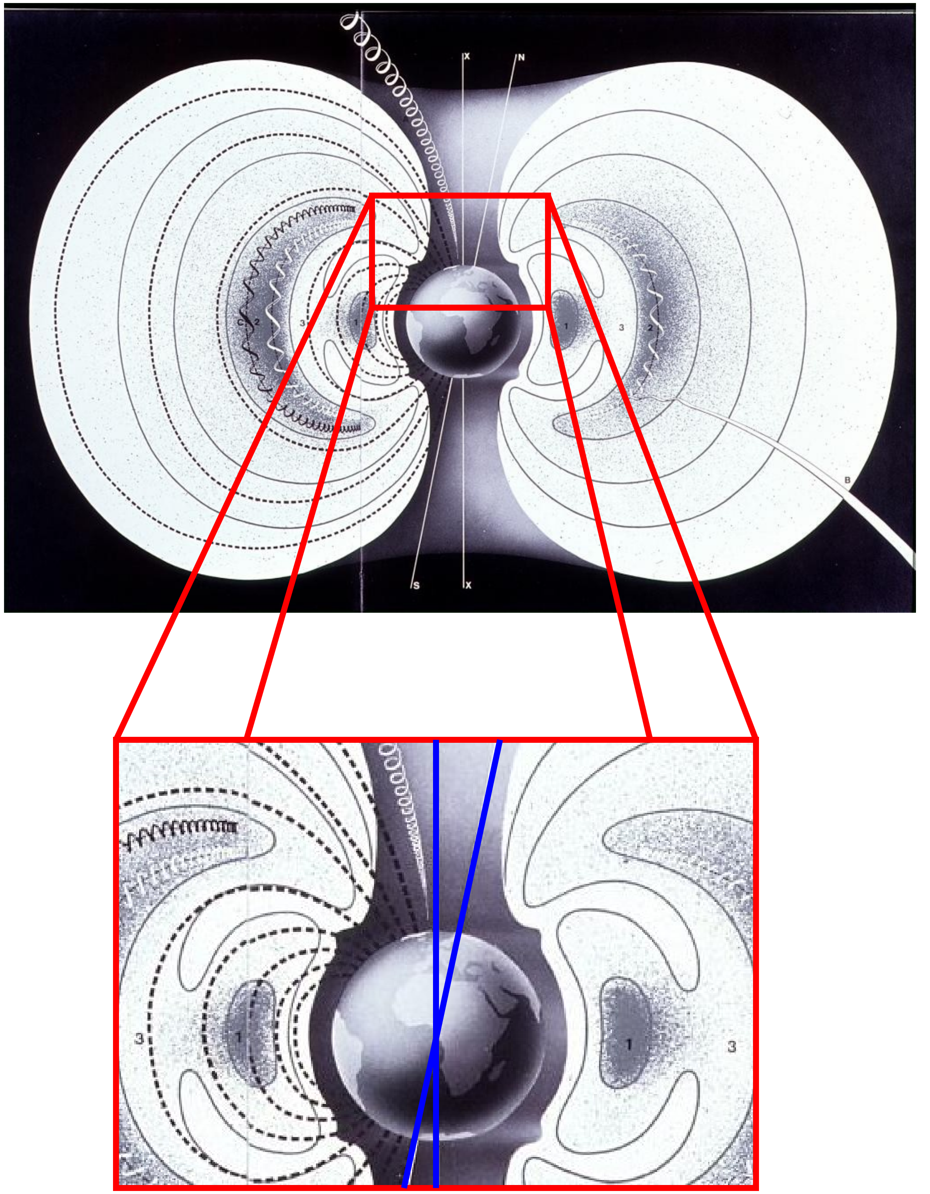
Permanent magnetization of Core ?

80% of field is dipole
20 % is non-dipole

---

2) FIELD AXIS not aligned with rotation axis

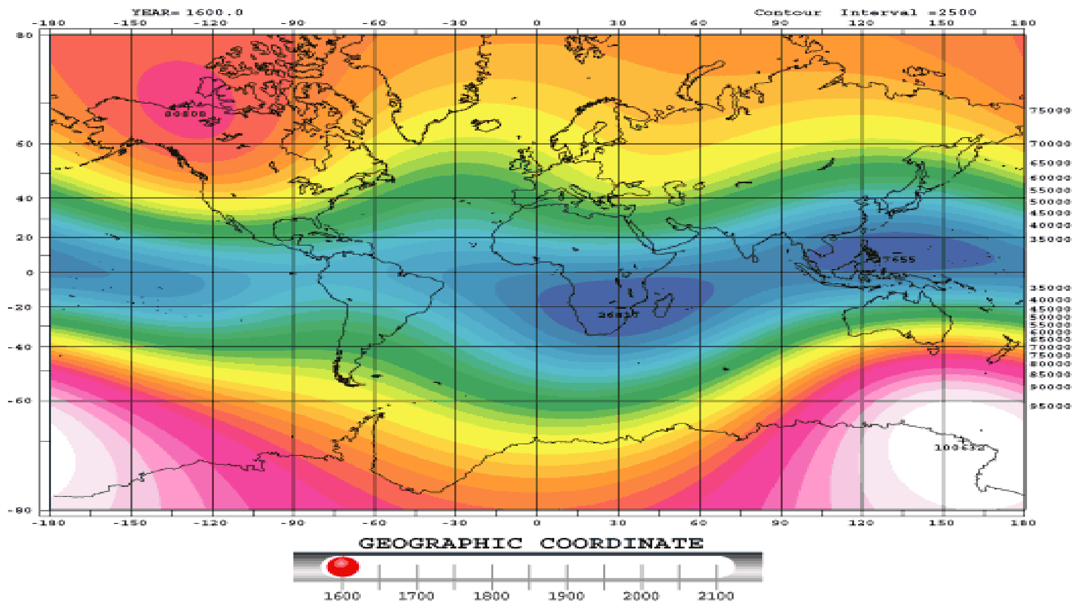
Pole separation } $\theta = 11^{\circ}$



MAGNETIC FIELD OF THE EARTH

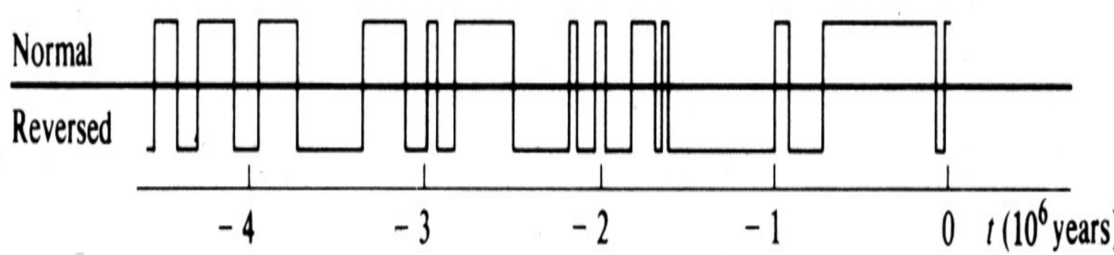
3) SECULAR VARIATION

Magnetic field does not have the same intensity at all places at all times



4) FIELD POLARITY REVERSAL

Field polarity reverses every 250,000 yrs. It has been 780,000 yrs. until the last reversal.



Is another reversal happening soon ? } Observations: 10% decrease in field intensity since 1830s

QUESTION STILL REMAINS

Is the permanent magnetization responsible for Earth's magnetic field ?

[NO]

From Statistical Mechanics we know:

Curie point temperature of most ferromagnets } $T_c \approx 1000K$

Core temperature of Earth } $T_{core} \approx 4200K$

At high temperatures ferromagnets lose their magnetization

DYNAMO THEORY

Branch of magnetohydrodynamics which deals with the self-excitation of magnetic fields in large rotating bodies comprised of electrically conducting fluids.

Earth's Core:

Inner Core:

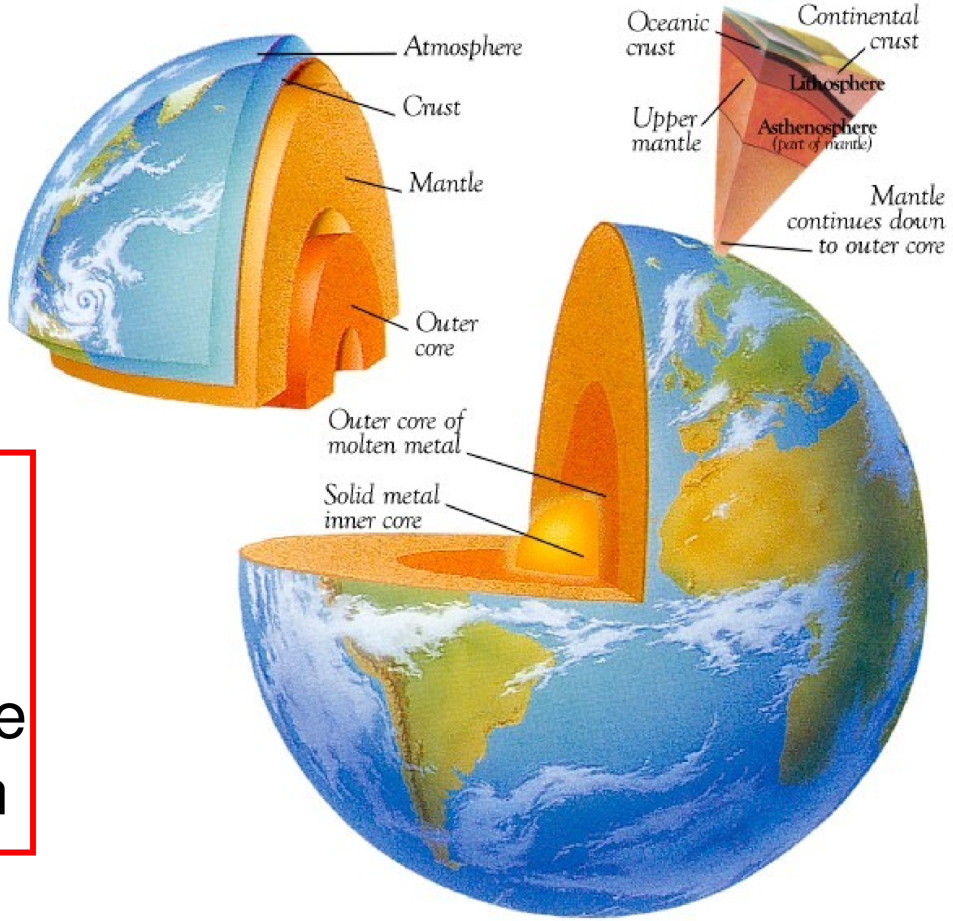
$$R_{Inner\ Core} \approx 0.19 R_{\oplus}$$

Iron & Nickel Alloy

Outer Core:

$$R_{Outer\ Core} \approx 0.55 R_{\oplus}$$

Molten Iron and admixture of silicon, sulphur, carbon



REQUIREMENTS FOR GEODYNAMO

1) CONDUCTING MEDIUM

Large amount of molten iron in outer core: comparable to 6 times the volume of the Moon

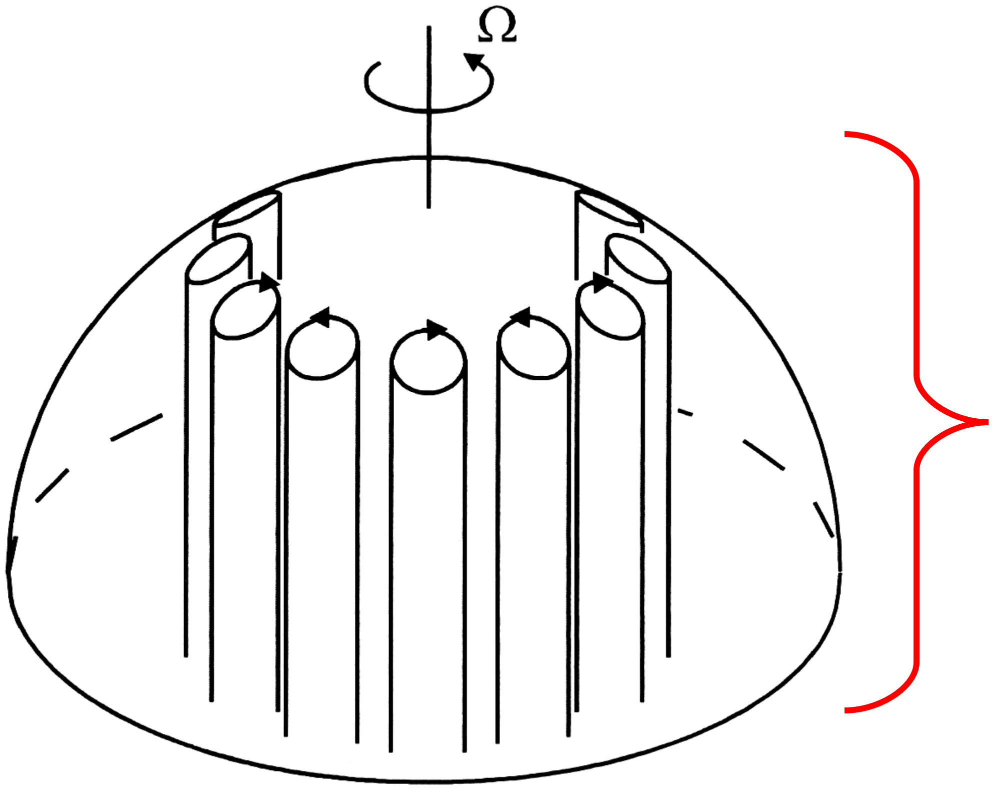
2) THERMAL CONVECTION

- Inner core is hotter than the mantle
- Temperature difference results in thermal convection.
- Blobs of conducting fluid in outer core rise to the mantle
- Mantle dissipate energy through thermal radiation
- Colder fluid falls down towards the centre of the Earth

REQUIREMENTS FOR GEODYNAMO

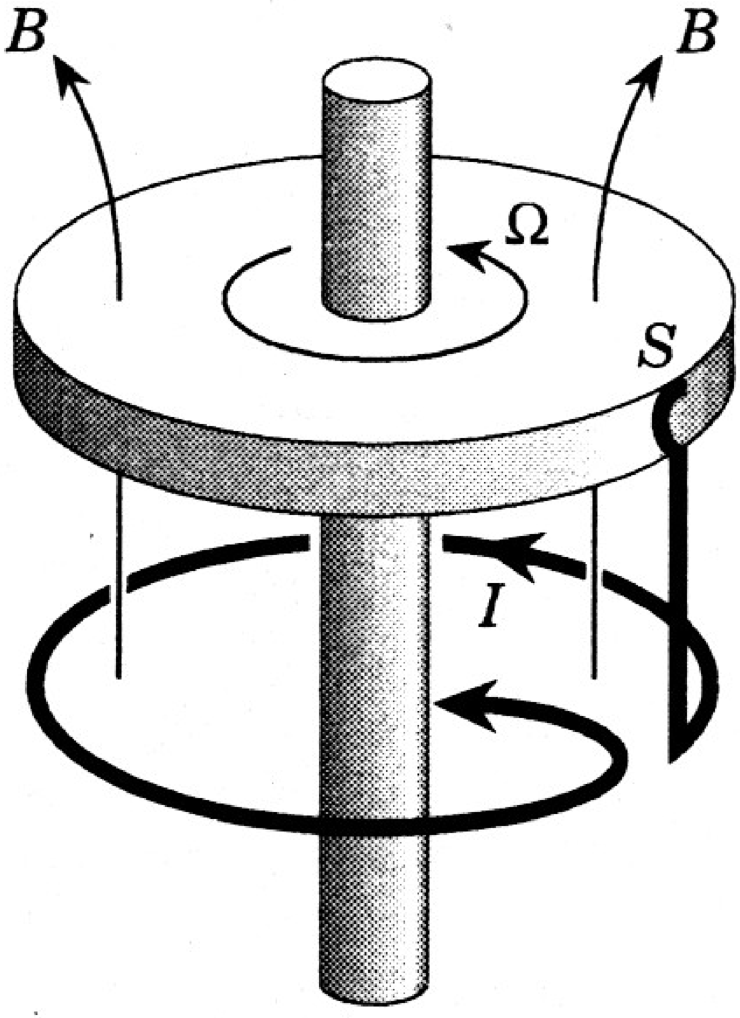
3) DIFFERENTIAL ROTATION

- Coriolis effect induced by the rotation of the Earth
- Forces conducting fluid to follow helical path



- Convection occurs in columns parallel to rotation axis
- These columns drift around rotation axis in time
- Result: Secular variation

HOMOPOLAR DISC DYNAMO



SETUP

- A conducting disc rotates about its axis with angular velocity $\mathbf{\Omega}$
- Current $\vec{I}$ runs through a wire looped around the axis
- To complete the circuit, the wire is attached to the disc and the axle with sliding contacts S

HOMOPOLAR DISC DYNAMO

Initially, magnetic field is produced by the current in the wire

$$\vec{B} = \vec{B}\hat{z}$$

This induces a Lorentz force on the disc and generates an Emf

$$\vec{f}_{mag} = \vec{u} \times \vec{B}$$

$$\Rightarrow \varepsilon = \int (\vec{u} \times \vec{B}) \cdot d\vec{r}; \qquad \vec{u} = \Omega r \hat{\phi}$$

$$= \frac{\Omega}{2\pi} \int \vec{B} \cdot d\vec{a}$$

$$= \frac{\Omega \Phi}{2\pi}$$

HOMOPOLAR DISC DYNAMO

Main equation describing the whole setup is:

$$\varepsilon = \frac{M\Omega I}{2\pi} = L\frac{dI}{dt} + RI$$

$$0 = \frac{dI}{dt} + \frac{1}{L}\left(R - \frac{M\Omega}{2\pi}\right)I$$

$$I(t) = I_o \exp\left[-\frac{t}{L}\left(R - \frac{M\Omega}{2\pi}\right)\right]$$

L = Self inductance of wire

M = Mutual inductance of Disc

R = Resistance of wire

System is unstable when $\Omega > \frac{2\pi R}{M}$ since the current increases exponentially

Disc slows down to critical frequency: $\Omega_c = \frac{2\pi R}{M}$

MATHEMATICAL FRAMEWORK

Most important equation in dynamo theory:

MAGNETIC INDUCTION EQUATION

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{u} \times \vec{B}) + \eta \nabla^2 \vec{B}$$

where η is the magnetic diffusivity

First term: $\nabla \times (\vec{u} \times \vec{B}) \Rightarrow$ Buildup or Breakdown of magnetic field (Magnetic field instability)

Second term: $\eta \nabla^2 \vec{B} \Rightarrow$ Rate of decay of magnetic field due to Ohmic dissipations

MATHEMATICAL FRAMEWORK

Quantitative measure of how well the dynamo action will hold up against dissipative effects is given by the Reynolds number

$$R_m \equiv \frac{\nabla \times (\vec{u} \times \vec{B})}{\eta \nabla^2 \vec{B}} \approx \frac{u_o L}{\eta}$$

where u_o is the velocity scale and L is the characteristic length scale of the velocity field

For any dynamo action $R_m > 1$

Otherwise, the decay term would dominate and the dynamo would not sustain

KINEMATIC DYNAMO MODEL

- Tests steady flow of the conducting fluid, with a given velocity field, for any magnetic instabilities.
- Ignores the back reaction effect of the magnetic field on the velocity field.
- Does not apply to geodynamo.
- Numerical simulations of this model prove important for the understanding of MHD equations.

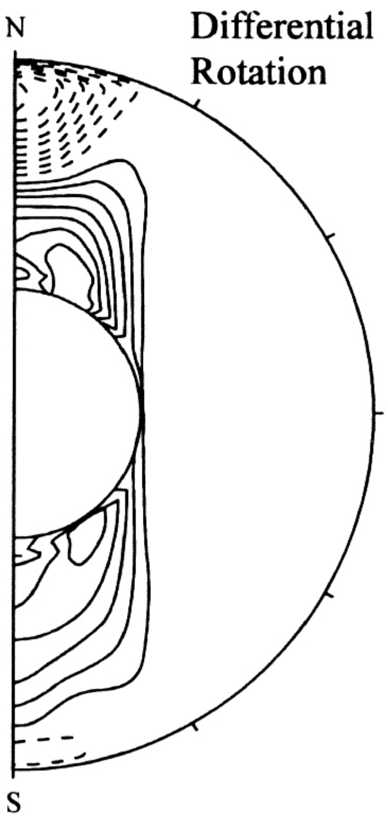
Important Aspects:

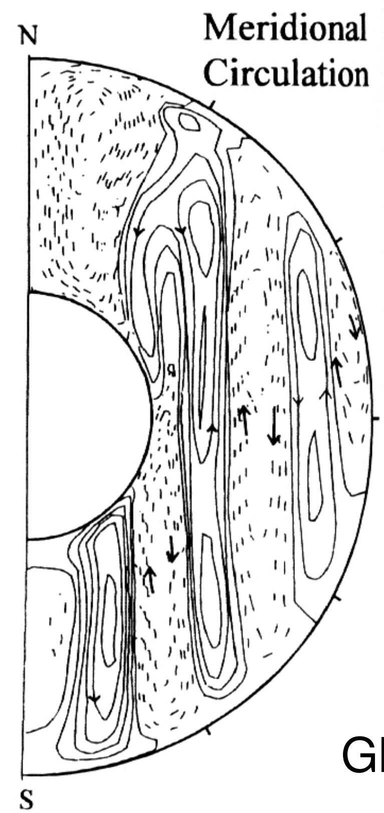
1) Differential Rotation
2) Meridional Circulation

KINEMATIC DYNAMO MODEL

Differential Rotation: Promotes large-scale axisymmetric toroidal fields

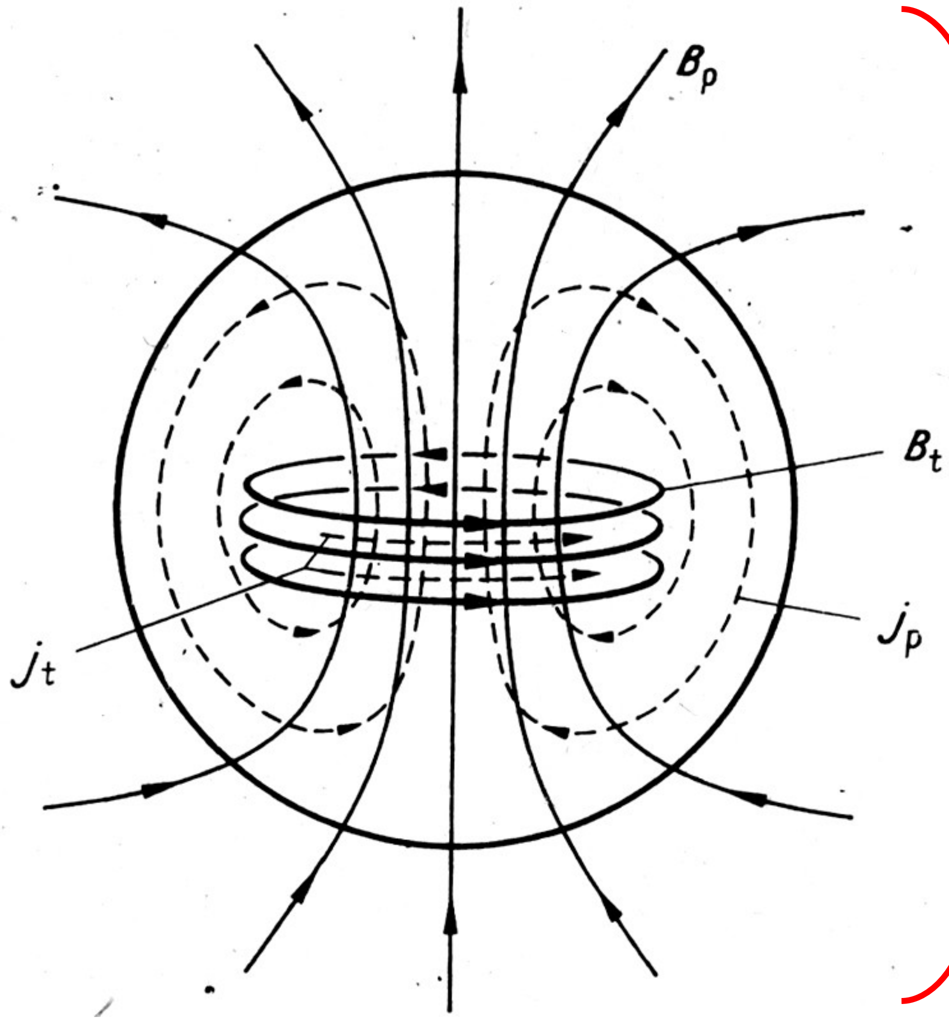
Meridional Circulation: Generates large-scale axisymmetric poloidal fields





Glatzmaier & Roberts

TURBULENT DYNAMO MODEL



- Correlation length scale of velocity field is very small
- Based on mean field magnetohydrodynamics
- Statistical average of fluctuating vector fields is used to compute magnetic field instabilities.

$$B = \overline{B} + B', \quad u = \overline{u} + u'$$

- Fluctuating fields have mean and residual components

PRESENT & FUTURE

Reverse flux patches along with magnetic field hot spots revealed by Magsat (1980) & Oersted (1999).

Supercomputer simulations are able to very closely model the Earth's magnetic field in 3D

Laboratory dynamo experiments have started to show some progress.

But there are LIMITATIONS !

Success in this field awaits advancements in satellite sensitivity, faster supercomputers, large scale models.


THANK YOU