JUAS
February 22nd 2016

# Introduction to MAGNETS I

Davide Tommasini

# *Content*

## Introduction to Magnets

## Fundamentals 1 : Maxwell

## Fundamentals 2 : Field Harmonics

# Organization of the Magnets Week

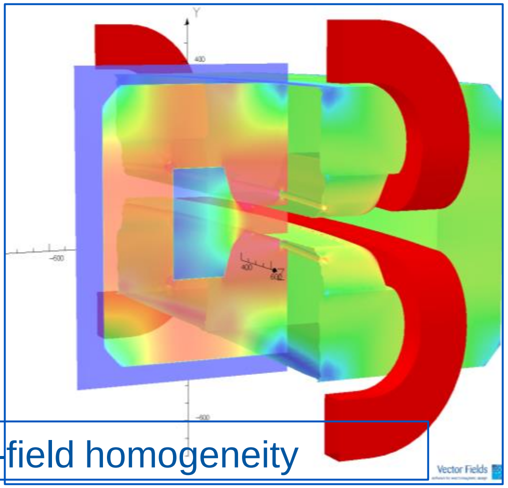
# WEEK 7

| Time | Monday Feb 22nd | Tuesday Feb 23rd | Wednesday Feb 24th | Thursday Feb 25th | Friday Feb 26th |
|---|---|---|---|---|---|
| 09:00 | **Introduction to Magnets I** lecture *D. Tommasini* | **Superconducting magnets** lecture - *M. Wilson* | **Mini-workshop Normal conducting Magnets** | *Bus leaves at 8:00 from JUAS* *(lunch at CERN)* **PRACTICAL WORKS AT CERN** RF coordinator: **F. Caspers** VACUUM coordinator: **P. Chiggiato** MAGNETS coordinator: **J. Bauché** SUPERCONDUCTIVITY coordinator: **A. Ballarino** BEAM MEASUREMENTS coordinator: **W. Farabolini** | *Bus leaves at 8:00 from JUAS* *(lunch at CERN)* **PRACTICAL WORKS AT CERN** RF coordinator: **F. Caspers** VACUUM coordinator: **P. Chiggiato** MAGNETS coordinator: **J. Bauché** SUPERCONDUCTIVITY coordinator: **A. Ballarino** BEAM MEASUREMENTS coordinator: **W. Farabolini** *Bus leaves at 17:30 from CERN* |
| 09:45 | **Introduction to Magnets II** lecture *D. Tommasini* | | | | |
| 10:00 | | **Coffee Break** | **Coffee Break** | | |
| 10:15 | | **Superconducting magnets** lecture - *M. Wilson* | *J. Bauche* *T. Zickler* | | |
| 10:30 | **Coffee Break** | | | | |
| 10:45 | **Normal Conducting magnets** lecture *T. Zickler* | | | | |
| 11:15 | | **Superconducting magnets** lecture - *M. Wilson* | | | |
| 12:15 | **LUNCH** | **LUNCH** | **LUNCH** | | |
| 14:00 | **Superconducting magnets** lecture - *M. Wilson* | **Superconducting magnets** lecture - *M. Wilson* | **Mini-workshop Superconducting Magnets** *P. Lebrun* *D. Schoerling* | | |
| 15:00 | **Superconducting magnets** lecture - *M. Wilson* | **Normal Conducting magnets** lecture - *T. Zickler* | | | |
| 16:00 | **Coffee Break** | **Coffee Break** | **Coffee Break** | | |
| 16:15 | **Normal Conducting magnets** lecture - *T. Zickler* | **Normal Conducting magnets** lecture - *T. Zickler* | *M. Wilson* | | |
| 17:15 | **Normal Conducting magnets** lecture - *T. Zickler* | **Normal Conducting magnets** lecture - *T. Zickler* | | **Visit CTF3 complex** *Bus leaves at 19:30 from CERN* | |
| 18:15 | | | | | |

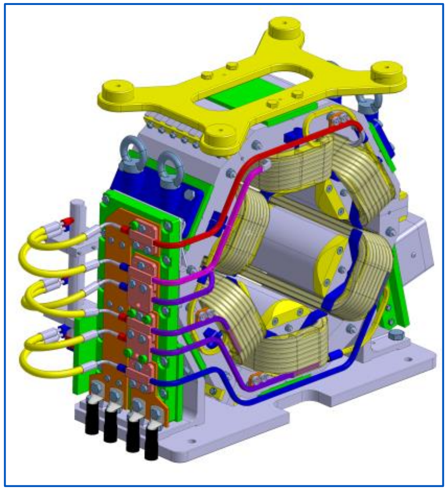
# Normal-conducting accelerator magnets

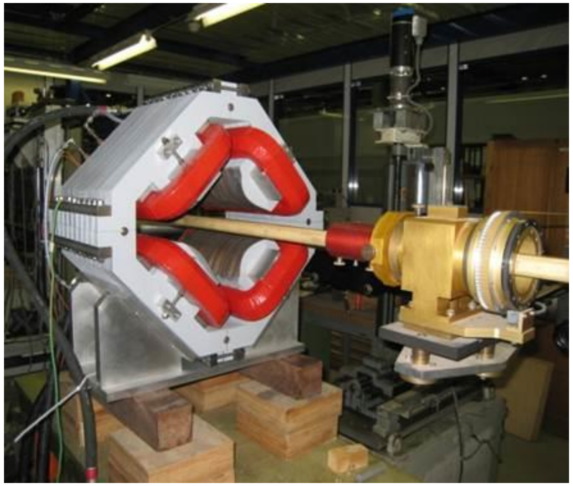
*Thomas Zickler*

How to design an accelerator magnet, with “real” examples



3D-field homogeneity



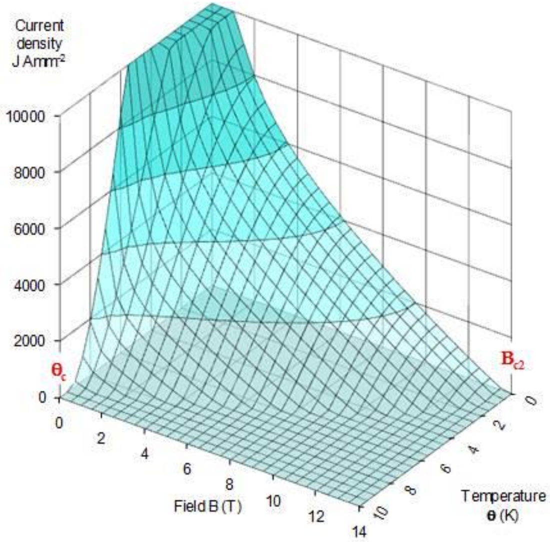


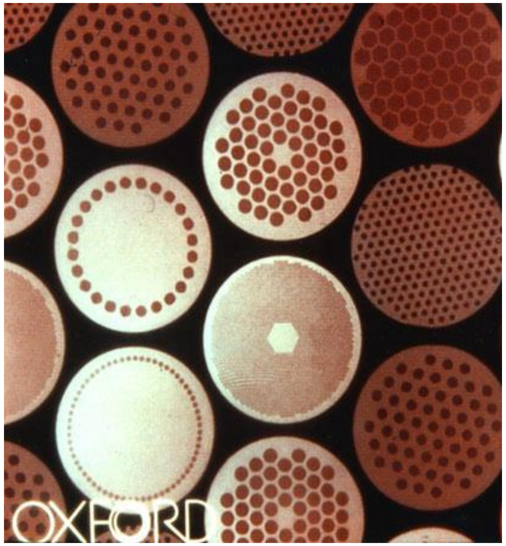
# Superconducting Accelerator Magnets

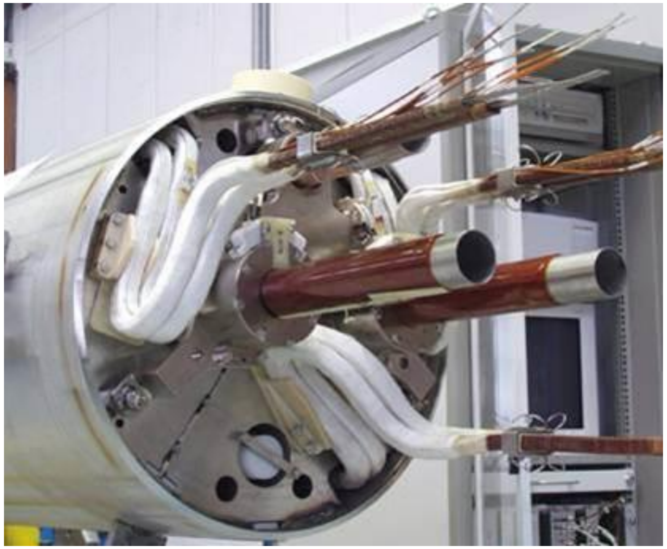
*Martin Wilson*

**Properties and behaviour of superconductors**

**Use of superconductors in magnets**



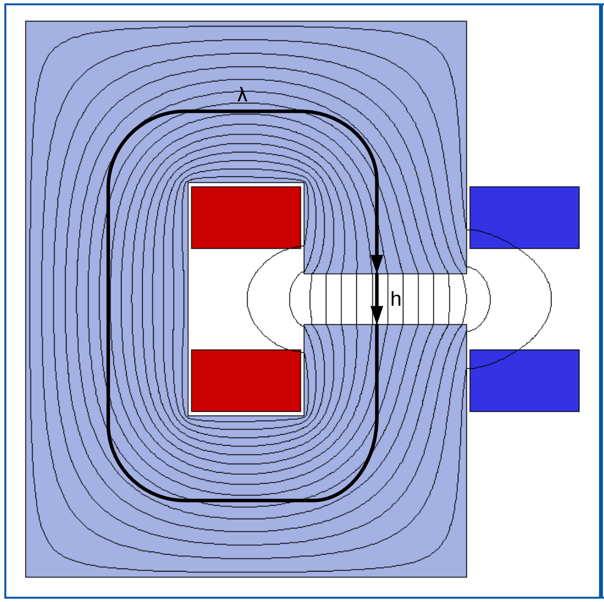



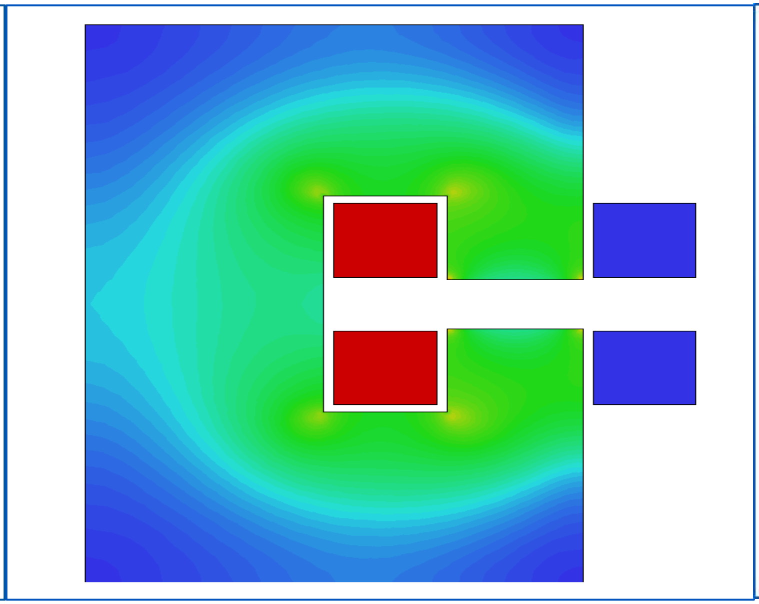



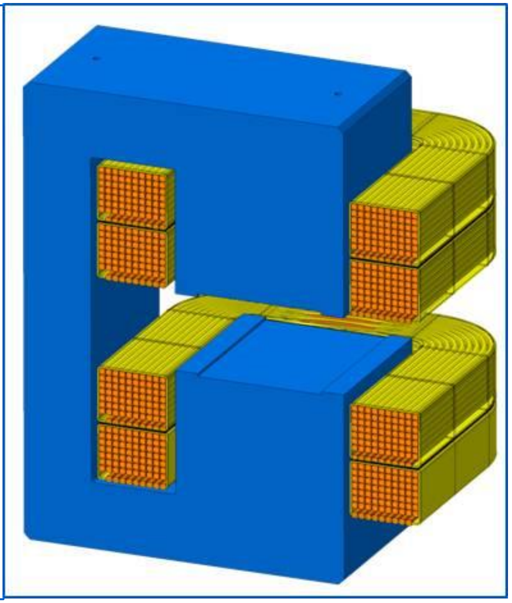
# Mini-workshop on normal conducting magnets

*Coordinated by Thomas Zickler*

- Goal: outline design of a normal conducting magnet
- Provide a short report of the results (*credit points*)



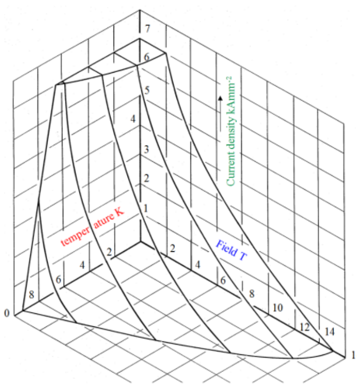


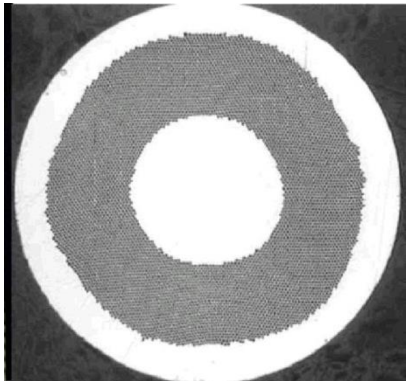
# Mini-workshop on superconducting magnets

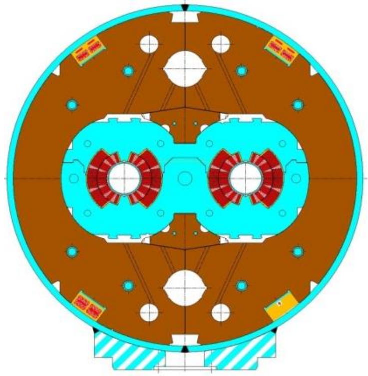
*Coordinated by Philippe Lebrun*

- Goal: outline design of a super-conducting magnet
- Provide a short report of the results (*credit points*)

| Superconducting material | Superconducting strand | Superconducting cable | Superconducting coil | Superconducting magnet |
|---|---|---|---|---|

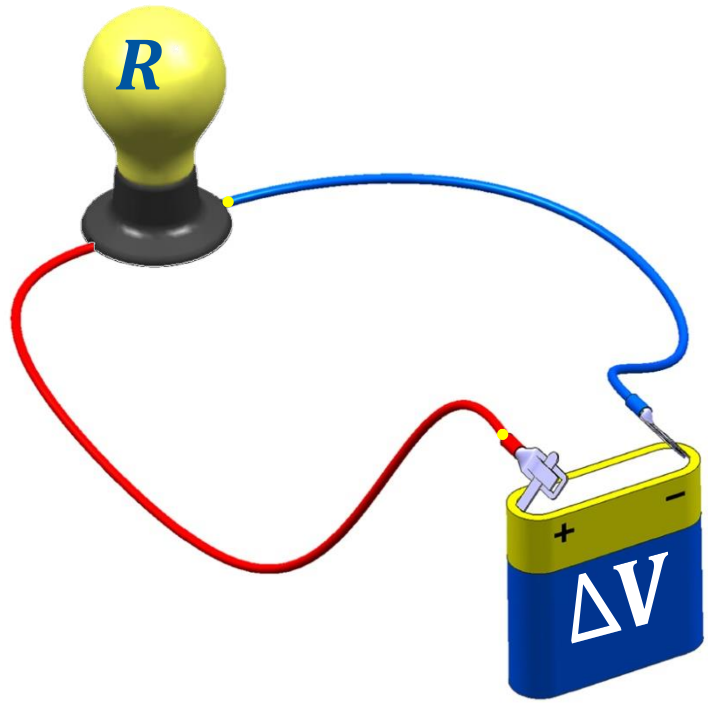




# Introduction to Magnets

# Electricity



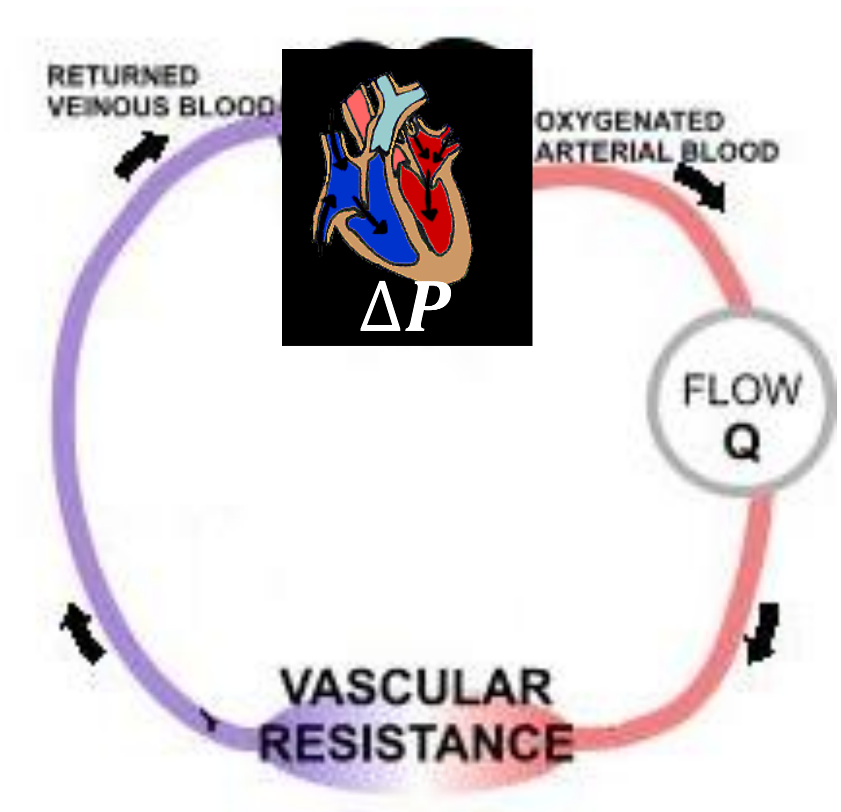

$$\frac{\Delta V}{\Delta l} = \rho \cdot J$$

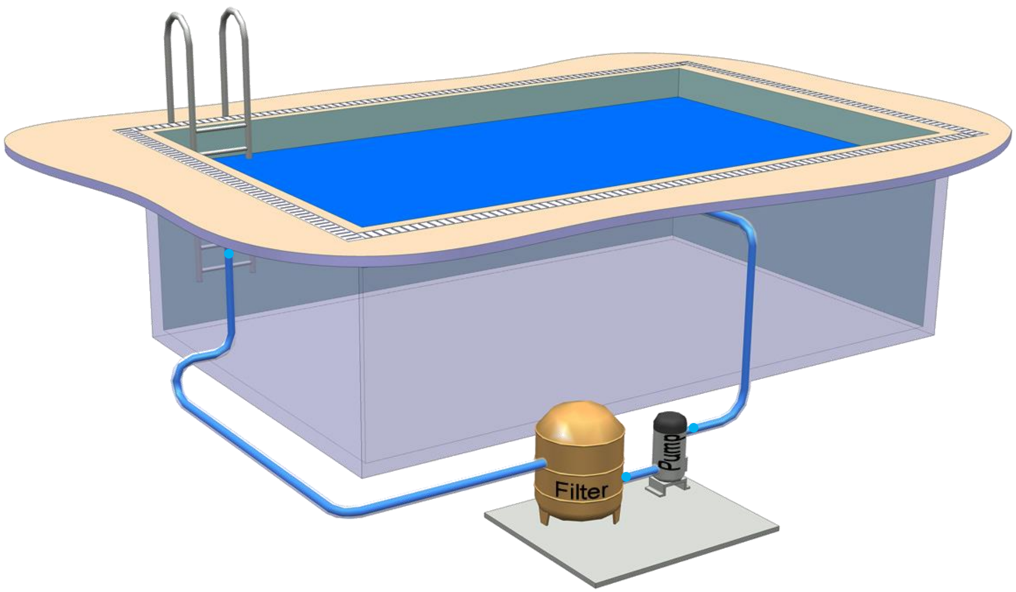
electric strength produces a ***J***

$$J \cdot S = I = \Delta V / R$$

**TEST:** **why *I is in red ?***

# Hydraulics



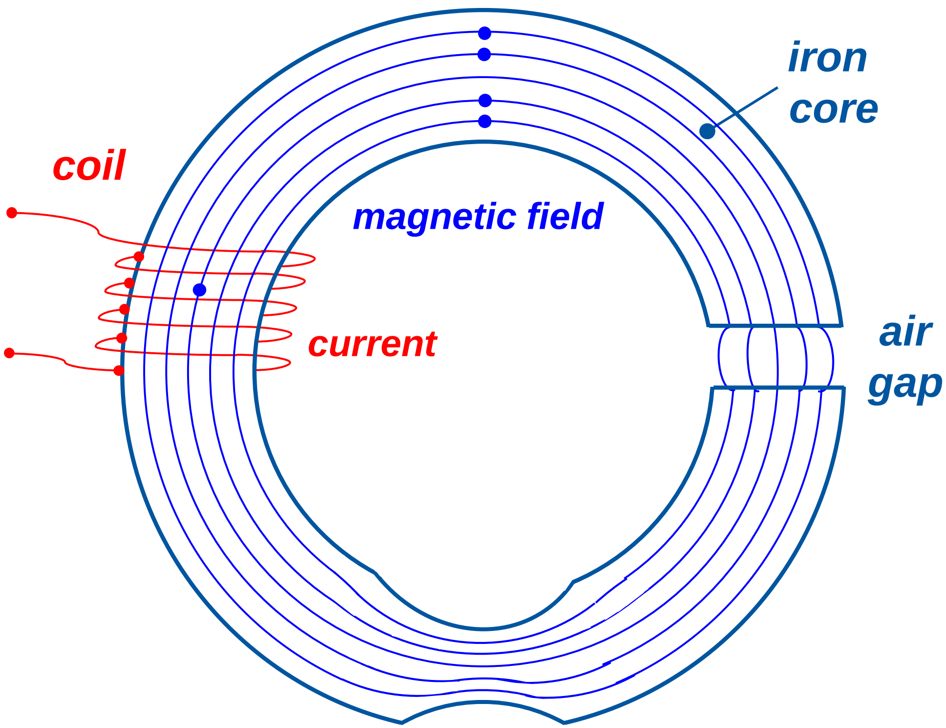




$$v \cdot S = Q = \Delta P / R$$

$$\frac{\Delta P}{\Delta l} = \lambda \cdot v$$

hydraulic strength
produces a ***v***

# Magnetism




$$\boldsymbol{H} = \rho \cdot \boldsymbol{B}$$

magnetic strength
produces a ***B***

$$\boldsymbol{B} \cdot \boldsymbol{S} = \boldsymbol{\varphi} = \boldsymbol{NI}/\boldsymbol{R} = \frac{\mathbf{1}}{\boldsymbol{R}} \oint \boldsymbol{H} \cdot \boldsymbol{dl}$$

NI= «magnetomotive force»

# B & H

In a given material, a

*magnetic field strength* ***H***

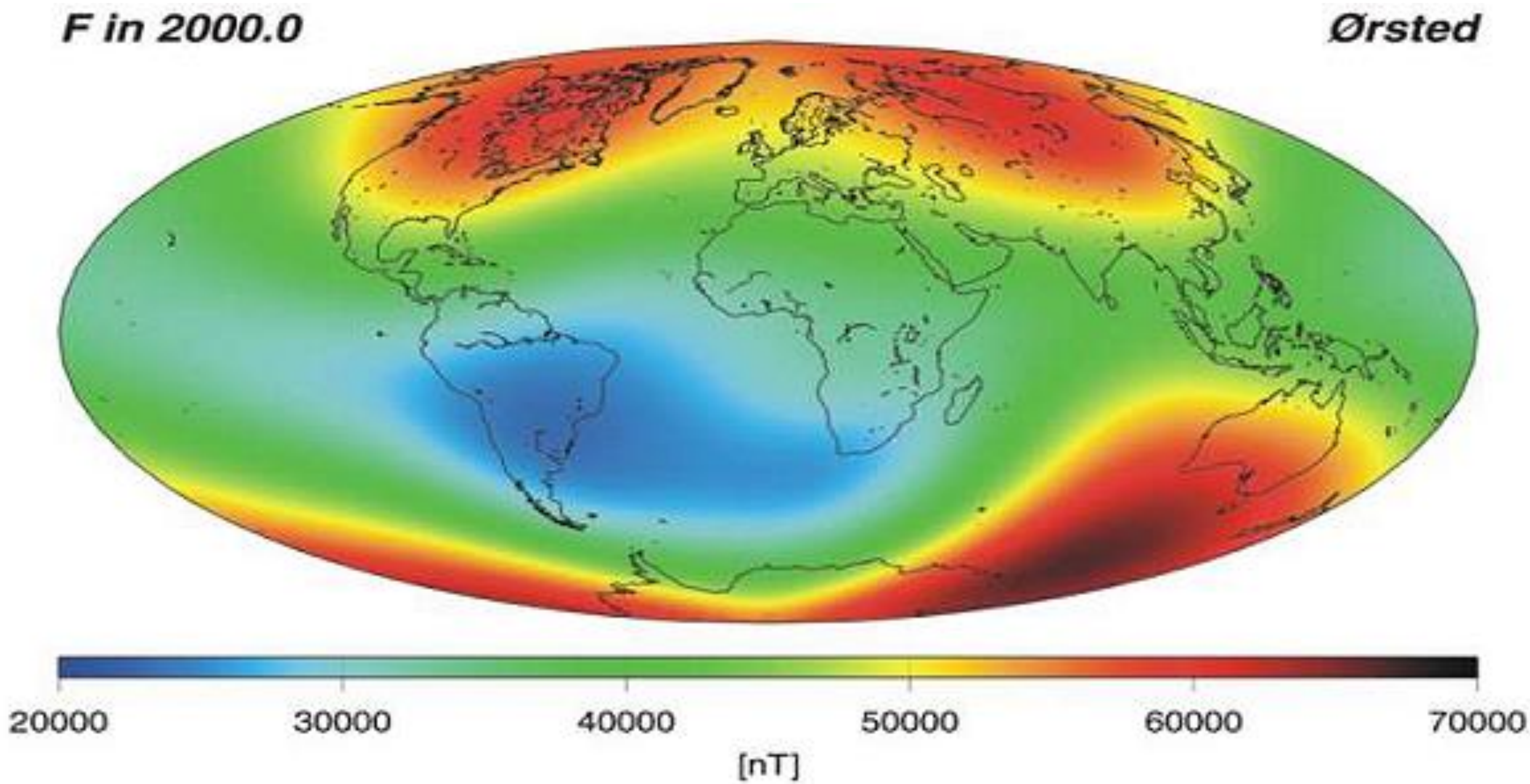
produces a

*magnetic field induction* ***B***

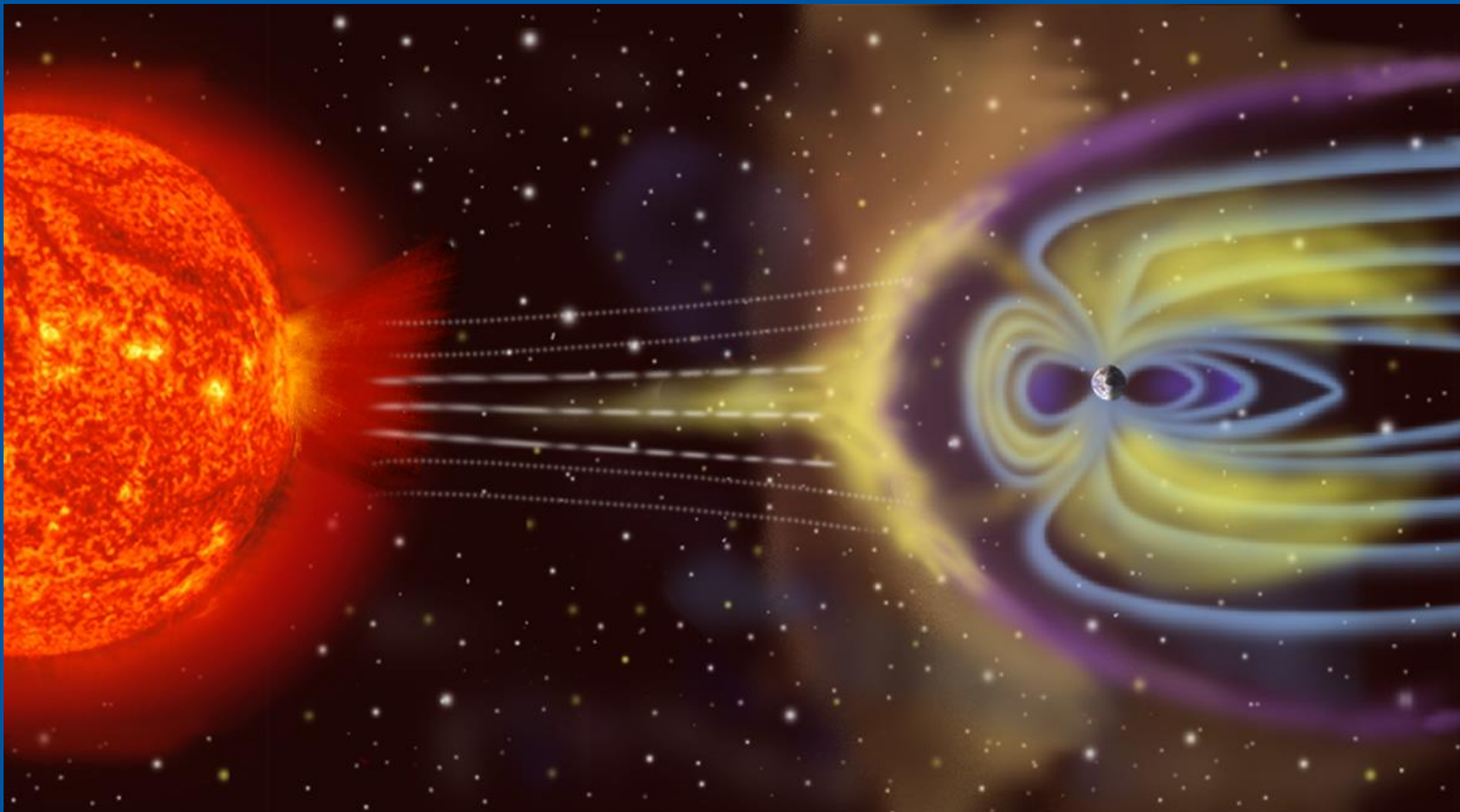
according to

$$\boldsymbol{B} = \mu_0 \cdot \mu_r \cdot \boldsymbol{H}$$

# FLUX




**Source: http://smsc.cnes.fr/OVH/**



# Inductance

The inductance is the equivalent of the inertia.

A large inertia (***I***)/inductance (***L***) means you need:

• a large force to suddenly increase the speed

• a large voltage to suddenly increase the current/field

✓ you can store energy in a wheel rotating at speed $\omega$

✓ you can  store energy in a coil supplied by a current ***i***

$$E = \frac{1}{2} I \cdot \omega^2 = \frac{1}{2} L \cdot i^2$$

When the magnetic field has to be quickly changed you want to keep the inductance low, typically by reducing the number of coil turns.

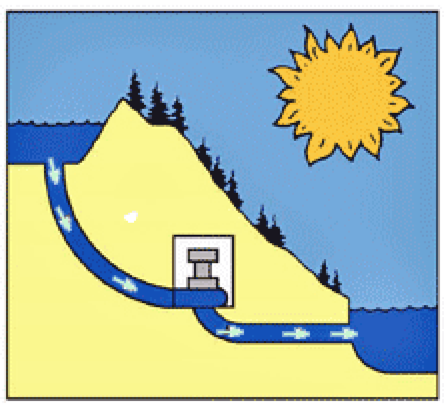
# Magnetic Energy

When you fill a volume with a magnetic field you are storing a «Magnetic Energy»

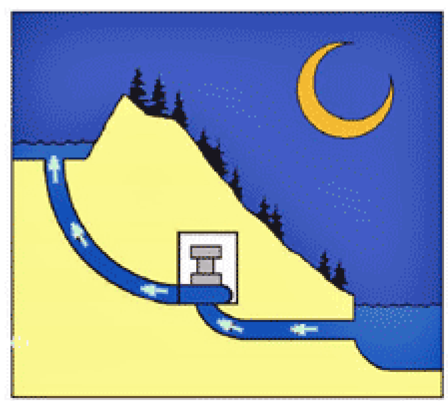
$$dE = \frac{1}{2} B \cdot H \cdot dV$$

This is the work you need to fill a volume dV with a field induction B

When you empty the volume you get back the energy, but not entirely.



Daytime: Water flows downhill through turbines, producing electricity



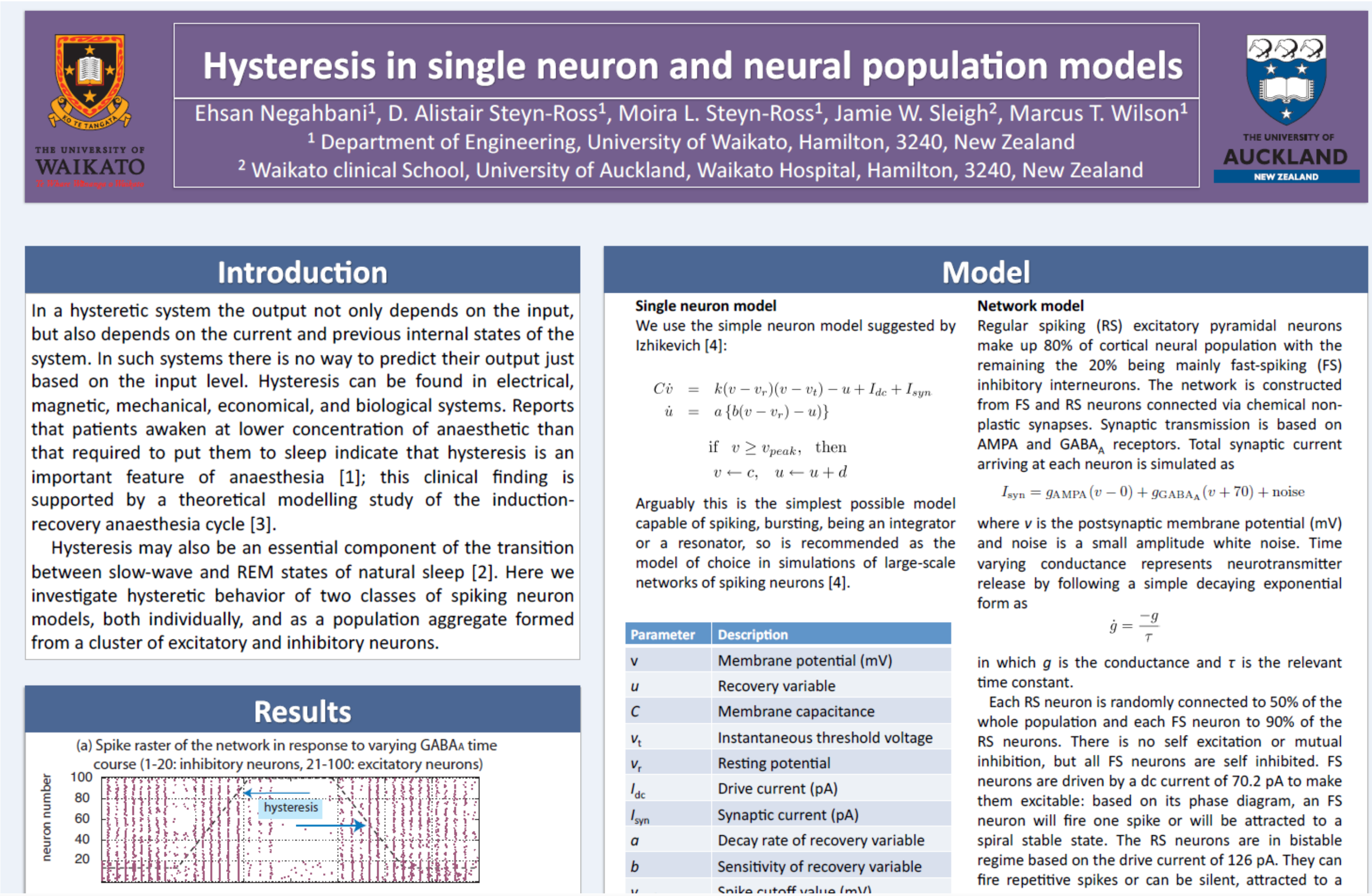
Nightime: Water pumped uphill to reservoir for tomorrow's use

http://www.usgs.gov/

# Hysteresis

Conied in 1890 by Sir James Alfred Ewing, derived from ὑστέρησις (lack, later)

A property of a system such that an output value incorporates some lag, delay or direction/history dependence from the corresponding input (ex in regulation).



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## Hysteresis in single neuron and neural population models

Ehsan Negahbani[1], D. Alistair Steyn-Ross[1], Moira L. Steyn-Ross[1], Jamie W. Sleigh[2], Marcus T. Wilson[1]

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[2] Waikato clinical School, University of Auckland, Waikato Hospital, Hamilton, 3240, New Zealand

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### Introduction

In a hysteretic system the output not only depends on the input, but also depends on the current and previous internal states of the system. In such systems there is no way to predict their output just based on the input level. Hysteresis can be found in electrical, magnetic, mechanical, economical, and biological systems. Reports that patients awaken at lower concentration of anaesthetic than that required to put them to sleep indicate that hysteresis is an important feature of anaesthesia [1]; this clinical finding is supported by a theoretical modelling study of the induction-recovery anaesthesia cycle [3].

Hysteresis may also be an essential component of the transition between slow-wave and REM states of natural sleep [2]. Here we investigate hysteretic behavior of two classes of spiking neuron models, both individually, and as a population aggregate formed from a cluster of excitatory and inhibitory neurons.

### Results

(a) Spike raster of the network in response to varying GABAA time course (1-20: inhibitory neurons, 21-100: excitatory neurons)



### Model

**Single neuron model**

We use the simple neuron model suggested by Izhikevich [4]:

$$C\dot{v} = k(v - v_r)(v - v_t) - u + I_{dc} + I_{syn}$$
$$\dot{u} = a\{b(v - v_r) - u\}$$

$$\text{if} \quad v \geq v_{peak}, \quad \text{then}$$
$$v \leftarrow c, \quad u \leftarrow u + d$$

Arguably this is the simplest possible model capable of spiking, bursting, being an integrator or a resonator, so is recommended as the model of choice in simulations of large-scale networks of spiking neurons [4].

| Parameter | Description |
|---|---|
| $v$ | Membrane potential (mV) |
| $u$ | Recovery variable |
| $C$ | Membrane capacitance |
| $v_t$ | Instantaneous threshold voltage |
| $v_r$ | Resting potential |
| $I_{dc}$ | Drive current (pA) |
| $I_{syn}$ | Synaptic current (pA) |
| $a$ | Decay rate of recovery variable |
| $b$ | Sensitivity of recovery variable |
| $v$ | Spike cutoff value (mV) |

**Network model**

Regular spiking (RS) excitatory pyramidal neurons make up 80% of cortical neural population with the remaining the 20% being mainly fast-spiking (FS) inhibitory interneurons. The network is constructed from FS and RS neurons connected via chemical non-plastic synapses. Synaptic transmission is based on AMPA and $GABA_A$ receptors. Total synaptic current arriving at each neuron is simulated as

$$I_{syn} = g_{AMPA}(v - 0) + g_{GABA_A}(v + 70) + \text{noise}$$

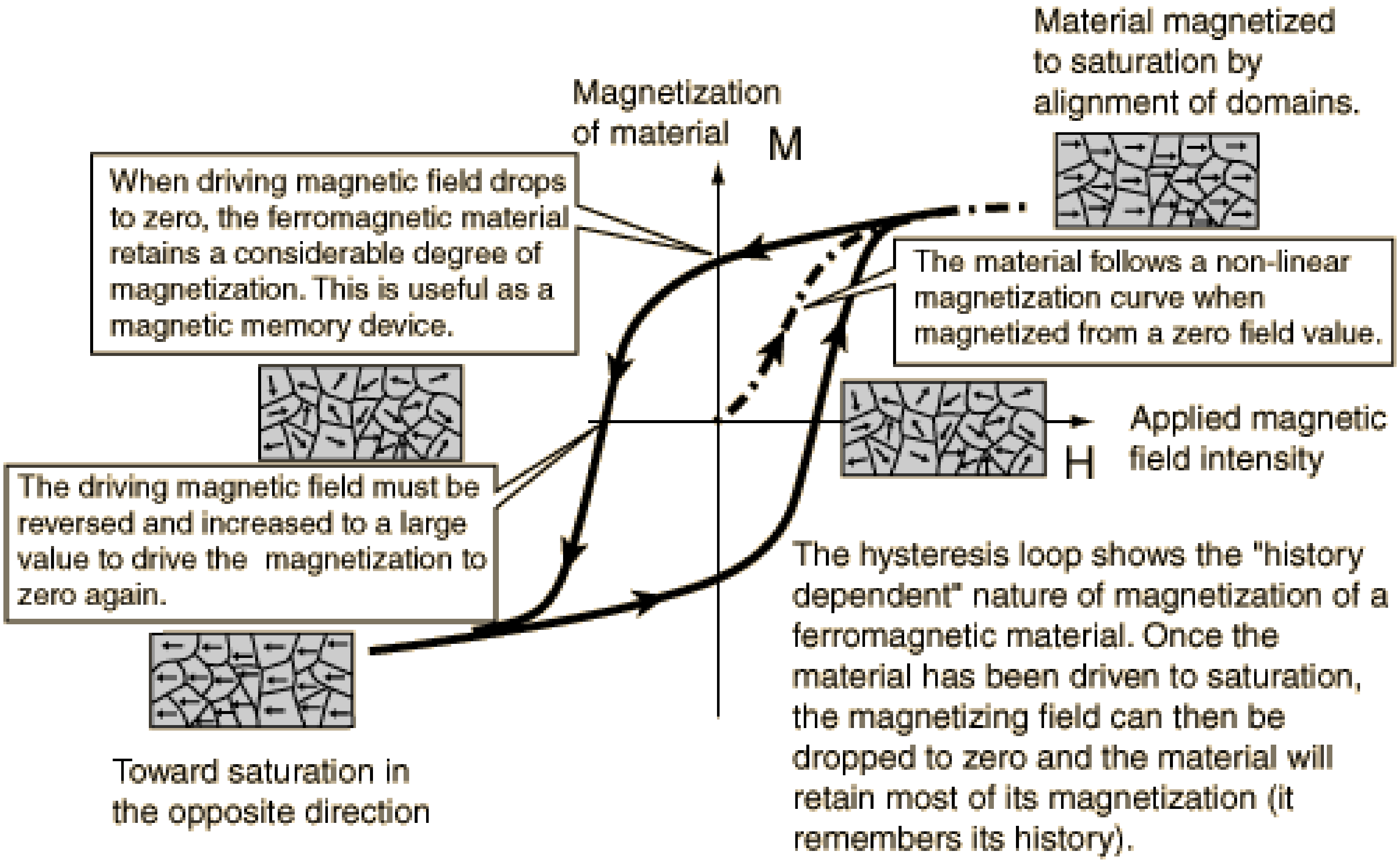
where $v$ is the postsynaptic membrane potential (mV) and noise is a small amplitude white noise. Time varying conductance represents neurotransmitter release by following a simple decaying exponential form as

$$\dot{g} = \frac{-g}{\tau}$$

in which $g$ is the conductance and $\tau$ is the relevant time constant.

Each RS neuron is randomly connected to 50% of the whole population and each FS neuron to 90% of the RS neurons. There is no self excitation or mutual inhibition, but all FS neurons are self inhibited. FS neurons are driven by a dc current of 70.2 pA to make them excitable: based on its phase diagram, an FS neuron will fire one spike or will be attracted to a spiral stable state. The RS neurons are in bistable regime based on the drive current of 126 pA. They can fire repetitive spikes or can be silent, attracted to a

# Hysteresis




http://hyperphysics.phy-astr.gsu.edu

# Technologies

## Permanent Magnets

The magnetic energy stored in the material is used in the magnetic circuit. This means that the magnetic field amplitude that you can produce in a given volume of air depends on:

1. the ***magnetic energy density*** that the permanent magnet material can «store»
2. the size (volume) of the permanent magnet

## Electromagnets

They can be essentially:

1. normal conducting: typically ***iron dominated*** because, below ***saturation*** the ***magnetization*** ampereturns are ***cheap***
2. superconducting: more complex than normal conducting, typically used only when strictly necessary profiting that the **superconducting** ampereturns are **cheap**. Used then when the required field is above iron saturation (> 2T) or even at lower fields when the air gaps are so large that powering the required ampereturns would be non economically advantageous with respect to a normal conducting version.

*Thanks*