Lecture 5 – September 13, 2006

Analysis of Random Uncertainties

and

Resistive Sensors

Analysis of Random Uncertainties

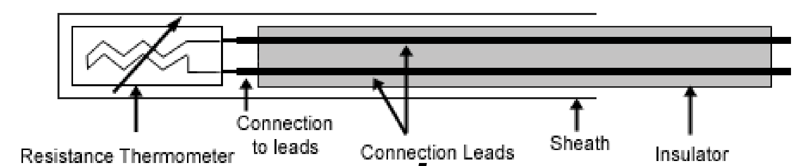
- Recap from last time
- Random versus systematic uncertainty
- Mean value
- Standard deviation
- Standard deviation of mean

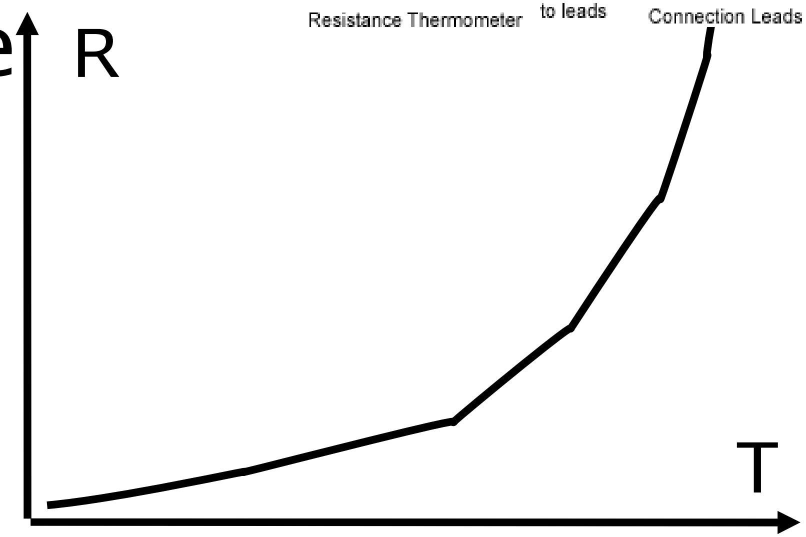
Resistive Sensors

- How to measure resistance
  - Wheatstones bridge
- Sensors
  - Temperature sensors
  - Strain Gauges
  - Photoconductors
  - Relative humidity sensors
  - Linear/angular position sensing
  - Giant Magnetoresistive Effect
  - Anisotropic Magnetoresistive Effect

Resistive Temperature Sensors

- Resistance varies with temperature
  - Some materials more than others
- Measure resistance, compute temperature
- We can model R(T) as a polynomial





$$R(T) = \sum_{i=0}^{\infty} a_i \left(T - T_0\right)^i$$

$$R(T) = R(T_0) + \alpha \left(T - T_0\right) + \beta \left(T - T_0\right)^2$$

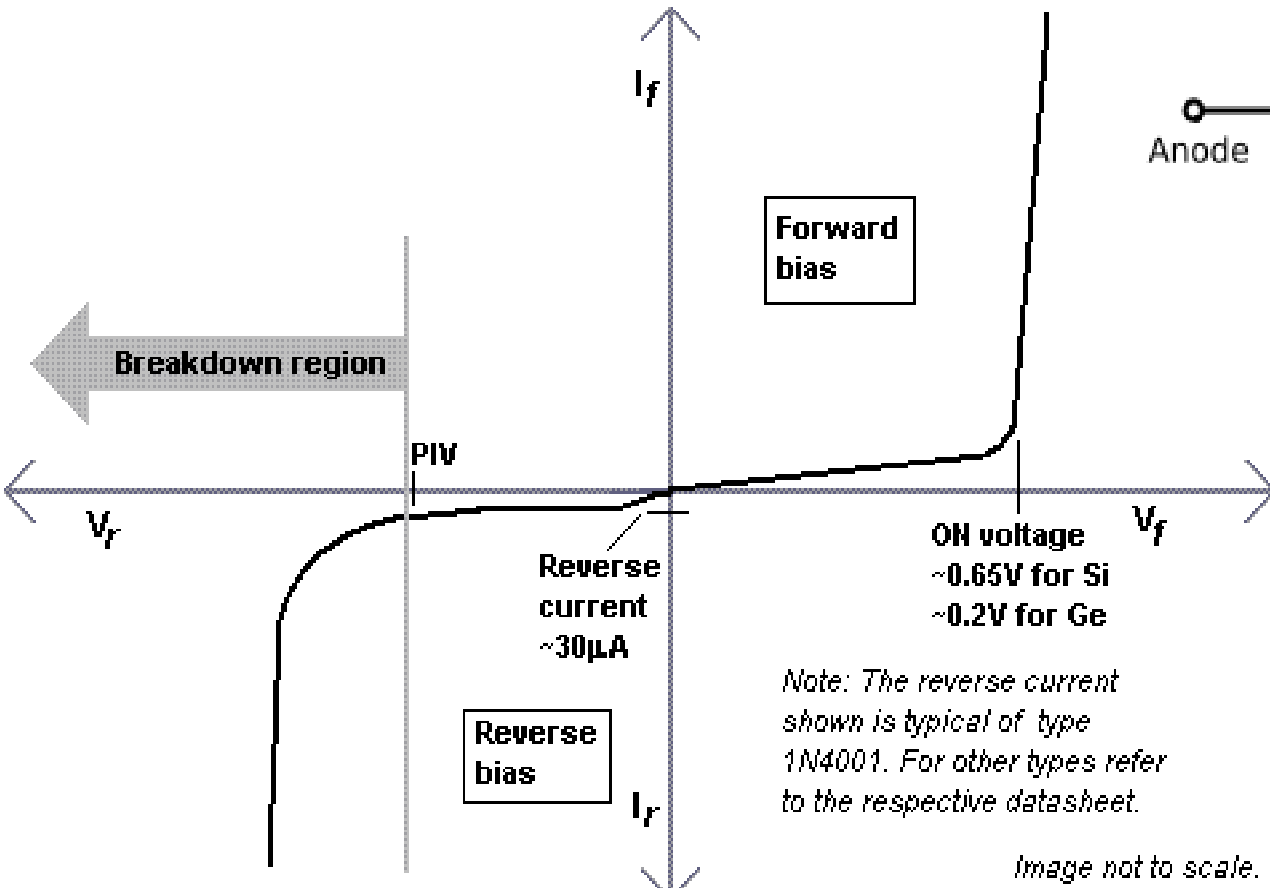
Temperature coefficient

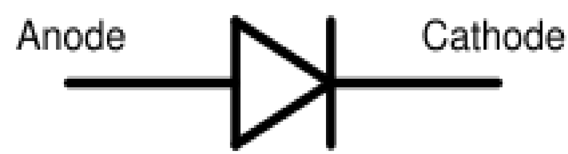
Resistive Temperature Sensors

- Metals versus semiconductors
  - Small versus large temperature coefficient
- Large temperature coefficient gives more precise temperature measurement
  - Because we are measuring change in resistance
  - Table 6.1

Resistive Temperature Sensors

- Diodes as resistive temperature sensors
  - Diode current and voltage varies with temperature





Resistive Temperature Sensors

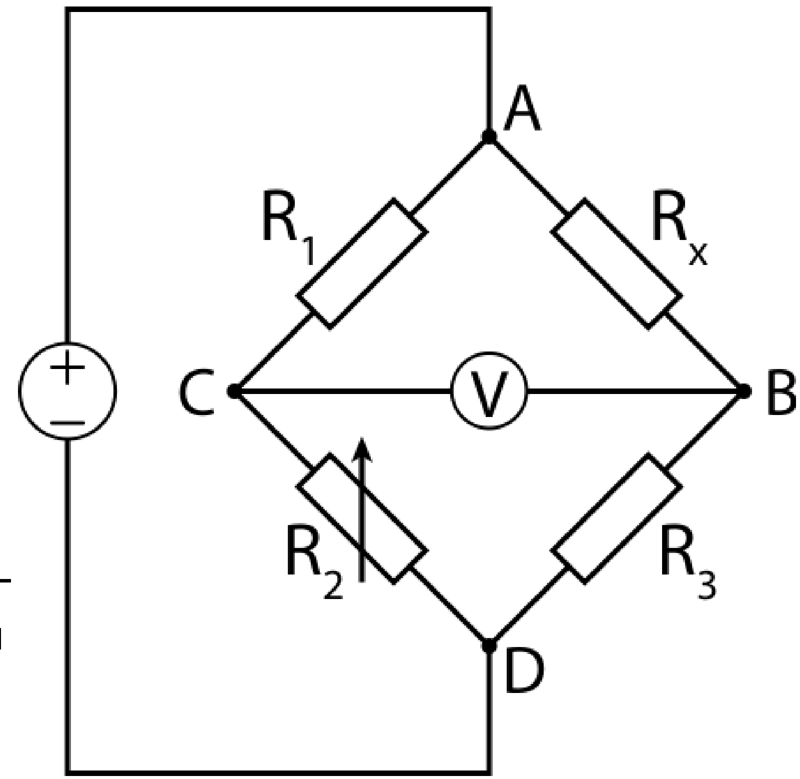
- Applications
  - Temperature measurements
  - Measure air/fluid flow

Wheatstone's Bridge

- Used to measure resistance

$$V_0 = V_B - V_C$$

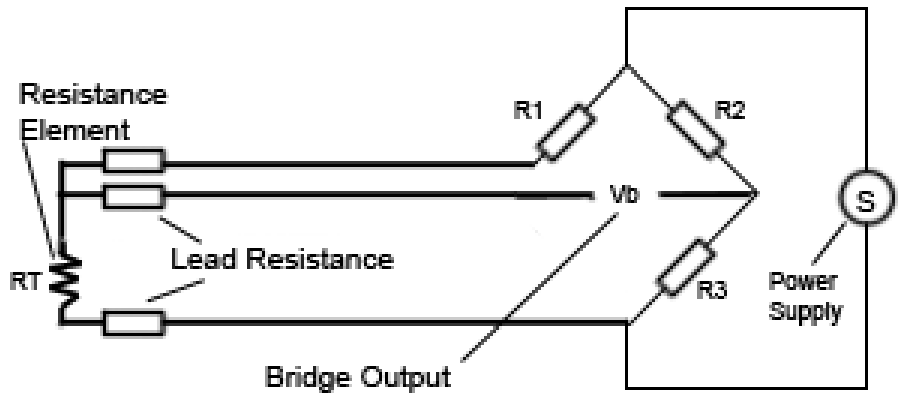
$$\frac{V_0}{V_A - V_D} = \frac{R_X R_2 - R_1 R_3}{(R_3 + R_X)(R_1 + R_2)}$$

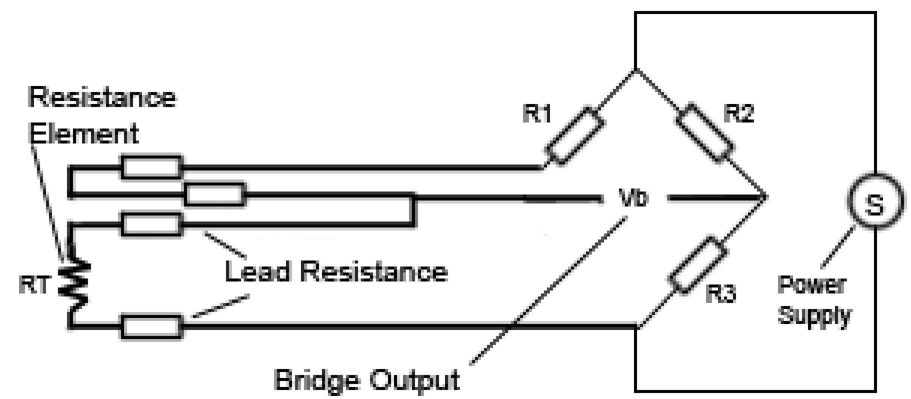


Balance bridge, change R_X, and V_0 is proportional to change in R_X. The uncertainty in ΔR_X is then proportional to the uncertainty in V_0

Resisitive Temperature Sensors

- Eliminating lead resistances
  - Several Wheatstone bridge designs





Resistive Strain Gauges

- Effect
  - Measure deformation of or forces on an object
- Mechanism
  - Strain gauges change resistance when stretched.
  - Bonded
    - Attached to object and deform with object
  - Unbonded
    - Used to measure forces acting on an object
  - Strain is deformation caused by stress

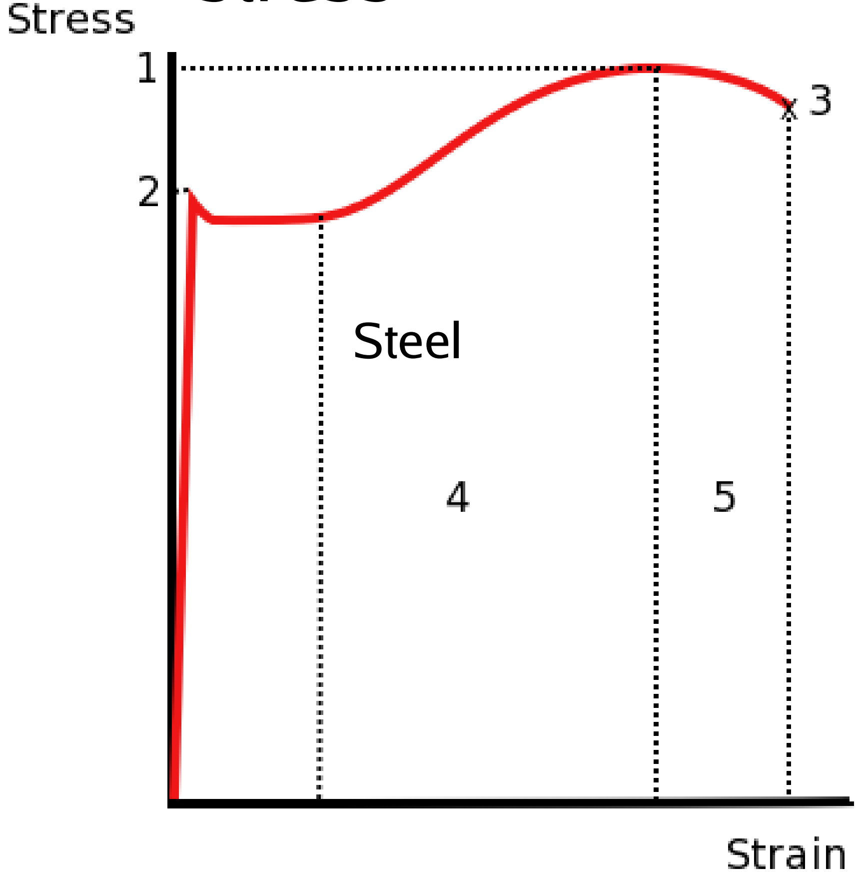
Resistive Strain Gauges

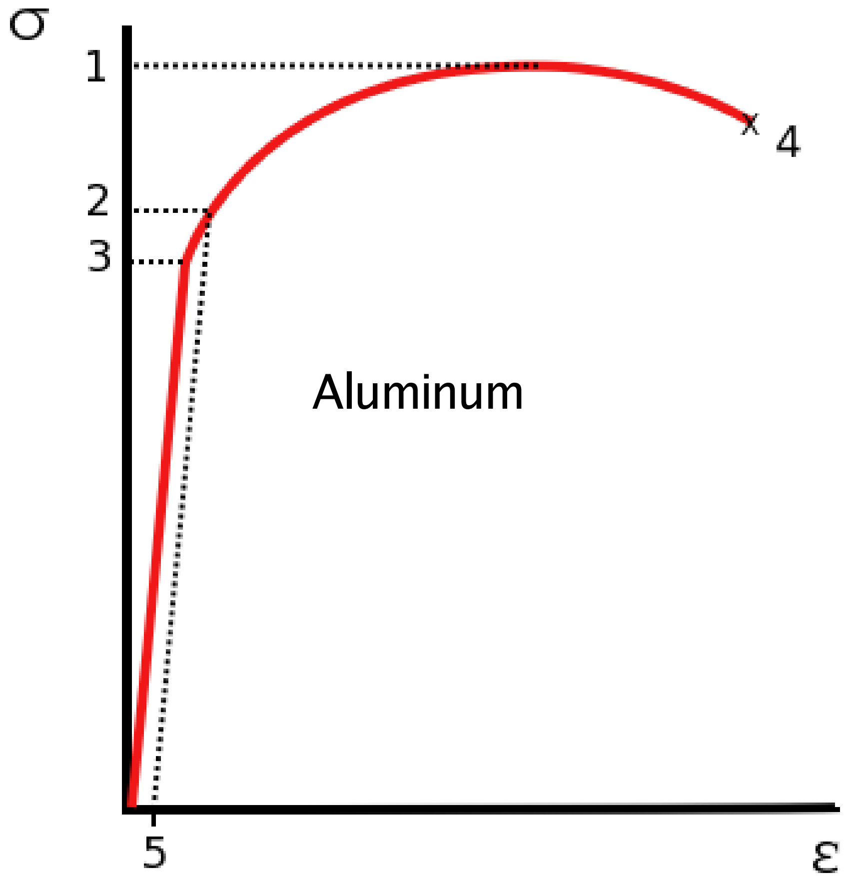
- Stress and Strain
  - Stress is the force on the object (stretching force)
  - Strain is the resulting deformation of the object
  - Hooke's law (spring equation) valid for small stress in “elastic region”

$$F = -kx$$

Resistive Strain Gauges

- Stress Strain curves
  - One stress for each strain, multiple strains for each stress





Resistive Strain Gauges

- Computing $\Delta R/R$ as a function of force or strain
- Gauge factor
  - Resistance varies linearly with strain, constant of proportionality is material dependent
- Resistance change is small. How do we measure it?

$$\Delta R = -\frac{L}{A^2}\Delta A + \frac{L}{A}\Delta\rho + \frac{\rho}{A}\Delta L$$

$$R = \frac{\rho L}{A}$$

$$\frac{\Delta R}{R} = -\frac{\Delta A}{A} + \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L}$$

Photoconductors

- Mechanism
  - Resistance decreases when material is illuminated
- Different from photodiodes/solar cells.
  - Photodiodes/Solar cells are p-n junctions which produce a V or current when illuminated.
  - Photoconductors are passive resistive elements whose resistance depends on illumination

Photoconductors

- Resistance

$$\frac{1}{R_T} = \frac{1}{R_D} + \frac{1}{R_P}$$

- Assignment
  - Figure 6.6, derive expression for V_0 in terms of P_i

Photoconductors

- Reminder: Description of op-amps and mathematical model.

Relative humidity sensing

- Effect
  - Conductivity between two contacts changes when humidity of surrounding air changes
- Dunmore Mechanism
  - Salt coated rod wound with metal wires
  - Salt absorbs water, releases ions which increase conductivity
  - Chemical process.

Relative humidity sensing

- Dunmore problems
  - Migration of ions at high voltages, which eventually increases resistance (Charging like a battery)
  - Chemical breakdown
- Dunmore Solution
  - Low voltage and AC signal. Wheatstone bridge will still work because frequency is small and there are no large capacitances.

Relative humidity sensing

- Practical use
  - Limited useful range of RH sensing
  - Wide-range instrument may require combining multiple sensors with different useful ranges

Relative humidity sensing

- Brady Mechanism
  - Water absorption in crystal lattice
  - Changes conduction band structure
  - Increased RH decreases resistance
  - Physical process
  - New technology. May replace chemistry-based RH sensors

Linear/angular position sensing

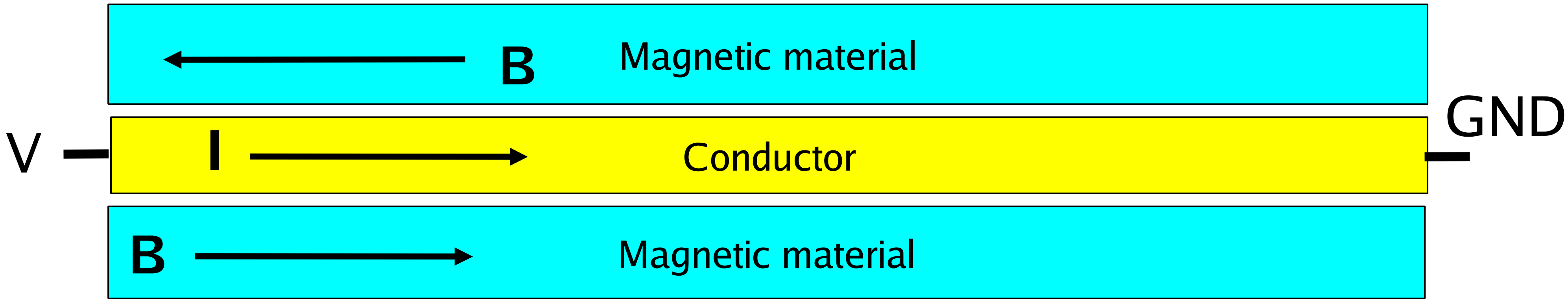
- Mechanism
  - Position sensed by voltage division
  - Linear voltage divider for linear position measurements
  - Helical voltage divider for angular position sensing
- Issues
  - Resistance must vary linearly with position, or at least in a known way with position.
  - Temperature coefficient must be small, or known and temperature must be measured.
  - Mechanical friction eventually wears resistor down.

Linear/angular position sensing

- Alternatives
  - Linear Variable Differential Transformers
  - Various optical encoding schemes
- Why not use these alternatives all the time?

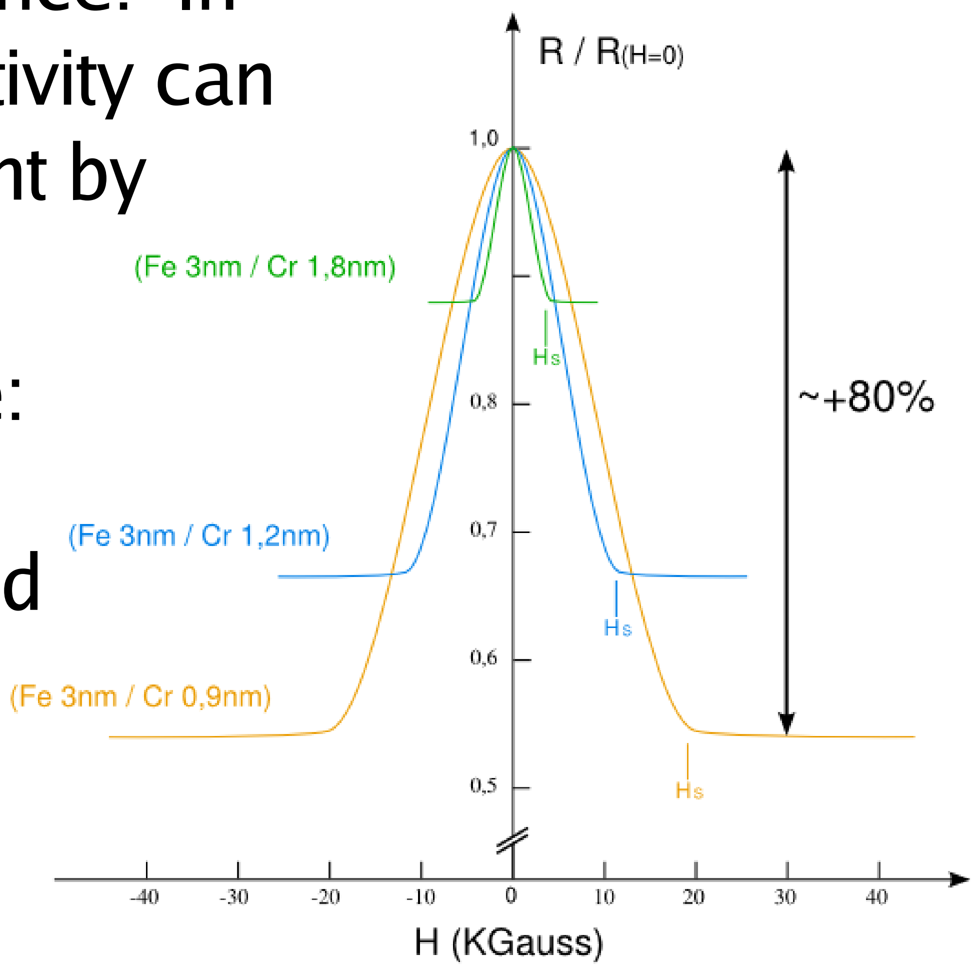
Giant Magnetoresistive Effect

- Effect
  - Resistance of a conducting layer sandwiched between two magnetic layers changes depending on the relative orientations of the B-field in the two magnetic layer.



Giant Magnetoresistive Effect

- Why the name?
  - Ordinary Magnetoresistance: In some materials the resistivity can be lowered by few percent by applying a magnetic field
  - Giant Magnetoresistance: In some layers of films resistance can be lowered by tens of percent by applying a magnetic field



Giant Magnetoresistive Effect

- Mechanism
  - Film of conducting material sandwiched between films of magnetic materials
  - Measure resistance of conducting material
  - Charge-carrier motion most restricted when fields are anti-parallel (High resistance)
  - Charge-carrier motion less restricted when fields parallel (low resistance)
  - Lowest energy state is anti-parallel fields
  - Imposing external field parallellizes film fields and lowers resistance.

Giant Magnetoresistive Effect

- Issues
  - Resistance varies non-linearly with applied field
  - Hysteresis
  - Both complicate field strength measurements
- Applications
  - Discrete field strength measurements
  - New miniaturization for magnetic storage devices

Anisotropic Magnetoresistive Effect

- Effect
  - Resistance varies with angle between conductor and applied magnetic field
  - Linear when arranged as a Wheatstones bridge
  - Can be used as electronic compass