Hyperfine Interactions Laboratory

Sub-nanoscopic investigation of materials via hyperfine interactions using radioactive isotopes

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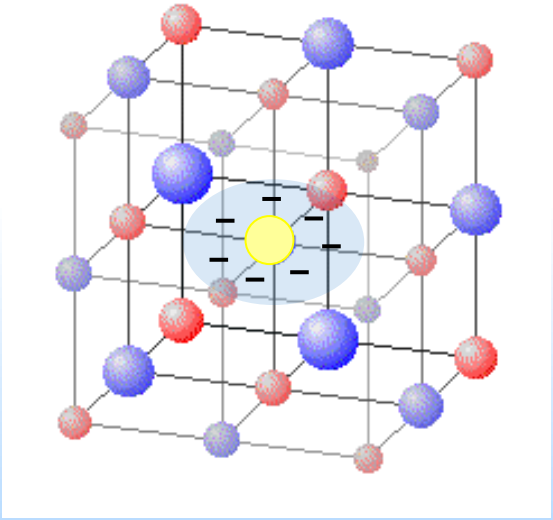
What are hyperfine interactions?

They are interactions between the nucleus (nuclear moments) and electrons (charge and spin densities)

Hyperfine Interactions

Electric Interaction



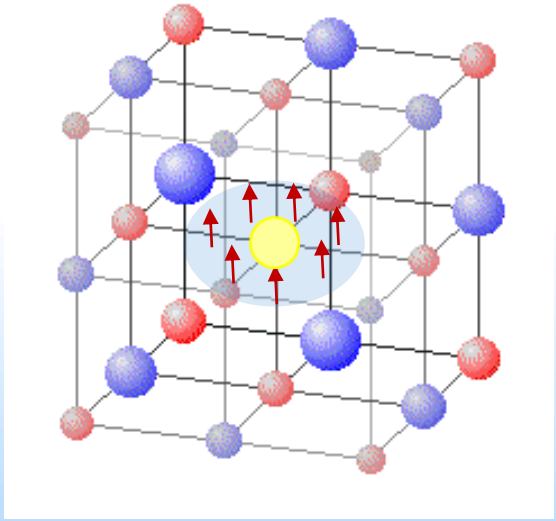
Electron charge density

Electric field Gradient (V_{ii})

HFI

Nuclear electric quadrupole moment

Magnetic Interaction



Electron spin density

Magnetic field (B_{hf})

HFI

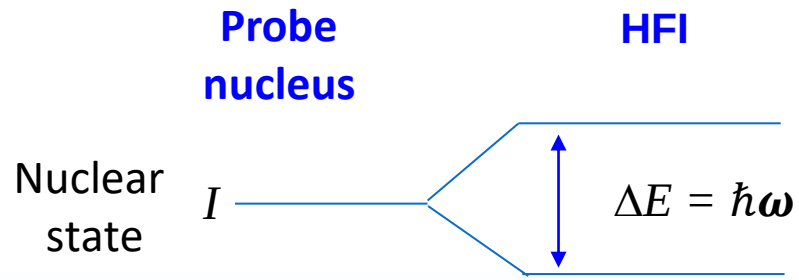
Nuclear dipole magnetic moment

Probe nucleus

What are the effects of hyperfine interactions on the nucleus?

The main effect is the splitting of the nuclear energy levels

Hyperfine Interactions



Electric Interaction

$$\omega_Q = \frac{eQV_{zz}}{4I(2I-1)\hbar}$$

$$\eta = \frac{V_{xx} - V_{yy}}{V_{zz}}$$

Magnetic Interaction

$$\omega_L = g_N \mu_N \frac{B_{hf}}{\hbar}$$

Dynamic interaction

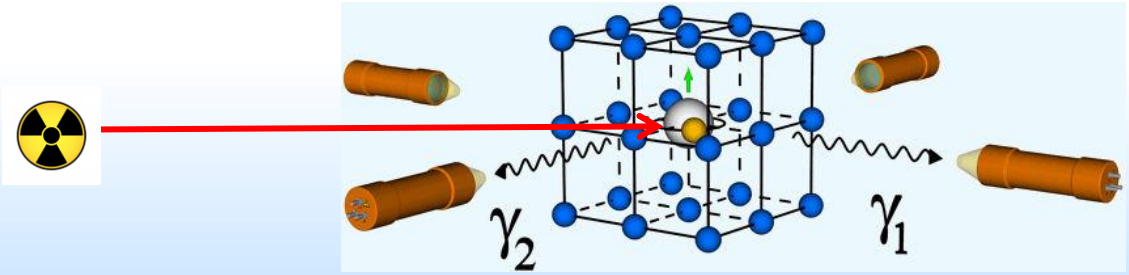
$$G_{22}(t) = \sum a_i \exp(-\lambda_i t)$$

How can we measure hyperfine interactions?

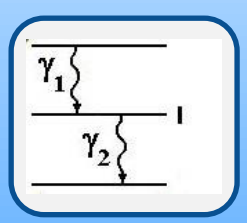
Among few techniques, perturbed angular correlations (PAC) uses radioactive probe nuclei

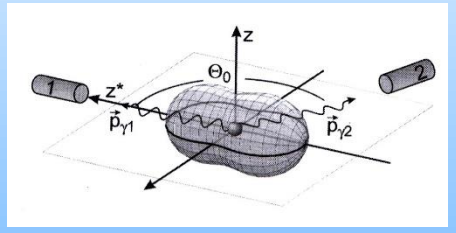
Hyperfine Interactions

Perturbed Angular Correlation (PAC)

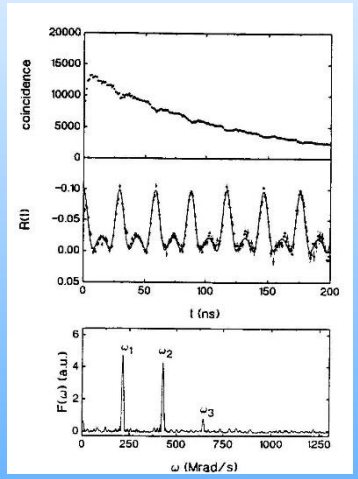


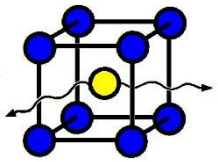
Radioactive probe nucleus





PAC measures the time dependence of the γ-ray emission pattern caused by hyperfine interactions





Probe nuclei

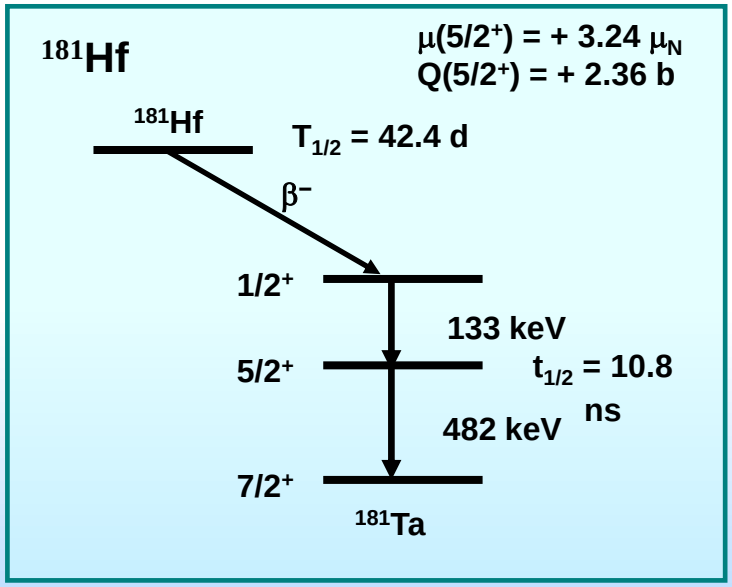
Advantages of PAC

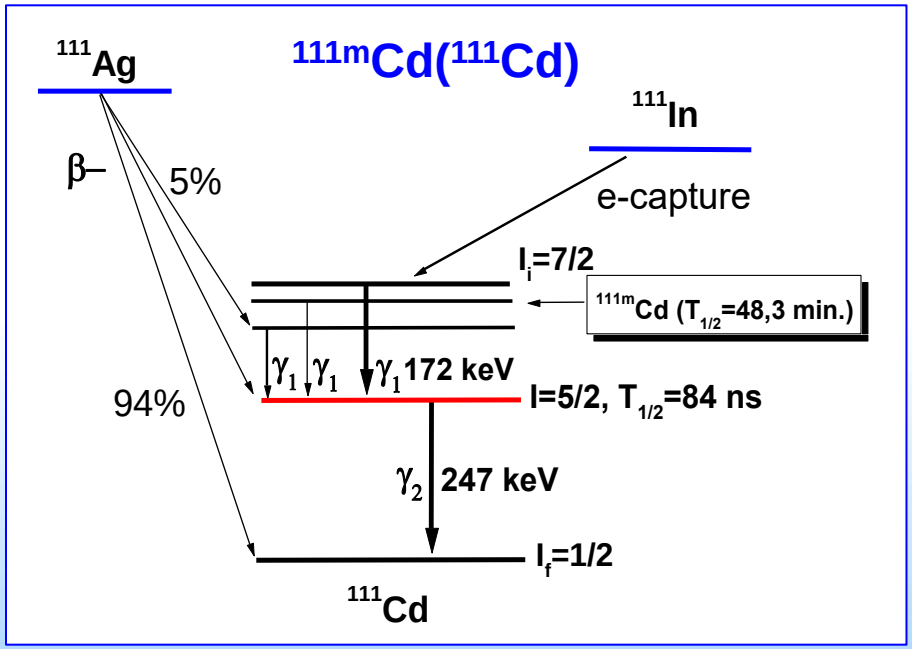
- It offers a local investigation of materials
- It can measure HFI at different crystalline sites or different regions of the material
- It can be used at any temperature, even very high ones.
- The concentration of probe nuclei is very small (< 1 ppm)
- It is very sensitive to symmetry (ideal for single crystals)
- It can investigate dynamical effects

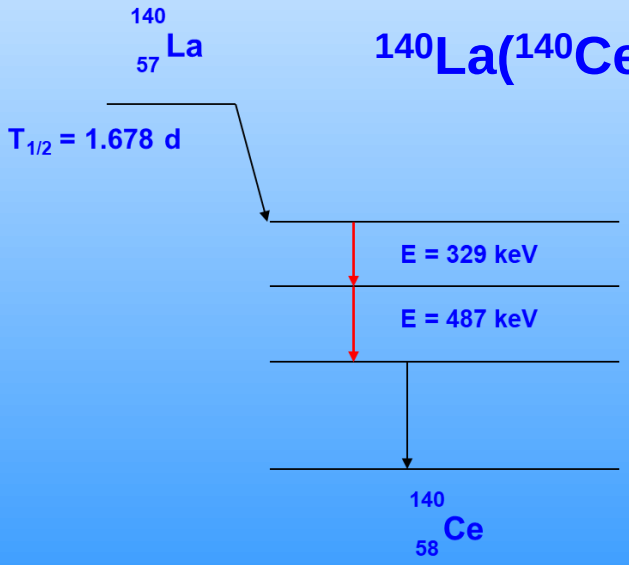
Although it is underutilized, the perturbed angular correlations technique offers considerable potential for studying materials.

THANK YOU

Probe nuclei

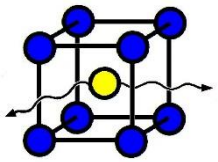






I = 4+, $T_{1/2}$ = 3.4 ns, Q=0.35 b

^{140}La is produced by neutron irradiation of natural La: ^{140}La(n,γ)^{140}Ce



Probe nuclei

Insertion of probe nuclei into the material (few ppm)

1. During synthesis or preparation of the material

- **Chemical synthesis**
- **Melting (metals)**
- **Physical processes**

2. Thermal diffusion into the material

3. Activation of the nucleus of a specific element in the material

4. Implantation of the probe nuclei into the material (ISOLDE/CERN)