Low Temperature Nuclear Orientation (LTNO)

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Some experimental questions:

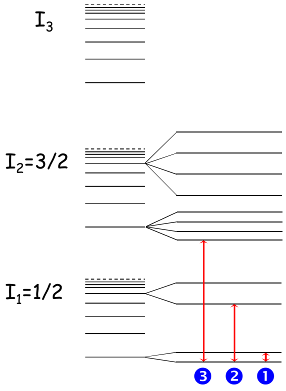
1) How do you measure temperature in an experiment at 100 K?
Can you distinguish between 90 K and 100 K in this way ?

2) How do you measure temperature in an experiment at 10 mK ?
Can you distinguish between 9 mK and 10 mK in this way?

3) How do you study isolated impurity atoms in a bulk matrix ?

?

Classification of nuclear methods

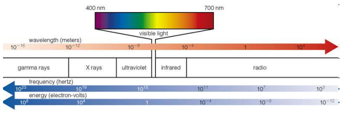


These 3 energy scales distinguish
3 different classes of experimental methods:

① • Nuclear Magnetic Resonance (NMR)
• Nuclear Quadrupole Resonance (NQR)

② • laser spectroscopy
• Electron Paramagnetic Resonance (EPR)

③ • Low-Temperature Nuclear Orientation (LTNO)
• NMR on Oriented Nuclei (NMR/ON)
• forward scattering of synchrotron radiation
• Mössbauer Spectrocopy (MS)
• Conversion Electron Mössbauer Spectrocopy (CEMS)
• Perturbed Angular Correlation spectroscopy (PAC)



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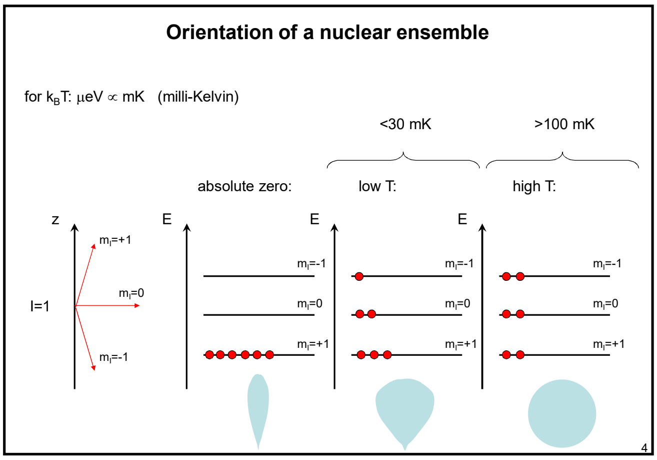


Orientation of a nuclear ensemble

for k_BT: μeV ∝ mK (milli-Kelvin)

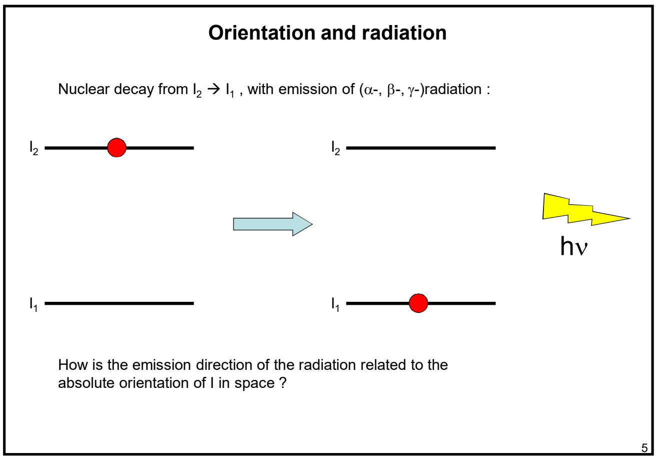
<30 mK

>100 mK

absolute zero:

low T:

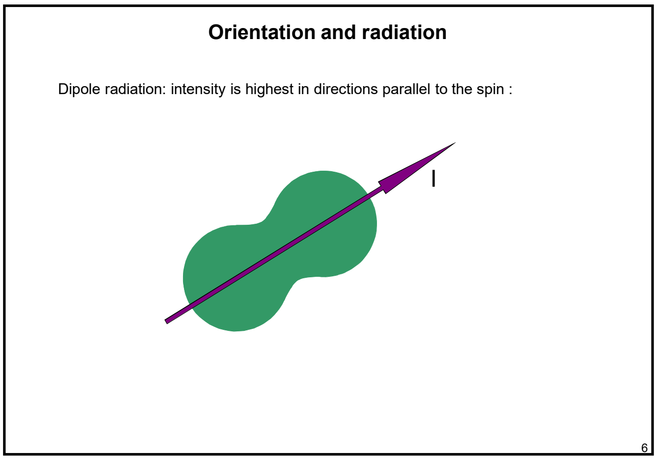
high T:



Orientation and radiation

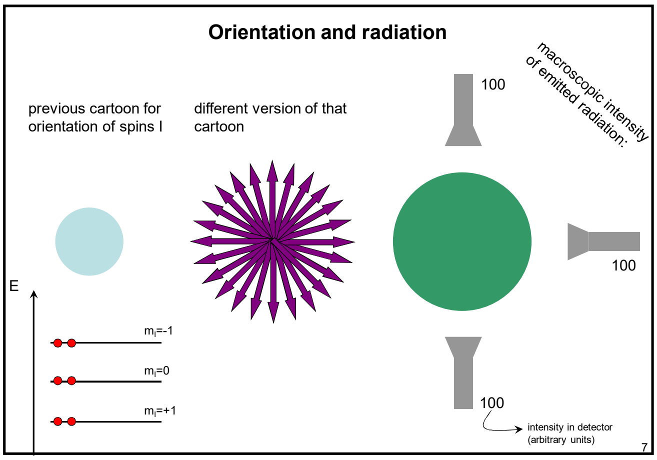
Nuclear decay from $I_2 \rightarrow I_1$, with emission of (α-, β-, γ-)radiation :

How is the emission direction of the radiation related to the absolute orientation of I in space ?



Orientation and radiation

Dipole radiation: intensity is highest in directions parallel to the spin :

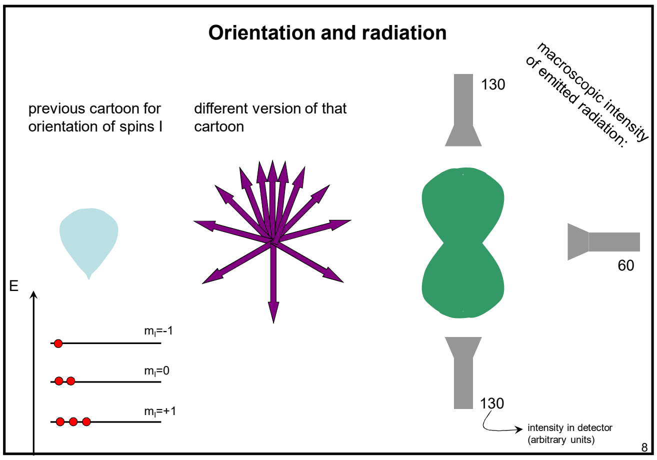


Orientation and radiation

previous cartoon for orientation of spins I

different version of that cartoon

macroscopic intensity of emitted radiation:



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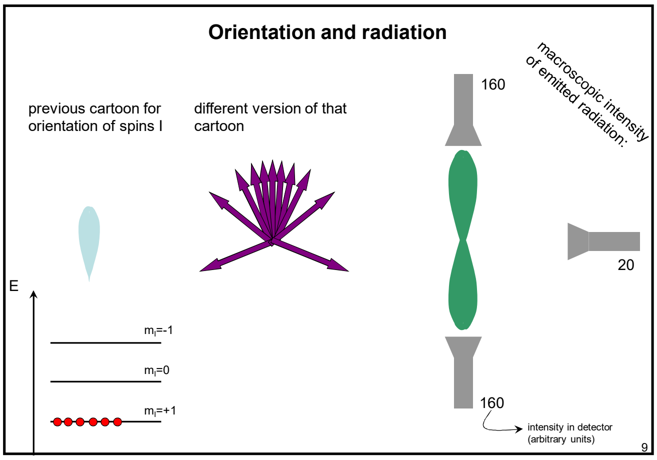


Orientation and radiation

previous cartoon for orientation of spins I

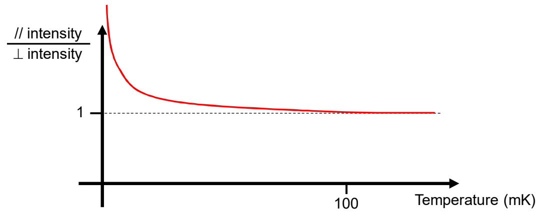
different version of that cartoon

macroscopic intensity of emitted radiation:

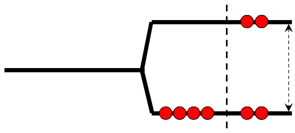
Orientation and radiation

Conclusion:

If temperature drops towards the mK region, nuclear orientation sets in and the count rates of detectors parallel and perpendicular to the z-axis become different from each other.



Low Temperature Nuclear Orientation



ΔE : Proportional to :

- nuclear moment (μ or Q)
- electronic property (hff or EFG)

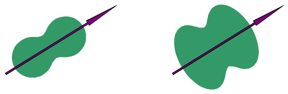
occupation depends on:

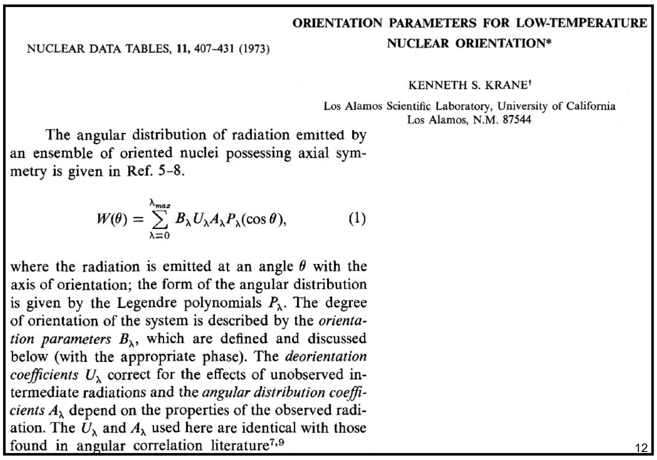
- ΔE
- temperature T

observed anisotropy in radiation depends on

- nuclear decay properties

(different transitions provide different anisotropies at the same ΔE and T)





NUCLEAR DATA TABLES, 11, 407–431 (1973)

ORIENTATION PARAMETERS FOR LOW-TEMPERATURE NUCLEAR ORIENTATION*

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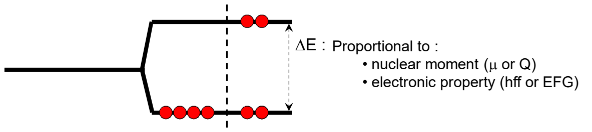
The angular distribution of radiation emitted by an ensemble of oriented nuclei possessing axial symmetry is given in Ref. 5–8.

$$W(\theta) = \sum_{\lambda=0}^{\lambda_{max}} B_\lambda U_\lambda A_\lambda P_\lambda(\cos\theta), \qquad (1)$$

where the radiation is emitted at an angle θ with the axis of orientation; the form of the angular distribution is given by the Legendre polynomials P_λ. The degree of orientation of the system is described by the *orientation parameters* B_λ, which are defined and discussed below (with the appropriate phase). The *deorientation coefficients* U_λ correct for the effects of unobserved intermediate radiations and the *angular distribution coefficients* A_λ depend on the properties of the observed radiation. The U_λ and A_λ used here are identical with those found in angular correlation literature[7,9]

Low Temperature Nuclear Orientation



ΔE : Proportional to :
- nuclear moment (μ or Q)
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occupation depends on:
- ΔE
- temperature T

observed anisotropy in radiation depends on
- nuclear decay properties

(different transitions provide different anistropies at the same ΔE and T)

LTNO = • measure anisotropy as a function of T
- determine ΔE if T is known
  - determine nuclear/electronic property if electronic/nuclear property is known
- determine T if ΔE is known (nuclear thermometer)

Low Temperature Nuclear Orientation

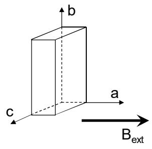
Example :

PHYSICAL REVIEW B VOLUME 49, NUMBER 17 1 MAY 1994-I

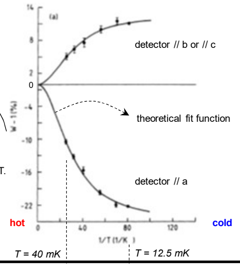
Low-temperature nuclear orientation on the Kondo system $Ce_xNd_{1-x}Ni$

The isotope ^{147}Nd has been oriented by means of low-temperature nuclear orientation on the pseudobinary series $Ce_xNd_{1-x}Ni$ for $x = 0.0, 0.1, 0.25, 0.5$, and 0.8. The results show that the compounds are magnetically ordered due to Nd-Nd interactions and no magnetic moment exists on cerium. The Kondo effect is present (for $x \neq 0$) as revealed by measurements of electical resistivity and thermoelectric power.

Host material: NdNi (orthorhombic: a≠b≠c)
Isotope: ^{147}Nd (I=5/2), 531 keV transition
external field = 0.7 T, // a-axis



W = "hot" counts (=1) minus counts in the same direction at temperature T.



Low Temperature Nuclear Orientation

Nuclear thermometers:

- Previous page: changes of a few mK strongly change the anisotropy.
- Invert this argument: measuring the anisotropy for a known case provides a T-measurement in the mK-region

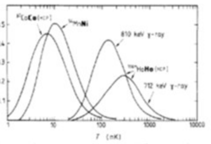


Figure 6. Sensitivity curves for three different NO thermometers. Two different gamma rays are indicated for the ^{166m}HoHo(HC) thermometer, which is useful in high applied magnetic fields and in a higher temperature range. The useful temperature range is that for which the sensitivity function is larger than about 0.1 (after Marshak 1983).

advantages of nuclear thermometers:

- other thermometry in this range is often unreliable
- various sensitivity ranges possible
- can be done under high applied field
- requires no electrical contacts with outside of cryostat
- a tiny extra sample (e.g. hcp-Co) does the job

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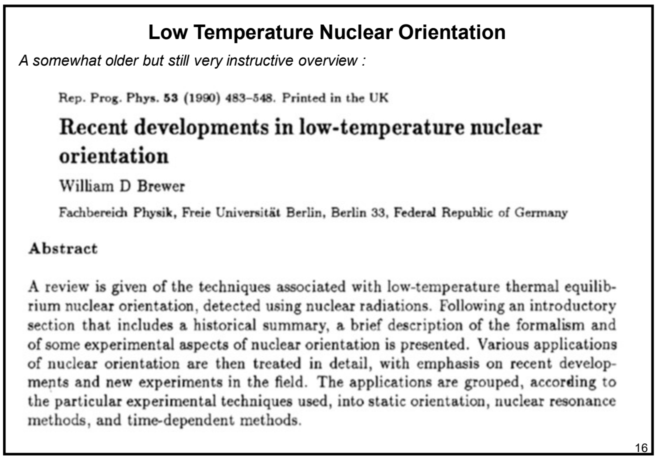

Low Temperature Nuclear Orientation

A somewhat older but still very instructive overview :

Rep. Prog. Phys. 53 (1990) 483–548. Printed in the UK

Recent developments in low-temperature nuclear orientation

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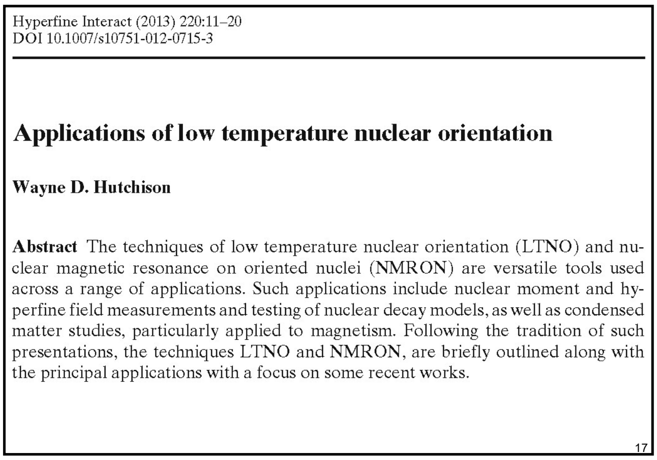
Abstract

A review is given of the techniques associated with low-temperature thermal equilibrium nuclear orientation, detected using nuclear radiations. Following an introductory section that includes a historical summary, a brief description of the formalism and of some experimental aspects of nuclear orientation is presented. Various applications of nuclear orientation are then treated in detail, with emphasis on recent developments and new experiments in the field. The applications are grouped, according to the particular experimental techniques used, into static orientation, nuclear resonance methods, and time-dependent methods.



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Applications of low temperature nuclear orientation

Wayne D. Hutchison

Abstract The techniques of low temperature nuclear orientation (LTNO) and nuclear magnetic resonance on oriented nuclei (NMRON) are versatile tools used across a range of applications. Such applications include nuclear moment and hyperfine field measurements and testing of nuclear decay models, as well as condensed matter studies, particularly applied to magnetism. Following the tradition of such presentations, the techniques LTNO and NMRON, are briefly outlined along with the principal applications with a focus on some recent works.