Isomeric states

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ISOMERIC STATES

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Abstract.

The 2 lectures of about one hour each starts with definitions and a short historical introduction. Since the whole concept of isomerism is based on the ability to measure lifetimes, typical experimental techniques will be reviewed. Different types of isomers will be discussed under the following headlines: 1) Spin isomers. 2) K-isomers. 3) Shape isomers, including fission isomers. The study of isomers has played a very important role in the infacy of nuclear structure physics because special structural features are isolated with high sensitivity. In the future experiments with Radioactive Accelerated Beams (RAB) a very high experimental sensitivity is also needed since the initial beam intensities will be small. The study of isomers are therefore suggested as some of the early experiments for the PIAFE project in Grenoble. The presence of an isomer opens the possibility of different types of time-dependent perturbed angular correlation measurements and evaluation of nuclear moments. Such measurements will be discussed briefly.

Definitions.

Isomeric states are excited nuclear states with a measurable lifetime. The distinction from other states is that its decay is not prompt within the experimental resolving time, and can be singled out experimentally. The whole concept is therefore somewhat ambigous and has been redefined according to the development of experimental techniques over the years. It is still an open question : what is an isomer and what is not?

Historical development.

In the beginning of the thirties isotopic masses had been measured and a systematic search for induced radioactivity was going on. The measurement of radioactivity from the heaviest elements had already been going on for a long time. Nuclear isomerism was first observed and understood in decay studies of ^{238}U where the daughter nucleus ^{234}Th decays into the excited 0^- state and the 4^+ ground state of ^{234}Pa. Previously they were called UX_2 and UZ respectively as a matter of classification. Feather and Bretcher (Proc.Roy.Soc.London(1938))suggested for the first time that the 1.18 min half-life and the 6.75 h half-life belonged to the same nucleus, the shortest being the excited state. Amaldi and coworkers and later Snell found that ^{80}Br was decaying with two different half-lives. This was the first of many isomers discovered by nuclear reaction studies. By improvement of experimental techniques a large number of isomers was discovered and they were found to cluster in islands near magic nucleon numbers. A correlation between a large change of angular momentum involved with the decay of the isomers and the prediction of the nuclear shell model was established.

Spin Isomers.

The even N = 81 isotones from ^{131}Sn to ^{149}Er serve as examples of spin isomers. They all have $h_{11/2}$ neutron hole states which decay by a M4 transition to a lower-lying $d_{3/2}$ excited or ground state. Some of them also have EC-decay to the daughter nucleusin competition with the small M4 transition rates. The systematic occurence of these isomers is used for mapping out particular shell model states over ranges of nuclei and is therefore a powerful method of investigating single particle motion in a mean field. The N = 81 isotones is one example, similar systematics have been established near Z = 50 and Z = 82.

K-Isomers.

Prolate deformed nuclei can accommodate angular momentum along an axis perpendicular to the symmetry axis or along the symmetry axis. States of the latter type are called deformation aligned and the former rotation aligned. Decay of the deformation aligned states into the rotation aligned is forbidden if the transition multipole order is smaller than the change of the K-quantum number between the states. The forbiddenness may result in long half-lives and such states are called K-isomers.
There is a large empirical body of hindrance factors which indicate a preference for decays which minimize the change of K. The theoretical understanding of these decays has been invoking band mixing induced by the Coriolis force, such that the final or intermediate states have finite amplitudes of high-K values. More recently, very sensitive experiments indicate that the dynamics of the decay is much more complicated. A barrier penetration mechanism through a sequence of states with different γ-deformation has been proposed.

Shape Isomers.

The most prominent example of shape isomerism is the fission isomer. The spontanous fission of these isomers was discovered by Polikanov in 1964 and the theoretical understanding of them was formulated in Copenhagen in the end of the sixties. These isomers are due to shell effects on the liquid drop barrier.

A potential well with twice the ground state deformation contains a spectrum of superdeformed states which decay into each other and by barrier penetration to either fission or to the less deformed ground states. The physics of these states is very similar to that of the more recently observed high spin superdeformed states.

Measurement of Nuclear Moments.

If the isomeric lifetimes are sufficiently long, the spatial radiation pattern of multipole transitions can be perturbed by external magnetic or electric fields. By interaction with external magnetic fields, the nuclear magnetic dipole moment can be determined by measurement of the Larmor-precession frequency. The comparison of such g-factors to factors calculated on the basis of intrinsic structures is very valuable for the understanding of the spectrum of excited states. The quadrupole moment of isomeric states can be determined by measurement of the quadrupole interaction when the isomer decays while recoiling in an electric field gradient. In experiment the field gradient of a single crystal is used and the isomer decays while recoiling inside its lattice. The sign of the quadrupole moment is of crucial importance since it distinguishes between prolate and oblate deformation.

Experimental Applications.

The presence of an isomer in the level spectrum opens certain experimental possibilities apart from those already discussed under measurement of moments. The isomer life-time makes it possible for example to select decays which populates this special level by electronic timing or use of pulsed accelerator beam, or both. In the case of ^{147}Gd which has an $I=49/2\ \hbar$ isomer at 8590 keV, it is possible to start the spectroscopy at this level by the requirement of a delayed, high multiplicity cascade following the prompt cascades observed in the beam burst. Other applications of this technique will be discussed.

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