# Nuclear isomers revisited

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Nuclear isomers or metastable nuclear states have been identified in many nuclei throughout the periodic table[1,2]. O. Hahn, co-discoverer of nuclear fission phenomenon, is credited with the discovery of nuclear isomerism way back in 1921 and its interpretation in terms of inhibited gamma decay was provided by Weizsacker in 1936. Even though isomers occur in different types[3] – shape isomers (decay inhibited due to shape mismatch), spin isomers (spin mismatch) and K-isomers (change in spin orientation with respect to axis of symmetry), the discussion here will be limited to spin isomers. In the early days of nuclear physics research, the study of isomers generated a lot of interest, because of the rather peculiar situation of having two nuclei with same Z and A values but different spin values. The nuclear isomers have half-lives at least 100 times more than typical gamma-decay times (~ $10^{-14}$ s) and their occurrence is widespread in odd-A nucleus with odd-N (neutron) number just below the magic numbers, $N = 50,82,126$ (ref. 2). Formation of isomers requires availability of widely different $j$ (angular momentum) orbits for the nucleons (protons and neutrons) at nearby energies in the shell model description of nuclei. This situation is prevalent in the medium–heavy nuclei mentioned above. Some examples of isomers may be given: $^{178}$Hf nucleus has an isomer, $^{178m}$Hf, located at $E_x = 2.4$ MeV with $J^\pi = 16^+$ and half-life of 31 years. $^{180}$Ta has an isomer, $^{180m}$Ta, with $E_x = 0.075$ MeV, $J^\pi = 9^-$ and half-life value of $10^{15}$ years and it ranks amongst the largest half-lives known. The isomers decay predominantly by electromagnetic processes (gamma decay or internal conversion). There are also instances where it has been observed that the decay is initiated by strong interaction ($\alpha$ or proton emission) or by weak interaction ($\beta$-decay of electron capture).

Nuclear isomers are usually produced through fusion reactions. When a swift moving heavy ion fuses with a moderately heavy target nucleus, a compound nucleus is formed at high excitation energies and with large angular momenta. The hot compound nucleus deexcites by emitting particles and gamma rays. In this process, the decaying nucleus might populate an isomeric state and its subsequent decay gets inhibited due to large spin change involved between the isomeric state and the lower energy state(s). Recently, partial fusion or break-up fusion reactions involving weakly bound projectiles (like $^{6,7}$Li, $^9$Be) have been found to be not only favourable but perhaps the only way to populate some of the spin isomers[3]. Scattering reactions utilizing the strong Coulombic interaction between two heavy nuclei have also been employed to produce these metastable states.

Recently, there has been renewed interest in the study of isomers, with the prospects of realizing enormous amount of stored energy in nuclei through the accelerated decay of isomer. If one has to manipulate the isomer to deexcite on a faster time scale, then it is essential to have a better understanding of nuclear structure of not only the isomer but also the neighbouring excited states. In principle, low energy (eV–keV) photons should be able to initiate an accelerated decay of isomer either by stimulated emission to a nearby lower energy state or absorption to a nearby higher energy state. In essence, the meta-stable state can be made to shed its stored energy on a faster timescale, resulting in considerable energy gain. From level density considerations, availability of nearby excited states having favourable spin values through which isomer could decay, is expected to be more probable in the case of isomers occurring at high excitation energies. Very recently encouraging results have been reported in several efforts made to initiate a faster decay of isomer. Collins *et al.*[4] have observed accelerated decay of 2.4 MeV, 31-year-old isomer in Hf ($^{178m}$Hf) induced by ~ 40 keV photons from a dental machine. They have reported increased decay rate of the isomer by 4 ± 2%. According to Collins *et al.*, this amounts to an energy gain of 60! The $^{229m}$Th isomer at $E_x = 3.5 \pm 1.0$ eV with a half-life of 45 h has received special attention because the excitation energy involved here is similar to the values one encounters in atomic excitations. Shaw *et al.*[5] have critically examined the UV spectrum from $^{233}$U and found a transition at 391 nm. According to the authors, this line could be a good candidate to be identified with the 3.5 eV isomer decay from $^{229m}$Th initiated by light. These studies are of basic interest from the point of view of understanding light (laser)–nucleus interaction. A complete understanding of this will lead to greater prospects of realizing the stored energy of isomer in a cheap way by use of low energy light sources. A beginning has been made in comprehending the 'isomer laboratory' and the ongoing efforts to tap the reservoir of stored energy through the isomer route hold promise for future.

1. de Shalit, A. and Feshbach, H., *Theoretical Nuclear Physics*, John Wiley and Sons, New York, 1990, vol. 1; Segre, E., *Nuclei and Particles*, W. A. Benjamin, Inc., New York, 1964.
2. Goldhaber, M. and Hill, R. D., *Rev. Mod. Phys.*, 1952, **24**, 179.
3. Walker, P. and Dracoulis, G., *Nature*, 1999, **35**, 399; Dracoulis, G., *et al.*, *J. Phys. G. Nucl. Particle Phys.*, 1997, **23**, 1191; Walker, P., *Phys. World*, May 1999, p. 19.
4. Collins, C. B. *et al.*, *Phys. Rev. Lett.*, 1999, **82**, 695.
5. Shaw, R. W., *et al.*, *Phys. Rev. Lett.*, 1999, **82**, 1109.

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