UCRL-ID-114980

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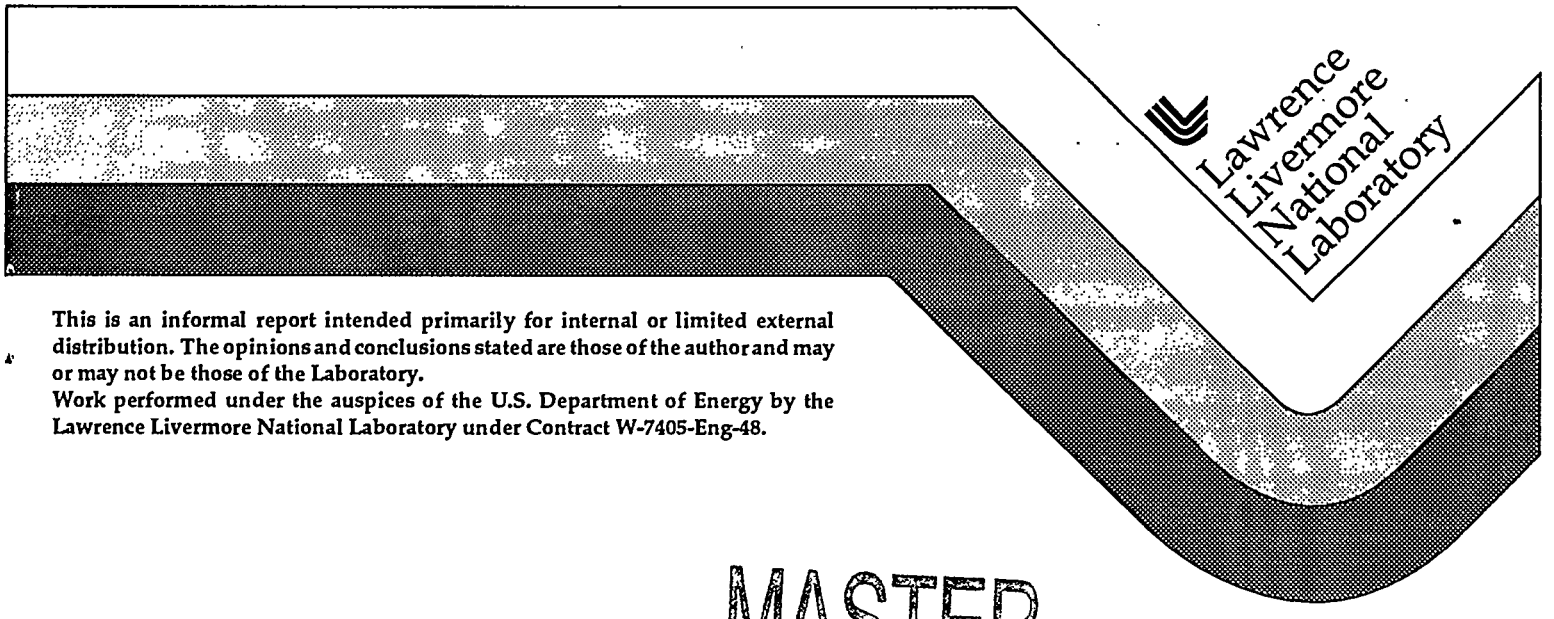
July 27, 1993



A New Atomic Mechanism for Nuclear Isomeric Energy Release: TE^2N

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In this short note we wish to describe schemes which mix atomic and nuclear energy levels and so permit transfer of nuclear energy to the atomic system from which it is extracted. In addition, we will describe a scheme for stimulating this transfer process which offers the possibility of multi-kilovolt coherent radiation. These ideas are based upon newly available, novel experimental techniques which permit the precise filling of atomic levels and the availability of a broad range of lasers. These new abilities permit the tuning of atomic levels so that they are degenerate or nearly degenerate with nuclear isomeric levels. Such processes permit the exploration of highly leveraged research which could lead to radiation free Ultra High Energy Density Materials in addition to X-Ray Lasers with Gamma ray energies.

In its simplest form, causing a degeneracy, within an atomic line width, between a long lived nuclear transition and an atomic transition, would transfer all or part of the nuclear excitation energy to the atomic electrons. These would then quickly emit the energy as x-rays as the atomic half life is much shorter than that of the nucleus. There are several evidences of the inverse of this phenomena in the laboratory where naturally occurring coincidences exist between the nuclear and atomic energy levels. This is referred to as NEET (Nuclear Electron Energy Transfer). As we will describe below, it has been a laboratory curiosity for over 20 years where it has been used to **excite** nuclear levels. However, controlled use of this phenomena has not been previously described nor has its use to **de-excite** isomers.

An adjunct to the process we have described is to take advantage of the availability of lasers to convert a near degeneracy of an atomic and nuclear transition to an actual degeneracy through a multi-photon process which alters the energy of the atomic state. Such processes have the potential to proceed quite rapidly. While this is generally thought of as increasing the energy of an atomic transition, an alternate scheme could be much faster. That is to use the laser to stimulate emission of a photon carrying away excess nuclear energy. This offers the possibility of using a low frequency laser to so speed up the transfer of isomeric energy to an atomic system that an inner shell vacancy will be created with sufficient rapidity as to cause an inversion*. This would present the potential of a high

energy X-Ray Laser pumped by the nuclear isomer. Such a lasing scheme would have the energy of a nuclear transition but would avoid one of the traditional problem of a gamma ray laser in that the levels would have **atomic** widths.

As we will outline all of the phenomena can be examined in a modest laboratory facility such as the Lawrence Livermore Electron Beam Ion Trap (EBIT), although implementation may require both high intensity and high power lasers .

DESCRIPTION OF NEET

The possibility of nuclear excitation from an electronic transition (NEET) has been studied for over 20 years, going back to the work of Morita[ref 1] in 1973. Its features have been recently described quite succinctly in a recent Physics Letter article [ref 2]. The concept is that if a nuclear transition and an atomic transition have the same multipolarity and are energy degenerate within the atomic line width, the atomic and nuclear levels will mix. As pointed out in reference 2 this process has been ferried experimentally by creating an atomic K shell vacancy and then detecting the subsequent nuclear decay half life. One might have expected that the decay would have the half life of the electron state; however, in many cases this is prevented by the Pauli exclusion principle. When an electron jumps from a higher shell into a lower shell it emits a photon which is absorbed by the nucleus, i.e. NEET. However, in general, in a time short compared to the inhibited atomic transition, an electron from a higher shell will fall into this vacancy, blocking the re-absorbtion of the energy from the nuclear transition by the atomic level.

This NEET process has been considered an academic curiosity even though Morita's original work on the subject was its examination as a mechanism for separating ^{235}U. This phenomena has been considered without application because the excitation probability is very small (10^{-4} to 10^{-8}) even for E1 and M1 transitions. Moreover, there are very few "naturally occurring" cases of the degeneracy necessary for the NEET process.

However, modern atomic techniques offer the great potential for engineering atomic transition energies such that many more nuclear-atomic line transition "coincidences" can be arranged. This can be accomplished microscopically by using lasers to create specific inner shell vacancies or by devices like E-BIT which depopulate an atom's electrons to some prescribed inner level. Macroscopically, the latter can be achieved by adjusting the temperature of a plasma containing these atoms. The relatively small yield can also be "engineered" by reducing competing processes by controlling atomic electron occupation in crucial orbits by E-Bit/laser interaction.

The most obvious high leverage use of anti-NEET (TE^2N) is the controlled de-excitation of nuclear isomers. As pointed out earlier, a nuclear level excited via NEET decayed with a slow nuclear lifetime because the process of re-transferring energy back to the fast decaying atomic system was prohibited by the lack of inner shell atomic vacancies, i.e. the lifetime for filling the created vacancy is usually much faster than an inhibited (high multipolarity) atomic transition. Clearly starting from a long lived nuclear state, removing the blocking atomic electron from a specific level would permit this relatively fast transfer and atomic decay. Moreover, in most isomer decays it is not necessary to transfer all of the nuclear energy. In many cases, causing a transition from the isomeric level to nearly any other level, which in general will transfer much less energy than the isomer has stored, will then cause the remainder of the isomeric energy to be quickly released as gamma rays. An example of this is $^{178}Hf^*$ whose isomer requires only 30Kev to initiate the release of 2.5 Mev stored in the isomer.

PROGRAM TO STUDY THIS PHENOMENA:

The most obvious and straight forward demonstration of the usefulness of this process would be to take a sample of ^{197}Au or ^{237}Np in their isomeric states and stimulate the decapitation, e.g. using EBIT. Unfortunately the experimental cases which have been identified to date all have Ms half-lives and so it is impractical to detect them in a controlled experiment. We need to expand our knowledge of atomic transitions for nuclei with reasonably long half lives (days or more) isomeric transitions. While we are generating this atomic level data base we can also make great strides in our computational understanding of this process and its justification.

Increasing nuclear decay lifetimes by changing atomic filling

^{235}U because of the intrinsic complexity of the atomic level structure of Uranium and the presence of a 73 volt nuclear spin isomer is an ideal candidate for studying this phenomena. This isomer normally decays by ejection of the 6S electron, normally bound by 48 electron volts into the continuum. This transition has a half life of approximately 21 minutes. The pure photon decay of the isomer, which would take place only in a stripped atom, has a calculated half life of billions of years. Hence to create a laboratory in which to study our phenomena, we could strip ^{235}U isomer of 11 electrons which would make the $5f_{7/2}$ level the last bound orbit with a binding energy of 112 electron volts. Hence, normal internal conversion would be energetically forbidden

in this special case. However, the $5d_{5/2}$ transition to the $6s_{1/2}$ (unfilled) level would have a transition energy of approximately 66 volts. The nucleus could internally convert by propagating a d electron up to the s level and getting rid of its extra energy with a second photon. One would expect this transition to be inhibited by the extra electromagnetic vertex but perhaps enhanced by an increase of the electron wave function overlap at the nucleus compared to the normal internal conversion. This is a calculable process and comparison with experiment would provide assurance that one had an accurate description of the phenomena. The signature of this "two photon internal conversion" would be the photon characteristic of the decay of the 6s to the 5d simultaneous with the low energy photon making up the extra energy.

Decreasing lifetime of a nuclear state with a laser:

Armed with this information one could calculate the enhancement of this decay rate when the system is exposed to a laser of the frequency of the extra photon. It is reasonable to expect that the lifetime would be decreased by perhaps at least three orders of magnitude but the precise numbers would undoubtedly depend critically upon things that must be calculated such as thermal broadening, intrinsic widths of the atomic levels, width of the laser, etc. Comparison of theory and experiment would provide assurance that one is in control of the description of the system, particularly if one enters a regime in which the external laser begins to perturb the atomic levels.

Using enhanced decay to pump X-Ray laser:

Based upon the above results one will be in a position to calculate the possibility that laser accelerated two photon internal conversion would produce an inversion in the primary atomic vacancy to permit spontaneous lasing. What one has in mind is a thin bar of isomeric material with the requisite outer electrons stripped by creation of a hot plasma. Shining a low frequency laser upon such a bar would enhance the transfer of most of the isomer energy to a relatively deep atomic level (in our model case, the 5d to 6s) but the extra low energy photon has the potential of contributing to gain in the low frequency external laser. If this process is fast enough, the primary photon, in our case some 66ev, could do a one pass lase. In effect this has the energy of a nuclear transition, the isomeric energy, but with atomic widths which should enormously reduce the criticality of the re-coil problem which has inhibited development of a gamma ray laser.

CONCLUSION

As a last comment, what we have described here is a "researchers" view of some interesting things that a program might look like. In the area of atomic physics LLNL is blessed with a "cadre" of physicists (V, A, L and X Divisions) capable of reformulating these physics ideas into a coherent applied program with realistic goals and actually executing such a program!

* This is only one of the processes which could cause such an inversion. The other two are by "dressing" the atomic transition to increase its energy to be coincident with the nuclear transition or by removing a specific bound electron vacancy with a laser or an electron beam to cause level shifts which would make an atomic transition degenerate with the nuclear transition. Stimulating the emission of a low energy photon carrying off the surplus energy of a nuclear transition contains the possibility that the stimulated emission will enhance the low energy lasing and might be the fastest of these processes.

Ref. 1: M. Morita, Prog of Theoretical Physics 49, 1574, (1973)
Ref. 2: A. Ljubieie, D. Kekez and B.A. Logan, Physics Letters B272, 1, (1991)

Work performed under the auspices of the United States Department of Energy at Lawrence Livermore National Laboratory (an equal opportunity employer) under Contract Number W-7405-ENG-48.

27 July 1993

Technical Information Department • Lawrence Livermore National Laboratory
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