NUCLEAR TRANSITIONS INDUCED BY ATOMIC EXCITATIONS

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ABSTRACT

In the two-step pumping scheme for a gamma-ray laser, an essential step is that of exciting the nucleus from a long-lived storage isomer to a nearby short-lived state that then decays to the upper lasing level. For a crystalline structure host, the radiation must be used efficiently so as not to destroy the crystal. High intensity sources of photons are available only for relatively low quantum energy, but it is difficult to couple a long-wavelength photon directly to the much smal`er nucleus. An experiment is proposed to induce this transfer by first exciting the atomic electrons. The nuclear excitation should occur by the exchange of a virtual photon in the near field of the electrons. As a test case, the 73 eV ^{235m}U isomer might be excited by electronic motions induced by a high-brightness UV laser. The conversion electrons from the decay of the isomer would be detected and a 26 minute decay curve would indicate induced nuclear transitions.

It has already been demonstrated that lasers can be used to excite nuclear transitions. In the experiments of Izawa and Yamanaka of Osaka University[1] the isomeric state of ^{235}U was produced by laser bombardment of natural uranium. The laser formed a plasma which in recombining excited the nucleus to its 73 eV isomeric state. The experimenters attributed this to the coincidence of electronic energy level differences with the nuclear excitation energy. The coined abbreviation NEET (Nuclear Excitation by Electron Transition) refers to this process. Goldanskii and Namiot, however, attributed the experimental results to inverse internal electron conversion (IIEC) wherein the nucleus is excited when the electrons make a transition from the continuum to a bound state.[2] They argued that the probability of a free-bound induced transition is about three orders of magnitude greater than the bound-bound induced transition probability for the Japanese experiment. In either case the nucleus is believed to be excited by an electron transition in the cooling plasma created by a strong laser pulse.

Yet another mechanism has been proposed to excite a nucleus with a laser pulse. It has been observed that the intense electromagnetic field from a high-brightness laser causes effects that indicate strong coupling of energy to the atoms.[3] It has been postulated[4] that once the laser electric field strength, as seen by the electrons in the focal volume of such a laser, approaches the field strength of the binding energy for these same electrons, chaotic and possibly correlated motion of the electrons may be produced. With such motion high multipolarity fields may be produced at the nucleus. In addition, the field from the electron
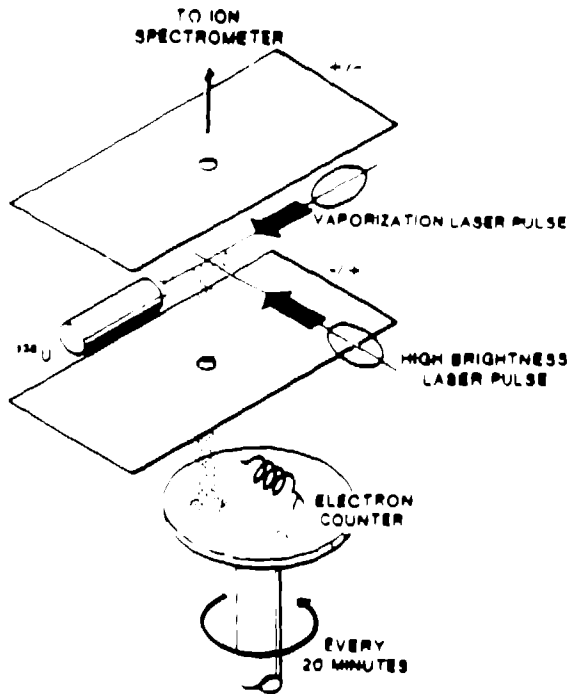
Fig. 1. Ion collection scheme. Gas puff in center is created by a vaporization laser pulse striking a ^{235}U sample. The high-brightness laser pulse strikes the puff. According to plate polarity, the ions are either analyzed in the spectrometer or collected and later counted.

motion would couple to the nucleus much more strongly than an external field alone would, since the electrons and nucleus interact through the near field. This same near-field effect is what causes internal conversion to dominate multipolar electromagnetic transitions at low energies.

The experiment proposed to test these effects is as follows The nucleus ^{235}U is chosen since its isomeric level at 73 eV is the lowest known and is within the energy transfer range of current high-brightness lasers. The isomer decays by internal conversion, emitting low-energy electrons. In the experiment a low density vapor of uranium is produced by pulsed laser evaporation of a small sample. The high-brightness laser is focused into this vapor. If the laser produces transfers to the excited nuclear state, these excitations can be detected by looking for electrons emitted in the later decay of the isomer. Typically the laser irradiations would occur at a rate of 10 per second for one isomeric half-life (26 minutes) followed by electron counting for a period of one or more half lives. An electron signal falling off in intensity with the half life of the isomer would indicate production of the isomer.

There are two possible collection schemes. In the first, the atoms are collected as the gas puff deposits on a surface. The conversion electrons, whose energies are typically 10 to 20 eV, can penetrate only a few monolayers through the surface. Thus the target gas density is limited since the high-brightness laser intersects only a small portion of the gas puff, and during the deposit the unexcited atoms tend to cover up those that experienced the strongest laser field. After the collection period, the deposit is moved in front of an electron counter for data acquisition. A retarding grid between the deposited atoms and the electron counter can offer rapid evidence whether or not the detected electrons have

less than 73 eV energy. In the second collection scheme, the gas puff irradiation occurs in a region of electric field produced by two parallel plates (Figure 1). The high-brightness laser ionizes nearly all of the atoms of interest, i.e. those atoms which experience the strongest field. The ions are extracted by the electric field to a collector where they are accumulated as before until counted. In this ion collection scheme the ratio of atoms collected from the beam interaction region to atoms collected from the rest of the gas puff is much higher, allowing the use of higher gas densities and therefore permitting detection of a smaller effect.

These experiments will be carried out for a wide range of vapor pressures and laser powers to map out the process. At the low vapor pressures proposed in these experiments, inverse internal electron conversion, which depends strongly on the plasma density, should be negligible. A cross-section for the conversion rate will be determined. It is conceivable that this method of exciting nuclear transitions may be of use in gamma-ray laser research,[5] perhaps serving as the required pumping process.

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