

NUCLEAR TRANSMUTATIONS INDUCED BY LOW ENERGY γ -RAYS

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The possibilities for low-energy γ -rays to induce nuclear transmutations and the relevance of this process to the solar neutrino experiments is discussed. A ^{197}Au target was exposed to ^{60}Co γ -rays and the cross-section for the formation of $^{196\text{m}}\text{Pt}$ found to be $(1.3 \pm 0.5) \times 10^{-31} \text{ cm}^2 \text{ keV}$. This result, with the error quoted at the 68% confidence level, should be still regarded as an upper limit on the probability of the process. Alternative much more sensitive detection techniques are suggested.

1. Introduction

The annoying solar neutrino puzzle has only been proven persistent by the recent addition of the Kamiokande result to the well known results of Davis¹⁾. A number of other experiments to measure various portions of the solar neutrino flux are well under way²⁾. The only candidate to measure the whole of the flux integrated over the last couple million years, and thus to check independently the rate of the basic p-p cycle in the past, is the production of ^{205}Pb ($T_{1/2} = 15 \times 10^6 \text{ y}$) by the solar neutrino capture in ^{205}Tl ³⁾. However, many other reactions also yield ^{205}Pb and careful subtraction of all such contributions is essential to the final interpretation⁴⁾. One of the possible exotic background processes which

has recently been proposed⁵⁾ is the Low-energy Gamma-ray Induced Nuclear Transmutation (which for convenience from here on we abbreviate as »LeGINT«). This would be a multistage process comprising resonant excitation of a short-lived (wide) excited state by an environmental low-energy gamma-ray, its subsequent decay to a lower lying state which would in turn live long enough to allow for an appreciable beta decay branching to one of its first neighbour isobars.

2. Order of magnitude estimate

The neutrino capture rate, $\sigma\Phi$, in ^{205}Tl is of the order of 100 SNU (1 SNU = 10^{-36} captures per second per target atom) and a background reaction with a rate of one tenth of that may be considered already as contributing significantly. If the flux of gamma-rays at the site of the Tl mineral deposit is, say, ten orders of magnitude smaller than the neutrino flux, i. e. equal to $\cong 10^{-2} \gamma/(\text{cm}^2 \text{ s keV})$, then a total cross-section σ_L for the LeGINT process of the order of $10^{-33} \text{ cm}^2 \text{ keV}$, which would otherwise be considered negligible, should be taken seriously. To see whether this is a realistic value we may take for the resonant excitation cross-section the values measured in various experiments on photoactivation of isomeric states, which also include the gamma-ray branching to the longer lived state, which are typically of the order of $10^{-28} \text{ cm}^2 \text{ keV}^6)$. This would leave us with the value of $\cong 10^{-5}$ for the beta branching from this state as the dangerous lower limit, what certainly seems unlikely high. The possible though yet unexplained non-resonant excitation mechanisms⁷⁾ would bring this to more likely values and the possibility for a number of different LeGINT channels to contribute to the total cross-section when two complex decay schemes are involved would push this limit further down. It thus seems that under favourable, or better say unfavourable, conditions the LeGINT processes might be relevant.

It is, however, very difficult to be more specific in the particular case of the Tl solar neutrino detector (as indeed in most other cases). Both the ^{205}Tl and ^{205}Pb have complex schemes of excited states numbering some 30 states each up to $\cong 2.6 \text{ MeV}$ (what is about the highest environmental gamma-ray energy). Among those states there are many with unknown lifetimes, spins and parities⁸⁾ making it impossible to judge with any confidence the overall probability for all the possible LeGINT channels. It is, on the other hand, readily seen that the cross-section of the order of the critical $10^{-33} \text{ cm}^2 \text{ keV}$ would upon exposing Tl to available high fluxes of gamma-rays for reasonably long irradiation times produce quantities of ^{205}Pb well within the reach of the ultra-sensitive detection methods being developed for the actual solar neutrino experiment⁹⁾ thus enabling a purely experimental determination of the contribution of the LeGINT processes.

3. Experimental data and results

Wishing to gain some more quantitative feeling for the LeGINT processes before those high-sensitivity techniques are available we decided to try to detect such a process by employing the low background gamma-ray spectroscopy to mea-

sure the activity of the conveniently short-lived and low Q -value first neighbour isobars induced by exposing the stable bottom isobar of the chain to the high flux of ^{60}Co gamma-rays. With this in mind our choice fell on ^{197}Au whose relevant part of the decay scheme together with its neighbours is shown in Fig. 1. Assu-

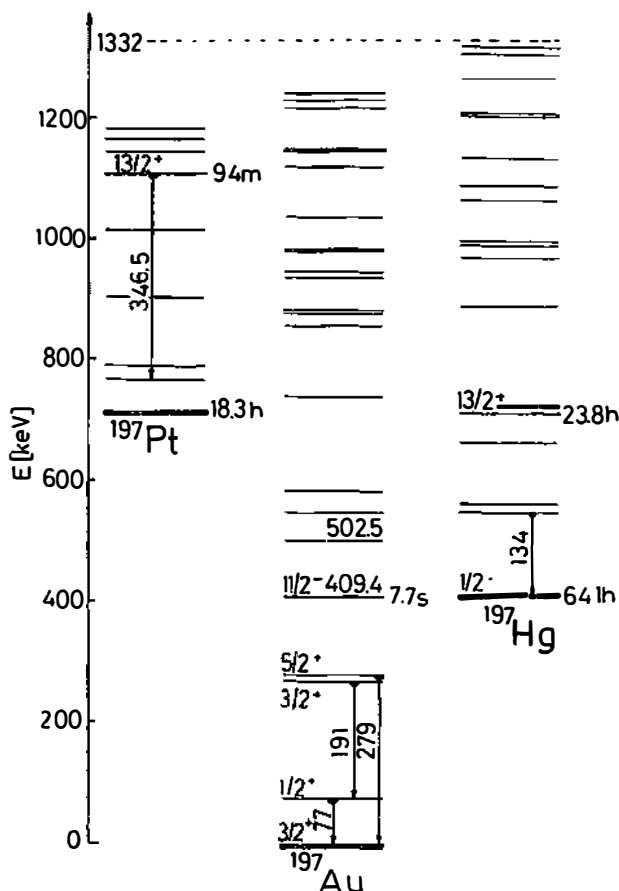


Fig. 1. The parts of the decay schemes of ^{197}Au and its neighbours relevant to LeGINT.

ming the available flux of gamma-rays, the analysis based on the detailed knowledge of the background spectrum of our shielded gamma-ray Ge spectrometer (used already in a number of experiments devoted to the pursuit of low-probability phenomena¹⁰⁾, on the criteria for the spectral detection limit¹¹⁾, on the detection efficiency, and supposing the optimum irradiation and spectral measurement times¹²⁾ as well as the optimum target thickness¹³⁾ showed that under extreme care the sensitivity of the method would be sufficient to reveal a total cross-section of the order of $10^{-32} \text{ cm}^2 \text{ keV}$. Judged by the detection properties only, the gamma-rays which should be sought for in the first place are those with transition energies marked in Fig. 1, the most promising one being the 346.5 keV transition in ^{197}Pt .

The experiments were thus performed optimizing the conditions for the activation and detection of the activity of ^{197m}Pt .

The gold disk of 34 g and a thickness of 2 mm was irradiated in a flux of $1.2 \times 10^{11} \text{ cm}^{-2} \text{ s}^{-1}$ ^{60}Co gamma-rays (6 cm away from the 5.5×10^{13} Bq source) for 10.3 ks in each run and after a cooling (transportation) time of 1.2 ks measured for 11 ks on the 25% efficiency Ge detector; ten equal runs were completed altogether. The background spectrum was measured for 610 ks with the gold disk in position, before and after the irradiations. Each of the ten spectra were integrated channel-by-channel in the regions of interest as well as by the Micro-SAMPO routine. The position of the most intensive background lines in the spectra did not change more than one channel during the whole experiment. Since the stability of the spectra was perfect all the ten spectra were added together and the sum spectrum finally analysed in the same way.

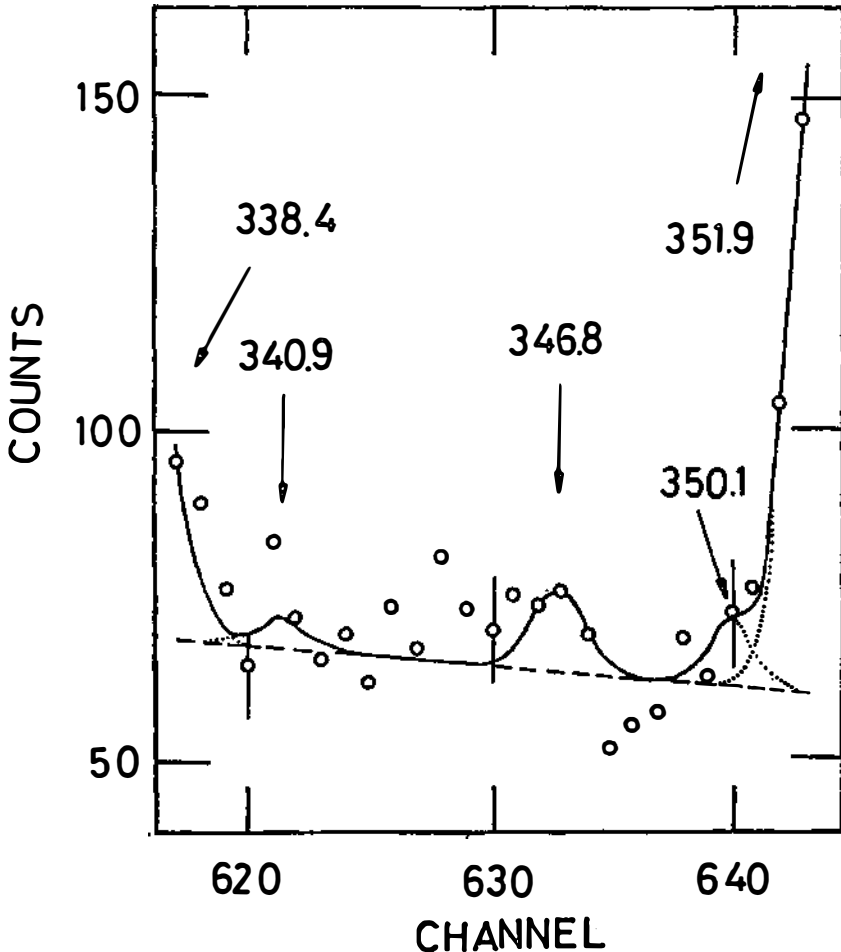


Fig. 2. a) The 346.8 keV regions of the γ -spectra: a) ^{197}Au activated with ^{60}Co γ -rays.

In seven out of ten spectra some non-zero intensity has been found always in the region of the 346.8 keV line. This region in the sum spectrum is depicted in Fig. 2a while the same region of the background spectrum is presented in Fig. 2b. The line shape in the sum spectrum is what Micro-SAMPO fitted in the auto-search mode at (346.5 ± 0.22) keV with an intensity of $(0.40 \pm 0.14) \times 10^{-3}$ counts per second. In the background, in a forced mode at 346.5 keV the intensity of $(0.03 \pm 0.08) \times 10^{-3}$ cps was found, the errors being quoted at the 68% confidence level. Assuming a uniform distribution of the gamma-ray flux over the entire range of the 1332 keV (noting that the real flux at the resonance could be both bigger or smaller than this value) the total cross-section for the activation of ^{197m}Pt corresponding to the spectral intensity quoted is:

$$\sigma_L = (1.3 \pm 0.5) \times 10^{-31} \text{ cm}^2 \text{ keV}.$$

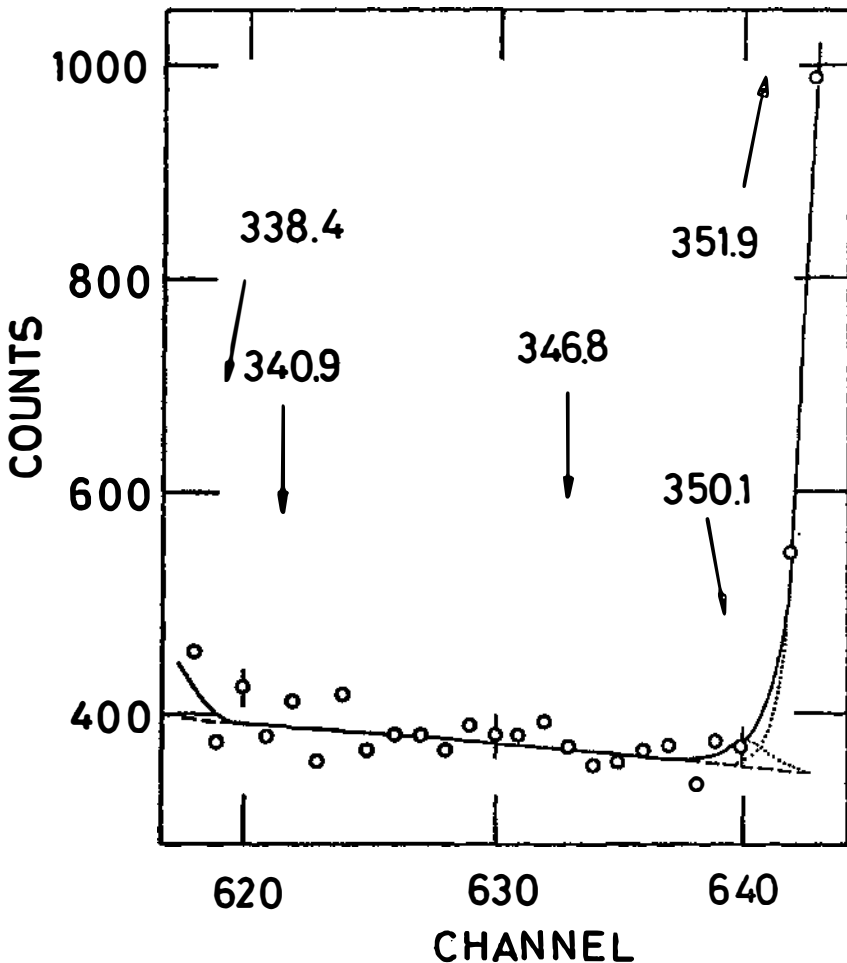


Fig. 2. b) background. The energies of the present background lines are also marked by arrows

The systematic uncertainties of the flux value at the resonance can affect the result obtained by an order of magnitude. This additional uncertainty is unessential for the detection of the LeGINT process, but must be taken into account in theoretical considerations.

4. Discussion

The unexpectedly high figure obtained calls for several comments. It points to the existence of an indirectly photoactivated high spin longer lived excited state in ^{197}Au in the range from 1100 to 1330 keV with a significant EC branching to the $^{197\text{m}}\text{Pt}$ state. This might be the 1231 keV, $I = 11/2^+$ state seen in the Coulomb excitation and angular distribution measurements¹⁴⁾ although without the data on the lifetimes of this and other states in this energy range conclusions are only tentative. One also cannot exclude the possibility of the involvement of an as yet unknown state in ^{197}Au having similar supersymmetric properties to the $^{197\text{m}}\text{Pt}$ state¹⁵⁾, of the relatively long half-life, and thus favouring the EC decay (one should note that in photoactivation of isomeric states the involvement of states and transitions not involved in other excitation modes is not uncommon, see Ref. 10 for instance). The situation is of course completely symmetric with respect to $^{197\text{m}}\text{Hg}$ to which the beta-minus decay would be even enhanced due to the potentially higher beta transition energy. If the 346.5 keV line in our spectrum is indeed a genuine one then the absence of the 134 keV line is due to the too short irradiation times as well as to the poor transparency of gold at this energy. Longer irradiation times alone, which we anyhow could not afford due to the perpetual clinical uses of the Co source, would thus not be helpful in this respect, without increasing the strength of the source at the same time.

A definite proof of the observation of the LeGINT process should give non-zero value for the cross section at 99% confidence level. Our present results do not meet this criterion, since at this (3σ) confidence level the measured value $\sigma_L = (1.3 \pm 1.5) \text{ cm}^2 \text{ keV}$ gives only an upper limit on the probability of the LeGINT process in gold.

Finally, the ^{71}Ga - ^{71}Ge solar neutrino detector presents an especially promising LeGINT case since both the nuclei possess extraordinarily rich schemes of low-lying excited states. Irradiation of larger quantities of gallium by high fluxes of gamma-rays and using one or the other of the two different ultra-sensitive techniques developed for the detection of the Ge atoms produced^{16, 17)} would reveal extremely small total σ_L cross-sections. Those sophisticated detection techniques would thus provide a unique tool for the detailed study of the LeGINT processes, and in particular of the part pertaining to the beta decays of excited nuclear states which are hardly observable otherwise. Due to the small gamma-ray fluxes at the sites of actual gallium experiments, however, the LeGINT processes, even if found significant, most probably would not constitute a threat to the solar neutrino experiment.

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NUKLEARNE TRANSMUTACIJE INDUKOVANE NISKOENERGETSKIM GAMA ZRAČENJEM

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Diskutovana je mogućnost indukovanja nuklearnih transmutacija niskoenergetskim gama zracima i relevantnost ovog procesa za detekciju solarnih neutrina. Meta ^{197}Au je ozračena gama zracima ^{60}Co i ustanovljeno je da presek za formiranje $^{197\text{m}}\text{Pt}$ iznosi $(1,3 \pm 0,5) \times 10^{-31} \text{ cm}^2 \text{ keV}$. Ovaj rezultat sa greškom na nivou poverenja od 68% još uvek određuje samo gornju granicu za verovatnoću procesa. Alternativne mnogo osetljivije tehnike detekcije su sugerirane.