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PROSPECTS FOR COHERENTLY DRIVEN NUCLEAR RADIATION BY COULOMB EXCITATION

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Возможности управляемого когерентного излучения ядер под действием кулоновского возбуждения

Обсуждаются возможные эксперименты по кулоновскому возбуждению изомеров с последующим высвобождением энергии. Также рассмотрена возможность когерентного кулоновского возбуждения ядер, включенных в решетку кристалла, при каналировании релятивистских частиц. Сдвиг фазы возбуждения соседних в решетке ядер может быть идентичен сдвигу фазы фотонов, излучаемых в переднем направлении. Таким образом, элементарная струна атомов может излучать характеристические ядерные гамма-кванты когерентно, а интенсивность излучения возрастает в результате суммирования амплитуд. Для данного нового типа коллективного излучения мессбауэровские условия должны иметь важное значение, а само излучение может оказаться перспективным в контексте проблемы создания гамма-лазера.

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Prospects for Coherently Driven Nuclear Radiation by Coulomb Excitation

Possible experiments are discussed in which the Coulomb excitation of nuclear isomers would be followed by sequential energy release. The possibility of the coherent Coulomb excitation of nuclei ensconced in a crystal by channeled relativistic heavy projectiles is considered. The phase shift between neighbor-nuclei excitations can be identical to the photon phase shift for emission in forward direction. Thus, the elementary string of atoms can radiate coherently with emission of characteristic nuclear γ rays and the intensity of the radiation could be increased due to the summation of amplitudes. The Mössbauer conditions should be important for this new type of collective radiation that could be promising in the context of the γ-lasing problem.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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1. INTRODUCTION

The creation of an externally-driven γ-ray source using triggered decay of nuclear isomers has been proposed and discussed in the special volume of Ref. [1]. Even earlier the idea was suggested [2] for nuclear Coulomb excitation applied to the pumping of a nuclear ensemble in future schemes for a γ-ray laser. Experimentally, triggering of the ^{178m2}Hf isomer in inelastic scattering reactions was tested in 1996–1997 by the «Hafnium Collaboration» using an in-beam multidetector system and an α-particle beam of the Orsay Tandem accelerator. Due to the restricted thickness and purity of the isomeric target, conclusive results have not been obtained or published, but partial analysis indicated that an excitation energy of about 300 keV is needed for successful triggering of this isomer. Many subsequent efforts were spent to find triggering of ^{178m2}Hf with low energy X-rays or synchrotron photons at $E_\gamma < 100$ keV, but definite evidence reproducible by different groups have not been obtained. A review of these experimental attempts is given in Ref. [3] for the ^{178m2}Hf isomer, most attractive for applications due to its long half-life, 31 y, and the high density of stored energy, 1.3 GJ/g. Nuclear spectroscopy with the Coulomb excitation technique was proved over many years as very valuable for measurements of strengths of nuclear transitions and it can be applied to search for and to quantitatively study triggering transitions in ^{178}Hf. In the present work, such an experiment is proposed and described in some detail, including the general scheme, background conditions, expected count rate and the absolute sensitivity.

The Coulomb excitation can also be valuable in another mode of application, i. e., for coherent nuclear excitation by relativistic heavy projectiles. It should be stressed immediately that such a process can provide coherence both in excitation and radiation of the nuclei ensconced in a crystal lattice. An elementary string of atoms in the lattice can radiate coherently at a frequency corresponding to the characteristic nuclear γ line. The Mössbauer conditions will clearly play an important role for this collective radiation. In the literature, many kinds of coherent radiation generated by charge particles in crystals were described, e. g., parametric radiation, channeling radiation, etc. In addition, the idea of a γ-lasing scheme has been described using short bursts of a crystallized ion beam in a cooler ring [4]. The multiple resonance excitation of each projectile nucleus by regular collisions in a crystal was considered in detail in Ref. [5]. In the present work, the idea of coherent radiation emitted by the lattice nuclei due to the Coulomb excitation by channeled relativistic heavy ions is discussed.

2. SEARCH FOR TRIGGERING LEVELS ABOVE THE ^{178m2}Hf ISOMER

In the experiment described in Ref. [6], the population of levels in bands built on isomers was successfully observed via Coulomb excitation reactions acting on the stable ^{178}Hf isotope in its ground state. Surprisingly, the cross section for this population was moderately high and this was attributed to strong K-mixing of different structure configurations at high angular momentum, i. e., between the band built on the $K = 16$ isomer and the ground-state $K = 0$ band. The interband transitions were eventually deduced from the results of Ref. [6] and they are displayed in Fig. 1, where the partial level scheme of ^{178}Hf is shown.

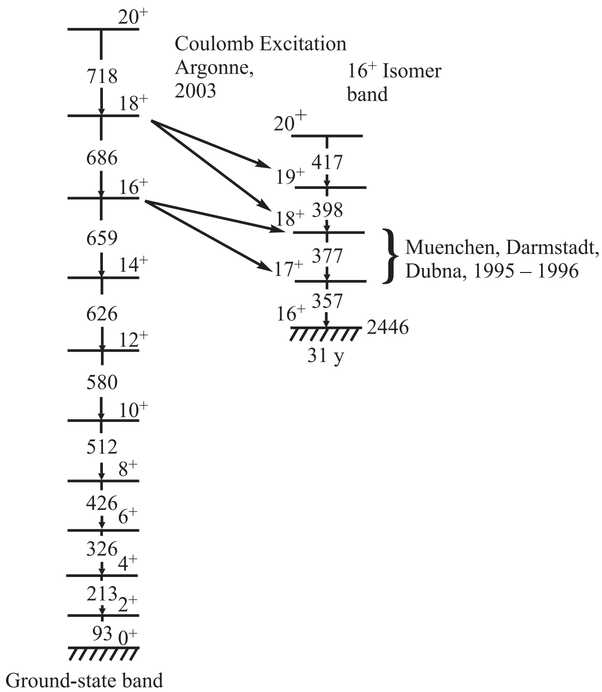

Fig. 1. Partial energy-level scheme for the ^{178}Hf nucleus

This observation suggests a special experiment with the aim to observe triggering of the ^{178m2}Hf isomer into the levels of the ground-state band via the Coulomb excitation, essentially as an inverse of the reaction observed in Ref. [6]. The magnitude of the cross section for the population of ^{178}Hf isomers [6] likewise promises significant probabilities for the reversed process of triggering. A successful new experiment will quantify parameters such as the energies, multipolarities and reduced matrix elements for energy-releasing trigger transitions. These parameters are needed to assess the feasibility of inducing a release of isomeric energy under an intense photon flux as suggested for some applications [7].

At this time, technical challenges restrict the availability of samples containing ^{178m2}Hf in an amount sufficient for preparation of a target suitable for standard in-beam γ-spectroscopic experiments. Therefore, it is necessary to consider the possibility of performing an experiment with ^{178m2}Hf nuclei as projectiles. Radioactive ion-beam facilities operate routinely at many laboratories and the long-lived ^{178m2}Hf nuclide should not be extraordinarily difficult for beam production.

The most critical issues which define the cost of an experiment and the quality of the measurements are the consumption rate and total available amount of ^{178m2}Hf. Taking into account the production parameters achieved for ^{178m2}Hf in the best reactions, one deduces that 10^{15} isomeric atoms can be accumulated by moderate-cost irradiations (for details, see Ref. [2]). Thus, about 10^{13} ions of ^{178m2}Hf can be delivered to the target in the Coulomb excitation experiment because of a typical 1% efficiency of accelerators. The isomer production is typically characterized by a relatively poor isomer-to-ground state ratio, lower than 5% in the best case. Therefore, the accelerated beam will contain mostly stable ^{178}Hf nuclei in the ground state with a little admixture of ^{178m2}Hf. A total beam current of about 1 particle nA is considered as it would not destroy the target foil.

It is important to understand why the consumption of isomeric material in the form of a beam is preferable to the use of small isomeric target. In-beam experiments provide the possibility of the Coulomb excitation of each accelerated nucleus as they impinge upon a thick target made of some material which can be obtained in sufficient quantity. A ^{178m2}Hf isomeric target would be restricted to about 1 μg/cm^2 thickness and this will provide an interaction probability that is a factor of 10^{-3}–10^{-4} lower than in the typical Coulomb excitation experiments. The gain factor for the isomer beam experiment is reduced by the efficiency of acceleration for the available material, about 10^{-2}, but an order-of-magnitude overall gain of interaction probability remains over an experiment with such a thin isomeric target. An additional advantage arises because the ^{178m2}Hf target creates a high-intensity background in γ detectors due to the spontaneous decay, while in the mode of an in-beam excitation experiment the radioactive nuclei are collected downstream, beyond the target and out of the detection area. In the latter version much better background conditions and much higher sensitivity of trigger detection may be provided. Contaminant activities can be removed without special efforts because the accelerator serves as a high-resolution mass analyzer.

A scheme of the experiment is as follows. A target made of low-background material like ^{208}Pb will be irradiated by a ^{178m2}Hf ion beam at an energy much lower than the Coulomb interaction barrier. The projectile-target γ spectrum due to the Coulomb excitation should be recorded in coincidence with the scattered ions. The use of a multidetector γ array is needed to obtain γ–γ and higher coincidences. The spectrum collected with the 5% «isomeric» beam will need to be compared with that obtained from a pure ground-state ^{178}Hf beam and the difference spectrum. This difference spectrum may contain cascades corresponding to population of high-spin levels both within the band built on the isomer and within the ground-state band (gsb). In the latter case, the population of high-spin members of the gsb may take place due to the single-step Coulomb excitation from the isomer if K-mixing is indeed significant as discussed in Ref. [6]. Observation of the corresponding γ cascades would then serve as a signal of isomer triggering.

As is the usual case in any experiment, the background intensity plays a significant role. One can analyze some restrictions on the scheme that originate from the presence of different backgrounds:

1) The beam energy should be relatively low, about 4 MeV/nucleon, in order to prevent population of $J \geqslant 14$ members of the gsb due to excitations of $J = 0$ ground states present in the beam. The probability for such multiple Coulomb excitations is drastically reduced at this low-beam energy [6] and triggering can therefore be clearly isolated.

2) The need to obtain coincidences between γ signals and the scattered projectile does not allow the use of a thick target that stops the beam. The detection of the scattered projectile defines the direction of the emitter motion, but the absolute speed varies due to energy losses in the target. The target thickness should be optimized for the successful Doppler correction and for Pb target a value of 4 mg/cm^2 is found to be satisfactory.

3) The Doppler correction is absolutely necessary. Otherwise, it would be difficult to observe narrow γ lines when those gammas are emitted in flight.

For the count rate estimation, single-step E2 Coulomb excitations from the 16^+ isomeric level to the 14^+, 16^+ and 18^+ levels of the gsb are calculated. The respective transition energies are known to be 331, 990 and 1,675 keV. The Weisskopf strength was assumed for these transitions due to the observation in Ref. [6] of strong K-mixing in the gsb at spins $J \geqslant 10$. Following this, $B_W(E2) \uparrow = 0.0297$ e^{2}b^2 is taken as the Weisskopf value for all transitions. With a mean projectile energy of 740 MeV, one finds values of the Coulomb excitation parameter of $\xi = 0.489$ for 331 keV, $\xi = 1.46$ for 990 keV and $\xi = 2.47$ for 1,675 keV transitions.

Assuming the c.m. solid angle for detection of scattered ions to be 5 sr and using the above-described parameters, an excitation rate of about 245 events/s is found for the 331 keV transition, about 3.2 events/s for the 990 keV and about $1.5 \cdot 10^{-2}$ events/s for 1,675 keV transition. These values correspond to an isomeric ion-beam intensity of $3 \cdot 10^8$ ions/s and high statistics of the events can be collected using a total of 10^{13} ions containing isomeric nuclei. The gamma background due to the Coulomb excitation starting from the 0^+ ground state would not be significant and, in addition, can be removed by subtracting a spectrum taken under the same conditions but with a pure ^{178}Hf ground-state beam. Thus, the triggering events can be reliably selected and the corresponding cross section deduced.

Direct observation of such transitions and characterization of their cross sections is essential for basic scientific knowledge and to assess the feasibility of applications.

3. THE COHERENT COULOMB EXCITATION IN CRYSTALS

Relativistic heavy-ion beams are available today at some accelerator facilities and additional possibilities will appear in the future. The status of such facilities will eventually change from exotic to more regular as tools for experimental physics. The enormous cost of these scientific instruments does not restrict progress in experimental methods. Recall, for instance, neutrino telescopes or free-electron lasers at TeV accelerators. Thus, without apology a new application is proposed here for heavy-ion beams at energies > 1 GeV/nucleon for the generation of coherent nuclear γ radiation.

A channeled particle can produce a regular consequent excitation of nuclei ensconced in one elementary string in a crystal. At relativistic energies, the phase shift in excitation of neighbor nuclei is almost the same as the phase shift of the deexcitation photons emitted in the forward direction. Accordingly, the coherent excitation and radiation of a whole string of atoms with emission of a characteristic nuclear γ line may happen. Such a possibility exists, in principle, but its amplitude depends on many concrete parameters and conditions. Below, some of these are characterized.

As is well known, channeling requires that $\Psi \leqslant \Psi_{\rm cr}$, where Ψ is the angle of a particle trajectory relative to the plane or axis of crystal. The critical angle of axial channeling $\Psi_{\rm cr}$ is normally estimated by the Lindhard equation. In the relativistic case, this has the form

$$\Psi_{\rm cr} = 2.4 \cdot 10^{-4} \sqrt{\frac{Z_1 Z_2}{Wd}}, \tag{1}$$

where $\Psi_{\rm cr}$ is expressed in rad, the total energy W — in GeV, and the interatomic distance d — in Å. The planar channeling wavelength in the harmonic approximation can be estimated with the expression

$$\lambda = \frac{\pi \cdot d_p}{\Psi_{\rm cr}}, \tag{2}$$

where the inter-plane spacing d_p is expressed in Å. One can combine Eqs. (1) and (2) when the axial channeling trajectory has zero orbital momentum and its plane is perpendicular to the crystal plane. At the trajectory maximum, the projectile moves most closely to the atomic plane and rows. For individual atomic collisions, the impact parameter varies slowly in this part of the trajectory. Numerical estimations indicate that a length of the trajectory of about $\lambda/10$ near the trajectory maximum can provide consequent collisions for coherent excitation of nuclei. At a larger longitudinal coordinate a transversal deviation appears and increases the impact parameter of collisions.

The experiment main idea is illustrated in Fig. 2: a channeled projectile passes near some individual atomic string and excites the nuclei in a series of consequent

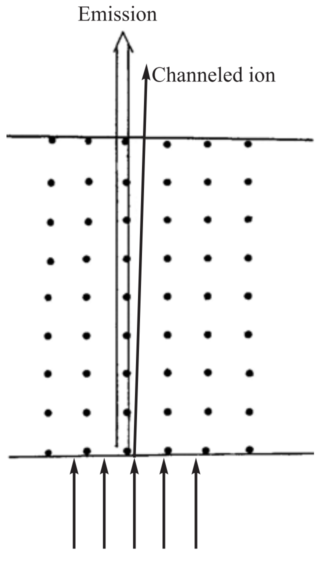

Fig. 2. Schematic view of the coherent nuclear excitation and radiation in a crystal by a channeled heavy ion

collisions. A flat trajectory is typical for channeling at high energies, and many collisions will be characterized by a similar impact parameter b. Finally, the whole string accumulates an excitation at the nuclear frequency mode and may radiate coherently with an intensity proportional to $(a \cdot N)^2$, where N is the number of excited nuclei and a is the excitation amplitude for an individual nucleus. A natural condition for coherency would be phase matching between excitation and radiation processes and this can be satisfied for the forward-angle photon emission along the string which was excited by the relativistic projectile. To provide an acceptable yield of radiation, the individual amplitude a must not be very small even though coherent enhancement takes place.

The impact parameter of atomic collisions in channeling conditions is normally restricted by the inequality of $b \geqslant u$, where $u \approx 5{\cdot}10^{-10}$ cm corresponds to the mean amplitude of thermal vibrations of atoms in the crystal. The probability of the nuclear Coulomb excitation is drastically reduced for distant collisions. But there exists an exception: in the case of $E1$ excitation, the cross section becomes very large at small angles of scattering, i. e., with the increase of b. In Fig. 3 the Coulomb excitation functions for $df/d\Omega$ and f are shown as given by the quasi-classical calculations of Ref. [8]. The basic parameters used in the Coulomb excitation theory and the cross-section expression for $E1$ excitation are

$$\eta_i = \frac{Z_1 Z_2 e^2}{\hbar \cdot v}; \quad \xi = \eta_i \frac{\Delta E'}{2E}; \tag{3}$$

$$\sigma = 2.5 \cdot 10^{-2} \frac{Z_1^2 A_1}{E} B(E1) f_{E1}(\eta_i, \xi), \tag{4}$$

where the projectile is characterized by atomic number Z_1, velocity v and kinetic energy E in the c.m. system. The recalculated excitation energy of a level is $\Delta E\prime = \Delta E(1 + A_1/A_2)$, and Z_2 and A_2 define the target nucleus. The cross section σ is expressed in barns, E — in MeV and the reduced probability of nuclear transition $B(E1)$ — in e^2 barn. One can see in Fig. 3 that the differential function calculated with $\xi = 0$ divergences at angles $\vartheta \to 0$. The divergence appears also for total cross-section values at $\xi \to 0$.

An infinite cross section is unphysical and the solution must lie in the used approximations implicit in the calculation of Eq. 4 [8]. It is important to note that the quasi-classical condition $\eta \gg 1$ is satisfied well in the case of very heavy ions even at high energies. Essentially relativistic collisions with $\gamma \gg 1$ require some modification of the theory, but it was already shown that in the typically used Born approximation such a modification does not reduce the cross sections from that calculated within the standard theory [8]. Thus, it can be expected that the $E1$ cross section will remain quite large even if more accurate approximations for relativistic ions are used.

For the present purposes, it is only important that the cross sections for small-angle scattering are high and consequently the total σ is high, as well. Large cross sections were experimentally confirmed in Darmstadt [9] for the $E1$ giant dipole resonance when excited in collisions of heavy nuclei at a moderate relativistic factor $\gamma = 1.45$ and with $\xi = 0.05$. In the current problem, the parameters are even more favorable: ξ must really be almost zero and higher γ values are defined by the other conditions. Thus, the cross sections should be orders-of-magnitude higher as compared to the value of 5 b observed in Ref. [9].

The coherence of neighbor nuclei in the crystal string depends on the phase shift between radiation they emit. The starting point of the excitation is defined

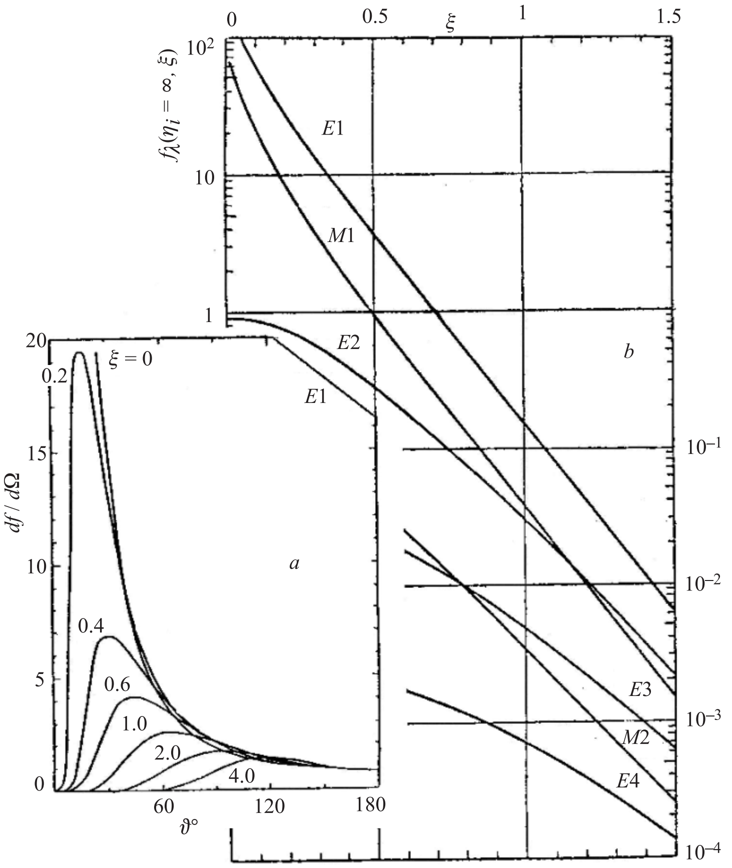

Fig. 3. The differential (a) and integral (b) Coulomb excitation functions taken from Ref. [8]. In (a) the $E1$ excitation angular distribution is normalized to unity at $\vartheta = 180°$

by the time mark due to arrival of the channeled ion and the radiation phase-shift is defined by the time-of-flight of photons from one nucleus to another for forward-angle emission. The following equation can be derived:

$$\Delta\varphi = 5.068 \cdot 10^2 \cdot E_\gamma \cdot d \cdot \frac{(1-\beta)}{\beta}, \tag{5}$$

where the phase shift $\Delta\varphi$ is expressed in rad, the inter-atomic distance d — in Å, the photon energy E_γ — in MeV, and $\beta = v/c$. A relatively small phase shift of about 5 mrad may be reached for photon energies $E_\gamma \leqslant 30$ keV at a β value very close to unity. However, the phase shift is periodic at $\Delta\varphi = 0$, 2π, 4π, etc. In such a case, a variety of options appears, provided that the following condition is satisfied:

$$2\pi(n-1) = 5.068 \cdot 10^2 \cdot E_\gamma \cdot d \cdot \frac{(1-\beta)}{\beta}, \tag{6}$$

where n is the harmonics order. Different values of β and E_γ can satisfy Eq. (6) with $n \geqslant 2$.

An essentially relativistic energy of the projectile would, nevertheless, be a necessary condition, as would some limitation of the emitted photon energy. These restrictions arise due to many additional requirements, not only due to the phase condition. The nuclei in the atomic string should be excited sequentially and a flat trajectory for high-energy channeling is appropriate to achieve this effect. Far-impact excitation with a reasonable probability takes place only at $\xi \to 0$, i. e., again at a high energy of the projectile. For the correlated Mössbauer emission, the crystal phonon spectrum should not be perturbed and the known restriction of $E_\gamma \leqslant 100$ keV naturally arises. In quantum theory, channeling is considered as a Mössbauer-type process, because for distant collisions the crystal-lattice vibrations (phonons) remain without perturbation.

In addition, the radiation damage of crystals is strongly reduced when channeled particles have high energies, allowing crystal targets to withstand irradiation for longer times. Ionization energy losses of heavy projectiles decrease in inverse proportional to their energy. At the same time, radiative energy losses are insignificant, unlike the case for a high-energy electron beam. Nevertheless, the possibility of correlated coherent γ emission under the Mössbauer conditions in a crystal might be questioned in the case of discussed scheme of excitation by channeled projectiles. Fortunately, a similar type of emission has already been experimentally observed [10] from ^{57}Fe nuclei in a crystal exposed to synchrotron radiation at the resonance energy.

It is necessary to select a candidate nucleus that is appropriate for the coherent Coulomb excitation scheme. The best one appears to be the stable ^{161}Dy isotope, contained in $^{\mathrm{nat}}$Dy with an abundance of 19%. Its level scheme is shown in Fig. 4. The first ($5/2^-$) and the third ($3/2^-$) excited levels are connected with the $5/2^+$ ground state by $E1$ transitions that are characterized by moderate $B(E1)$ strengths. The transitions are partially converted, but the photon-emission branch remains competitive, being near 30%. The transitions have energies of $E_\gamma =$ 25.65 and 74.57 keV that are potentially useful for the discussed scheme.

The $M1$ multipolarity can be found in many nuclei, but the Coulomb excitation $M1$ cross section is much lower than that for $E1$ transitions, although it also grows drastically at $\xi \to 0$. The ^{161}Dy nuclide may be unique suited to this scheme among stable isotopes, with $E1$ multipolarity of the useful transitions, with the exception of ^{181}Ta. But the latter nuclide has transitions characterized by much lower $B(E1)$ values. Dysprosium can exist in the form of single crystals, either in hexagonal symmetry as a metal crystal or in cubic as Dy_2O_3 oxide.

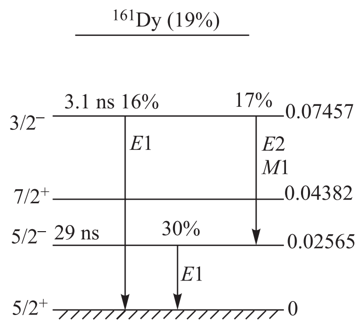

Fig. 4. Partial energy-level scheme of the ^{161}Dy nucleus showing the ground-state and three lowest excited levels. Energies are in MeV and spin, parity, half-life, multipolarity and γ-emission branches are given

It is useful to numerically evaluate examples for coherent excitation of the 25.65 keV level in ^{161}Dy via the basic harmonic ($n = 1$) and the 74.57 level via the second harmonic ($n = 2$). For better definition, here it is assumed that the Dy crystal is exposed to relativistic ^{208}Pb ions. Some magnitude of phase shift on the order of $\Delta\varphi = 5$ mrad should be acceptable for each atom, because the total phase shift after consequent excitation of 100 nuclei along the string reaches a value of only 0.5 rad, or $\pm 14°$.

Inserting into Eq. (5) the values $\Delta\varphi = 0.005$, $E_\gamma = 0.02565$ MeV and typical crystallographic $d = 4$ Å, one deduces (1–β) $\approx 10^{-4}$, i. e., $\gamma \approx 71$ and a kinetic energy $E_k \approx 66$ GeV/nucleon. In this essentially relativistic case, the collision parameter remains relatively high, $\eta \approx 5.0$, and the Coulomb excitation parameter is close to zero at $\xi = 2.5 \cdot 10^{-8}$. As discussed above, the cross section of $E1$ Coulomb excitation should be very high for such values of these parameters. The coherent radiation of 100 nuclei should be significantly enhanced in addition.

The channeling wavelength and photon absorption for a crystal of finite thickness must be also evaluated. The half-absorption length for 25 keV photons in Dy material is about 20 μm and a crystal of comparable thickness should be applicable. Using Eqs. (1) and (2), one deduces the channeling wavelength of $\lambda \approx 6.5$ μm, and this means that three full oscillations will occur in the crystal. Consequently, six trajectory maxima can serve as sources of coherent radiation. The total yield of radiation is thus enhanced due to many factors although absolute estimations are still difficult. The counter-productive interference corresponds to a radiation phase-shift range of $\pi \leqslant \Delta\varphi \leqslant 2\pi$, but this will appear only at distances of about thousands of atomic layers.

The Mössbauer correlations probably do not survive over such distances anyway. Even in the case of perfect correlations, one point should be discussed.

Although radiation absorption does not significantly restrict the described scheme, there arises the question whether the radiation transmits through the crystal layer, or whether the nuclear-mode excitation is bound to the string of atoms and is emitted from matter only at the surface of the crystal and the photon is emitted to the outside. In the later variant, the absorption does not suppress the radiation at all and only the positive and negative phases along the string are important. This may restrict the target thickness even more than absorption conditions.

The (1–β) value for the excitation of the third level in ^{161}Dy at 74.57 keV with the second harmonic ($n = 2$) has been estimated by Eq. (6). The resonance kinetic energy E_k = 2.42 GeV/nucleon and corresponding relativistic parameter $\gamma = 3.58$ were deduced. The channeling wavelength in this case decreases to 1.4 μm, or about $3.5 \cdot 10^3$ atomic layers. The condition of consequent multiple excitation of nuclei in the string is still conserved and many trajectory maxima take place on the projectile path through the crystal. Negative phases do not arise in this case because the phase shift becomes a multiple of 2π. The crystal can be as thick as 100 μm, because of the significantly lower absorption coefficient for 75 keV photons as compared to 25 keV.

The Mössbauer conditions are relatively good for 75 keV photons in a heavy Dy crystal if kept at liquid nitrogen temperature. The disadvantage of the scheme with excitation of the third level in ^{161}Dy at the second harmonics arises due to the increased radiation damage of the crystal at lower projectile energy: 2.42 GeV/nucleon instead of 66 GeV/nucleon as needed for the first level. The energy transferred to the lattice and to electron excitations is also increased and this may disturb the Mössbauer emission of radiation. However, this problem can be solved only after experimental studies. The yield of radiation would also be unknown until measured experimentally.

A kinetic energy of heavy ions near 1 GeV/nucleon is available at GSI, Darmstadt, and such an experiment can be arranged within reasonable expenses. The 74.57 keV transition should be resonantly excited at 4th harmonics by a projectile with a kinetic energy of about 1,110 MeV/nucleon. It would be interesting to test experimentally whether or not the Mössbauer conditions in a crystal survive at such energies. The concrete details of properties for Dy crystals are significant, but in the present work only a general scheme is discussed for a new type of experiments on the coherent Coulomb excitation of nuclei in a crystal lattice by relativistic heavy projectiles. A technical proposal can be developed later.

4. SUMMARY

New possible applications of the nuclear Coulomb excitation are discussed. In the first scheme, a radioactive ion-beam facility should be used for acceleration of ions containing isomeric ^{178m2}Hf to study triggering levels in this nuclide that may cause a release of the isomer energy. The second scheme may be potentially promising to achieve lasing of nuclear radiation. There is considered the coherent excitation and radiation of nuclei ensconced in a crystal lattice and exposed to a relativistic heavy-ion beam. The equations for resonance harmonics are formulated and other peculiarities important for realization of such a process are discussed. Among them are: the special cross-section behavior of the $E1$ Coulomb excitation, properties of radiation absorption, channeling trajectory parameters and the Mössbauer conditions for coherent emission. A realistic test experiment is formulated linked to the existing possibilities at GSI, Darmstadt, for production of relativistic heavy-ion beams.

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