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Strong dipole excitations around 1.8 MeV in ^{238}U

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In high resolution photon scattering experiments on the actinide nucleus ^{238}U, three dipole excitations have been found in the energy region around 1.8 MeV. The experiments yielded model independent information about the energies, spins, gamma decay branching ratios, cross sections, and the lifetimes of these $J=1$ states which lie in the energy region of the electron-positron lines observed by the EPOS and ORANGE Collaborations at the GSI Darmstadt.

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Throughout the past decade the emission of electron-positron pairs has been studied intensively in heavy ion collisions with energies close to and slightly above the Coulomb barrier. The e^+e^- sum spectra measured at the GSI Darmstadt by the EPOS and ORANGE Collaborations indicated narrow lines superimposed on a broad bump for different nuclei [1–5]. In the U+U, U+Th, U+Pb, and U+Ta systems a number of discrete lines appear at sum energies between 555 and 815 keV, a review of the results can be found in Ref. [5]. Recent experiments at Argonne with the APEX setup at the ATLAS linac give no evidence for such lines [6]. In the inverse fundamental process of Bhabha scattering no evidence for a resonance structure around the corresponding energies has been found [7–11]. One possible explanation for the observation of an e^+e^- line may be the existence of a strong nuclear excitation which decays partly via internal pair conversion (IPC). The electron-positron line at, e.g., 634 keV should then stem from an excitation at 634 keV $+2m_0(e^-)$ = 1658 keV if the line is from a source at rest. We want to stress, however, that IPC from a moving source does not in general give rise to a sharp sum energy line. Internal pair conversion favors dipole transitions. For a detailed interpretation of the results from the heavy ion reactions it is therefore useful to know all strong dipole excitations of the nucleus in this excitation energy range, i.e., between 1.5 and 1.9 MeV. It is the aim of this paper to give a "complete" survey of the dipole states in this energy region in ^{238}U.

An experimental method which is very well suited for a systematic and complete investigation of strong dipole excitations in a given energy interval is the scattering of real photons using bremsstrahlung as a source. This method has been used extensively in numerous studies over the past years, a prominent example of which is the work on the magnetic scissors mode at energies around 3 MeV studied at the accelerators in Stuttgart and Darmstadt (see, e.g., [12–14]).

The scattering of real photons is a spin and strength selective method because the levels are populated from the ground state as resonances. Therefore one observes in these experiments, all levels which have $B(E1)$, $B(M1)$ or $B(E2)$ ground-state transition strengths above a certain detection limit. The discrete lines resulting from resonantly absorbed and reemitted photons are superimposed on a continuous background of nonresonantly scattered bremsstrahlung photons. This background increases exponentially with decreasing photon energy. It is possible to improve the peak-to-background ratio in a given energy interval considerably by reducing the end-point energy of the incoming photon beam. In the present experiment on ^{238}U performed at the Stuttgart Dynamitron accelerator we have used an end-point energy of 2.5 MeV to investigate the energy range between 1.5 and 1.9 MeV with optimal sensitivity.

As the electromagnetic excitation mechanism is well understood it is possible to extract the decay widths (i.e., lifetimes) of the excitations in a simple and model independent way. For this purpose we determined the absolute photon flux by the simultaneous measurement of well-known dipole excitations in the nuclei ^{7}Li and ^{27}Al. The validity of this photon flux calibration procedure has been verified recently [15]. Figure 1 shows the photon scattering spectrum of ^{238}U in the energy region between 1.6 and 2.0 MeV. A strong deexcitation to the ground state and the corresponding transition to the first excited state at 45 keV can be observed for the three marked levels. The other lines stem from the α decay of uranium.

In the photon scattering experiments only $J=1$ and, to a lesser extent, $J=2$ levels can be excited from the

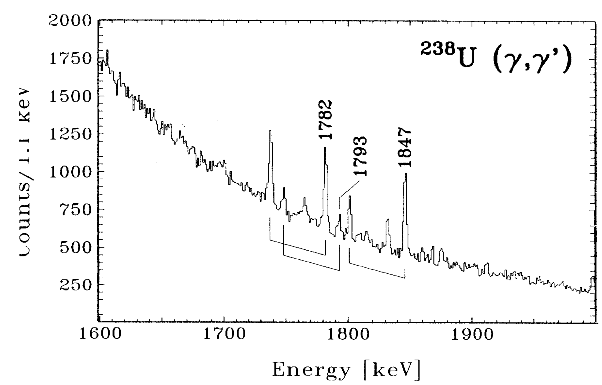

FIG. 1. Photon scattering spectrum of ^{238}U in the energy region between 1.6 and 2.0 MeV measured at an angle of 131 degrees. The brackets underneath the spectrum connect the ground-state transitions from the $J=1$ levels with the corresponding transitions to the first 2^+ state.

TABLE I. Excitation energies E_x, branching ratios $R=B(1\rightarrow2^+)/B(1\rightarrow0^+)$, integrated cross sections I_s, ground-state decay widths Γ_0, and half-life times $T_{1/2}$ for the three $J=1$ levels in ^{238}U around 1.8 MeV.

Energy (MeV)	R	I_s (eV·b)	Γ_0 (meV)	$T_{1/2}$ (fs)
1.782	0.55 ± 0.05	21.9 ± 2.5	9.3 ± 1.1	33 ± 4
1.793	1.11 ± 0.28	5.1 ± 1.0	2.8 ± 0.9	80^{+40}_{-20}
1.846	0.51 ± 0.05	23.0 ± 2.6	10.0 ± 1.5	31 ± 4

0^+ ground state. The ratio of the scattering intensities at angles of 95 and 131 degrees with respect to the incoming photon beam allows an unambiguous spin assignment. For the three observed states at 1.782, 1.793, and 1.846 MeV we measured ratios $W(95)/W(131)$ of 0.57 ± 0.08, 0.57 ± 0.25, and 0.62 ± 0.07, respectively. These values are close to the expected value of $W(95)/W(131)=0.7$ for a $J=1$ level and exclude unambiguously a ratio $W(95)/W(131)=2.2$ expected for a $J=2$ level. We can therefore assign $J=1$ to the three observed levels.

Table I summarizes the results of the photon scattering experiment. Below we discuss the levels in detail.

The J=1 level at 1.782 MeV. This is the lowest level for which the decay has been observed in the present photon scattering experiment. The transition at 1.737 MeV to the 2_1^+ state coincides with a gamma line following the α decay of uranium. Data from an off beam, natural activity measurement of the same target sample allowed the correction of this effect. This yielded a branching ratio to the first excited state of $R=B(1\rightarrow2)/B(1\rightarrow0)=0.55\pm0.05$. From the Alaga rules one can therefore assign a K-quantum number $K=1$. In case of positive parity the ground-state decay width $\Gamma_0=9.3\pm1.1$ meV amounts to a $B(M1)\uparrow$ strength of $(0.43\pm0.05)\mu_N^2$, in case of negative parity the $B(E1)\uparrow$ strength is $(4.7\pm0.6)\times10^{-3}$ e^2 fm^2.

In ^{238}U$(n,n'\gamma)$ experiments γ transitions at 1.782 and 1.737 MeV were observed [16] but were not placed in the level scheme. In a recent experiment of McGowan and Milner at Oak Ridge [17] with a ^{238}U$(\alpha,\alpha'\gamma)$ reaction $J^\pi=2^+$ was assigned to a level at 1.782 MeV on the basis of an angular distribution measurement. The transition to the 2_1^+ state was observed in this experiment too. A Coulomb excitation experiment in Darmstadt showed a line at 1.782 MeV in the γ spectrum which should stem from a nucleus of the ^{238}U region. However no corresponding transition to the first excited state has been observed in this measurement [18]. As shown above we can exclude a $J=2$ assignment for the level excited at 1.782 MeV in the photon scattering experiment by about 20σ and the $J=1$ assignment is therefore unambiguous. Combining this with the results from the other experimental probes the existence of a doublet of a $J=1$ and $J^\pi=2^+$ level at 1.782 MeV is highly likely.

The J=1 level at 1.793 MeV. This level is populated more weakly than the two neighboring $J=1$ states and was not observed in earlier photon scattering experiments by our group with higher photon end-point energy [19,20]. The branching ratio to the 2_1^+ state $R=1.11\pm0.28$ deviates strongly from the expected values for a pure $K=0$ ($R_{\rm theo}=2.0$) or $K=1$ ($R_{\rm theo}=0.5$) state. A possible explanation may be K mixing with neighboring levels [21]. This K mixing may suggest a negative parity for the level. In case of positive parity the ground-state decay width $\Gamma_0=2.8\pm0.9$ meV amounts to a $B(M1)\uparrow$ strength of $(0.13\pm0.04)\mu_N^2$, in case of negative parity the $B(E1)\uparrow$ strength is $(1.4\pm0.5)\times10^{-3}$ e^2 fm^2.

The J=1 level at 1.846 MeV. The transition strength to this level is comparable to that of the 1.782 level. The branching ratio $R=0.51\pm0.05$ allows a K-quantum number assignment $K=1$. In case of positive parity the ground-state decay width $\Gamma_0=10.0\pm1.5$ meV amounts to a $B(M1)\uparrow$ strength of $(0.41\pm0.06)\mu_N^2$, in case of negative parity the $B(E1)\uparrow$ strength is $(4.6\pm0.7)\times10^{-3}$ e^2 fm^2. These results are in excellent agreement with an earlier experiment of our group with a higher photon end-point energy [20].

To summarize, we have excited in our strength-selective photon scattering experiments three $J=1$ levels around 1.8 MeV in ^{238}U. Comparing our results with the results from other experimental probes it seems that at 1.782 MeV a doublet of a $J=1$ and a $J=2$ level is formed. We have no parity information for these levels but the branching ratio of the two strongest $J=1$ states at 1.782 and 1.846 MeV allows a $K=1$ assignment which empirically favors positive parity. An additional experiment using a Compton polarimeter in our setup could clarify this point. We note that the energies of the lines at 1782 and 1793 keV coincide with the energies of narrow e^+e^- lines observed with the EPOS setup at the GSI Darmstadt in the U+Th and U+Pb systems, respectively [5]. From the absolute transition strengths measured in our measurement it may be possible to estimate for these excitations the effect of internal pair conversion on the e^+e^- spectra.

A high precision photon scattering measurement with an end-point energy of about 1.5 MeV to investigate the lowest-lying states in ^{238}U is planned for the near future.

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