Level structure of ^{114}Te

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High-spin states of ^{114}Te have been studied using the ^{89}Y(^{28}Si,$p2n$) and ^{89}Y(^{29}Si,$p3n$) reactions at beam energies of 106 and 108 MeV, respectively. γ-γ and particle-γ-γ coincidences, directional correlations of oriented states, and excitation functions have been measured using six BGO Compton suppressed Ge detectors and several particle detectors. We established the states of ^{114}Te up to 9 MeV excitation energy and found the new two-phonon 2_2^+, 4_2^+, and 6_2^+ states. The properties of the states in ^{114}Te are discussed in comparison with the other even-even tellurium isotopes.

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Nuclei at $Z = 50$ including other regions of shell closure have been known to exhibit a shape coexisting structure [1]. In recent years many attempts to search for the deformed intruder states near the $Z = 50$ shell closure have revealed compounding observations of well-isolated rotational cascades in a variety of neighboring nuclei such as Cd ($Z = 48$) [1,2], Sn ($Z = 50$) [1,3,4], Sb ($Z = 51$) [5,6], and I ($Z = 53$) [7]. Such collectivity is now commonly understood as being caused by particle-hole excitation, and coexists with spherical ground states. In the case of Te ($Z = 52$) isotopes, however, evidence for shape coexistence has not been so clear though some favoring evidence in ^{112}Te [8], ^{116}Te [9], and ^{118}Te [10] was recently reported. To date many experimental results, mostly studied in low excitation energy, have defied a clearcut observation of well-deformed rotational bands built on the intruder state, therefore, it would be a natural consequence to search for them in high-spin and high-excitation states.

The even-even Te isotopes have a vibrational structure in their low-lying states that has been well interpreted in terms of a collective model known as interacting boson approximation 2 (IBA-2) [11–13]. In addition to the quadrupole excitations, several sidebands based on two-quasiparticle excitations have been observed [9,12,14]. The states of ^{114}Te were previously known up to the 10^+ state at about 4-MeV excitation energy by Lönnroth *et al.* [14], and reported up to 9 MeV by Janzen [15]. No evidence for collective properties due to a rotational-like γ-ray cascade built on the proton particle-hole or two-quasiparticle excitation has appeared in ^{114}Te so far.

The purpose of the present study is to establish high-spin states and to examine their structural properties in ^{114}Te. We performed two experiments differing in projectile, but with the same target. In the first experiment, the ^{89}Y(^{29}Si,$p3n$) fusion-evaporation reaction at a beam energy of 108 MeV was used to populate the excited states of ^{114}Te. The beam was provided by the 12 UD tandem accelerator at the University of Tsukuba in Japan. The ^{89}Y target was a self-supporting metallic foil of 6.4 mg/cm^2 in thickness. To establish a level scheme we carried out an excitation function measurement at beam energies of 102, 104, 106, 108, and 110 MeV and γ-γ coincidence measurement at a beam energy of 108 MeV using a γ-ray detector array that consists of 6 high-purity (HP) Ge detectors with BGO anti-Compton shields [16]. A second experiment was carried out using the ^{89}Y(^{28}Si,$p2n$) reaction at a beam energy of 106 MeV to further identify very weak γ-ray transitions not observed in the first experiment. In the latter experiment, charged particle-γ-γ and charged particle-neutron-γ-γ as well as γ-γ coincidence measurements were performed with a charged-particle multiplicity counter array consisting of 25 small ΔE-type Si detector segments [17] and three neutron counters made of NE213 liquid scintillator. About 5×10^7, in the first experiment, and 9.2×10^7, in the second experiment, twofold or higher-fold coincidence events were written onto EXABYTE tapes for later off-line analysis. The data were recalibrated to 0.5 keV/channel and sorted into 4096×4096 channel triangular matrices, which were then analyzed with a computer program MSA.

Figure 1 shows the examples of the coincidence spectra of γ rays assigned to ^{114}Te. The ordering of the γ-ray transitions has been determined from coincidence relationships, relative intensities, and excitation functions. Information on γ-ray multipolarities was obtained from directional angular correlation ratios selecting coincidence events between the two detectors positioned at angles of 0° and 117° to the beam axis. The level scheme of ^{114}Te deduced from our experiments is shown in Fig. 2. The present work enabled us to establish the level scheme up to 9468-keV excitation energy, which is extended up much higher than that of Lönnroth *et al.* [14] and the level scheme of the present work agrees well with that of Janzen [15]. The 682-635-617 keV γ-ray cascade (labeled 5 in Fig. 2) is newly established feeding the core 2^+ and 4^+ states. These being levels tentatively assigned as J^π of 2_2^+, 4_2^+, and 6_2^+, they may well be identified as two-phonon states also seen in ^{116}Te [9], ^{118}Te [12], and ^{120}Te [12] isotopes. In addition to the 6_2^+ state, a level at 2606 keV decaying to the core 4^+ and 6^+ states via 1122 and 389 keV lines, respectively, has been assigned as 6_3^+. Band 4 built on the 10_2^+ level at 3919 keV consists of a series of stretched quadrupole transitions. Its cascade, however, shows irregular transition energies that cannot be explained as a collective band built on the two-quasiparticle excitation only. Bands 1 and 2 seem to be signature partners to each other based on the two-quasiparticle excitation with the $h_{11/2}$ coupled to the $g_{7/2}$ shell configuration. But the states above 12^- at 4823 keV show a characteristic of noncollective excitations.

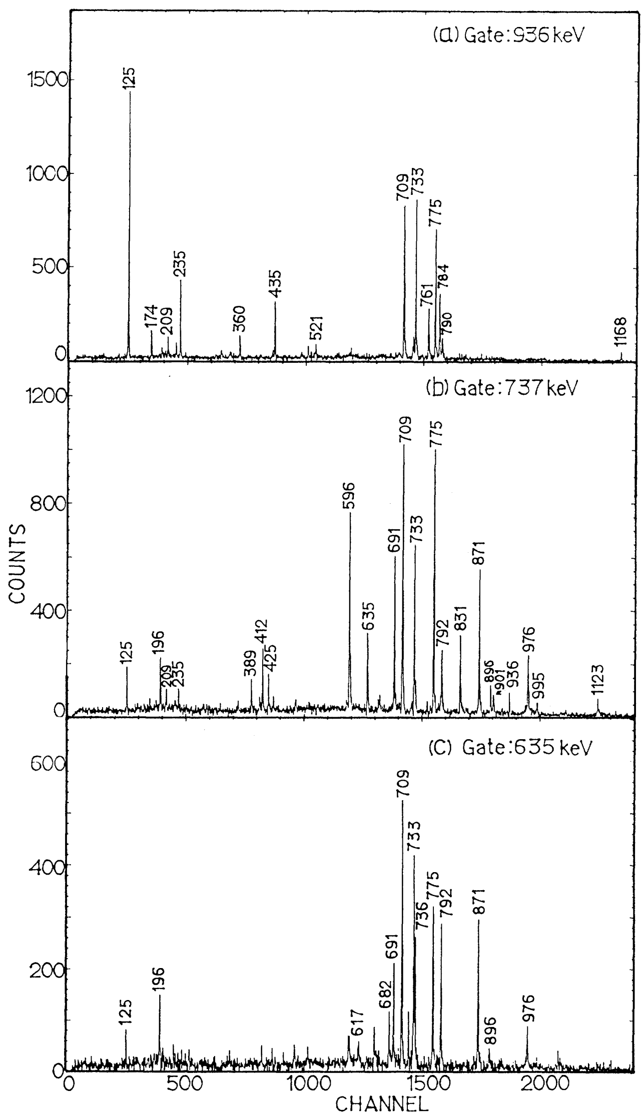

FIG. 1. Examples of γ-γ-p coincidence spectra for ^{114}Te product of the ^{89}Y+^{28}Si at $E_{\rm Si} = 106$ MeV by gating the (a) 936, (b) 737, and (c) 635 keV. γ-ray energies are in keV.

As seen in Fig. 2, no candidate for a rotational-like band built on the intruder state is found quite up to high spins. This is in accord with the previous result by Janzen [15]. After having not observed a rotational-like γ-ray cascade in the first experiment, we carefully examined γ-γ coincidence data of the second experiment gated by the proton and/or neutron evaporation in the hope that this particle gating could enhance γ-ray intensities from the rotational-like cascade. But the result turned out to be the same. A possible explanation, only in view of experimental facts, about not observing a rotational cascade is that such deformed rotational bands could be populated with very weak γ-ray transitions de-exciting high excitation states which the present experiment might not go into. Most recent investigations for high-spin states in ^{112}Te [8], ^{116}Te [9], and ^{118}Te [10] having identified the deformed bands characterized by a rotational-like cascade, a further refinement of both reaction and detection may bring about some positive results on ^{114}Te in the future.

We show the systematic behavior in the states of even-even $^{112-120}$Te isotopes in Fig. 3. The qualitative features of the ^{114}Te level scheme are similar to those of ^{116}Te, ^{118}Te, and ^{120}Te isotopes and, in particular, the cascade of the 6_3^+, 8_2^+, and 10_2^+ states much resembles that of the 2150, 3000, and 3445 keV states in ^{118}Te. It is noted that a state at 3246 keV feeds the 6_2^+ state in ^{116}Te, which was not assigned in [9], might be assigned as 8_2^+ consistent with the systematic trend of ^{114}Te and ^{118}Te.

Theoretical studies of low-lying positive-parity states up to 8^+ in $^{112-128}$Te were done in the framework of the neutron-proton interacting boson approximation (IBA-2) without and with configuration mixing by Sambataro [11] and Rikovska *et al.* [13], respectively. They showed that the IBA-2 provides a good description of the properties of the collective states with $J^\pi \leq 8^+$ as a quadrupole excitation. We cited the calculated levels of the ground-band states in $^{112-120}$Te by Rikovska *et al.* in Fig. 3. To explain noncollective excitations above the ground-band states, Van Ruyven *et al.* investigated the states of ^{118}Te and ^{120}Te nuclei using the one broken-pair model (BPM) [12]. By following their explanation the $J^\pi = 6_3^+$, 8_2^+, 10_2^+, 7^-, 8^-, and 9^- states in ^{114}Te, as also seen in ^{118}Te, might be interpreted as two-quasiparticle configurations, i.e., $\pi(1g_{7/2}2d_{5/2}); 6_3^+, \pi[6_3^+ \otimes 2^+]; 8_2^+, \nu(1h_{11/2})^2; 10_2^+$, $\nu(2d_{3/2}1h_{11/2}); 7^-$, $\nu(1g_{7/2}1h_{11/2}); 8^-$, and $\nu(1g_{7/2}1h_{11/2}); 9^-$, respectively. It should be noted that the $J^\pi = 8_2^+$ state was classified as a member of the band based on the $J^\pi = 6_3^+$ state (6_2^+ in ^{118}Te).

It is very interesting to see more about whether the reason why a rotational band on the intruder states could not be identified is due to simply a lack of our detector's efficiency, as mentioned above, or no real presence of such deformed states in ^{114}Te. One answer to this question was given by Rikovska *et al.* [13], who considered a strong mixing between the normal vibration-like band and the deformed band on intruder states. They showed by in-

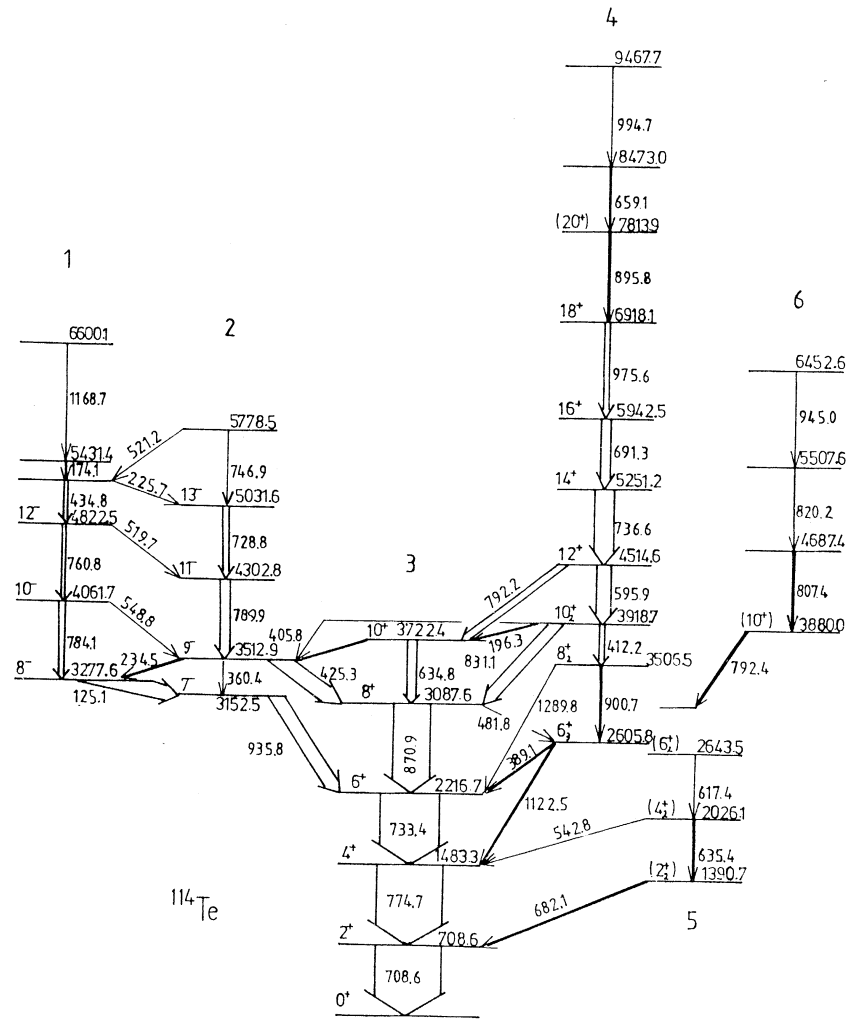

FIG. 2. Level scheme of ^{114}Te deduced in the present in-beam study. The width of the arrows indicates the transition intensity. Level and transition energies are in keV.

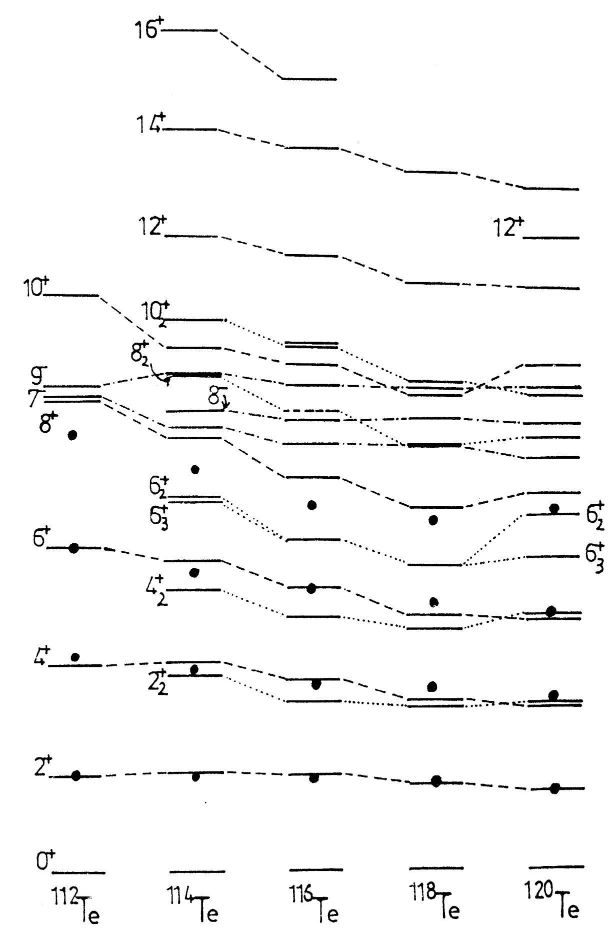

FIG. 3. Systematics of experimental level energies of $^{112-120}$Te isotopes. For comparison, theoretical calculations of the ground state using IBA-2 without configuration mixing in [13] are shown as the solid circles.

troducing the intruder configuration of the proton boson number $N_\pi = 3$ (note that the normal configuration is $N_\pi = 1$) that IBA-2 calculations taking into account mixing with an intruder 4p-2h configuration could reproduce very well all trends of the states in $^{116-124}$Te, especially energy levels of the 0_2^+, 2_2^+ (2_3^+), and 4_2^+ (4_3^+) states. It could be naturally explained that the 2_2^+, 4_2^+, and 6_2^+ states and/or 6_3^+ and 8_2^+ states in ^{114}Te are attributed to the intruder-mixed bands. Similarly, even though the nature of the states with $J^\pi > 10^+$ is not easy to understand, this irregular sequence of the states is likely to be caused by a possible admixture of the 4p-2h excitations having the $\pi[(d_{5/2})^2 \otimes (g_{7/2})^2 \otimes (g_{9/2})^{-2}]$ configuration.

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