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Search for an isomeric state in ^{19}C

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Abstract

A search for an isomeric state in the neutron-rich nucleus ^{19}C is reported. The existence of an isomer in the nucleus is predicted by shell model calculations which also predicts the ground-state of the nucleus to be $1/2^+$. An isomeric transition is however not observed in the present investigation. An

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estimation of upper limit of isomer ratio in the beam is discussed. Furthermore, the non-observation of an isomer includes the possibility of ^{19}C having a different ground state spin. The ^{17}C and ^{17}B nuclei were also investigated for delayed gamma transitions but do not exhibit any isomeric transition.

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Keywords: NUCLEAR REACTIONS ^{1}H (^{19}C , $^{19}\text{C}'$), (^{17}C , $^{17}\text{C}'$), (^{17}B , $^{17}\text{B}'$), $E_{\text{lab}} = 53$ MeV/nucleon; measured prompt and delayed E_{γ} , I_{γ} . $^{17,19}\text{C}$, ^{17}B deduced transitions. ^{19}C deduced no isomeric state.

1. Introduction

The isomeric states are usually observed in nuclei close to the shell closures. Examples in stable nuclei concentrate strongly around the $N(Z) = 50, 82$. These islands of isomerism found an explanation based on the shell model [1]. In later times advances beyond the stability line brought in new signatures of isomers around sub-shell closures. The most pronounced region is $N = 40$ for the nickel isotopes [2]. Shape coexistence is also associated to isomerism and an isomer for ^{43}S was observed around the $N = 28$ shell closure [3]. An isomer was observed in ^{32}Al which is near the region of $N = 20$ island of inversion [4]. There was also a suggestion on isomeric transition in ^{34}Si [5]. The finding of an isomeric state has been reported in ^{12}Be [6], at the breaking of the $N = 8$ shell closure.

The findings of new magic numbers ($N = 6, 16$) [7,8] and disappearance of conventional ones ($N = 8, 20$) for nuclei close to the drip line raise interesting question whether new regions of isomerism are associated with them. The structure of these light neutron-rich nuclei is mostly probed by reaction studies assuming the secondary beam of nuclei to be in the ground state. The presence of a long-lived isomeric state may bring in major modifications to our present understanding on these nuclei.

It is known from reaction studies that in sd -shell neutron-rich nuclei orbital reordering takes place whereby the $2s_{1/2}$ orbital is lowered crossing the $d_{5/2}$ and even the $p_{1/2}$ in some cases [9]. The resultant effect is that these orbitals become closely spaced. Thus one may expect low lying excited states for these nuclei. It should be noted here that finding of the first excited state to a large extent depends on the detection capability. An excited state at low energy below few tens of keV in these unstable nuclei is difficult to detect by the present methods.

Investigations on isomers in the vicinity of the $N = 16$ shell closure might lead to interesting structure information. The ^{19}C nucleus attracts attention, being a candidate of one-neutron halo. Shell model calculation, with the WBP interaction suggest an abnormal ground state spin of $1/2^+$ for this nucleus [10]. The large reaction [11] and Coulomb dissociation [12] cross sections are favorable towards this spin assignment. The momentum distribution probed in different ways, has been investigated by several groups [13–18]. The analyses has largely suggested the ground state spin to be $1/2^+$, but possibilities of $3/2^+$ and $5/2^+$ spins have been mentioned in Refs. [15,16]. There has been no confirmation on the ground state spin from magnetic moment measurement yet. Much less information exists on the excited states of ^{19}C . The predictions on the excited states with the WBP

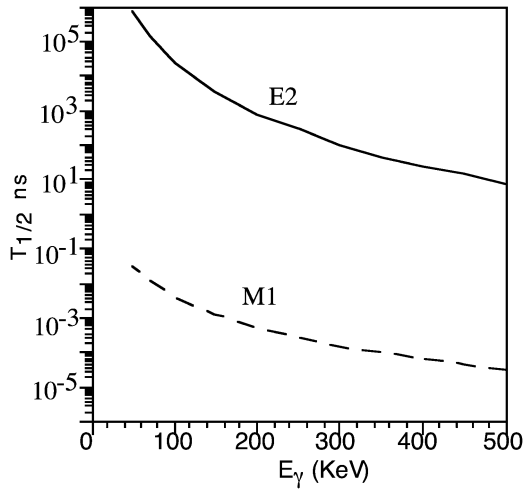


Fig. 1. Weisskopf estimate of the half lives of states de-exciting by E2(M1) transition is shown by solid(dashed) lines.

interaction, in the shell model, shows the first excited state with a spin of $5/2^+$ to be located at excitation energy around 190 keV. This state is predicted to be long-lived with $T_{1/2} \sim 1.2 \mu\text{s}$ [10]. The second excited state ($3/2^+$; 625 keV) is predicted to be very short lived (170 ps). Thus, search for an isomeric transition is important to confirm on the this assignment of levels in ^{19}C and its ground state spin.

Recently in-beam gamma spectroscopy of ^{19}C detected a low-energy prompt gamma transition at around 200 keV [19]. In a Weisskopf estimate (Fig. 1), such a low energy prompt transition should be M1 in nature. This implies that the transition of Ref. [19] must be a decay from $3/2^+$ to $5/2^+$ or vice versa, if they are single particle states. Thus, assuming the ground state of ^{19}C is $1/2^+$, a suggestion can be made that this decay corresponds to the de-excitation of a higher excited state to the first excited state. No other excited state was observed in the prompt gamma measurement of Ref. [19] where the gamma detection threshold appears to be slightly less than 200 keV. It can thus be considered that the first excited state was not observed in the prompt gamma measurement because of its long-lived (isomeric) nature as predicted by shell model. However, possibility of presence of a prompt gamma transition below the detection threshold of Ref. [19] cannot be ruled out either.

If the ground state of ^{19}C is $1/2^+$ then its first excited state should most likely have a spin of $5/2^+$ or $3/2^+$. WBP interaction predicts it to be $5/2^+$. So the transition from first excited to ground state should be E2 in nature. The Weisskopf estimate (Fig. 1) shows a lifetime of ~ 1 micro sec for a low energy (~ 200 keV) E2 gamma transition. An E2 transition is also the only mode of decay from $3/2^+$ to $1/2^+$ if the states are single particle in nature. Thus, search for an isomeric state in ^{19}C nucleus became extremely important. The presence of the isomeric transition will clearly confirm the predictions of the shell model. On the other hand, the absence of an isomeric state will either suggest an alternative arrangement of the levels in ^{19}C (which may lead to a different spin assignment for its ground state) or it may suggest that the states are not single particle in nature.

The presence of a long-lived isomeric state has another important effect. Depending on the lifetime of isomer and the location of reaction target from source of production, the secondary beam will contain a mixture of two spin states that are incident on the reaction target. So it is important also to find the upper limit of isomer ratio in the beam. If this ratio is appreciable, then we need to reconsider on results of previous reaction studies that have assumed the beam to be only in its ground state.

In this article we report the first search for delayed (isomeric) transitions in ^{19}C , ^{17}C and ^{17}B . The results, as will be discussed later, show no clear evidence of an isomeric transition in any of these nuclei. Considering the ground state spin for the ^{19}C nucleus to be $1/2^+$, the non-observation of an isomer helps to put an upper limit on isomer ratio in the beam. It however also has another important implication that the isomeric state might not exist. The ground state spin in such condition has a possibility of being either $3/2^+$ or $5/2^+$. The observation of delayed transitions following beta-decay of these nuclei is also discussed.

2. Experiment

The experiment was performed at the RIKEN, Ring Cyclotron facility. The experimental setup is shown schematically in Fig. 2. A cocktail of ^{19}C and ^{17}B secondary beams were produced by bombarding a ^{22}Ne primary beam on a 8 mm thick Be target. The secondary beam was identified using energy-loss (ΔE), time-of-flight (TOF) and magnetic rigidity information. The beam was then impinged on a liquid H_2 target in order to study inelastic scattering leading to prompt gamma decays. For this purpose the H_2 target was surrounded by an array of NaI(Tl) detectors. The observations for the prompt gamma transitions will be reported elsewhere [20]. The energy of ^{19}C at mid-plane of H_2 target was 53 A MeV. The beam was then stopped in a stack of silicon detector telescope ($500\ \mu\text{m} + 2\ \text{mm} + 2\ \text{mm} + 500\ \mu\text{m}$) located $\sim 1\ \text{m}$ downstream of the H_2 target. The time of flight from the production target to the stopping detectors was nearly 250 ns. The silicon telescope was first surrounded by four plastic scintillators on four sides. This was meant for detecting beta rays. The box of plastic scintillators was then surrounded by Ge clover detectors which were meant for detecting the delayed gamma transitions from isomeric decay. The silicon detector stack was placed outside vacuum in an environment of

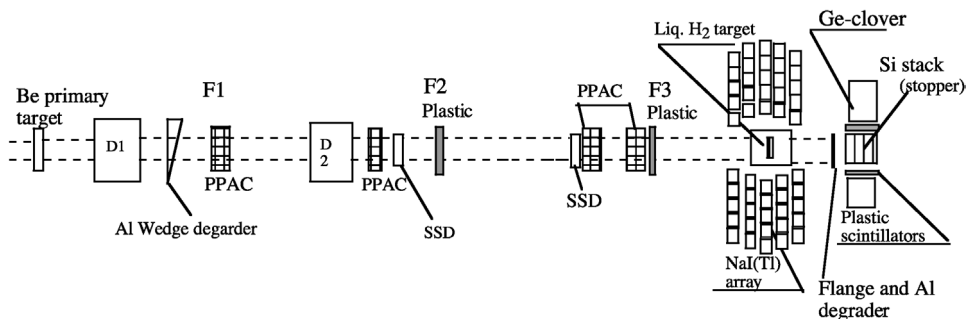


Fig. 2. Schematic view of the experimental setup.

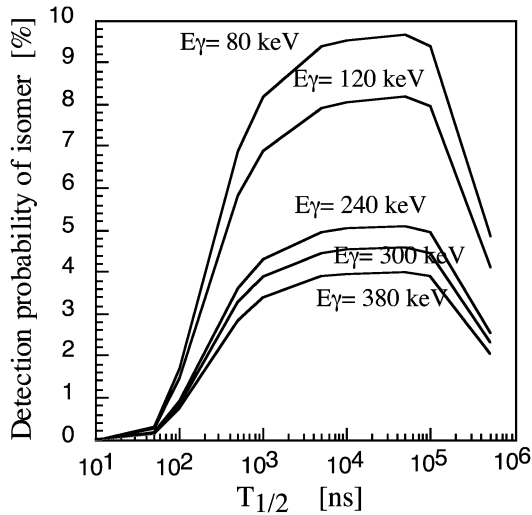


Fig. 3. Isomer detection probability as a function of half-life of isomeric state. The different curves show the probability of different energies of gamma transition.

dry N_2 . An Al flange at the end of the H_2 target chamber was used to keep the vacuum for the upstream beam-line and H_2 target chamber. To ensure stopping in the silicon stack, the energy of the secondary beam was degraded by adding further Al plates externally in air near the flange. The beam profile was monitored by tracking using two parallel plate avalanche counters placed upstream of the H_2 target. The particle identification was done by $\Delta E-E$ using the silicon stack.

The detection threshold for gamma rays was ~ 30 keV and the maximum limit of gamma ray detection was set to 1600 keV. The efficiency of gamma detection by the Ge detectors was measured by placing standard ^{133}Ba , ^{152}Eu sources in the silicon detector position. This resulted in efficiencies of 9.7% around 80 keV, 4% around 300 keV and 3.5% around 450 keV. The time gate for isomer detection was 500 μs . Each Ge clover crystal was independently triggered by the beam. The plastic scintillators provided the trigger signal. The total beam rate was ~ 850 pps for the ^{19}C setting of the separator. The fraction of ^{19}C was nearly 20% of the total rate. Dead time was nearly 50%. A different setting of the fragment separator allowed the study of gamma spectroscopy of ^{17}C . A hard veto condition using the signals from each of the plastic scintillators was applied to the respective Ge clovers crystals to eliminate background from beta-rays. The detection probability of the isomer with the above mentioned measuring conditions is shown in Fig. 3 as a function of half-life of the isomeric state.

3. Analysis

The gamma decay spectrum for ^{19}C events identified in the silicon stack is shown in Fig. 4(a). For the discussion hereafter we focus the attention on the low energy part of the spectrum less than 700 keV. Several prominent peaks are seen in this region. These include

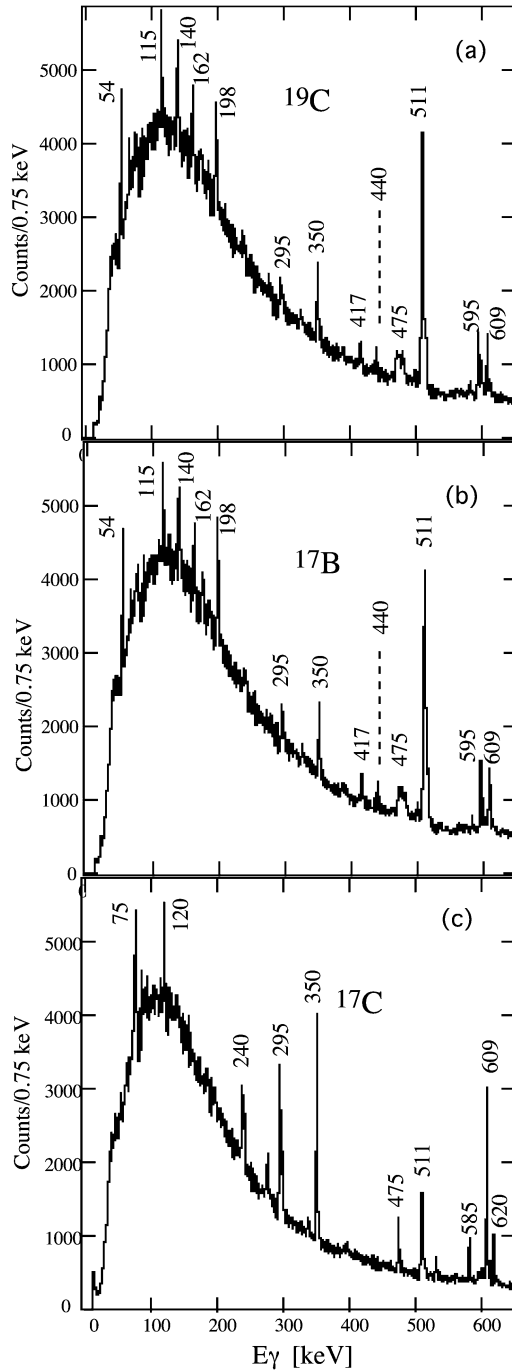


Fig. 4. The gamma energy spectra for ^{19}C , ^{17}C , ^{17}B are shown in (a), (b), (c), respectively. The spectra for ^{17}B and ^{17}C have been normalized by the ratio of the nuclei identified at SSD with respect to ^{19}C .

peaks from room background which can be identified from data without beam. The peaks at 75, 86, 95, 240, 295, 350, 511, 585, 609 keV correspond to room background. The large continuous background seen in the lower end of the spectrum arises from Compton scattering. This continuous background is also present for room background data. The peaks are now compared to that associated with ^{17}B nuclei identified at SSD (Fig. 4(b)). It is found that all the peaks are identical for both ^{19}C and ^{17}B nuclei. This makes it less likely for these peaks to correspond to isomeric transition in ^{19}C or ^{17}B . To make further confirmation we search for delayed gamma transitions in ^{17}C . This was not a contaminant fragment, but was obtained in a separate secondary beam setting of the fragment separator. We discuss below the observed peaks and their possible origin.

The transitions observed are of two main classes. Firstly, we have very delayed gamma emission from successive beta decay daughters. Secondly we have gamma emission from nuclei formed by neutron capture. It is clearly observed that the peaks for, e.g., at 54, 140, 162, 174, 185, 417, 440, 595 keV considered to be associated with neutron capture on Ge are much reduced in intensity for ^{17}C . This is probably because the ^{17}C being a less neutron rich nucleus, gives rise to less neutrons in the environment. The peak at 66 keV is considered to be associated with ^{28}Al which maybe formed by neutron capture on ^{27}Al .

It is firstly noted that any beta decay branch of ^{19}C to the bound excited states of ^{19}N is not observed. Gamma transitions from ^{18}N at 115 and 472 keV correspond to the beta delayed-neutron branch of ^{19}C . This observation is consistent to previous reports in Ref. [21]. We further observe γ -transition at 475 keV which can be associated with ^{17}N arising from beta-delayed two-neutron emission. An alternative or additional source for production of ^{17}N is the beta decay of ^{17}B followed by decay of ^{17}C . The presence of the closely spaced 472 and 475 keV transitions lead to a rather wide peak in the spectrum (Fig. 4(a), (b)) for the $^{19}\text{C}, ^{17}\text{B}$ setting of the fragment separator. In ^{17}C setting, the peak at 620 keV corresponds to ^{17}N formed by beta decay of ^{17}C [22]. This peak is not observed for the $^{19}\text{C}, ^{17}\text{B}$ setting.

The peaks at 198 and 325 keV attract interest since they are not observed for setting with ^{17}C beam. One likely origin of these peaks maybe ^{71}Ge , produced by neutron capture on ^{70}Ge . There is also a possibility that the peaks can be associated with beta decay of ^{17}B to excited states of ^{17}C . The energies of these levels agree with that reported recently by Stanoiu et al. [19] within experimental errors. If that is true, then this is a new observation, and no discussion on beta decay to bound states of ^{17}C exists in the literature. Observations on beta-delayed neutron emission on ^{17}B has been discussed in Ref. [23].

Another alternative origin of these two peaks (198 and 325 keV) could be related to gamma decay from states of ^{19}F and ^{20}F nuclei, respectively. However, the branch to this path firstly, must be relatively small since it is a beta decay process of three steps $^{19}\text{C} \rightarrow ^{19}\text{N} \rightarrow ^{19}\text{F}$, compared to the high intensity of 198 keV line observed. Furthermore, this assignment may not be possible because both the present and existing studies [21] have shown that ^{19}C decays mostly to unbound states of ^{19}N , thus forbidding the path to formation of ^{19}F .

The time sequence of the gamma spectrum was also studied using different time gates. The prompt peak in the time spectrum ($T = \text{TDC calibration}$) appears around $T = 400$ ns. The location of this prompt peak can be used to relate the TDC spectrum to the real time with the knowledge that the time-of-flight from the production target to stopping detector

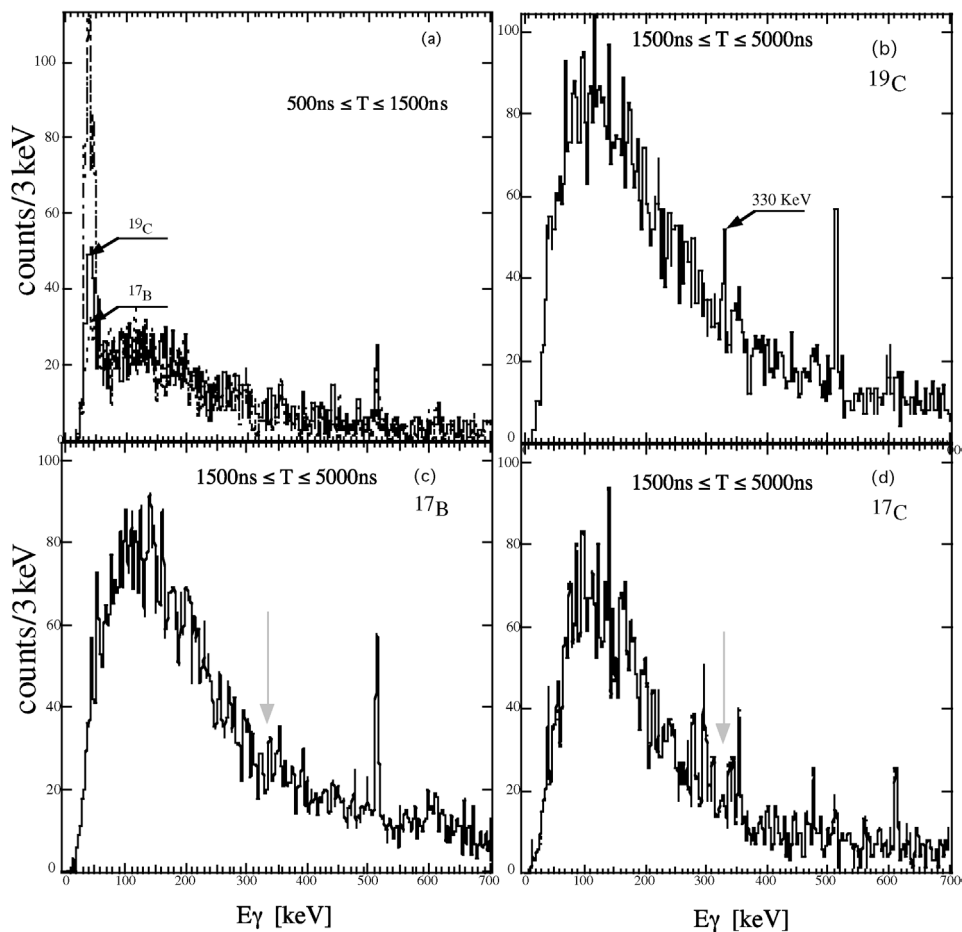


Fig. 5. The gamma ray energy spectra for time ranges of (a) $500 \leq T \leq 1500$ ns and (b)–(d) $1500 \leq T \leq 5000$ ns. The solid/dotted/dashed-dotted lines in (a) are for $^{19}\text{C}/^{17}\text{B}/^{17}\text{C}$.

is around 250 ns. Fig. 5(a) shows the gamma energy spectra for $^{17,19}\text{C}$, ^{17}B within the time window of 500–1000 ns which is beyond the prompt peak. It is seen that for all nuclei a large peak is observed around 40 keV. This peak most likely corresponds to the de-excitation from ^{28}Al excited state (a nucleus which may be formed by neutron capture on ^{27}Al). A puzzling aspect is the relative intensity of the peak for the different nuclei. It seems to be strongest for ^{17}C . This is not yet understood because, we would expect the neutron capture to be less for ^{17}C ($A/Z = 2.83$) than ^{17}B ($A/Z = 3.4$).

Probing a little further beyond, the gamma energy spectrum for a time range of 1500–5000 ns is shown in Fig. 5(b). It is interesting to see the presence of a peak around 330 keV for ^{19}C , which does not appear for the other nuclei. This peak was found to disappear when the spectrum was studied in the time range of 5000–10 000 ns. We thus, take a look now at the time spectrum gated for the region $320 \leq E\gamma \leq 340$ keV (including the background).

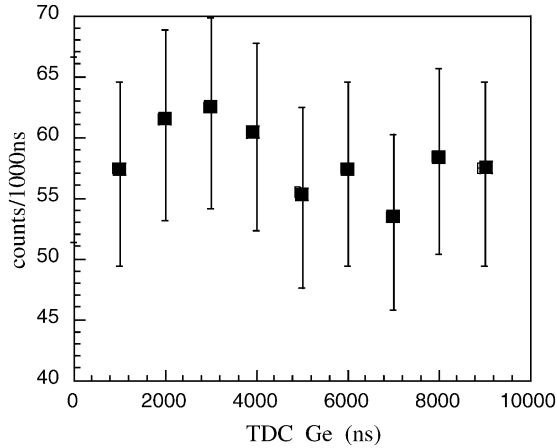


Fig. 6. Partial time spectrum of Ge detectors gated for $320 \leq E\gamma \leq 340$ KeV.

The distribution was however very flat (Fig. 6) and did not show any decay character. It is thus felt that this peak is not an isomeric transition in ^{19}C . It maybe beta delayed gamma emission of some daughter nucleus or a statistical fluctuation.

The correlations between the gamma-rays in the individual crystals of one clover as well as between two different clovers were studied for finding any possible cascade transitions. No signature of a cascade could be found.

It thus appears that the present data does not show any signature of an isomeric transition in ^{19}C . Within our detection conditions, an estimate of counts under the peak (after subtraction of the background) at 417 keV in Fig. 4(a) suggests that any transition should be detectable if it has total counts > 2000 . This is thus an upper limit number of isomer detectable at the silicon stopping detector and contains the effect of transmission loss through the fragment separator RIPS. The total number of ^{19}C beam events ($N_{^{19}\text{C}(\text{beam})}$) identified at the SSD also contains the same transmission loss through RIPS. The upper limit ratio of isomer in secondary beam at the production target can thus be estimated taking into account the detection conditions. It is shown in Fig. 7 as a function of gamma-ray energy. The different symbols show the conditions for different possible half-lives ($T_{1/2}$) of the isomeric state. It is found that if the isomeric state has a short half-life ~ 100 ns and an excitation energy (E_{ex}) ~ 300 keV, then the ^{19}C secondary beam at the site of production, may contain at most 7% of the isomeric state. This percentage increases for shorter half-lives and higher E_{ex} and can become as significant as 50% for a half-life of 50 ns and 350 keV excited state. Half-lives shorter than this cannot be detected by our setup. The experiment shows that there is insignificant probability of isomers of longer half-lives.

If there are N_{iso}^0 isomers at the production target, then Fig. 8 shows the ratio of isomer that maybe present at a possible reaction target position placed after flight time ' t ' from the production target. It is seen that for targets located at flight times ≤ 100 ns and if the isomeric state has a half-life ~ 50 ns then this ratio is ~ 0.3 . Now multiplying this to the upper limit of isomer obtained in Fig. 7 we may obtain appreciable contribution ($\sim 15\%$ for $E_{\text{ex}} = 350$ keV) of isomers in the secondary beam incident on a reaction target at such

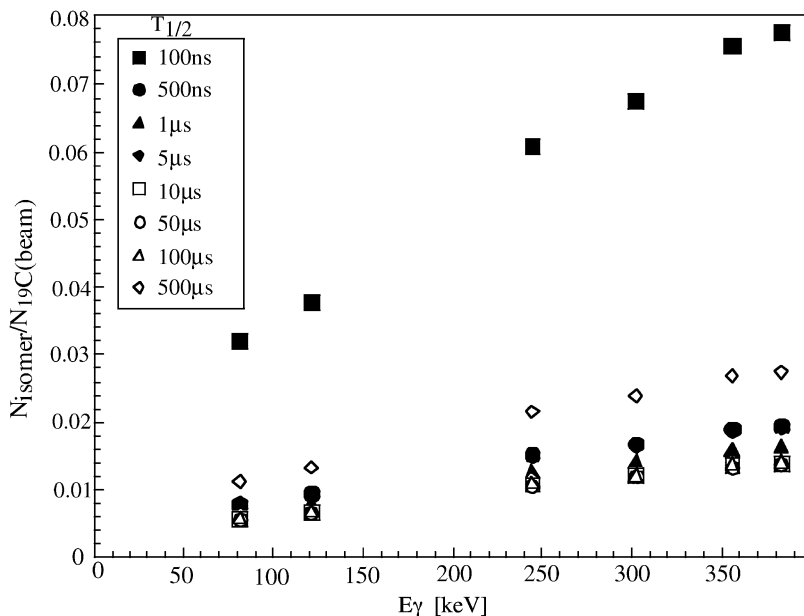


Fig. 7. Upper limit estimation of ratio of isomers in the beam at the production target. The symbols denote conditions for different half-lives of the isomeric state as indexed in the figure.

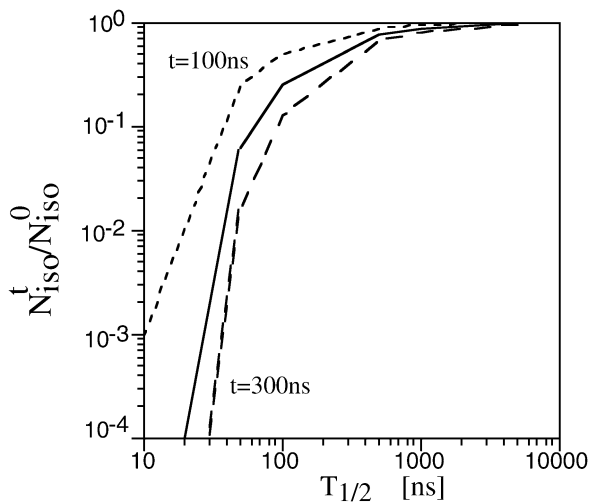


Fig. 8. Ratio of number isomer present after flight-time ‘t’ to the number of isomer at source ($t = 0$). The short-dashed/solid/long dashed lines correspond to $t = 100$ ns/200 ns/300 ns.

location. This maybe a possible scenario in very high energy experiments. If the isomeric state does exist in such a large ratio, then it may affect the analysis of reaction observables which have so far assumed the ^{19}C beam to be purely in its ground state.

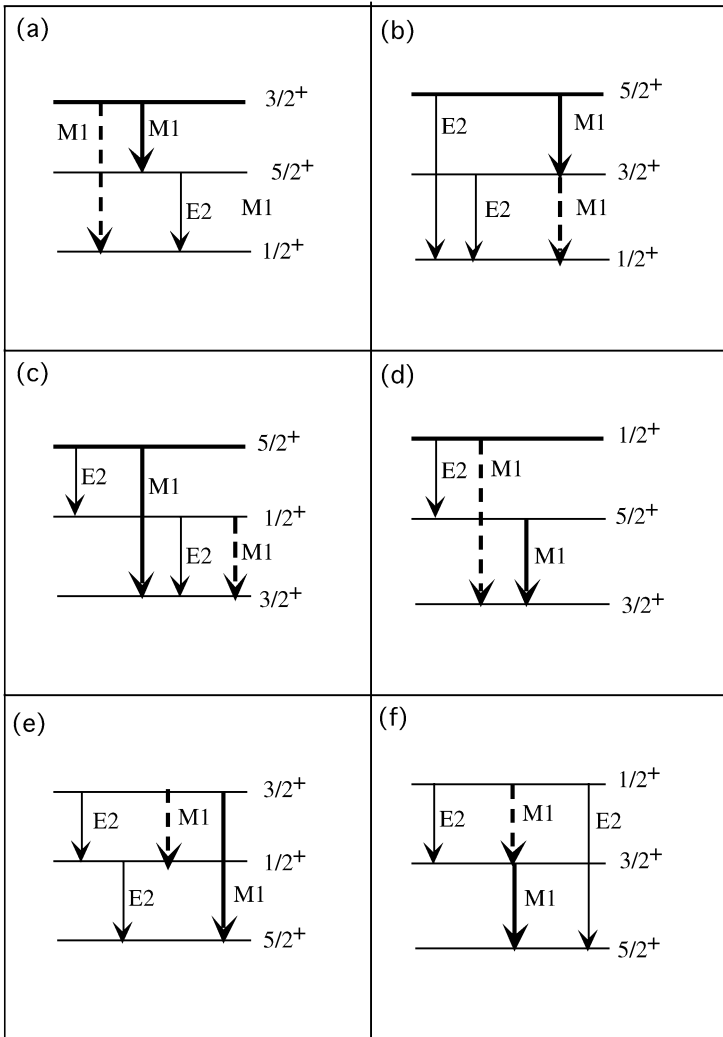


Fig. 9. The possible level sequence and associated gamma transitions for ^{19}C having ground state spin $1/2^+$ (a), (b), $3/2^+$ (c), (d) and $5/2^+$ (e), (f). The dashed lines show transitions possible only if the states are not single-particle in nature.

The present experiment clearly shows that probability of existence of an isomeric state lower than 300 keV (having $T_{1/2} > 100$ ns) is negligible. Thus, an isomeric state (if exists) should be located at $E_{\text{ex}} > 300$ keV. This delineates that the observations do not agree with the predictions of shell model (WBP interaction) which predicts a level sequence shown in (Fig. 9(a)) with $5/2^+$ state ~ 190 keV [10]. Within the same level sequence, if the energy of the first excited state is higher than the shell model predictions and is larger than 300 keV ($T_{1/2} < 100$ ns), then there maybe 7% or higher isomer admixture in the beam (at the site of production). In such case the prompt gamma decay (~ 200 keV) observed in

Ref. [19] must correspond to de-excitation of second ($5/2^+$) excited state to the isomeric state ($3/2^+$). Thus the second excited state should be located around 500 keV or higher. This is possible, if the neutron separation energy (S_n) of ^{19}C is larger than this value (as suggested by Coulomb dissociation) 580 ± 90 keV [24]. The existing mass measurements however lead to a much smaller S_n (160 ± 110 keV) [25]. A reconfirmation on S_n from mass measurements is thus essential.

The second alternative for level sequence keeping the ground state spin unchanged is shown in Fig. 9(b). This is however not predicted by any existing model calculations. In this scheme if the states are single particle in nature, then the $3/2^+$ level should also have an isomeric nature. The $5/2^+$ level would then have two decay branches, a fast M1 transition and a more slow E2 transition. This mixing will lead to a short half-life for the $5/2^+$ state. Thus, the prompt gamma transition ~ 200 keV should correspond to the de-excitation of $5/2^+$ level to $3/2^+$ level. The non-observation of the isomeric state in this scheme shows that the $3/2^+$ -state maybe located ≥ 300 keV. This possibility can exist only if $S_n > 500$ keV.

There exists however a possibility that the ground state and the excited states are not single particle in nature. In such case a faster M1 transition maybe allowed between the $3/2^+$ and $1/2^+$ levels in the above scheme. This may then lead to a cascade decay of two prompt gamma transitions from $5/2^+$ to $3/2^+$ level.

The possibility of ^{19}C having a different ground state spin of $3/2^+$ or $5/2^+$ also exists. The level sequence and the different possibilities of transition are shown in Fig. 9(c)–(f). The level sequence of Fig. 9(c) is predicted by deformed Hartree–Fock model in Ref. [26]. The non-observation of an isomeric transition in condition of Fig. 9(c) suggests that either the $5/2^+$ state is located above the particle emission threshold (S_n) or that the $1/2^+$ state is not single particle in nature allowing it to decay by a fast M1 transition. Same argument holds for the $1/2^+$ state in Fig. 9(d).

The possible transitions with a $5/2^+$ ground state spin for ^{19}C are shown in Fig. 9(e), (f). The upper limit of isomeric state estimated ($E_{\text{ex}} \geq 300$ keV possible only) in this experiment taken together with the prompt gamma observation ($E \sim 200$ keV) of Ref. [19], shows that the configuration in Fig. 9(e) is not possible if the states are single particle in nature. It is otherwise possible, provided $S_n > 500$ keV. Fig. 9(f) on the other hand suggests that the configuration is possible under several conditions. Firstly, if the states are non-single particle in nature decaying by prompt transition cascade in which case, a delayed transition is very weak and may not be observed. Possibility of the $1/2^+$ state being located at $E_{\text{ex}} \geq 300$ keV exists.

4. Summary

In summary, the first observations on the search for an isomeric state in ^{19}C are reported. Measurements for ^{17}C and ^{17}B are also performed and compared to the observations from ^{19}C . Several delayed gamma-ray peaks are observed for ^{19}C but they mostly coincide with the observations for the contaminant fragment ^{17}B as well. Thus no clear signature of an isomeric transition can be found in ^{19}C . A possibility appeared at around 330 keV but could not be confirmed from the time characteristics. The estimated upper limit of isomer

in the beam at the site of production shows that the probability of existence of an isomeric state at $E_{\text{ex}} < 300$ keV is negligible.

From the above discussion it is understood that the level sequence in ^{19}C can be clarified if we search for cascade gamma transitions. The presence of a cascade prompt gamma transition will mean that only configurations shown in Fig. 9(b) and 9(f) are possible. The absence of such cascade prompt gamma transition together with non-observation of the isomeric transition discussed in this article on the other hand will rule out these configurations.

The confirmation on one neutron separation energy of ^{19}C from mass measurements and absence of cascade gamma will help to confirm on or eliminate the configurations shown in Fig. 9(a) and (e).

A possibility of beta-delayed gamma transitions from ^{17}B decaying through the excited states of ^{17}C at 198 and 325 keV is suggested. Although alternative sources of these transitions have been mentioned too. Thus, it would be useful to have a more clear confirmation on this by an alternative measurement.

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References

- [1] P. Marmier, E. Sheldon, *Physics of Nuclei and Particles*, vol. II, Academic Press, San Diego, and references therein.
- [2] R. Grzywacz, et al., *Phys. Rev. Lett.* 81 (1998) 766;
M. Lewitowicz, et al., *Nucl. Phys. A* 654 (1999) 687c;
H. Grawe, et al., *Nucl. Phys. A* 704 (2002) 211c.
- [3] T. Werner, et al., *Phys. Lett. B* 335 (1994) 259.
- [4] M. Robinson, et al., *Phys. Rev. C* 53 (1996) R1465.
- [5] S. Nummela, et al., *Phys. Rev. C* 63 (2001) 044316.
- [6] S. Shimoura, et al., *Phys. Lett. B* 560 (2003) 31.
- [7] A. Ozawa, et al., *Phys. Rev. Lett.* 84 (2000) 5493.
- [8] R. Kanungo, et al., *Phys. Lett. B* 528 (2002) 58.
- [9] I. Tanihata, *J. Phys. G* 22 (1996) 157, and references therein.
- [10] E.K. Warburton, et al., *Phys. Rev. C* 42 (1992) 923;
B.A. Brown, private communication, <http://www.nsl.msu.edu/~brown/resources/decay/gamma.htm>.
- [11] A. Ozawa, et al., *Nucl. Phys. A* 691 (2001) 599.
- [12] T. Nakamura, et al., *Phys. Rev. Lett.* 83 (1999) 1112.
- [13] D. Bazin, et al., *Phys. Rev. Lett.* 74 (1995) 3569;
D. Bazin, et al., *Phys. Rev. C* 57 (1998) 2156.
- [14] V. Maddalena, et al., *Phys. Rev. C* 63 (2001) 024613.

- [15] T. Baumann, et al., *Phys. Lett. B* 439 (1998) 256.
- [16] R. Kanungo, et al., *Nucl. Phys. A* 677 (2000) 171.
- [17] M. Chiba, et al., *Nucl. Phys. A* 741 (2004) 29.
- [18] F.M. Marques, et al., *Phys. Lett. B* 381 (1996) 407.
- [19] M. Stanoiu, et al., *Eur. Phys. J. A* 20 (2004) 95.
- [20] Z. Elekes, et al., *Phys. Lett. B*, in press.
- [21] A. Ozawa, et al., *Nucl. Phys. A* 592 (1995) 244.
- [22] J.P. Dufour, et al., *Z. Phys. A* 324 (1986) 487.
- [23] G. Raimann, et al., *Phys. Rev. C* 53 (1996) 453.
- [24] G. Audi, et al., *Nucl. Phys. A* 729 (2003) 337.
- [25] N. Orr, et al., *Phys. Lett. B* 258 (1991) 29;
J. Wouters, et al., *Z. Phys. A* 331 (1998) 229.
- [26] H. Sagawa, et al., *Phys. Rev. C* 70 (2004) 054316.