yields asymptotic cross sections which satisfy Pomeron factorization well.

We acknowledge gratefully the assistance of Dr. D. Kreinick, Mr. G. Featherston, Mr. Rolf Brocker, and the staffs of the University of Pennsylvania, Brookhaven National Laboratory, and Fermilab for making this work possible.

---

*Work performed under the auspices of the U. S. Energy Research and Development Administration.

†Present address: Brookhaven National Laboratory, Upton, N. Y. 11973.

[1] The boundaries of the acceptance are $60.75° \leq \theta_c^{\text{lab}} + 3.3°/(p_c^{\text{lab}} - \Delta p_c) \leq 64.25°$ and $0.3\ \text{GeV}/c \leq p_c^{\text{lab}} - \Delta p_c \leq 0.6\ \text{GeV}/c$. Here ΔP_c is the momentum lost by particle type c in traversing the apparatus; to sufficient accuracy it is given by $\Delta P_c = (0.0015\ \text{GeV}/c)/\beta_c^3$.

[2] A. H. Mueller, Phys. Rev. D 2, 2963 (1970).

[3] Representative reviews are H. Boggild and T. Ferbel, Annu. Rev. Nucl. Sci. 24, 451 (1974); R. G. Roberts, in *Phenomenology of Particles at High Energies*, edited by R. L. Crawford and R. Jennings (Academic, London and New York, 1974); and T. Ferbel, SLAC Report No. 179, 1974 (unpublished).

[4] J. Erwin *et al.*, Phys. Rev. Lett. 33, 1352 (1974).

[5] P. A. Baker *et al.*, Nucl. Phys. B89, 189 (1975).

[6] R. Schindler *et al.*, Phys. Rev. Lett. 33, 862 (1974); J. Whitmore *et al.*, Phys. Lett. 60B, 211 (1976).

[7] E. W. Beier *et al.*, to be published.

[8] V. Blobel *et al.*, Nucl. Phys. B69, 454 (1974).

[9] R. E. Hendrick *et al.*, Phys. Rev. D 11, 536 (1975).

Blocking Effect in the Transitional Nuclei ^{189,191,193}Au

Y. Gono, R. M. Lieder, M. Müller-Veggian, A. Neskakis, and C. Mayer-Böricke
Institut für Kernphysik der Kernforschungsanlage Jülich, D-517 Jülich, West Germany

(Received 26 July 1976)

The study of high-spin states in ^{189,191,193}Au revealed that the $h_{11/2}$ proton-hole rotation-aligned bands are terminated by isomeric $\frac{27}{2}^-$ states most probably of $(\pi h_{11/2}{}^{-3})_{27/2^-}$ configuration. The relatively low excitation energies of these isomers can be understood qualitatively if the concept of blocking as used in the rotation-alignment model is modified by taking into account a reduction of the proton pairing gap energy in these odd-mass Au nuclei.

Recent in-beam γ-spectroscopy and radioactive decay studies of the odd-mass Au iostopes $^{187-195}$Au[1-6] revealed many interesting features. A remarkable result of these studies is the existence of bands originating from the $h_{11/2}$ proton-hole state in ^{187,189,191,193,195}Au (Refs. 1–6) as well as from the $h_{9/2}$ proton state in ^{187,189,191}Au (Refs. 2–4). The bands originating from the $h_{11/2}$ proton-hole state in ^{191,193,195}Au have been interpreted by Tjøm *et al.*[1] as rotation-aligned bands within the framework of the rotation-alignment (RAL) model[7] in which the odd nucleon is coupled to a symmetric rotating core. Calculations[8] using an axially asymmetric rotating core yielded a better agreement with the experimental results for these bands. The $h_{11/2}$ and $h_{9/2}$ bands observed in ^{187,189}Au (Refs. 2 and 3) have been similarly interpreted. In order to understand the existence of the $h_{9/2}$ and $h_{11/2}$ rotation-aligned bands in these Au nuclei, it has been assumed, in the framework of the RAL model, that they have a prolate shape in the $h_{9/2}$ state and an oblate shape in the $h_{11/2}$ state.[2] From calculations[9] in the framework of the triaxial-rotor-plus-particle model, this shape coexistence was attributed to different asymmetry parameters γ. In case of ^{189}Au, $\gamma = (37\pm 2)°$ for the $h_{11/2}$ band and $\gamma = (23\pm 2)°$ for the $h_{9/2}$ band.[9] These values are essentially the asymmetry parameters of ^{190}Hg and ^{188}Pt which are considered as the core nuclei of ^{189}Au in the two respective states.[9]

Although the low spin states of the $h_{11/2}$ bands in ^{193,195}Au can be well understood also in the framework of the particle-vibration coupling model,[10] the RAL model has been applied more commonly to explain high-spin yrast states. Therefore, this latter model has been applied in the present work to interpret the bands observed in ^{189,191,193}Au.

Prior to our study, the $h_{11/2}$ proton-hole rotation-aligned bands were definitely established up to $\frac{23}{2}^-$ in ^{187,189,191,193}Au (Refs. 1–3) and up to $\frac{19}{2}^-$ in ^{195}Au (Ref. 1). It was the aim of the present study to reinvestigate ^{189,191,193}Au in order to extend the $h_{11/2}$ bands to higher spin states for the following reason. In the Hg core nuclei ^{190,192,194}Hg 10^+ iosmers have been observed[11] which are considered to have a $(\pi h_{11/2}{}^{-2})_{10^+}$ two-proton-hole configuration. The upper portion of the ground-state bands (gsb) in ^{192,194}Hg (Ref. 11) built on top of these 10^+ states may be interpreted as $h_{11/2}$ two-proton-hole rotation-aligned bands.[12] This interpretation derives support from the fact that the gsb in ^{192,194}Hg and the $i_{13/2}$ neutron rotation-aligned bands in ^{191,193}Hg have a very similar level structure,[11] which means that the occupation (blocking) of a $i_{13/2}$ neutron state in the odd-mass Hg nuclei does not affect the behavior of the core nuclei. However, the blocking of the completely aligned $h_{11/2}$ proton state in the odd-mass Au nuclei may give rise to a level structure different from that of the core nuclei. In analogy to the blocking effect observed in the region of the deformed nuclei,[7] it may be expected that the aligned $h_{11/2}$ three-proton-hole states in the odd-mass Au nuclei are shifted upwards in excitation energy with respect to that of the 10^+ states in the corresponding even-mass Hg core nuclei.

In the present study of ^{189,191,193}Au, iomeric $h_{11/2}$ three-proton-hole states of spin and parity $\frac{27}{2}^-$ have been found to lie lower in excitation energy than the 10^+ (as well as 8^+) states of the Hg core nuclei. This is an unexpected and new result and an interpretation will be presented in this Letter.

The states of the gold isotopes ^{189,191,193}Au were populated using $(\alpha, 4n)$ and $(\alpha, 6n)$ reactions. The isotopically enriched ^{191}Ir (89%) and ^{193}Ir (98%) targets of metallic powder glued on a Mylar backing were bombarded with 51- or 77-MeV α-particle beams from the Jülich isochronous cyclotron JULIC. The resulting γ radiation was studied by means of standard in-beam γ spectroscopy. The level schemes of ^{189,191,193}Au resulting from these experiments are shown in Fig. 1. The high-spin parts of the level schemes of ^{191,193}Au could be considerably extended with respect to the results obtained by Tjøm *et al.*[1] For ^{189}Au the placement of the levels obtained by Deleplanque *et al.*[2] could be confirmed in the present work except for the location of the 125.6- and 1038.8-keV lines. However, for some states in ^{189}Au different spin-parity assignments have been derived using the results of the present γ-ray angular distribution measurements and considering the systematics revealed from this study of ^{189,191,193}Au. Detailed discussions concerning these new states will be presented elsewhere.

In ^{189,191,193}Au isomeric states with half-lives of $T_{1/2} = 11$, 6, and <3 ns, respectively, were found. These isomers de-excite by stretched quadrupole transitions into the $\frac{23}{2}^-$ states as deduced from the present γ-ray angular distribution measurements. It is highly unprobable that these transitions are of $M2$ multipolarity since their transition probabilities for ^{189,191,193}Au are about one, two, and three orders of magnitude larger, respectively, than the Weisskopf estimates for $M2$ transitions which have been calculated using the formula given in the Nuclear Data Tables. These γ rays in ^{189,191,193}Au are considered, therefore, as $E2$ transitions so that the isomers have been assigned as $\frac{27}{2}^-$ states. The iso-

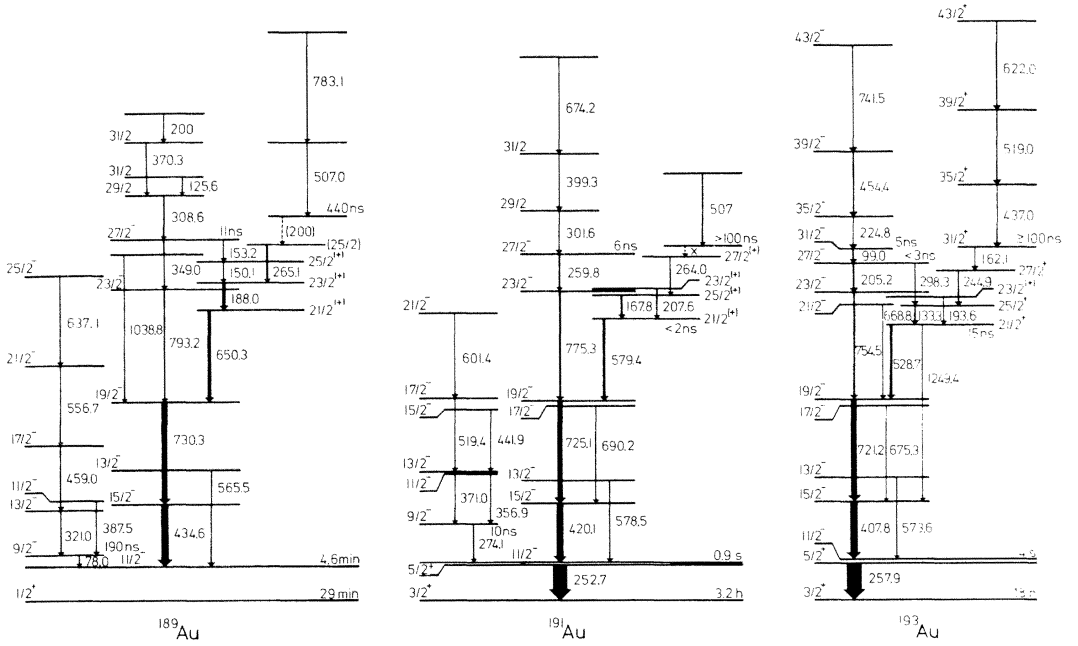

FIG. 1. Level schemes of ^{189,191,193}Au.

merism of the $\frac{27}{2}^-$ states in ^{189,191,193}Au may be understood if these states originate from the coupling of a $h_{11/2}$ proton hole either to the 8^+ states or to the 10^+ isomers in the core nuclei ^{190,192,194}Hg, which are considered[11] to have predominantly the $(\pi h_{11/2}^{-2})_{8^+}$ and $(\pi h_{11/2}^{-2})_{10^+}$ configurations, respectively. Therefore these $\frac{27}{2}^-$ isomers may have fully aligned $(\pi h_{11/2}^{-3})_{27/2^-}$ three-proton-hole configurations.

The $\frac{27}{2}^-$ isomers in ^{189,191,193}Au lie lower in excitation energy with respect to the $\frac{11}{2}^-$ band heads than the 8^+ states and the 10^+ isomers in the neighboring even-mass Hg core nuclei.[11] As pointed out earlier, a shift to higher excitation energies of the $\frac{27}{2}^-$ isomers was expected from the blocking of the completely aligned state. The blocking effect was used to explain the absence of backbending in certain high-j rotation-aligned bands of odd-mass deformed nuclei.[7] Stephens[7] explained this observation considering that in the framework of the RAL model the energy difference between aligned one- and three-quasiparticle states is larger than the one between the zero- and aligned two-quasiparticle states. This conclusion is based on the consideration that in an odd-mass nucleus, in which the completely aligned state is blocked, (i) less Coriolis energy and (ii) $2\hbar$ less angular momentum are gained by breaking a pair than in an even-mass nucleus. The reduction of the energy gain by these two effects was estimated to be about 1 MeV for $i_{13/2}$ neutrons assuming[7] that in deformed nuclei the pairing gap energy is approximately the same for odd-mass and even-mass nuclei. It appears to be necessary, however, to take into account the difference of the proton pairing gap energy for blocking of proton states in the transitional nuclei considered here because of the low density of proton levels in the vicinity of the $Z = 82$ shell closure. An estimate of this effect using Eq. (25) of Nilsson and Prior[13] indicates that in the odd-mass Au nuclei the proton pairing gap energy $2\Delta_p$ may be reduced by about 1 MeV in comparison with that of the even-mass Hg core nuclei which is sufficient at least to cancel the other two effects mentioned above. Consequently the rotation-aligned $(\pi_{11/2}^{-3})_{27/2^-}$ three-proton-hole states are expected to appear at fairly low excitation energies, in agreement with the experimental observation for the $\frac{27}{2}^-$ isomers in ^{189,191,193}Au.

From the present study, it can be concluded that in the discussion of the blocking effect it is important to take into account the reduction of the pairing gap energy in odd-mass nuclei relative to even-mass nuclei in order to understand, in the framework of the RAL model, the excitation energy of the $(\pi h_{11/2}^{-3})_{27/2^-}$ three-proton-hole states in the transitional nuclei ^{189,191,193}Au.

We would like to acknowledge fruitful and stimulating discussions with Professor A. Faessler and Dr. H. Toki. The technical assistance given by Mr. H. M. Jäger is gratefully appreciated.

---

[1] P. O. Tjøm, M. R. Maier, D. Benson, Jr., F. S. Stephens, and R. M. Diamond, Nucl. Phys. A231, 397 (1974).

[2] M. A. Deleplanque, C. Gerschel, N. Perrin, and V. Berg, Nucl. Phys. A249, 366 (1975); V. Berg, R. Foucher, and Å. Höglund, Nucl. Phys. A244, 462 (1975).

[3] M. A. Deleplanque, C. Gerschel, M. Ishihara, N. Perrin, V. Berg, C. Bourgeois, M. G. Desthuilliers, J. P. Husson, P. Kilcher, and J. Letessier, J. Phys. (Paris), Lett. 36, L205 (1975).

[4] Y. Gono, R. M. Lieder, M. Müller-Veggian, A. Neskakis, and C. Mayer-Böricke, in *Proceedings of the International Symposium on Highly Excited States in Nuclei, Jülich, Federal Republic of Germany, 1975*, edited by A. Faessler, C. Mayer-Böricke, and P. Turek, (Kernforschungsanlage Jülich GmbH, Jülich, Federal Republic of Germany, 1975), Vol. 1, p. 70.

[5] E. F. Zganjar, J. L. Wood, R. W. Fink, L. L. Riedinger, C. R. Bingham, B. D. Kern, J. L. Weil, J. H. Hamilton, A. V. Ramayya, E. H. Spejewski, R. L. Mlekodaj, H. K. Carter, and W. D. Schmidt-Ott, Phys. Lett. 58B, 159 (1975).

[6] H. Beuscher, P. Jahn, R. M. Lieder, and C. Mayer-Böricke, Z. Phys. 247, 383 (1971).

[7] F. S. Stephens, Rev. Mod. Phys. 47, 43 (1975).

[8] J. Meyer-ter-Vehn, Nucl. Phys. A249, 111, 141 (1975); H. Toki and A. Faessler, Nucl. Phys. A253, 231 (1975).

[9] J. L. Wood, R. W. Fink, E. F. Zganjar, and J. Meyer-ter-Vehn, Phys. Rev. C 14, 682 (1976).

[10] V. Paar, Ch. Vieu, and J. S. Dionisio, to be published.

[11] R. M. Lieder, H. Beuscher, W. F. Davidson, A. Neskakis, and C. Mayer-Böricke, Nucl. Phys. A248, 317 (1975).

[12] C. Flaum and D. Cline, University of Rochester Report No. UR-NSRL-103, 1975 (to be published).

[13] S. G. Nilsson and O. Prior, K. Dan. Vidensk. Selsk., Mat.-Fys. Medd. 32, No. 16 (1961).