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HIGH-SPIN STATES IN DOUBLY ODD ^{114}I

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Abstract

High-spin states have been identified in doubly odd ^{114}I produced in the ^{60}Ni(^{58}Ni,3pnγ) reaction. Two rotational band structures have been observed. One band exhibits no signature splitting, while the second exhibits a large signature splitting. These bands are interpreted in terms of $\pi g_{9/2} \otimes \nu h_{11/2}$ and $\pi g_{7/2} \otimes \nu h_{11/2}$ quasiparticle configurations, respectively.

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Collectivity in doubly odd iodine (Z=53) isotopes is manifest as strongly coupled ΔI=1 bands. These bands have been identified in the series of odd-odd nuclei ranging from ^{116}I up to ^{122}I [1], and have been associated with the $\pi g_{9/2} \otimes \nu h_{11/2}$ quasiparticle structure. These collective structures involve particle-hole proton excitations (1p-1h) across the Z=50 shell gap via the $\pi g_{7/2} - \pi g_{9/2}$ level crossing at prolate deformation ($\beta_2 \sim 0.2$), which appears to stabilise deformed core configurations [2]. Related ΔI=1 bands have also been observed in the odd-A $^{113-127}$I isotopes [3–6]. The full proton configuration in these ΔI=1 bands, relative to the Z=50 core, is the 4-particle 1-hole $\{\pi g_{9/2}^{-1} g_{7/2}^{2} d_{5/2}^{2}\}_{9/2^+}$ structure. Other coexisting rotational bands, built on $\pi g_{7/2} \otimes \nu h_{11/2}$ [7] and $\pi h_{11/2} \otimes \nu h_{11/2}$ [8] quasiparticle configurations, have also been identified in odd-odd iodine nuclei. Results for the lighter ^{114}I isotope are presented in this article. A strongly coupled band has been observed and again associated with the $\pi g_{9/2} \otimes \nu h_{11/2}$ quasiparticle structure. In addition, a second structure with a large signature splitting is attributed to the $\pi g_{7/2} \otimes \nu h_{11/2}$ quasiparticle configuration.

High-spin states in neutron-deficient ^{114}I were populated with the ^{60}Ni(^{58}Ni,3pn)^{114}I reaction at a bombarding energy of 250 MeV. The ^{58}Ni heavy-ion beam was provided by the Tandem Accelerator Superconducting Cyclotron (TASCC) facility at the Chalk River Laboratories, while the target consisted of two self-supporting foils of ^{60}Ni, each of nominal thickness 480 μg/cm^2. Coincident γ-γ data were acquired with the 8π spectrometer, consisting of 20 Compton-suppressed HPGe detectors plus a 71-element BGO inner-ball calorimeter, which provides γ-ray sum-energy, H, and fold, K, information. Data were written onto magnetic tape for events in which two or more suppressed HPGe detectors registered in prompt time coincidence with ten or more elements of the inner ball (fold $K \geq 10$). Under this condition, approximately 3.3×10^8 events were recorded to tape.

In a previous study of the ^{58}Ni + ^{60}Ni reaction at Daresbury, the POLYTESSA array was coupled to the recoil separator [9], and both mass information (A) and charge information (Z) were recorded. This allowed a unique assignment of γ-ray transitions to the $^{114}_{53}$I nuclide [10]. In the off-line analysis of the Chalk River data for ^{114}I (3pn channel), only events with a total sum-energy in the range $7.0\leq H \leq 12.2$ MeV were incremented into a symmetrised $E_\gamma - E_\gamma$ matrix. This low sum-energy condition suppressed events from competing 3-particle evaporation channels (e.g., the 3p channel into ^{115}I [12] and the α2p channel into ^{110}Te [13]), which have higher average H and K distributions relative to the 4-particle channels. In this matrix, ^{114}I (3pn) was only populated with 13% of the strength of ^{114}Te (4p). Furthermore, both ^{115}I (3p) and ^{112}Te (α2p) were significantly stronger than ^{114}I, despite the low sum-energy condition. Analysis of the data was facilitated by the graphical analysis package ESCL8R [11]. The transitions assigned to ^{114}I are shown in the decay scheme presented in Fig. 1, where two structures are shown; the two structures are not in prompt coincidence with each other, which implies the existence of isomers. Indeed, from the systematics of the heavier doubly odd iodine isotopes [1], band 1 is expected to decay into a high-spin isomer with $I = 6, 7$ [1]. Examples of gated spectra, showing transitions in bands 1 and 2, are presented in Fig. 2. Due to the weakness of the ^{114}I transitions, angular correlation information could only be determined for a very limited number of transitions: the 560, 702, and 735 keV transitions of band 2 are consistent with stretched quadrupole transitions, while the 310 keV transition appears to be a stretched dipole. This does, however, define the lowest state of the favoured signature of band 2 as the state depopulated by the 310 keV dipole, and presumably this state feeds the bandhead of band 2 via the 65 keV (dipole) transition.

Band 1 in Fig. 1 consists of strong ΔI=1 transitions with weaker ΔI=2 crossover transitions. The strong dipole transitions and the lack of signature splitting imply that a high-Ω orbital is involved in the configuration, namely the $\pi[404]9/2^+$ Nilsson orbital arising from the $\pi g_{9/2}$ subshell below the spherical Z=50 shell gap. The similarity to heavier odd-odd iodine isotopes [1], as depicted in Fig. 3, thus suggests a $\pi g_{9/2} \otimes \nu h_{11/2}$ quasiparticle structure for this band. From this comparison we assign a tentative bandhead spin of $I^\pi = 8^-$, as shown in Figs. 1, 3. The decreasing γ-ray energies, apparent in Fig. 3 as the neutron number decreases, suggests increasing collectivity for the lighter isotopes.

Band 2 shows two signature components with a large signature splitting, which indicates that both the odd proton and odd neutron reside in low-Ω orbitals. The Fermi level lies near several orbitals exhibiting this feature, namely $\pi h_{11/2}$ ($\Omega = 1/2$), $\pi g_{7/2}$ ($\Omega = 1/2, 3/2$), and $\nu h_{11/2}$ ($\Omega = 1/2, 3/2$) orbitals. Calculations based on the Total Routhian Surface (TRS) formalism [14–16] predict the lowest energy configuration to be the $(\pi, \alpha) = (-, 1)$ signature of the $\pi g_{7/2} \otimes \nu h_{11/2}$ structure at low frequency, with shape parameters ($\beta_2 \approx 0.176$, $\beta_4 \approx 0.030$, $\gamma \approx +9°$). Another configuration, which becomes increasingly favoured with increasing frequency, is the (+,1) signature of the $\pi h_{11/2} \otimes \nu h_{11/2}$ structure, with calculated shape parameters ($\beta_2 \approx 0.200$, $\beta_4 \approx 0.043$, $\gamma \approx +7°$). Cranked Woods-Saxon calculations, performed at the former deformation, are presented in Fig. 4, which shows single quasiparticle orbitals as a function of rotational frequency. The two possible structures exhibiting a large signature splitting are the $\pi g_{7/2} \otimes \nu h_{11/2}$ quasiparticle configuration (**Be/Ae** or **Be/Bf**) and the $\pi h_{11/2} \otimes \nu h_{11/2}$ quasiparticle configuration (**Ee/Ef**). Since the **E** orbital rapidly increases in energy at low frequency, the former configuration is favoured. The **Be** configuration has odd spins and negative parity; hence a spin and parity of 7^- is proposed for the lowest member of the favoured signature of band 2, as shown in Fig. 1, by coupling low-Ω $\pi g_{7/2}$ and $\nu h_{11/2}$ orbitals. The bunching together of several transitions in band 2 (996-964-978-994) implies that a quasiparticle pair alignment is taking place. Indeed, the calculations of Fig. 3 predict such alignments at $\omega_{fg} = 0.44$ MeV/$\hbar$ ($\nu h^2_{11/2}$) and $\omega_{EF} = 0.49$ MeV/$\hbar$ ($\pi h^2_{11/2}$), the ω_{ef} and ω_{AB} alignments being blocked for the **Be** configuration. Since the **fg** alignment is lowest in frequency, this suggests that the favoured signature of band 2 progresses into the $\pi g_{7/2} \otimes \nu h^3_{11/2}$ quasiparticle structure (**Befg**) at the highest spins in Fig. 1.

In summary, a level scheme has been deduced for doubly odd ^{114}I for the first time. Two band structures have been identified and are interpreted in terms of $\pi g_{9/2} \otimes \nu h_{11/2}$ and $\pi g_{7/2} \otimes \nu h_{11/2}$ quasiparticle configurations, respectively.

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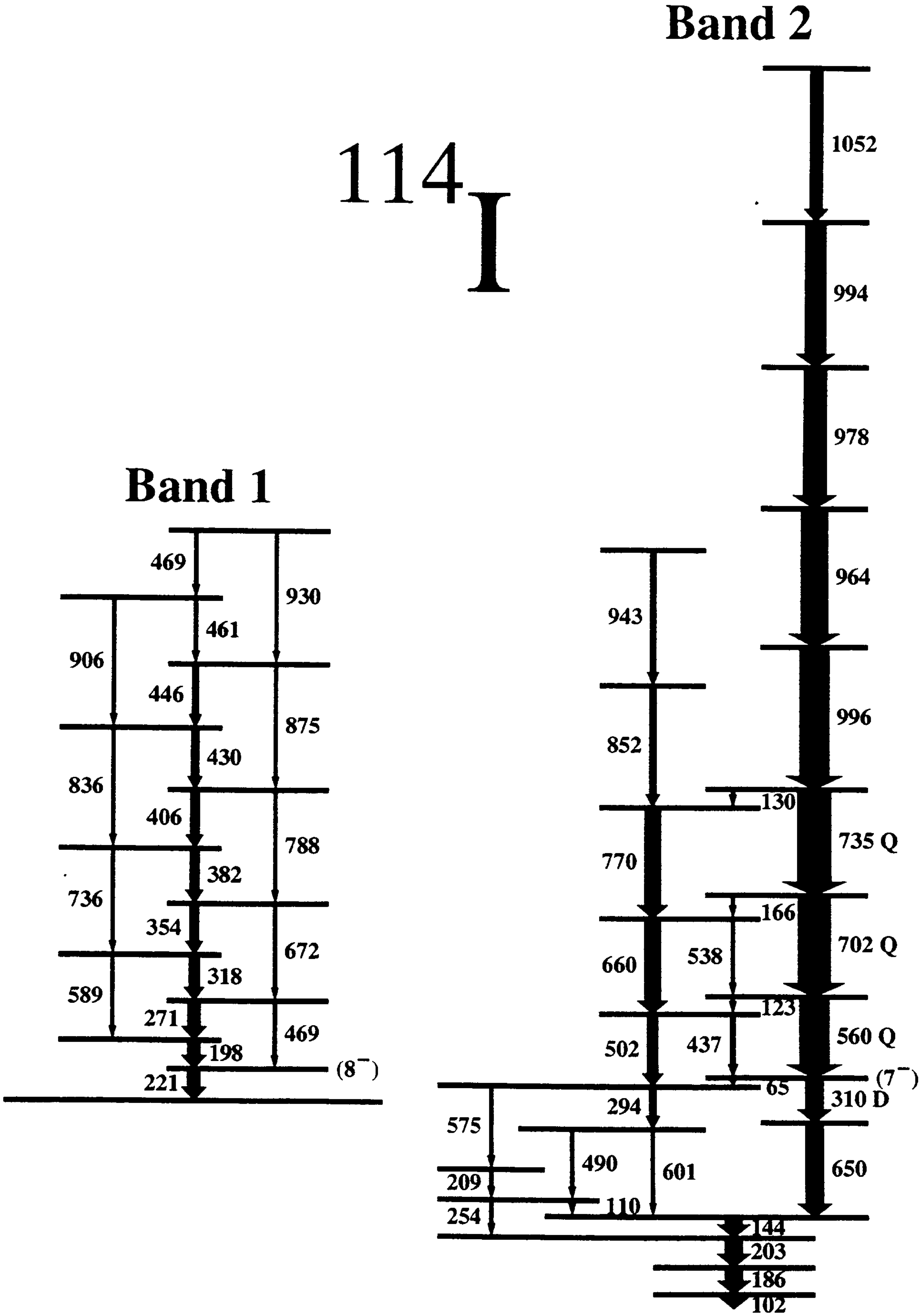
FIGURE CAPTIONS

Fig. 1. - Proposed level scheme for doubly odd ^{114}I with transition energies labelled in keV. Measured quadrupole (Q) and dipole (D) transitions are indicated. The relative excitation energy of bands 1 and 2 is unknown.

Fig. 2. - Gated spectra showing transitions in band 1 (a) and band 2 (b). Transitions assigned to ^{114}I are labelled by their energies in keV. Due to the weakness of ^{114}I in the data, contamination is evident in the spectra; transitions from ^{112}Te are indicated in (b) by the diamonds, while unknown lines only in coincidence with the 560-keV gate are indicated by circles.

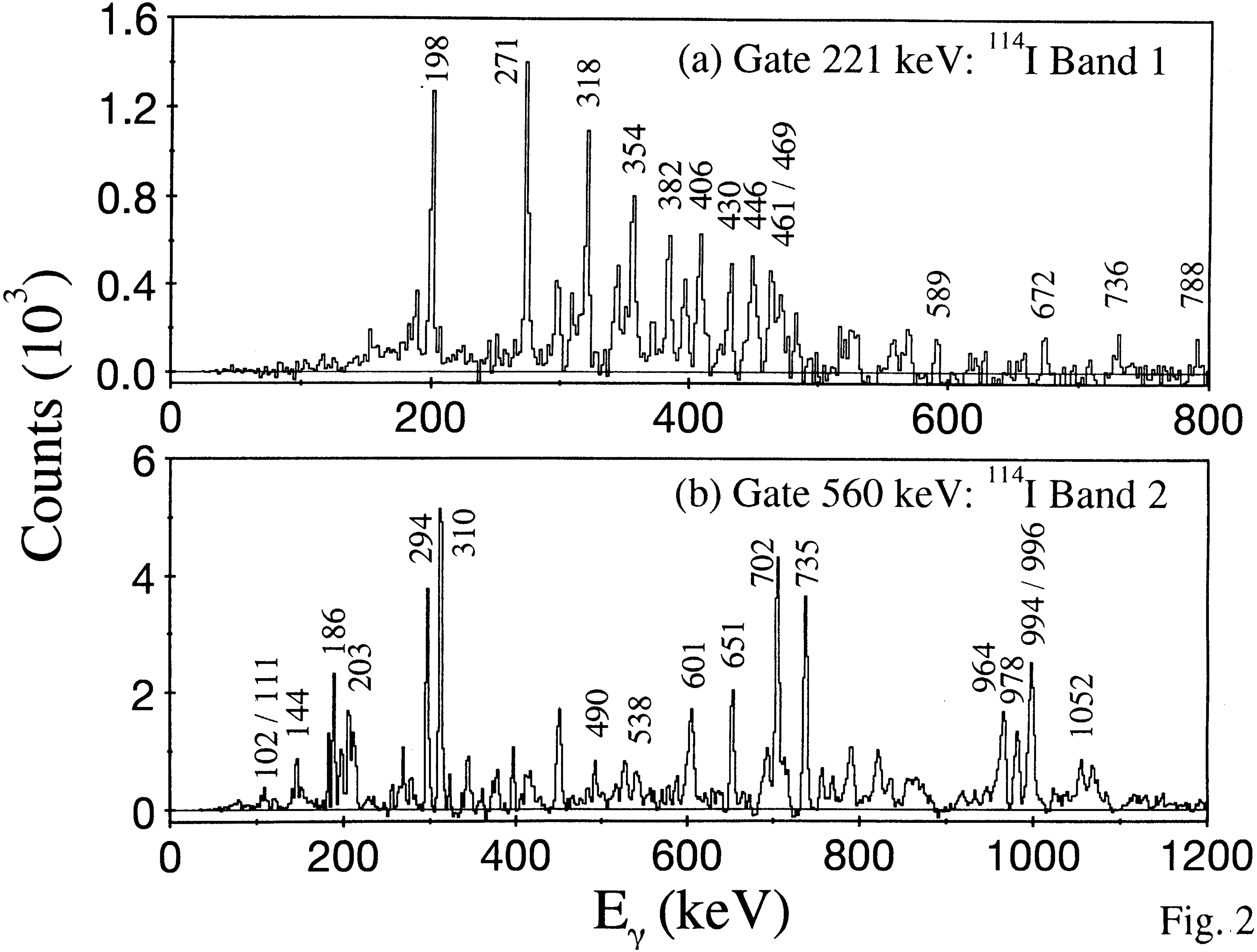
Fig. 3. - Systematics of strongly coupled $\pi g_{9/2} \otimes \nu h_{11/2}$ bands in doubly odd iodine isotopes [1], including the new band 1 of ^{114}I.

Fig. 4. - Representative cranked Woods-Saxon quasiparticle routhians for protons (a) and neutrons (b) calculated with deformation parameters β_2=0.176, β_4=0.030, and γ=+9°. The parity and signature (π,α) of the levels are: (+,+1/2) – solid lines; (+,–1/2) – dotted lines; (–,–1/2) – dashed lines; (–,+1/2) – dot-dashed lines. Quasiparticle-alignment frequencies for protons (ω_{EF}, ω_{AB}) and neutrons (ω_{ef}, ω_{fg}) are indicated by the arrows.



114I
Band 1
Band 2
469
930
906
461
446
875
836
430
406
788
736
382
354
672
589
318
271
469
198
(8⁻)
221
1052
994
978
964
943
996
852
130
770
735 Q
166
702 Q
660
538
123
560 Q
502
437
(7⁻)
65
310 D
294
575
490
601
650
209
110
254
144
203
186
102

Fig. 1



(a) Gate 221 keV: 114I Band 1
198
271
318
354
382
406
430
446
461 / 469
589
672
736
788
(b) Gate 560 keV: 114I Band 2
102 / 111
144
186
203
294
310
490
538
601
651
702
735
964
978
994 / 996
1052
Counts (10^3)
1.6
1.2
0.8
0.4
0.0
6
4
2
0
0
200
400
600
800
1000
1200
E_γ (keV)

Fig. 2

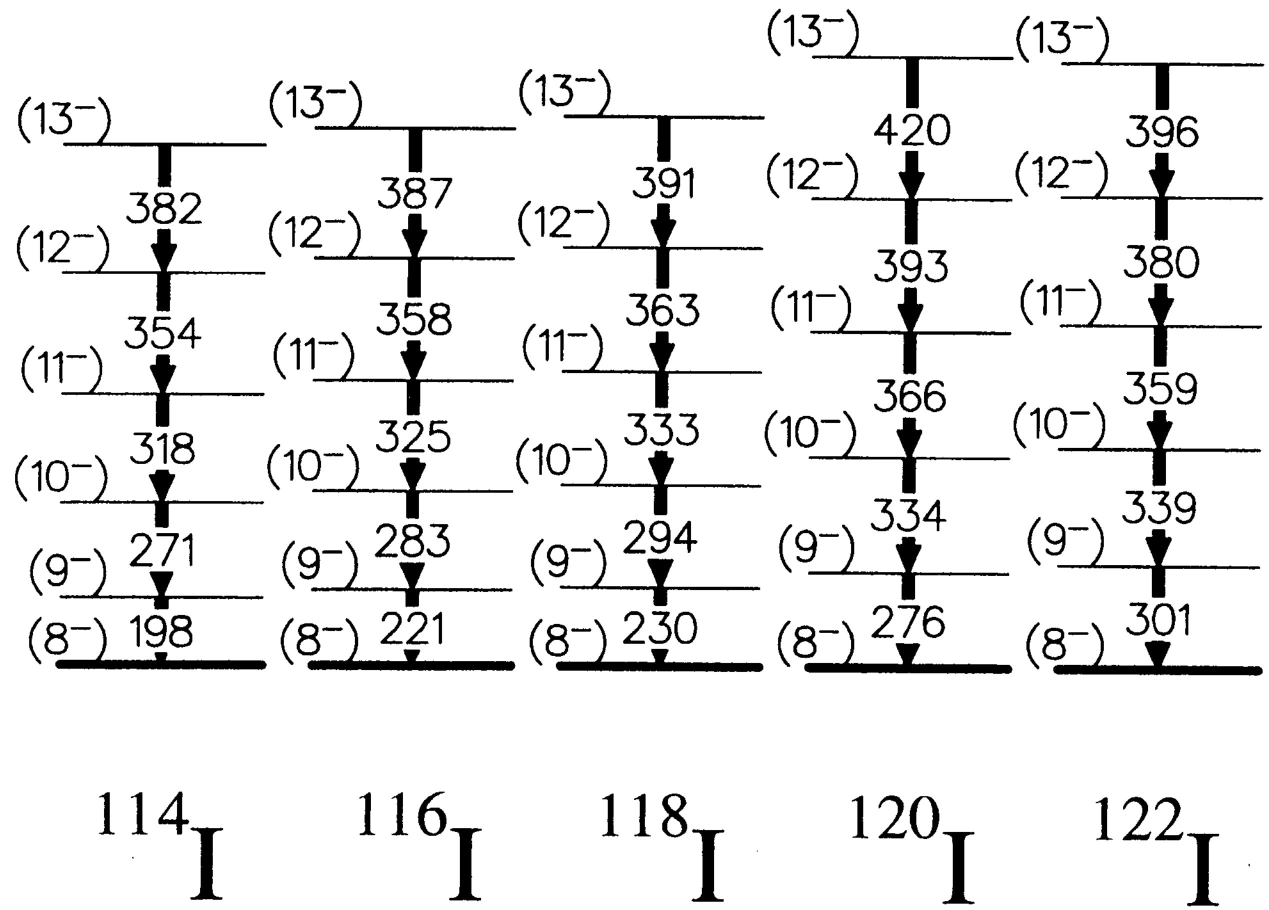

(13⁻) 382 (12⁻) 354 (11⁻) 318 (10⁻) 271 (9⁻) 198 (8⁻)
(13⁻) 387 (12⁻) 358 (11⁻) 325 (10⁻) 283 (9⁻) 221 (8⁻)
(13⁻) 391 (12⁻) 363 (11⁻) 333 (10⁻) 294 (9⁻) 230 (8⁻)
(13⁻) 420 (12⁻) 393 (11⁻) 366 (10⁻) 334 (9⁻) 276 (8⁻)
(13⁻) 396 (12⁻) 380 (11⁻) 359 (10⁻) 339 (9⁻) 301 (8⁻)
114I
116I
118I
120I
122I

Fig. 3

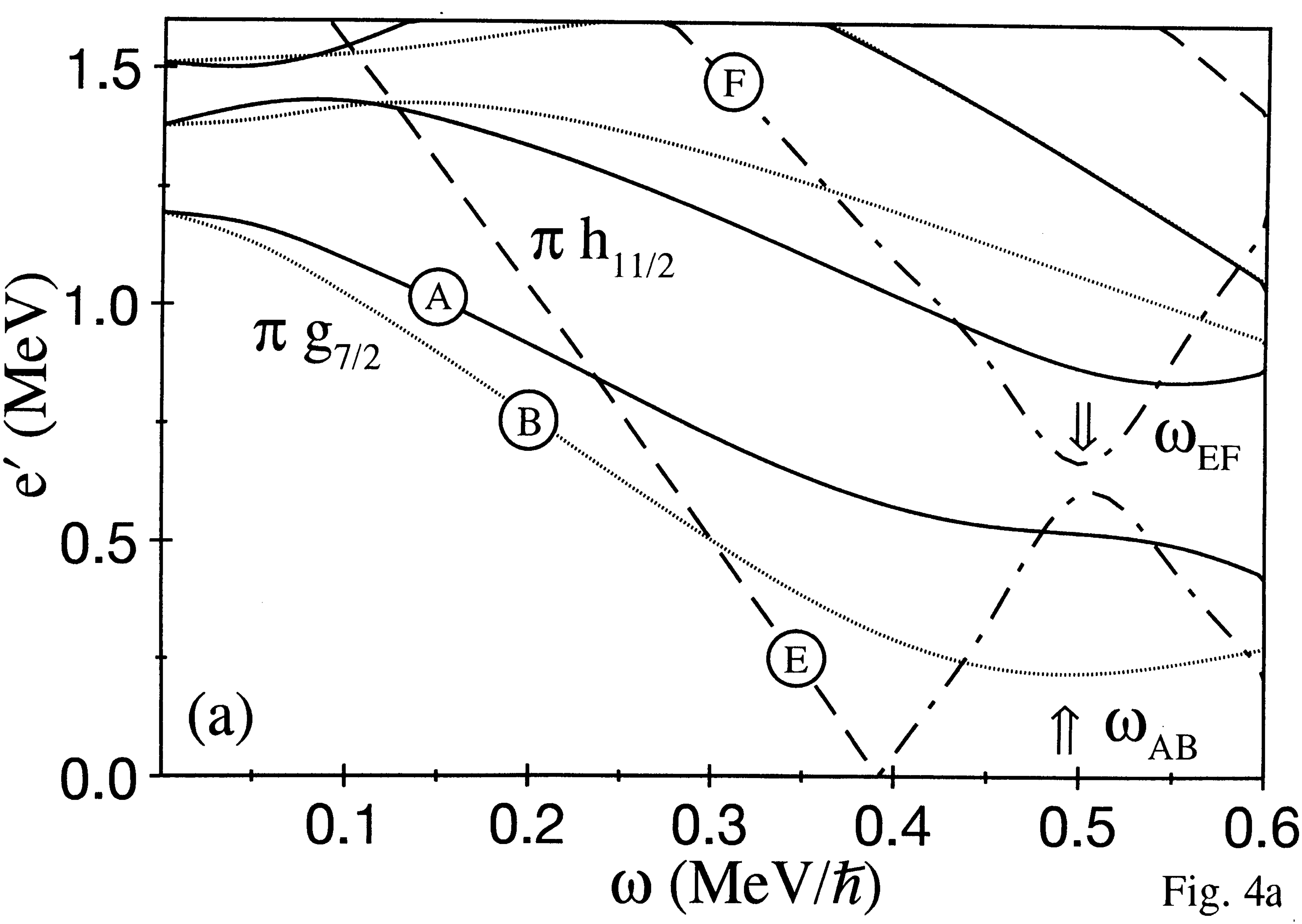


Fig. 4a

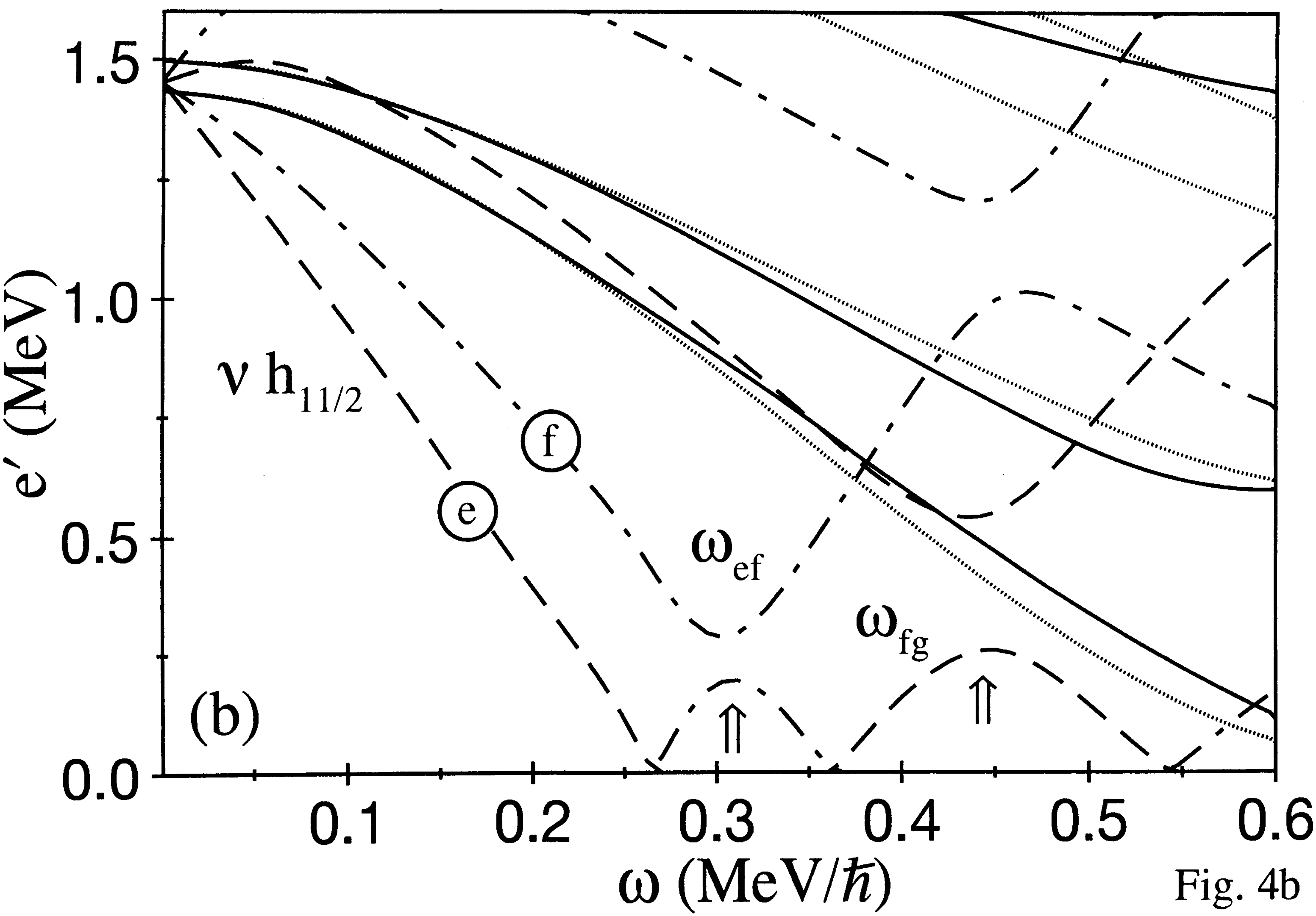


Fig. 4b