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Band Structure of Nuclear Levels and Pairing Correlation Interactions

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The modern theory of superconductivity applied to a statistical model of nuclei predicts the phase transition energy all at 2.73 Mev or so for a wide range of mass number. This transition energy curve is identified with cne of the curves which were found by Sakai from a plot of the number of levels against the excitation energy.

IN the previous paper[1] the influence of the pairing interaction of two nucleons on the nuclear energy level density was studied with the aid of the modern theory of superconductivity. Following the work of Sano and Yamasaki[2], a statistical model of nucleus was employed to examine an over-all character of the excited states. The empirical formula for the pairing energy ($\approx 2\Delta(0)$) proposed by Nemerovsky and Adamchuk[3] and that for the level dentity parameter a obtained by Abdelmaleck and Stavinsky[4] were used to calculate the transition temperature θ_c, excitation energy ε_c, entropy S, specific heat C and the total level density w(E). In contrast with the result of Sano and Yamasaki, the transition energy calculated from the equation

$$\varepsilon_c = a\theta_c^2 + \frac{1}{2} g\Delta^2(0) = 0.479 a\Delta^2(0) \tag{1}$$

predicts a value of about 3 Mev for nuclei within a wide range of mass number ***A***. In the present paper we would like to illustrate that this prediction is in good agreement with direct experimental data of the transition energy.

A few years ago Sakai[5] found a band structure in the energy spectra of the low lying excited states below several Mev. He plotted directly the number of levels N, instead of the usual level density, against the excitation energy E for even-even, odd-A and odd-odd nuclei of $A \leq 40$ and for even-even nuclei of $A > 40$. Typical examples of such plot are illustrated in Fig. 1. Two or three breaks can be found for each nucleus, and therefore the spectra of low lying states of any nucleus consist of three or four bands. The breaks are the edges of such bands.

Next he plotted the position of breaks as a function of mass number ***A*** and obtained four smooth curves as shown in Fig. 2. The existence of these curves

(1) J. L. Hwang, Chin J. Phys. 3, 35 (1965)
(2) M. Sano and S. Yamasaki, Prog. Theoret. Phys. (Kyoto), 29, 397 (1963).
(3) P. E. Nemirovsky and Yu. V. Adamchuck, Nuclear Phys. 39, 551 (1962).
(4) N. N. Abdelmalek and V. S. Stavinsky, Nuclear Phys. 58, 601 (1964).
(5) M. Sakai, JAERI (Japan Atomic Energy Research Institute), No. 1020, 66 (1962).

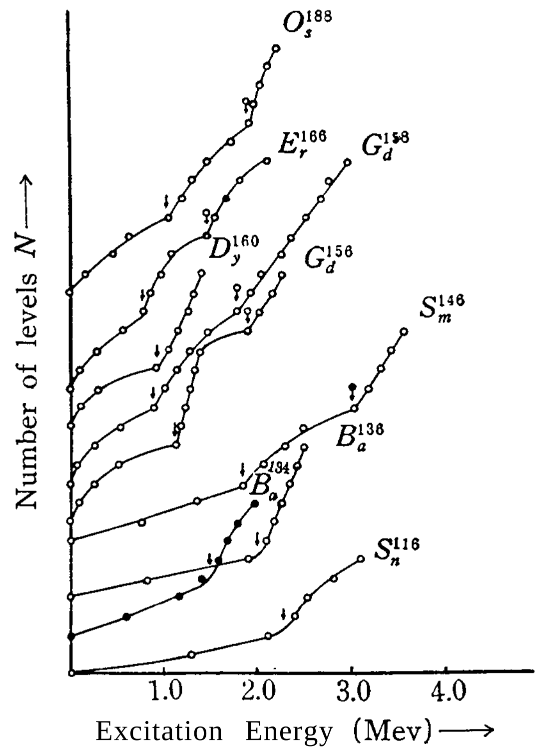

Fig. 1. Level density diagram, reproduced from Sakai (Ref. 3).

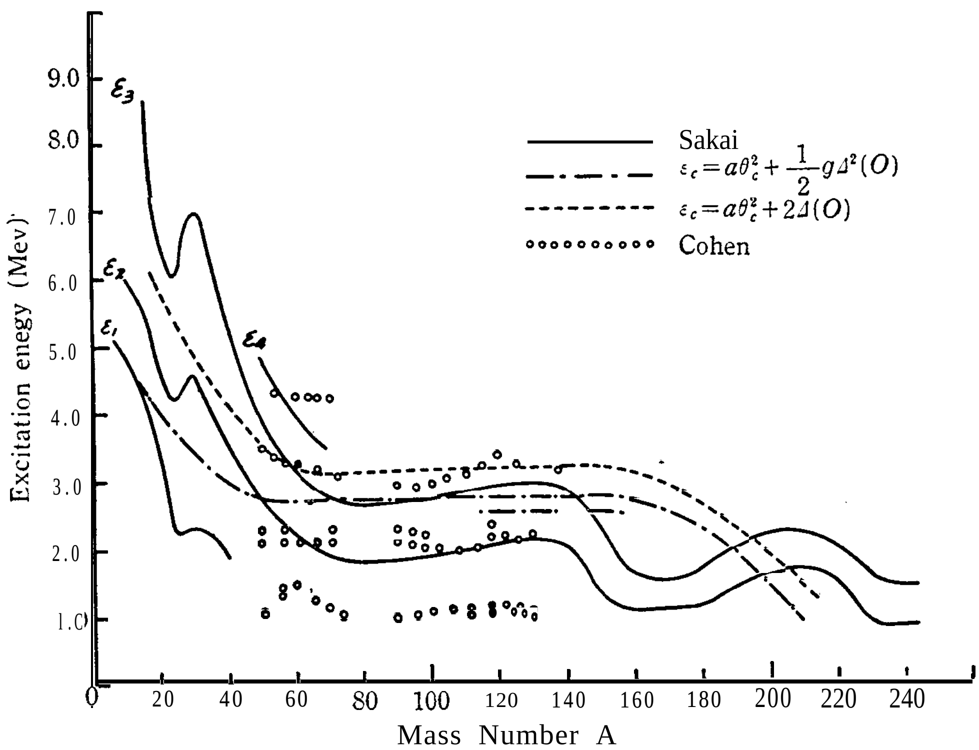

Fig. 2. Band structure of nuclear levels and the transition energy curves.

was also confirmed by the anomalous peaks in the spectra of inelastically scattered protons measured by Cohen[6]. Aside from the fourth curve (designated by ε_4) each curve can be interpreted as follows:

The first curve (ε_1)

The first breaks of odd-odd and odd-A nuclei for A,(45 constitute this curve. It corresponds to the edge of the vibrational band resulting from a coupling between a single particle and the collective motion of the even-even core. The coupling is assumed to be the one phonon quadrupole type.

The second curve (ε_2)

The first breaks of all even-even nuclei and the second breaks of odd-odd nuclei of $A\leq 40$ as well as of odd-A nuclei of $A\leq 45$ lie on this curve. For even-even nuclei it is interpreted as the lower limit of the energy band due to the two quasi-particle excitation. For odd-odd and odd-A nucleus it can be looked as a result of the same mechanism as the first curve but with a different type of coupling, namely, with emission and absorption of one octopole phonon.

The third curve (ε_3)

The second breaks of all even-even nuclei form this curve. It is thought to be ' a result of the one phonon octopole vibration, or alternatively to be a result of the four quasi-particle excitation. An intimate correlation can be found between the position of appearence of the negative parity state and this curve.

The existence of the fourth curve has still not been well established because of limited number of data. The dips of the second and the third curves in the region $150\leq A\leq 190$ can be explained by a deformation of nucleus.

Here we wish to identify the second curve (ε_2) with the transition energy curve Eq. (1). The first intrinsic excited state of an even-even nucleus is a level with two quasiparticles and of energy

$$2E_j=2\{(\varepsilon_j-\lambda)^2+\Delta^2(0)\}^{1/2},$$

which is of order $2\Delta(0)$, since $\varepsilon_j-\lambda\ll A$. Here ε_j is the single-particle energy ignoring pairing force and I is an average Fermi level. On the other hand the usual expression for the excitation energy of the Fermi, gas is given by

$$\varepsilon_F=a\theta^2.$$

Therefore the excitation energy with the pairing force is simply

$$\varepsilon\approx a\theta^2+2\Delta(0),$$

and the transition energy ε_c corresponding to the critical temperature θ_c is

$$\varepsilon_c\approx a\theta_c^{\,2}+2\Delta(0). \tag{2}$$

(6) B. L. Cohen, Phys. Rev. 105, 1549 (1957).

Sakai also attributed the second curve (ε_2) to this equation but neglecting the first term. The second term of Eq. (1) and that of Eq. (2) are apparently different; the former is quadratic in the pairing energy. Neverthless when ε_c is plotted against A both equations show a similar character and coincide reasonably with the second curve, as can be seen from Fig. 2.

Thus we have seen that the statistical theory of nucleus can be shown to be effective also for inclusion of the pairing interactions if the choice of data for the pairing energy and the level density parameter is appropriate.