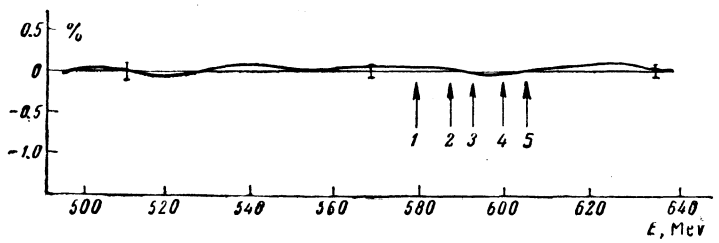

Dependence of the quantity $[\sigma(E)-\bar{\sigma}(E)]/\bar{\sigma}(E)$ on the proton energy E. The thresholds of the reactions $pp \to pp\pi^0\pi^0$(1), $pp \to d\pi^0\pi^+$(2), $pp \to pn\pi^0\pi^+$(3), $pp \to pp\pi^+\pi^-$(4), and $pp \to nn\pi^+\pi^+$(5) are indicated by arrows.

stitute for Nuclear Research was shaped by a system of collimators, and then was sent through three identical thin-walled ionization chambers. The first chamber served as a monitor. The second and third chambers, with the polyethylene target placed between them, formed the differential ionization chamber. The current i_2 from this differential chamber was proportional to the amount of weakening of the beam in passing through the target, i.e., to the product of the total cross section and the beam intensity J. The current i_2 was amplified and recorded on the chart of a recording potentiometer.

As the thickness of the filter by which the proton beam was slowed down was smoothly increased, a curve was traced on the chart of the potentiometer; this curve shows the variation of the quantity $i_2 \sim \sigma J$ as the proton energy E is decreased. Simultaneously another potentiometer registered the change of the current $i_1 \sim J$ from the monitoring chamber. The desired quantity $\sigma(E)$ was obtained by dividing i_2 by i_1. This operation was performed by a continuously acting electronic device, whose output, proportional to i_2/i_1, was recorded on the chart of a third potentiometer. The measurements were repeated many times to eliminate the effects of small fluctuations in the current from the differential chamber.

The energy of the beam was determined to an accuracy better than 1 Mev (cf. reference 5). The energy resolution was ±5 Mev and was due to the dispersion of the beam (±3 Mev)[5] and energy losses in the target (±4 Mev).

The results of the measurements are shown in the diagram. It shows the fractional deviation of the measured cross section $\sigma(E)$ from the smoothed energy dependence $\bar{\sigma}(E)$ found by averaging over a broad range of energies; in the region in question this smoothed dependence is linear.[4] As can be seen from the diagram, in the entire range studied, 490 — 640 Mev, there are no anomalies in the energy dependence of the total cross section for pp interaction that exceed the errors of measurement (0.1 percent).

It follows from this that there is little probability that a bound state "π meson + nucleon" with binding energy close to zero exists.

At the same time control experiments were made with a graphite target. The energy dependence of the total cross section for carbon should not contain any appreciable anomalies, owing to the motions of the nucleons in the carbon nucleus. In agreement with this, the measurements showed that for carbon the deviation of $\sigma(E)$ from $\bar{\sigma}(E)$ does not exceed 0.05 percent.

In conclusion we take the occasion to thank A. I. Baz', L. I. Lapidus, and B. Pontecorvo for a discussion of this work.

[1] E. Wigner, Phys. Rev. **73**, 1002 (1948). A. I. Baz', JETP **33**, 923 (1957), Soviet Phys. JETP **6**, 709 (1958).

[2] L. Fonda, Inelastic Collisions and Threshold Effects, Preprint, 1960.

[3] Zinov, Konin, Korenchenko, and Pontecorvo, JETP **36**, 1948 (1959), Soviet Phys. JETP **9**, 1386 (1959). V. I. Gol'danskii and Ya. A. Smorodinskii, JETP **36**, 1950 (1959), Soviet Phys. JETP **9**, 1387 (1959).

[4] Dzhelepov, Moskalev, and Medved', Doklady Akad. Nauk SSSR **104**, 380 (1955). Chen, Leavitt, and Shapiro, Phys. Rev. **103**, 211 (1956).

[5] I. M. Vasilevskii and Yu. D. Prokoshkin, Атомная энергия (Atomic Energy) **7**, 225 (1959).

Translated by W. H. Furry
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EFFECT OF TEMPERATURE ON HYPERFINE STRUCTURE OF GAMMA RADIATION

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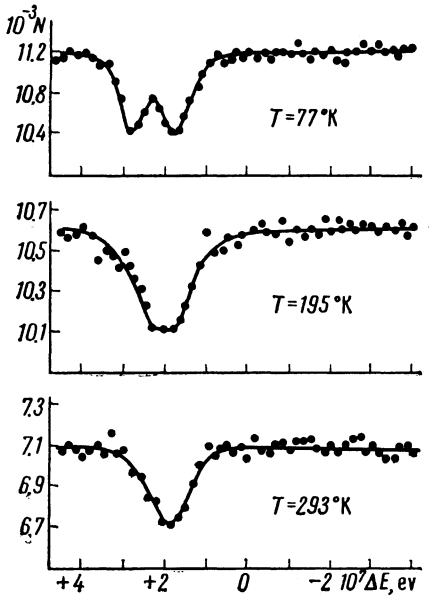
IN investigating the resonance absorption of γ quanta with energy 23.8 kev by Sn^{119} nuclei, it was found[1] that in a white tin crystal (β-Sn) at liquid

nitrogen temperature the lines of radiation (or absorption) are split into two components. The existence of such a splitting was later confirmed by other measurements[2] in which we used as the source of γ quanta Sn^{119m} which was contained as a constituent of a polycrystal of β-Sn (at liquid nitrogen temperature), while the absorbers were various compounds containing tin. The observed splitting was interpreted as a hyperfine structure of the γ ray caused by an interaction of the quadrupole moment of the Sn^{119} nucleus in the excited state with the inhomogeneous electric field in the β-Sn crystal.

In the present work we have investigated the effect of temperature of the β-Sn crystal on the magnitude of the quadrupole interaction. When the temperature of the crystal is changed, there is a change in the amplitude of the thermal vibrations of the atoms and a change in the interatomic distances; consequently, one may expect a change in the gradient of the electric field at the Sn^{119} nucleus. As a source of γ quanta, we used Sn^{119m} contained in a polycrystal of SnO_2. It was shown earlier[2] that for SnO_2 there is no splitting of the radiated line, and the radiation of γ quanta without energy loss to recoil occurs with high probability even at room temperature. The source thickness was 6 mg/cm^2. By measurements with SnO_2 absorbers of various thicknesses it was shown that in such a source the effect of broadening of the radiated line because of self-absorption is negligible. For example, with a SnO_2 absorber of thickness 4 mg/cm^2 the line width in the absorption spectrum was 6×10^{-8} ev, which is close to twice the natural width of the 23.8 kev excited state of Sn^{119}.

The measurements of the spectrum of the resonance radiation were carried out in an apparatus which was described briefly earlier.[1] In all the measurements the source (SnO_2) was at room temperature, while the absorbers (natural β-Sn) were at liquid-nitrogen temperature, dry-ice temperature, and room temperature. We used absorbers of various thicknesses in the range from 5 to 50 mg/cm^2, prepared either from rolled tin foil, or by sputtering of metallic tin in vacuum onto an organic backing. Typical resonance absorption spectra are shown in the figure (along the abscissa, we give the quantity $\Delta E = Ev/c$, where E = 23.8 kev, v is the velocity of the source with respect to the absorber; along the ordinates, we give the intensity of γ radiation passing through the absorber, proportional to the total number of recorded pulses N). In the upper part of the figure is shown the absorption spectrum for an absorber of β-Sn, 5 mg/cm^2 thick, at liquid nitrogen temperature. One sees two absorption maxima corresponding to the quadrupole splitting of the absorption line. The separation of the maxima is $(1.10 \pm 0.15) \times 10^{-7}$ ev, which agrees with the value obtained by us earlier.[1,2] The middle part of the figure shows the absorption spectrum for a β-Sn absorber 12 mg/cm^2 thick at dry-ice temperature, and the lower part of the figure for an absorber 30 mg/cm^2 thick at room temperature. For such absorber thicknesses and temperatures there is no essential broadening of the absorption line because of absorber thickness. Control measurements with an absorber of $SnNb_3$ (there is no quadrupole interaction[1] in the $SnNb_3$ crystal) showed that in the absence of splitting the line width in the absorption spectrum corresponds to the natural width of the excited state. The lines in the absorption spectrum shown in the figure have considerably greater width (1.4×10^{-7} ev for dry-ice temperature and 1.05×10^{-7} ev for room temperature). In the two last spectra the hyperfine structure components are no longer resolved, but the observed line widths and their dependence on temperature shows the presence of quadrupole splitting in these cases also. For the magnitude of the quadrupole splitting at temperatures 195 and 293° K we obtain the values $(8.0 \pm 1.5) \times 10^{-8}$ and $(4.6 \pm 1.4) \times 10^{-8}$ ev, respectively. Thus we observe a decrease in the magnitude of the quadrupole interaction as the temperature of the crystal increases. This dependence is a consequence of the temperature variation of the average of the components of the tensor of the electric field gradient along the prin-



cipal axis $\langle q \rangle = \langle \partial^2 V/\partial z^2 \rangle$, and the angular orientation of this tensor with respect to its static direction. In addition, with temperature there may be some change also in the asymmetry parameter $\eta = |(q_{xx} - q_{yy})/q_{zz}|$. The calculations of Kushida et al.[3] lead to the following dependence of the value of the splitting on the temperature: $\Delta = a(1 + bT + c/T)$. The constants a, b, and c are functions of volume and can be obtained from measurements of the dependence of Δ on pressure for different temperatures. A comparison of the experimental data with theoretical computation should enable one to determine the quadrupole moment of the Sn^{119} nucleus in the excited state.

The dependence found in the present work for the quadrupole splitting as a function of temperature explains the result of Boyle, Bunbury, and Edwards[4] who observed no splitting of the absorption line in the β-Sn crystal. In their work the absorber was at room temperature, in which case the quadrupole splitting does not exceed in magnitude the width of the line in the absorption spectrum even for a thin source. But the width of their source was such that as a result of self-absorption the line width of the radiated line was increased by a factor of two compared to the natural width. Under such conditions of the experiment, the quadrupole splitting could not be observed. (In the work of Picou et al.[5] the quadrupole splitting was also not observed at liquid nitrogen temperature, which is possibly explained by the use in their work of extremely thick source and absorber.)

As we see from the figure, the influence of the temperature shows itself not only in the magnitude of the quadrupole splitting, but also in the location of the centers of the absorption curves in the spectra. The observed line shift with changing temperature exceeds by several factors the value of the so-called "temperature shift"[6] and contradicts the data of the work of Boyle et al.,[7] who found good agreement with the theory. The reason for this discrepancy is difficult to analyze, since these authors do not give all the necessary data; it is possible that in their work there was an influence on the measured effect of the change in line shape with change in temperature, which was not taken into account. One may assume that the change in internal field in the β-Sn crystal with changing temperature not only leads to a change in the value of the quadrupole interaction, but also changes the energy of the γ transition as a whole, which has an effect on the observed shifts in the absorption line.

[1] N. N. Delyagin et al., JETP **39**, 220 (1960), Soviet Phys. JETP **12**, 159 (1961).

[2] V. A. Bryukhanov et al., JETP **40**, 713 (1961), Soviet Phys. JETP **13**, 499 (1961).

[3] Kushida, Benedek, and Bloembergen, Phys. Rev. **104**, 1364 (1956).

[4] Boyle, Bunbury, and Edwards, Preprint, (1960).

[5] J. L. Picou et al., Preprint, (1960). Cf. also E. Cotton, J. Phys. Radium, Paris, **21**, 265 (1960).

[6] R. V. Pound and G. A. Rebka, Phys. Rev. Letters **4**, 274 (1960).

[7] A. J. F. Boyle et al., Proc. Phys. Soc. (London) **76**, 165 (1960).

Translated by M. Hamermesh
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RATIO OF $\pi N \rightarrow \pi\pi N$ REACTION CROSS SECTIONS OF 290 Mev AND π-π INTERACTION

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THE process of the production of the second meson in the reaction $\pi N \rightarrow \pi\pi N$ at different energies has recently been widely used to obtain information on the π-π interaction. In the collision of a π meson and a proton above the threshold for the production of the second meson ($\sim$170 Mev) the following processes are possible:

$$(1)\ \pi^- + p \rightarrow n + \pi^+ + \pi^-, \quad (2)\ \pi^- + p \rightarrow p + \pi^0 + \pi^-,$$
$$(3)\ \pi^- + p \rightarrow n + \pi^0 + \pi^0, \quad (4)\ \pi^+ + p \rightarrow n + \pi^+ + \pi^+,$$
$$(5)\ \pi^+ + p \rightarrow p + \pi^+ + \pi^0.$$

In order to explain certain qualitative features of the π-π interaction, it is of interest to establish relations between the cross sections of the above processes. Of these reactions, (1) and (2) have been investigated in detail at an energy of the primary meson of the order of 1 Bev.[1-3] At lower energies only reaction (1) has been studied in detail.[4-6] The cross section for it at 290 Mev was found to be $\sigma_1 = 0.61 \pm 0.13$ mb.[5] The cross section of reaction (2) has not been measured directly.