Comment on \((p, n)\) Cross Sections

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Recently, Howe\(^1\) measured the excitation cross sections of \((p, n)\) reaction from \(^{64}\text{Cu}, \) \(^{65}\text{Cu}, \) \(^{64}\text{Zn}, \) \(^{66}\text{Zn}, \) and \(^{68}\text{Zn}\) and suggested that the large variations from isotope to isotope in the magnitude of the \((p, n)\) cross section seem to be an indication of the occurrence of interactions other than compound nucleus formation process. In that paper, the \((p, n)\) cross sections were measured at energies up to 12 Mev, and the cross
sections were compared with the total reaction cross sections based on Shapiro's argument\textsuperscript{3} that the \((p, n)\) cross section is the same as the total reaction cross section in the low energy region since the neutron emission mode is considered as the most predominant one so far as the energy is not very high. Although this argument is certainly justified for many cases, careful note on binding energy of the last proton must be taken in discussing the reaction mechanism.

The purpose of the present note is concerned with the fact that the large variations from isotope in the magnitude of the \((p, n)\) cross section, as pointed out by Howe, may be or may not be explained by the use of compound nucleus picture. The calculations are made for the isotopes of Ni, Cu and Zn from among the many available data\textsuperscript{5} on \((p, n)\) cross section since the variations from isotope to isotope of these nuclei considerably differ from each other in spite of these elements are in neighboring atomic number.

The method of the calculation, based on the usual compound nucleus model, is same as before. In the evaluation of the excitation cross sections, the nuclear radius is assumed to be \(R=1.5 \times A^{1/3}\) \textit{fermi} and the constant \(a\) which appears in level density formula, is chosen as \(a=2\) \text{Mev}^{-1} for all elements undertaken. The cross sections for compound nucleus formation by proton are estimated from Shapiro's paper,\textsuperscript{3} and the separation energies are determined by the use of Wapstra's table.\textsuperscript{4} In the numerical integration to obtain the excitation cross sections, the evaluations at low excitation energies become somewhat uncertain because of the technique of the numerical calculation and then one must devote efforts to the determination of the threshold energies in \((p, n)\) reactions. The threshold energy for \((p, n)\) reaction is given by \(E_{th}=S_n-S_p\), where \(S_n\) and \(S_p\) are the separation.
energies of neutron and proton from the compound nucleus, respectively. For the most cases, the difference between the threshold energies determine the variation from isotope to isotope in the magnitude of the cross section at low excitation energy region, and with increasing the excitation energy the varia-
tion is governed by the competitive processes of other kinds of particle or of secondary emitted particles, in other words, the threshold energies of other decay modes play an important role for the behavior of the excitation function.

The comparisons between the experimental cross sections and the calculated ones are made in Figs. 1, 2, and 3, where the calculated cross sections are represented by the solid curves and the numbers added to each curves refer to the mass numbers of target nuclei. From these figures, it is apparent that the calculations based on the compound nucleus model may explain the variations from isotope to isotope in the magnitude of the \((p, n)\) cross section fairly well. For the cases of Cu and Zn (Figs. 2 and 3), some considerable disagreements in absolute values of the cross sections are observed. As the reason for these disagreements, one may consider the two facts; one is the discrepancy between the experimentally determined threshold energy and the estimated one, and the other is the fact that in the present calculations for all cases the decay probabilities are calculated for compound nucleus of \(^{64}\text{Cu}\) except for the relations of the separation energies and of the even-odd rule. If the calculations are made more rigorously for each cases, one may expect better agreement between experiment and calculation. Thus we may conclude that the large variations from isotope to isotope in the magnitude of \((p, n)\) reaction, as measured by Howe, are not the evidence for the non-compound nuclear process but offer an example as to the usefulness of the compound nucleus picture in such an energy region.

2) M. M. Shapiro, Phys. Rev. 90 (1953), 171.