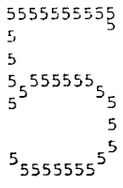

SUMMARY AND CONCLUSION

Low energy (p,n) reactions, proceeding through the formation of compound nucleus, provide useful experimental data for investigating the proton - nucleus optical model potential and for the spectroscopy of isobaric analog states in the compound system.[8,9] The main advantages of studying (p,n) reactions below the Coulomb barrier are : (a) the enhanced compound nucleus decay widths due to the absence of Coulomb forces in the exit channel, (b) possibility of attaining excellent energy resolution for charged particle beams using electrostatic accelerators, (c) high sensitivity for observing isobaric analog resonances particularly for incident proton energies below the (p,n) threshold for the ground state analog of the target, (d) approximate equality of the (p,n) cross section and the optical model reaction cross section because of very small contributions from other non-elastic channels, and (e) possibility of observing single particle resonances in (p,n) strength functions as a function of energy. An experimental measurement of total (p,n) cross section at smaller energy interval (much less compared to the average widths of compound nuclear resonances) serves two purposes - (i) isobaric analog resonances can be seen in the fine structure excitation functions and these can be shape analysed to deduce the spectroscopic factors, and (ii) the excitation function averaged over suitable energy interval to smoothen out compound nuclear fluctuations can be analysed using the optical model.

The present study is an exploitation of the above mentioned advantages of fine structure (p,n) excitation functions. Absolute cross sections have been measured for the reaction ^{55}Mn (p,n)^{55}Fe and ^{80}Se (p,n)^{80}Br from near threshold upto about 5.5 MeV at 5 keV interval using targets of thicknesses ~ 5 keV for 4 MeV protons and a 4π geometry neutron counter. The reproducibility of the data has been very good as is evident from fig. (3.3) and indicates that errors due to target non-uniformity and beam stability are negligible. Prominent resonances in both the reactions have been studied in finer energy steps (~ 1 keV for ^{55}Mn and 2.5 keV for ^{80}Se) using appropriate thinner targets to determine the resonance shapes accurately. The fine structure excitation functions have been averaged over 100 keV energy interval to produce a smooth function corresponding to thick target measurements. Such thick target excitation functions agree well with the previous measurements of Johnson et al.[14]

Isobaric Analog Resonances

The fine structure excitation functions show all the prominent IARs observed in previous studies of (p,p), (p,γ) and (p,n) reactions on these targets. In addition the IAR at E_p = 5.245 MeV has been observed for the first time in the reaction ^{80}Se (p,n)^{80}Br. Coulomb displacement energy ΔE_c has been deduced for several resonances in both the reactions studied. The individual values of this quantity are found to differ from level to level by less than about 30 keV as expected[1] and the average ΔE_c values are in good accord with those deduced from other sources.[30]

The isobaric analog resonances have been analysed using Robson's formalism[7] as modified by Johnson et al.[36] For a typical case of the 1.54 MeV resonance in the reaction ^{55}Mn (p,n)^{55}Fe, Breit-Wigner analysis has also been done in order to study the relative merits of the two prescriptions. It is found that a combination of the two methods works better to

unambiguously derive the proton partial width whose value would be free from parameter dependences. In the case of ^{80}Se (p,n)^{80}Br reaction, however, resonances have been analysed only by Robson-Johnson formalism after taking guidance about parameter values (like the channel radius etc.) from the ^{55}Mn case.

Spectroscopic factors for the states in ^{56}Mn and ^{81}Se have been derived from the experimental proton partial widths using the method of Thompson et al[41]. These are presented in Table 3.4 for the states in ^{81}Se. The values obtained in the present (p,n) study are found to agree well with those obtained in the study of the ^{80}Se (d,p)^{81}Se reaction in contrast to the very different value obtained from elastic scattering measurements. In this way the IAR spectroscopy through (p,n) reaction is found to be superior to elastic scattering at least at sub-Coulomb energies.

A detailed investigation of the dependence of spectroscopic factor on the parameters of the neutron OMP has been carried out for a typical case of the 1.54 MeV resonance in ^{55}Mn (p,n)^{55}Fe reaction. The spectroscopic factor is found to be a continuous but widely varying function of the OMP parameters as can be seen in fig. (3.6). A quantity called "Reduced Normalization" as defined according to Carlson et al[44] has also been calculated and is found to be almost independent of the neutron OMP parameters.

The spectroscopic factor for the 0.213 MeV 2^+ state in ^{56}Mn as deduced from the analysis of the observed analog resonance at E_p = 1.543 MeV in ^{55}Mn (p,n)^{55}Fe reaction is found to be lower by an order of magnitude than the corresponding value obtained from (d,p) studies. This discrepancy has been ascribed to the doublet nature of levels in ^{56}Mn around 0.215 MeV.[13,32] Thus whereas the spectroscopic factor deduced from (d,p) reaction represents

the combined strength of the 2^+ and 4^+ levels in the doublet, the strength seen in (p,n) measurement corresponds only to the 2^+ state (this is because the 4^+ state cannot be observed in (p,n) reaction with appreciable probability due to the mismatch of angular momenta at these low energies). The fact that 0.213 MeV 2^+ state has only 40% of the total strength in the doublet as observed in (p, γ) studies[13] explains the lower value of the spectroscopic factor observed in the present work.[29]

Proton Optical Model Potential

Studies of the proton nucleus OMP at sub-Coulomb energies carried out over the last decade have pointed out two peculiar trends of the OMP at these low energies as compared to the established systematics at higher energies : (i) the energy dependence of the real potential is much larger, and (ii) the strength of the imaginary potential shows abnormal behaviour as a function of target mass. The later point has been observed in two separate studies in the mass region A = 45 - 80 (using a real potential whose energy dependence was much larger, b = 0.85 for the linear approximation $V(E) = V_0 - b.E$)[20] and A = 90 - 130 (using a real potential with b = 0.32 as used at higher energies).[10] These anomalies in the depth W_0 of the imaginary potential , therefore, cannot be treated uniformly as the value of b substantially affects the sensitivity of data to OMP parameters. It is now widely accepted that the energy dependence of the proton OMP is larger at lower incident energies around the Coulomb barrier than at higher energies.[93] The earlier analyses have been inadequate in not giving due consideration to the enhanced role of Coulomb correction for both the real and imaginary potentials. Hence there has been a need to investigate the proton OMP at sub-Coulomb energies by using all the experi-

mental data simaltaneously in a coherent way and using a real potential having the accepted larger energy dependence.

The present work has attempted to meet this requirement by analysing (p,n) excitation functions for forty five nuclei in the mass region A = 40 - 140 including our own measurements on ^{55}Mn and ^{80}Se and taking other data from literature. A simple optical model potential with only a complex central nuclear part and a Coulomb potential has been used for the analysis. Spin-orbit potential has been omitted throughout. For the present data in the energy range E_p = 2 - 7 MeV, an average value of b = 0.85 has been used. As in the case of analysis of (p,n) excitation functions for tin isotopes by Johnson et al[52], three parameters, namely the depths V_0 and W_0 of the real and imaginary potential and the imaginary diffuseness a_w have been varied to fit the data. Other parameters have been fixed according to the established systematics at higher energies. To avoid parameter ambiguities, a scheme of step-by-step deduction of parameter systematics has been adopted in the following way :- (i) the real potential has been systematized and fixed during the three parameter search in the first step, (ii) a two parameter search has been carried out in the second step to deduce the systematics of a_w and fix it accordingly, and (iii) in the final step W_0 has been determined using a single parameter search. This approach has helped to preserve the quality of fits at all stages as can be seen in figs. (4.4) and (4.5).

In an attempt to systematize the real potential depth as a function of A and Z, the Coulomb correction ΔV_c has been found to be much more significant at sub-Coulomb energies than hitherto believed. and is commensurate with the larger energy dependence at these energies (for

b = 0.85, $\Delta V_c = 1.13Z/A^{1/3}$). Corresponding to this value of ΔV_c , the strength of the isovector term comes out to be ≈ 22 MeV which is in good agreement with the values obtained previously.(63)

To systematize the imaginary potential as a function of A and Z in an unambiguous way, an weighted average of the volume integral per nucleon has been used throughout, the weighting factor being decided by the minimum in various parameter searches. After fixing the isovector contribution to the imaginary volume integral per nucleon according to the systematics available in literature ($J_{W_1}/A = 140 \pm 40$ MeV fm^3), the Coulomb correction $J_{\Delta W_c}/A$ has been determined as a function of $Z/A^{2/3}$ (this parametrization for the volume integral of Coulomb correction having a Woods-Saxon derivative form factor being used for the first time in the present work). The Coulomb correction contribution for imaginary potential is found to be very high, although values available in literature are too scanty to allow a meaningful comparison. A part of the strength of the imaginary potential is found to be correlated to the quadrupole deformation of nuclei, thus emphasizing the role of nuclear structure effects in the imaginary part of the optical model potential.(1,2)

A global potential for the energy and mass range under investigation has been deduced. The applicability of this potential to other data sets and in the extended mass and energy region has been investigated by comparing its predictions for (a) the elastic scattering on ^{94}Zr, ^{116,120}Sn at several energies in the range E_p = 5 - 9 MeV, (b) the absorption cross sections for heavier nuclei like ^{165}Ho, ^{181}Ta and ^{209}Bi in the energy range E_p = 6 - 10 MeV. and (c) p-wave neutron strength functions for the mass range A = 50 - 150 where 3p resonance has been experimentally seen. In general the predictions agree well with experimental data in view of the fact that no attempt was

made to vary the parameters to fit the data. The neutron OMP obtained by flipping the isovector part is found to reproduce the shape of the p-wave strength function.

Conclusion

The conclusions derived from the present investigation of sub-Coulomb (p,n) excitation functions as described in this thesis are the following :-

(p,n) reactions at sub-Coulomb energies prove to be an important tool to study the spectroscopy of single particle states in the compound nucleus at high excitation which are analogs of the low lying levels of the target plus neutron system. The superiority of (p,n) reactions over elastic scattering is demonstrated by the observation of a new IAR in the case of ^{80}Se which was not seen in earlier (p,p) studies. The spectroscopic factors deduced from the present (p,n) experiments compare well with those from (d,p) reaction studies on the same targets. The dependence of the spectroscopic factor on neutron OMP parameters can be avoided by using the "Reduced Normalization" which is found to be almost independent of all parameter variations.

A comprehensive analysis of a large body of experimental data on (p,n) excitation functions for medium mass nuclei has been presented for the first time. The OMP parameters have been systematized as smooth functions of target mass and charge. The Coulomb correction to both the real and imaginary potential emerges as much more important at sub-Coulomb energies than hitherto believed. The behaviour of the strength of absorption as a function of target mass appears to be much less anomalous and a large part of the strength can be attributed to a smooth dependence on A and Z. A part of the remaining strength is seen to be correlated to the quadrupole deformation of nuclei, thus emphasizing the role of nuclear structure in deciding the strength of absorption. A global potential has been derived from the present analysis

of (p,n) data which is found to reproduce other data on elastic scattering, absorption cross sections and neutron strength functions as well. This global potential can thus be used over the entire mass range above A≈ 40 and upto energies several MeV above the Coulomb barrier, above which the usual higher energy optical model parameters become applicable. The present work thus complements the earlier systematics at higher energies above 10 MeV.