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Off-shell behaviour of $^{32}S(n,n)^{32}S$ total cross-section and $^{32}S(d,p)^{33}S$ reaction to the continuum

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Abstract. Two features of $^{32}S(d,p)^{33}S$ reaction to the continuum, the parallelism between the excitation function of the energy differential stripping cross-section $d^2\sigma/d\Omega\, dE$ and the total neutron ^{32}S elastic scattering cross-section and the dependence of the ratio $(d^2\sigma/d\Omega\, dE)/\sigma_{tot}(n,n)$ on the transferred angular momentum l are explained by a model in which neutron stripping to the resonant states is essentially determined by the off-energy shell total neutron-target cross-section. At low excitation energies of the resonance the off-shell behaviour of the neutron scattering amplitude is very strong which leads to a big enhancement of the stripping cross-section relative to the total neutron-target cross-section. The model provides a good description of the measured (d,p) to (n,n) cross-section ratio corresponding to $l>0$ resonance. However it may not be appropriate for performing the calculations for s-wave resonances.

Keywords. Off-shell scattering; stripping cross-section; n-target scattering.

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1. Introduction

It has been demonstrated both experimentally and theoretically (Lipperheide 1970; Fuchs *et al* 1972; Lipperheide and Mohring 1972, 1973; Baur and Trautmann 1974; Bommer *et al* 1976) that there exists a connection between differential cross-sections for (d,p) transfer reaction to a resonant state and the total neutron cross-section for the same target. This is reflected in the near parallelism between the excitation functions of the energy differential cross-sections for the (d,p) reactions to the continuum and the total neutron target elastic scattering cross-sections. It is also noticed that the transitions to the resonances of high l-values are strongly enhanced in (d,p) reaction with respect to the neutron scattering. Hence the ratio of the (d,p) energy differential cross-section at some fixed angle to the total neutron-target elastic cross-section depends strongly on the orbital angular momentum l of the transferred particle. This is an important observation, as it serves to determine the orbital angular momentum of the resonances populated in the (d,p) reaction without necessarily measuring the cross-sections for all angles.

There has been several methods (Baur and Trautmann 1974, 1976; Huby and Mines 1965; Huby and Kelvin 1975; Schlessinger and Payne 1972; Vincent and Fortune 1970, 1973) to calculate the stripping reactions to unbound states. One class of these methods employs the distorted wave Born-approximation (DWBA) in a form similar to that used in the description of stripping to bound states of the residual nucleus.

Various methods in this class differ by the way they describe the wave functions of the resonant state (Vincent and Fortune 1970; Schlessinger and Payne 1972; Vincent and Fortune 1973; Baur and Trautmann 1976; Brinati and Bund 1978; Satchler 1983). However in all these methods radial integrals involving the DWBA amplitudes are slowly converging (Cooper *et al* 1982). Therefore, the numerical calculations involved in these methods pose some problem (Huby 1985). On the other hand, Lipperheide (1970), Lipperheide and Mohring (1972) and Fuchs *et al* (1972) have proposed a method to calculate the cross-section for stripping reactions to resonant states, where the convergence difficulties of the DWBA approaches are not present. In this method the (d, p) stripping cross-section is parametrized in terms of the off-shell scattering amplitude of the transferred neutron with respect to the target nucleus, which can be determined, for example through an extension of its corresponding on-shell form via the R-matrix theory.

Although this model has been used to describe the similarity seen in the (d, p) spectra and the (n, n) cross-section on the ^{15}N and ^{24}Mg target nuclei rather successfully, some questions regarding the general applicability of this method are yet to be answered. For example, one would like to know if this method is applicable for the resonances seen in these reactions corresponding to all l values. In particular it would be of some interest to know if this model can also be used reliably to perform calculation for $l = 0$ resonances.

In this paper our aim is to study the $^{32}S(d, p)^{33}S$ reaction to the continuum following this method. This reaction has the attractive feature that here the s-wave resonances show up very clearly along with those of higher l-values, in contrast to reactions studied earlier ($^{15}N\,(d, p)\,^{16}N$ (unbound) $^{24}Mg\,(d, p)\,^{25}Mg$ (unbound)) where the s-wave resonances are either not seen or are very weakly seen. Therefore, this reaction provides a good example for calculating the stripping reaction to the continuum leading to resonances of all kind.

In the next section we very briefly describe the model. The calculations for $^{32}S(d, p)^{33}S$ (unbound) reactions are presented in §3 and the results are discussed. The final section contains our summary and conclusions.

2. Stripping cross-section and off-shell scattering amplitude

In the plane wave Born approximation, the differential cross-section for three-body final state in continuum in terms of the off-shell total cross-section for each partial wave l is given by (Shapiro 1963; Bell 1964; Lipperheide and Mohring 1972)

$$\left(\frac{\mathrm{d}^2\sigma}{\mathrm{d}\Omega\,\mathrm{d}E}\right)_l = \frac{2m^2}{(2\pi\hbar)^3}\frac{\mathbf{q}_p}{\mathbf{q}_d}\frac{|M(\mathbf{q}_d, \mathbf{q}_p, \mathbf{q})|^2}{\left[\frac{1}{m}(\frac{1}{2}\mathbf{q}_d - \mathbf{q}_p)^2 + B_d\right]^2} \times \frac{\mathbf{q}}{m}\sigma_l^{\text{total}}(\mathbf{q}, E), \tag{1}$$

where $E = q_d^2/4m - q_p^2/2m - B_d$ and $\mathbf{q} = \mathbf{q}_d - \mathbf{q}_p$ are energy and momentum transfers in the relative coordinate system and m is the mass per nucleon. $\mathbf{q}$ is a function of the angle of emission of the proton in the centre of mass system. M is the amplitude for virtual deuteron break-up and is related to the deuteron form factor $G(\frac{1}{2}\mathbf{q}_d - \mathbf{q}_p)$

and to the off-energy shell distance (S) as follows:

$$M(\mathbf{q}_d, \mathbf{q}_p, \mathbf{q}) = -[(\tfrac{1}{2}\mathbf{q}_d - \mathbf{q}_p)^2/m + B_d]\cdot G(\tfrac{1}{2}\mathbf{q}_d - \mathbf{q}_p), \tag{2}$$

$$S = \frac{q^2}{2m} - E = (\tfrac{1}{2}\mathbf{q}_d - \mathbf{q}_p)^2/m + B_d, \tag{3}$$

where B_d is the deuteron binding energy. By using the optical theorem, one can write the off-shell total cross-section in terms of the imaginary part of the off-shell forward scattering amplitude

$$\mathbf{q}\sigma_l^{\text{total}}(\mathbf{q}, E) = 4\pi\hbar \,\mathrm{Im}\, f_l^{(el)}(\alpha = 0^\circ, \mathbf{q}, \mathbf{q}', E), \tag{4}$$

where α is the c.m. angle for off-shell scattered neutron with respect to the target.

To simplify the calculation of the off-shell scattering amplitude, we assume, following Lipperheide and Mohring (1972), that it can be extracted from the corresponding on-shell cross-section by multiplying the latter by a smooth function called "off/on" ratio. We further assume that the relationship between the potential scattering and the resonant scattering existing in the on-shell total neutron cross-section remains the same also in the off-shell total neutron cross-section. Therefore the off-shell cross-section (like their on-shell counterpart) involves narrow resonances superimposed on a background governed by potential scattering. In order to find an expression for the off-shell scattering amplitude near a resonance in terms of its on-shell value, we apply Gellmann and Goldberger's two potential theorem (Levin and Feshbach 1973). The off-shell T-matrix elements are given by

$$T_{fi} = T_{fi}(P) + T_{fi}(R). \tag{5}$$

The potential scattering matrix elements $T_{fi}(P)$ describe the slowly varying background amplitude with respect to energy and yields the off-shell hard sphere terms. The resonance scattering matrix elements $T_{fi}(R)$ on the other hand describe the rapid variation of the off-shell resonance scattering amplitude with respect to the energy.

Hence the general form of the off-shell scattering amplitude is given as (Lipperheide and Mohring 1972; Fuchs *et al* 1972)

$$-\frac{2\pi\hbar^2}{m} f(\alpha, \mathbf{q}, \mathbf{q}', E) = \langle \mathbf{q}' | v_{\mathbf{q}\mathbf{q}'} | q \rangle + \frac{\langle \mathbf{q}' | v_{\mathbf{q}',\lambda l} | \lambda l \rangle \langle \lambda l | v_{\mathbf{q},\lambda l} | \mathbf{q} \rangle}{E - E_\lambda + \frac{i}{2}\Gamma_\lambda^{\text{off}}}, \tag{6}$$

where α is the c.m. angle for off-shell scattered neutron, $v_{\mathbf{q}'\mathbf{q}}$ is the single particle potential (potential scattering) and $v_{\mathbf{q},\lambda l}$ shows coupling between the resonance term and the potential terms. $\Gamma_\lambda^{\text{off}}$ is the off-shell neutron partial width and $|\lambda l\rangle$ is the compound state characterizing the resonance.

The off-shell total cross-section is then given by

$$\begin{aligned}\mathbf{q}\sigma_{\lambda l}^{\text{total}}(\mathbf{q}, E) &= 4\pi\hbar \,\mathrm{Im}\, f_{\lambda l}^{(el)}(\alpha = 0^\circ, \mathbf{q}, \mathbf{q}', E) \\ &= \frac{m}{\hbar} \frac{\Gamma_\lambda^{\text{off}} |\langle \mathbf{q} | v_{\mathbf{q},\lambda l} | \lambda l \rangle|^2}{(E - E_\lambda)^2 + \frac{1}{4}(\Gamma_\lambda^{\text{off}})^2}. \end{aligned} \tag{7}$$

Similarly for the on-shell neutron scattering with the condition $q^2 = q'^2 = k^2 = 2mE$, one can express the total cross-section as

$$k\sigma_{\lambda l}^{\text{total}}(E) = 4\pi\hbar \,\text{Im}\, f_{\lambda l}^{(el)}(\beta = 0, E)$$
$$= \frac{m}{\hbar} \frac{\Gamma_\lambda^{\text{on}} |\langle k | v_{k,\lambda l} | \lambda l \rangle|^2}{(E - E_\lambda)^2 + \frac{1}{4}(\Gamma_\lambda^{\text{on}})^2}, \tag{8}$$

where β is the c.m. angle of the scattered neutron and $\Gamma_\lambda^{\text{on}}$ is the on-shell neutron partial width. Comparing (8) with the single level single channel R-matrix expression for total cross-section (Lane and Thomas 1958) we recognize that the term $|\langle k | v_{k,\lambda l} | \lambda l \rangle|^2$ depends on the hard sphere phase shift $\exp(2i\delta_l)$, inverse of the momentum k, the reduced width γ on and the penetration factor $P_l(ka/\hbar)$ for the R-matrix channel radius $r = a$. Therefore the magnitudes of the matrix element $|\langle k | v_{k,\lambda l} | \lambda l \rangle|^2$ and the on-shell total cross-section can be estimated through the R-matrix fitting process.

From (7) and (8) we can relate off-shell total (n, n) cross-section to the corresponding on-shell cross-section (for each λl resonance) by

$$\mathbf{q}\sigma_{\lambda l}^{\text{total}}(\mathbf{q}, E) = \frac{F_{\lambda l}(\mathbf{q}, E)}{F_{\lambda l}(k, E)} k\sigma_{\lambda l}^{\text{total}}(E), \tag{9}$$

where $F_{\lambda l}(\mathbf{q}, E)/F_{\lambda l}(k, E)$ is the so-called "off/on" coefficient given by

$$F_{\lambda l}(\mathbf{q}, E)/F_{\lambda l}(k, E) = N\{|\langle \mathbf{q} | v_{\mathbf{q},\lambda l} | \lambda l \rangle|^2 / |\langle k | v_{k,\lambda l} | \lambda l \rangle|^2\}, \tag{10}$$

where

$$N = \frac{\Gamma_\lambda^{\text{off}}}{\Gamma_\lambda^{\text{on}}} \cdot \frac{(E - E_\lambda)^2 + \frac{1}{4}(\Gamma_\lambda^{\text{on}})^2}{(E - E_\lambda)^2 + \frac{1}{4}(\Gamma_\lambda^{\text{off}})^2}. \tag{11}$$

As remarked earlier, the terms in curly brackets in (10) can be related to the quantities appearing in the R-matrix theory. Lipperheide and Mohring (1972) suggested several simple "intuitive" forms for this term. However we found the following simple form most suitable in the sense that it provides the best fit to the experimental data for the (d, p) stripping to the continuum.

$$[|\langle \mathbf{q} | v_{\mathbf{q},\lambda l} | \lambda l \rangle|^2 / |\langle k | v_{k,\lambda l} | \lambda l \rangle|^2] = \left(\frac{\mathbf{q}}{k}\right)^{l-3} \cdot \left(\frac{\gamma_\lambda^{\text{off}}}{\gamma_\lambda^{\text{on}}}\right)^{l-3} \cdot \frac{P_l(\mathbf{q}a/\hbar)}{P_l(ka/\hbar)}. \tag{12}$$

In (12) P_l's are the neutron penetrabilities at the channel radius $r = a$. γ's are the reduced widths. Implicit in form (12) is the assumption that the penetrability $P_l(\mathbf{q}a/\hbar)$ as used in the R-matrix theory can reproduce the essential features of the $\mathbf{q}$ dependence of the off-shell amplitude. The position and widths of an isolated resonance should remain unaltered when going from the on-shell to the off-shell description, only the height and generally the shape of the resonance will change (Lipperheide and Mohring 1972). Hence the value of the constant N in (11) and the ratio $(\gamma_\lambda^{\text{off}}/\gamma_\lambda^{\text{on}})$ should be equal to unity. Therefore we adopt the following procedure to test the suitability of the present method to describe the (d, p) stripping to continuum states. We calculate the on-shell reduced width $\gamma_\lambda^{\text{on}}$ by performing a single-channel multilevel R-matrix fit to the total neutron elastic scattering data on the particular target nucleus. The corresponding off-shell reduced width can be derived from the partial width of the resonances seen in $^{32}S(d,p)$ reaction to the continuum on the same target by using the relation

$$(\gamma_\lambda^{\text{off}})^2 = \Gamma_\lambda^{(d,p)}(\theta_L)/2P_l(\mathbf{q}a/\hbar). \tag{13}$$

With this one can determine the ratio $(\gamma_\lambda^{\text{off}}/\gamma_\lambda^{\text{on}})$. For the present model to be applicable the value of this ratio should be closer to unity.

With the help of equations (9) to (13) the total off-shell cross-section as required in (1) can be estimated and the cross-section for (d,p) reaction to continuum can be calculated. Although (1) is derived in the plane-wave Born approximation we have taken into account the distorted wave effects qualitatively by multiplying the cross-sections calculated by equation (1) by the ratio $\omega = [(d\sigma/d\Omega)_{\text{DWBA}}/(d\sigma/d\Omega)_{\text{PWBA}}]$ which has been extracted from the work of Mukherjee *et al* (1977) and Shyam and Mukherjee (1976).

In the next section we present our numerical results for the $^{32}S(d,p)$ reaction.

3. Calculation for $^{32}S(d,p)^{32}S$ (unbound) and discussion

In this section first we examine the suitability of the present model in describing the (d,p) reaction to the continuum by following the procedure described in the last section. We concentrate on the ^{32}S target. As remarked earlier, for the applicability of this model the ratio of the reduced widths $(\gamma_\lambda^{\text{off}}/\gamma_\lambda^{\text{on}})$ should turn out to be closer to unity.

$\gamma_\lambda^{\text{on}}$ has been determined by performing the single-channel multilevel R-matrix fit to the total neutron elastic scattering data on ^{32}S target (Peterson *et al* 1950). Actually several measurements of $^{32}S(n,n)^{32}S$ reaction at low neutron energies and their R-matrix analysis have been reported (Halperin *et al* 1980; Jungmann *et al* 1982; Das and Mukherjee 1985). Here however, we chose the data of Peterson *et al* (1950) to determine $\gamma_\lambda^{\text{on}}$ by the R-matrix analysis due to the following reason. Bommer and coworkers (Bommer 1974; Bommer *et al* 1976) have used the (n,n) total cross-section data from this reference to determine the ratio of their measured (d,p) cross-section to (n,n) total cross-section. In order to have a consistent comparison of this ratio calculated in our model with those determined experimentally by Bommer *et al*, we should also use the data of Peterson *et al* (1950) for $n + {}^{32}S$ elastic scattering into our analysis. A typical example of the R-matrix fit achieved to the data of Peterson *et al* is shown in figure 1. It should be noted that between neutron energies of 0·02 and 1·1 MeV, 15 isolated resonances are clearly seen. These have also been observed in $^{32}S(d,p)^{33}S$ (unbound) reaction by Bommer *et al* (1976). The value of χ^2 for 74 data points is 0·754 giving a χ^2 per datum equal to 0·01. The R-matrix channel radius is $a = 10$ fm. $\gamma_\lambda^{\text{off}}$ is determined from the partial width of the resonances seen in the reaction $^{32}S(d,p)^{33}S$ (unbound) measured by Bommer *et al* (1976) at the outgoing proton angle of 10°.

The results for the 15 resonances which are ordered according to increasing l values are shown in table 1. It is seen that in general the ratio $(\gamma_\lambda^{\text{off}}/\gamma_\lambda^{\text{on}})$ is within 20% to unity. However for certain cases particularly for $l = 0$ resonances, the deviations from unity are of the order of 30–50%. Since the uncertainties in the measurement of $\Gamma_\lambda^{(d,p)}(\theta_l)$ (used in the calculation of $\gamma_\lambda^{\text{off}}$) are typically of the order of 10 to 20%, the large

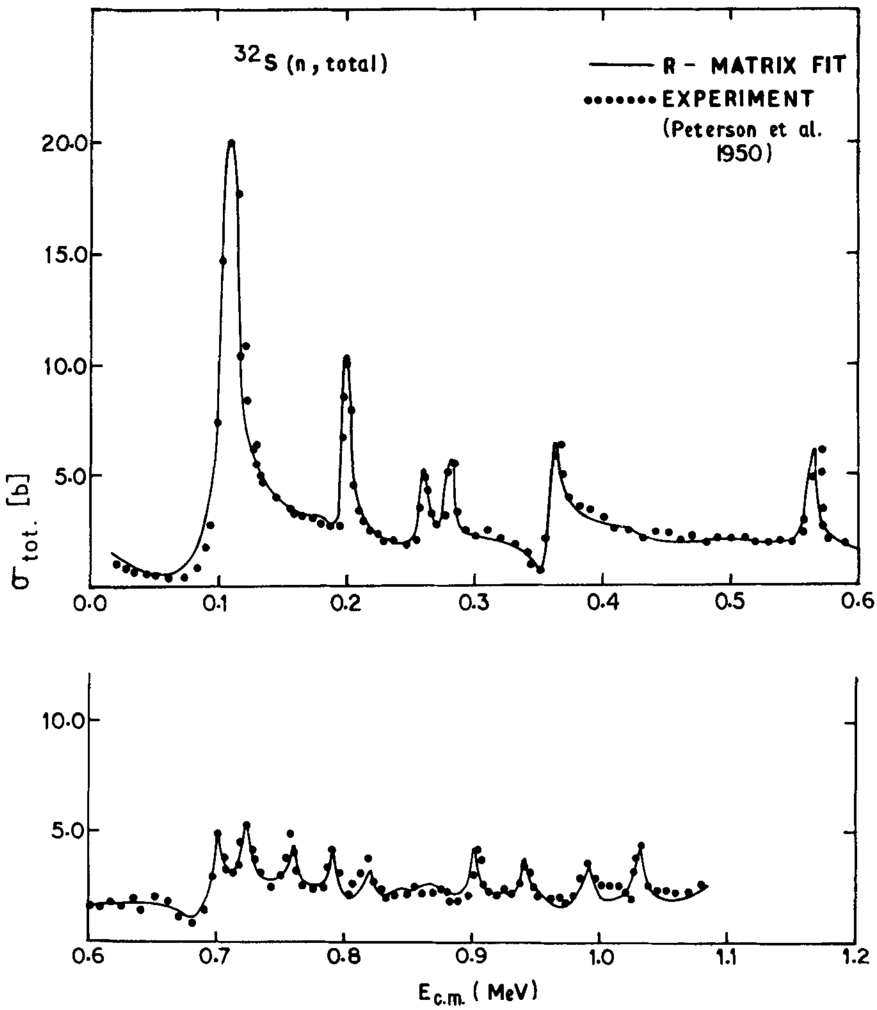

Figure 1. Multilevel single channel R-matrix fit to the total neutron elastic scattering cross-section data of Peterson *et al* (1950) (shape-fitting).

deviations in the values of $(\gamma_\lambda^{\text{off}}/\gamma_\lambda^{\text{on}})$ from unity for $l=0$ resonances are beyond the experimental uncertainties. Therefore it can be said that application of this model is more reliable for some $l>0$ resonances, at least for the reaction being investigated in this paper.

One can already see the strong dependence of off-shell effects on l values of the resonances by looking at the "off/on" ratio shown in table 1 and plotted in figure 2 as a function of off-shell distances (defined by equation (3)) for some resonances. A plot between S and the angle θ of the outgoing proton for various excitation energies of the residual nucleus is shown in figure 3. For larger values of off-shell distance S, the value of "off/on" coefficient changes by at least one order of magnitude with a change in the value of l by one unit. Therefore, the orbital angular momentum l is a decisive quantity in determining the off-shell effects in the low energy region. This result suggests that the excess momentum imparted to the neutron in the (d, p) reaction

Table 1. Ratio of the off-shell reduced width and to its on shell value and "off/on" coefficient.

J_π (*a*)	l (*b*)	E_x (MeV) (*b*)	$E_{c.m.}$ (MeV) (*b*)	J^π	$\gamma_\lambda^{off}/\gamma_\lambda^{on}$	$F_{\lambda l}(\mathbf{q}, E)/F_{\lambda l}(k, E)$
$1/2^+$	0	8·752	0·108	$1/2^+$	0·45	0·15
$1/2^+$	0	9·010	0·366	$1/2^+$	0·73	0·16
$1/2^+$	0	9·318	0·674	$1/2^+$	0·96	0·18
(?)	0	9·607	0·963	$1/2^+$	1·00	0·22
$1/2^-$	1	8·839	0·195	$1/2^-$	0·80	0·45
$1/2^-$	1	8·910	0·266	$1/2^-$	0·89	0·45
$3/2^-$	1	8·926	0·282	$3/2^-$	1·00	0·45
$1/2^-$	1	9·348	0·704	$1/2^-$	1·20	0·50
$3/2^-$	1	9·363	0·719	$3/2^-$	1·20	0·48
$3/2^-$	1	9·539	0·895	$3/2^-$	1·14	0·53
$1/2^-$	1	9·666	1·022	$3/2^-$	0·95	0·57
$5/2^+$	2	9·211	0·567	$5/2^+$	0·87	2·81
$(l > 1)$	2	9·400	0·756	$5/2^+$	0·88	1·89
$5/2^+$	2	9·436	0·792	$5/2^+$	1·00	2·02
$5/2^+$	2	9·564	0·920	$5/2^+$	0·99	1·79

$E_{c.m.} = E - B_n, B_n = 8{\cdot}643$ MeV; Channel radius = 10F.
(*a*) Halperin *et al* (1980); (*b*) Bommer *et al* (1976).

over its on-shell momentum enables it to penetrate more easily through the centrifugal barrier. This effect increases with l i.e. with the height of the barrier.

Now using this "off/on" ratio, the angular distribution for the reaction $^{32}S(d, p)^{33}S$ (unbound) leading to several transitions in ^{33}S have been calculated. Some typical results are shown in figure 4 as a function of the off-shell distance S. The experimental data have been taken from Liljestrand *et al* (1975). We see from this figure that as the value of l increases the agreement between the calculation and experimental data becomes better, the agreement for $l = 0$ resonances being the worst, particularly for larger values of S (i.e. scattering angle). This once again points towards the possible inadequacy of the present method to describe $l = 0$ resonances.

From figure 4 one notices a somewhat conspicuous property of the angular distributions of the (d, p) reaction to unbound states. They are devoid of any structure and any noticeable l-dependence. They look all very similar for all states and they convey the impression that no dramatic effects occur in the range of off-shell variable accessible to a (d, p) experiment. However, some changes do occur in their magnitude in traversing the distance from $S = 0$ (on-shell neutron scattering) and the smallest value of S available to (d, p) reaction. On the other hand, the l-dependence of the stripping enhancement factor $R[= (d\sigma/d\Omega)_{\theta_L}/\sigma_{tot}(n, n)]$ is very dramatic. By measuring R it is indeed possible to make unambiguous assignments of l values to the resonances. We have calculated R by the present method for all the resonances shown in table 1. In figure 5, this is plotted as a function of $(E_x - B_n)$.

The agreement between R as calculated by us and those measured by Bommer *et al* (1976) is reasonable. As discussed earlier the distorted wave effects are included qualitatively by multiplying our calculated cross-section ratios R by the factor ω. The

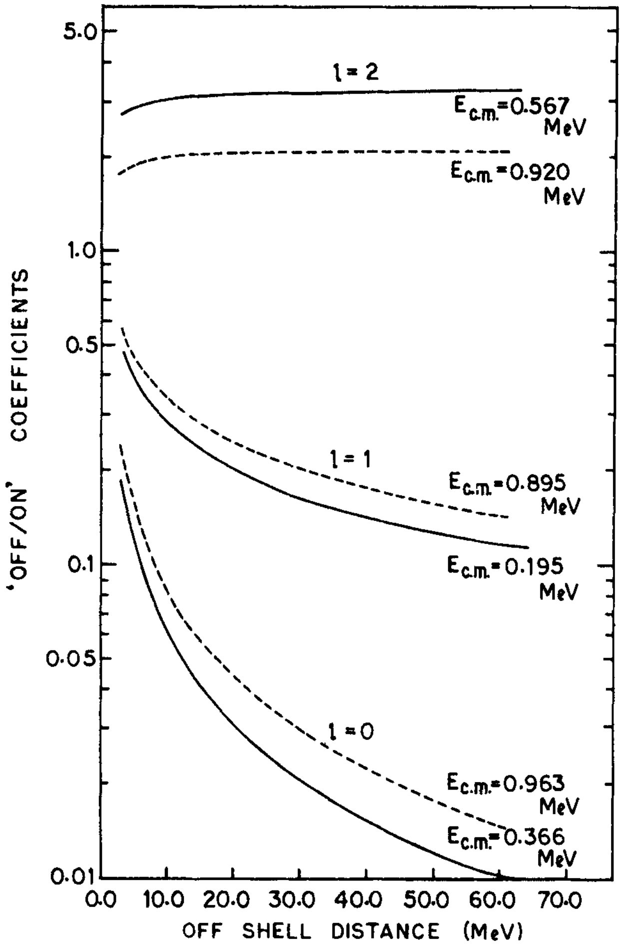

Figure 2. "Off/on" coefficient as a function of the off-shell distance S for different orbital angular moment l and different neutron energies.

resulting values of cross-section ratios are shown by crosses joined by broken lines in figure 5. We note that while for resonances corresponding to $l = 1$ and $l = 2$, the inclusion of finite range effects does not alter much the nature of agreement between experimental data and theory, it has a strong effect on $l = 0$ resonances. However it should be noted that the PWBA calculation as performed by Mukherjee *et al* (1977) is not reliable for *s*-wave resonances. Once again, therefore, the situation for *s*-wave resonances is rather discouraging.

It would be interesting to compare the stripping enhancement factor R as calculated by our method with that calculated in the DWBA. In figure 6 we show this comparison. The DWBA results have been taken from Mukherjee *et al* (1977). It is very encouraging that the results of our simple model are very close to those of DWBA where the numerical computations are very involved and difficult.

Thus the present method can be used reasonably satisfactorily to analyse the data on (d, p) stripping to unbound states for resonances corresponding to orbital angular momentum $l > 0$. However, its applicability for $l = 0$ resonances is in some doubt, at

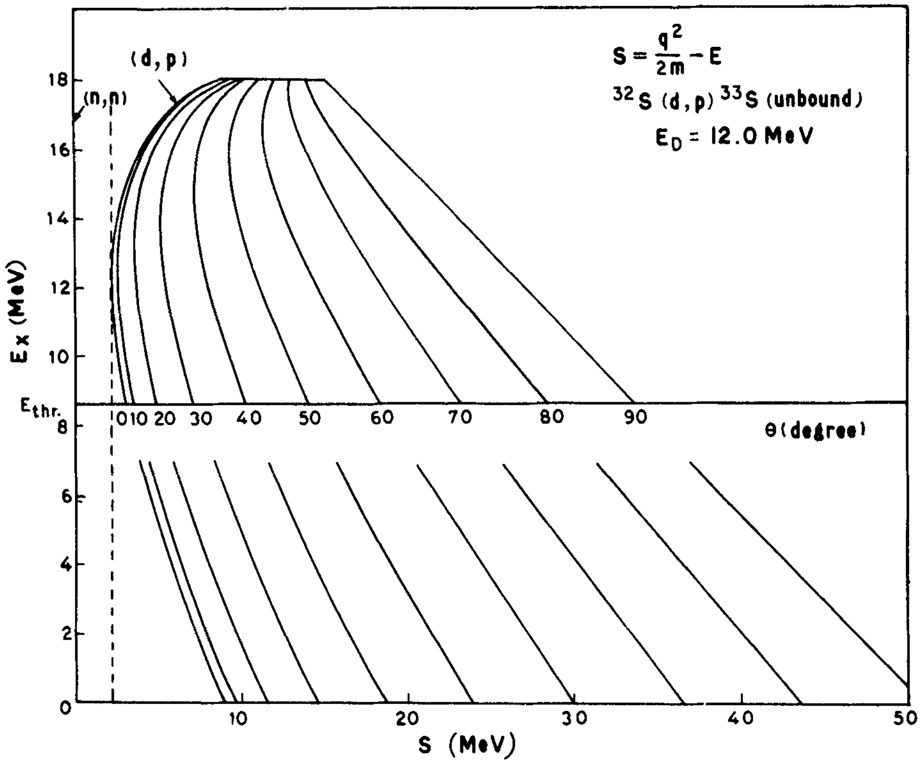

Figure 3. Values of off-shell variable S as a function of the outgoing proton angle θ for the reaction $^{32}S(d,p)^{33}S$ for several excitation energies of the residual nucleus.

least, for the reaction studied in this paper. In the present analysis we have used a simple method to calculate the off-shell total cross-section for neutron target scattering. Of course better prescriptions to calculate this have been discussed by Lipperheide and Mohring (1973) and by Mohring and Lipperheide (1975). However the main conclusions arrived at by these authors are almost the same as those obtained by us using this simple method. Therefore, our method which is computationally simple has a merit of its own. A note of caution may, however, be added here. For $l = 0$, the use of penetrability may not adequately describe the off-shell effects in the resonance. This is because our formula (12) assume that for $l = 0$ resonances the l-dependence of the off-shell amplitude is given solely by $(\mathbf{q}/k)^{-3}$ which may not in general be true.

4. Summary and conclusion

In this work we have studied the reaction $^{32}S(d,p)^{33}S$ (unbound) and its intimate relationship with the $^{32}S(n,n)^{32}S$ reaction within a model in which the stripping cross-section to unbound states is expressed in terms of the off-shell scattering amplitude for the neutron-target scattering. Thus in this model the problem of the slow convergence of the radial integrals involved in the standard DWBA description of such reaction is avoided from the outset.

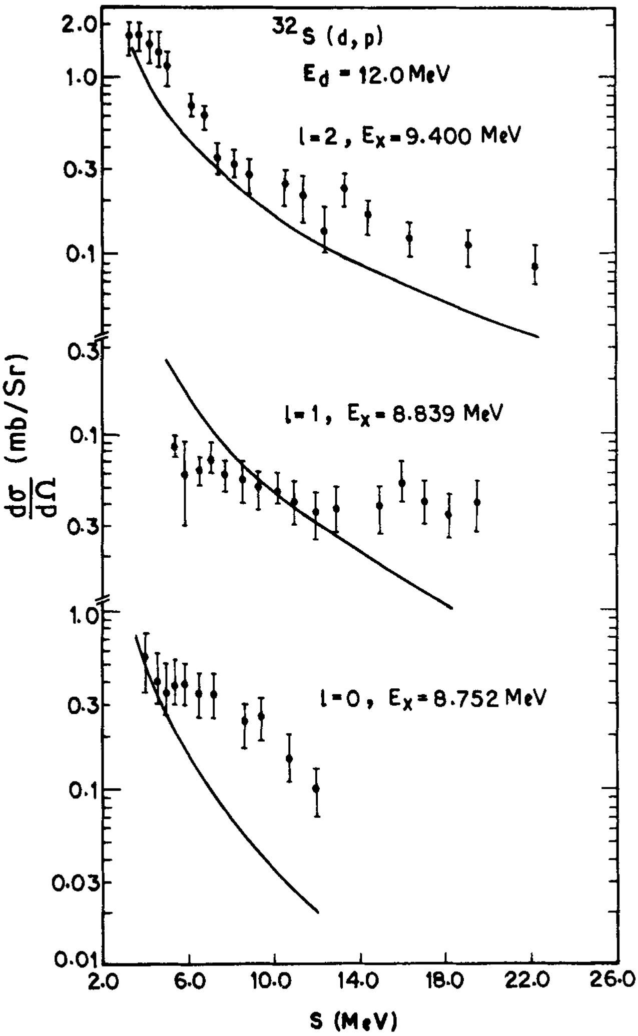

Figure 4. Proton angular distributions for $^{32}S(d,p)$ plotted against the off-shell distance S. Experimental angular distributions are of Liljestrand *et al* (1975).

The model provides a reasonable description of measured angular distributions and the (d,p) to (n,n) cross-section ratios. Even the absolute magnitudes for these cross-sections are reproduced.

Our work confirms that the resonances seen in the n-target elastic scattering and those in (d,p) reactions essentially come about from the same mechanism, the later being the off-shell continuation of the former. The success of the simple intuitive form used by us to calculate the off-shell scattering amplitude may suggest that to a first approximation the off-shell behaviour of the resonant scattering amplitude could be described by the penetration factor, except perhaps for the s-wave resonances, where this model may not be applicable as such.

We have taken into account the distorted wave effect approximately by simply multiplying the plane-wave expression of the cross-section by the distortion factor

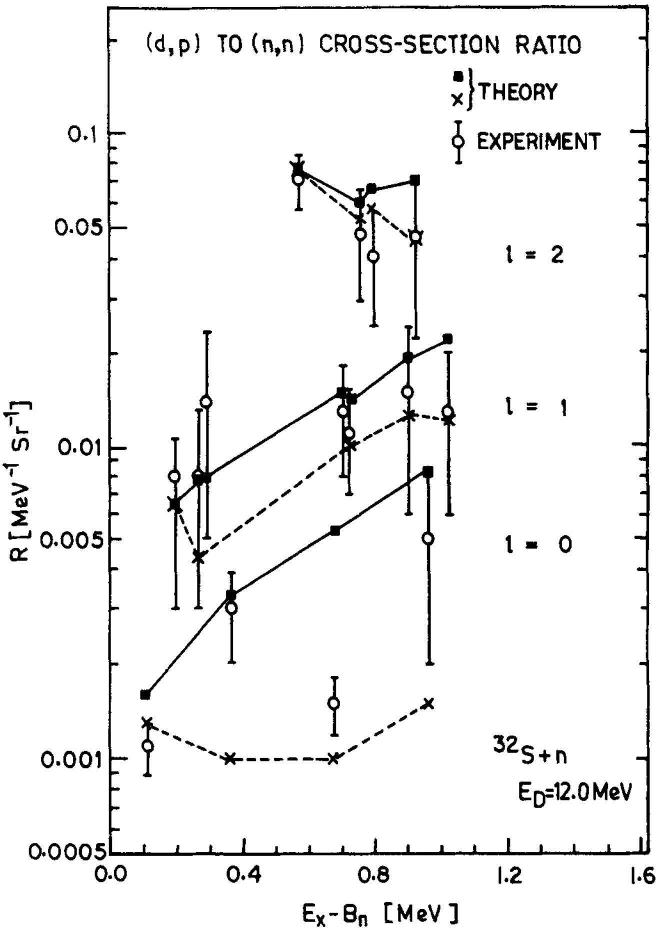

Figure 5. Cross-section ratios (solid curves) for the on-shell symmetric resonances observed in $^{32}S(d,p)$ and $^{32}S(n,n)^{32}S$ plotted against the excitation energy E_x in ^{33}S minus the neutron threshold $B_n = 8{\cdot}643$ MeV. The experimental data are of Bommer *et al* (1976). The dotted curves are obtained by the inclusion of distorted wave effects.

which is the ratio of DWBA to PWBA cross-sections at the stripping angle of interest. These cross-sections have been taken from the literature. Obviously, it would be desirable to take into account the distorted wave effects in a better way than what is done here. This can be done by folding the off-shell elastic amplitude with distorted waves. This, however, will inevitably bring in the problem of the slow convergence of the integrals which we wanted to avoid at the first place. Nevertheless, it is quite likely that the off-shell effects of (d, p) reaction to the continuum established here may not be quenched out due to distortion effects.

An interesting open problem is to use this model to study the proton transfer reaction into the resonant states and its relation to the corresponding elastic scattering. Although the on-shell proton cross-section diverges, it remains finite in a single partial wave.

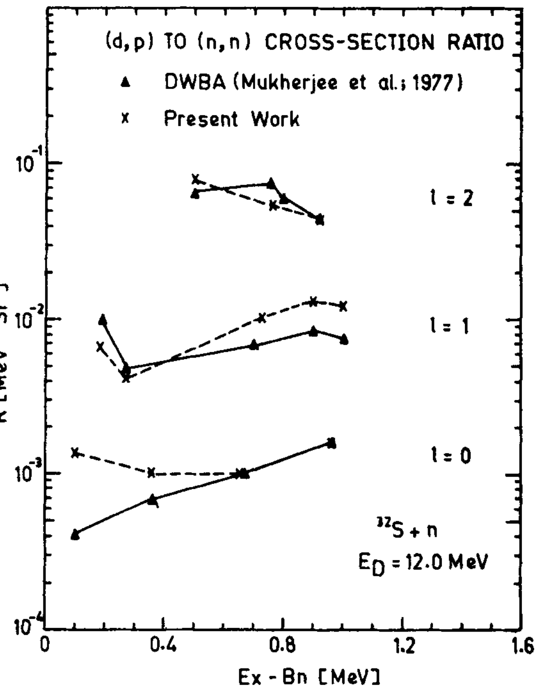

Figure 6. Comparison of the stripping enhancement factor (R) as calculated in this work with that calculated in DWBA by Mukherjee *et al* (1977).

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