# Analysis of Continuum Spectra of (n,d) Reactions with Direct Reaction Model

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# Abstract

Higher energy deuteron emission spectra in the continuum region in nucleon induced reactions, i.e. (p,d) and (n,d) reactions, are not reproduced well by the usual pre-equilibrium reaction model. The one-step direct pick-up reaction model gives better predictions for the (p,d) reactions at incident energies of several tens MeV region. The present study aims to establish a method to analyze the continuum spectra of both the (p,d) and (n,d) reactions in the direct reaction scheme.

# Introduction

There have been many works on one-nucleon transfer reactions. However, works on the (n,d) reaction have been yet scarce. As the (n,d) reaction data are not easy to be measured experimentally, it is desired to prepare a model which gives a reliable theoretical prediction, and to use it as a substitute of experimental results.

For the (p,d) reaction continuum spectra, we adopted an approach suggested by Lewis [1]. Here continuum spectra is assumed as an incoherent sum of all shell contribution and an asymmetric lorentzian form for the response function is adopted in DWBA-based cross sections calculation [2]. Similar procedure is used here to analyze the (n,d) reaction data with global optical potentials. The present work for the (n,d) reactions is an extension of the (p,d) reaction analyses . In this paper, we analyze the <sup>58</sup>Ni(p,d)<sup>57</sup>Ni and <sup>nat</sup>Fe(n,d) <sup>nat</sup>Mn reactions in ensemble by this model.

# Experimental Data

## (p,d) reactions:

The data were referred from the report [3] of the experiments performed at the TIARA facility of JAERI. A proton beam of 68 MeV from the AVF cyclotron was lead to the HB-1 beam line. Energy distributions of light ions emitted from the target were measured using a E-E counter telescope, which consisted of two thin silicon E- detectors and a CsI(Tl) E- detector with photo-diode readout.

## (n,d) reactions:

The data were referred from the report [4] of the experiments performed at the <sup>7</sup>Li(p,n) neutron source of the TIARA facility of JAERI. A spectrometer was used, which consisted of three counter telescopes mounted on a vacuum chamber to reduce the energy loss of secondary particles and charged particles in the air.

# **Theoretical Analysis**

## **Theoretical Analysis**

In the present method, the theoretical calculations of the double differential cross-sections have been done by considering a direct reaction model as an incoherent sum of the direct reaction components, which are based on DWBA predictions and expressed as below:

$$\frac{d^2\sigma}{d\Omega dE} = 2.30 \sum_{l,j} \left[ \frac{C^2 s_{l,j}(E)}{2j+1} \times \left( \frac{d\sigma}{d\Omega} \Big|_{l,j}^{DW}(E) \right) \right]$$

where  $d\sigma/d\Omega_{l,i}^{DW}(E)$  is the cross-section calculated by a DWBA code DWUCK [5] and

 $C^2S_{l,j}(E)$ , the spectroscopic factor expressed as

$$C^{2}S_{l,j}(E) = \left(\sum C^{2}S_{l,j}\right) \times f_{l,j}(E).$$

where  $\sum C^2 S_{l,j}$  is the sum of the spectroscopic factors of all the predicted states and the distribution of strength function over the spectra is obtained by using an asymmetric Lorentzian function [6-8]

$$f_{l,j}(E) = \frac{n_0}{2\pi} \frac{\Gamma(E)}{\left(|E - E_F| - E_{l,j}\right)^2 + \Gamma^2(E)/4},$$

and

$$\int_{0}^{\alpha} f_{l,j}(E) dE = 1$$

where n<sub>0</sub> is the renormalization constant and E<sub>F</sub> the Fermi energy. The Fermi energy can

Sample colspan="2">Sample colspan="2">Sample colspan="2">Sample colspan="2">Sample colspan="2">Sample colspan="2">Sample colspan="2">Sample colspan="2"           V         r         V         r         V         Sample colspan="2"           V         r         V         V         V         V         V         V         V         V         V         V         V         V         V         V         V         V         V          Sample colspan="2"         V         V          Sample colspan="2"          Sample colspan="2"	Tab	le I. C	Optio	al n	node	l para	amete	ers u	sed	in the		/BA
SPAIR(p, d) STN1:VVararWVr'a'VVSFasasProton32.111.200.671.207.363.111.280.544.511.020.59Poutoroa1.200.671.26bc1.280.544.511.020.59Neutrone1.250.671.280.641.280.544.511.020.59Neutrone1.250.671.28Vraaaa1.001.010.59Poton30.041.200.671.280.641.010.590.541.641.010.59Potone1.250.651.281.280.544.331.010.59Protone1.250.671.281.280.544.341.020.59Protone1.250.671.281.280.544.341.020.59Protona1.200.677.112.301.280.544.341.020.59Protone1.250.671.281.280.544.341.020.59Protone1.250.671.281.280.544.341.020.59Protone1.250.671.281.281.280.544.341.020.59		calcu	latio	on fo	r <sup>58</sup> ]	Ni(p,d	) <sup>57</sup> Ni	and	Nat	'e(n,d)	)Mn	
V         r         a         rc         W         W         w         a         voto         m <td><sup>58</sup>Ni(p,d)<sup>57</sup></td> <td>Ni:</td> <td></td>	<sup>58</sup> Ni(p,d) <sup>57</sup>	Ni:										
(MeV)       (fm)		V	r	а	rc	Wv	Ws	r'	a'	Vso	r <sub>so</sub>	aso
Proton       32.11       1.20       0.67       1.26       7.36       3.11       1.28       0.54       4.51       1.02       0.59         Neutron       e       1.25       0.65       i.26       i.28		(MeV)	(fm)	(fm)	(fm)	(MeV)	(MeV)	(fm)	(fm)	(MeV)	(fm)	(fm)
Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Neutron       e       1.25       0.65	Proton	32.11	1.20	0.67	1.26	7.36	3.11	1.28	0.54	4.51	1.02	0.59
Neutron       e       1.25       0.65         **Fe(n,d)*3*Mr:       **       i       k	Deuteron	а	1.20	0.67	1.26	b	C	1.28	0.54	d	1.02	0.59
**Fe(n,d)**Mn:ParticleVrar.cW.W.r'a'V.sor.soass. (fm)(fm	Neutron	е	1.25	0.65								
Particle         V         r         a         rc         Wv         Ws         r'         a'         Vso         rso         asso           Mettron         30.04         1.20         0.67         7.11         2.38         1.28         0.54         4.33         1.01         0.59           Deuteron         a         1.20         0.67         1.26         b         c         1.28         0.54         4.01         0.59           Proton         e         1.25         0.65         1.26         b         c         1.28         0.54         4.0         1.01         0.59           Proton         e         1.25         0.65         1.26         b         c         1.28         0.54         4.34         1.02         0.59           Proton         e         1.20         0.67         7.11         2.30         1.28         0.54         4.34         1.02         0.59           Proton         e         1.20         0.67         7.11         2.26         1.28         0.54         4.34         1.02         0.59           Proton         1.20         0.67         7.11         2.26         1.28         0.54         4.34 <td><sup>54</sup>Fe(n,d)<sup>53</sup></td> <td>Mn:</td> <td></td>	<sup>54</sup> Fe(n,d) <sup>53</sup>	Mn:										
(MeV)(fm)(fm)(fm)(fm)(fm)(fm)(fm)(MeV)(fm) <th< td=""><td>Particle</td><td>v</td><td>r</td><td>а</td><td>rc</td><td><math>W_{v}</math></td><td>Ws</td><td>r'</td><td>a'</td><td><math>V_{so}</math></td><td>Г<sub>зо</sub></td><td>a<sub>so</sub></td></th<>	Particle	v	r	а	rc	$W_{v}$	Ws	r'	a'	$V_{so}$	Г <sub>зо</sub>	a <sub>so</sub>
Neutron       30.04       1.20       0.67       7.11       2.38       1.28       0.54       4.33       1.01       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.01       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.54       d       1.01       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.54       d       1.01       0.59         Seffe(n,d) <sup>95</sup> Mn:        r       a       r       New V       Wev       Ws       r'       a'       Vso       rso       asso         Neutron       29.65       1.20       0.67       7.11       2.30       1.28       0.54       4.34       1.02       0.59         Proton       e       1.20       0.67       7.11       2.30       1.28       0.54       4.34       1.02       0.59         Proton       1.20       0.67       7.11       2.26       1.28       0.54       4.34       1.02       0.59         Proton       2.9.46       1.20       0.67 <td< td=""><td></td><td>(MeV)</td><td>(fm)</td><td>(fm)</td><td>(fm)</td><td>(MeV)</td><td>(MeV)</td><td>(fm)</td><td>(fm)</td><td>(MeV)</td><td>(fm)</td><td>(fm)</td></td<>		(MeV)	(fm)	(fm)	(fm)	(MeV)	(MeV)	(fm)	(fm)	(MeV)	(fm)	(fm)
Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.01       0.59         Proton       e       1.25       0.65       1.26	Neutron	30.04	1.20	0.67		7.11	2.38	1.28	0.54	4.33	1.01	0.59
Proton       e       1.25       0.65       1.26 $^{56}$ Fe(n,d) $^{55}$ Mn:	Deuteron	а	1.20	0.67	1.26	b	C	1.28	0.54	d	1.01	0.59
5%Fe(n,d)55Mn:         Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       rso       Aso         Neutron       29.65       1.20       0.67       7.11       2.30       1.28       0.54       4.34       1.02       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d.       1.02       0.59         Proton       e       1.25       0.65       1.26       b       c       1.28       0.54       d.       1.02       0.59         Proton       e       1.25       0.65       1.26          1.02       0.59         Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       rso       aso         (MeV)       (fm)       (fm)       (fm)       (fm)       (MeV)       (fm)       (fm) <t< td=""><td>Proton</td><td>е</td><td>1.25</td><td>0.65</td><td>1.26</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	Proton	е	1.25	0.65	1.26							
Particle         V         r         a         r         W         Ws         r'         a'         Vso         rso         aso           (MeV)         (fm)         (fm)         (fm)         (MeV)         (MeV)         (fm)	<sup>56</sup> Fe(n,d) <sup>55</sup>	Mn:										
(MeV)(fm)(fm)(fm)(MeV)(MeV)(fm)(fm)(MeV)(fm)(MeV)(fm)Neutron29.651.200.677.112.301.280.544.341.020.59Deuterona1.200.671.26bc1.280.54d1.020.59Protone1.250.651.26bc1.280.54d1.020.59Protone1.200.671.26WvWsr'a'VsoFsoaso(MeV)(fm)(fm)(fm)(fm)(fm)(MeV)(fm)(fm)(fm)(fm)Neutron29.461.200.677.112.261.280.544.341.020.59Protona1.200.671.26bc1.280.54d1.020.59Protona1.200.671.26bc1.280.54d1.020.59Protona1.200.671.26bc1.280.54d1.020.59Proton29.281.200.677.112.221.280.54d1.020.59Deuterona1.200.671.26bc1.280.54d1.020.59Proton29.281.200.671.26bc1.280.54d1.020.59 <tr< td=""><td>Particle</td><td>V</td><td>r</td><td>a</td><td>rc</td><td>Wv</td><td>Ws</td><td>r'</td><td>a'</td><td>Vso</td><td>r<sub>so</sub></td><td>aso</td></tr<>	Particle	V	r	a	rc	Wv	Ws	r'	a'	Vso	r <sub>so</sub>	aso
Neutron       29.65       1.20       0.67       7.11       2.30       1.28       0.54       4.34       1.02       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.20       0.67       1.26       b       c       1.28       0.54       4.34       1.02       0.59         Potton       29.46       1.20       0.67       1.26       b       c       1.28       0.54       4.34       1.02       0.59         Poton       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       a       r_c       W_v       W_s       r'       a'       V_so       r_so       R_so       M_so       M_so       1.02       0.59		(MeV)	(fm)	(fm)	(fm)	(MeV)	(MeV)	(fm)	(fm)	(MeV)	(fm)	
Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       1.26       1.26       1.26         S <sup>5</sup> /Fe(n,d) <sup>58</sup> Mn       Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       Fso       Aso         (MeV)       (fm)       (fm)       (fm)       (fm)       (fm)       (MeV)       (MeV)       (fm)       (fm) <td>Neutron</td> <td>29.65</td> <td>1.20</td> <td>0.67</td> <td></td> <td>7.11</td> <td>2.30</td> <td>1.28</td> <td>0.54</td> <td>4.34</td> <td>1.02</td> <td>0.59</td>	Neutron	29.65	1.20	0.67		7.11	2.30	1.28	0.54	4.34	1.02	0.59
Proton       e       1.25       0.65       1.26 $5^{7}$ Fe(n,d) $5^{66}$ Mn       **       *	Deuteron	а	1.20	0.67	1.26	b	C	1.28	0.54	d	1.02	0.59
5°7Fe(n,d) <sup>56</sup> Mn         Particle       V       r       a       r.c       W.v       Ws       r'       a'       V.so       r.so       Asso         (MeV)       (fm)       (fm)       (fm)       (fm)       (MeV)       (MeV)       (fm)       (fm)       (fm)       (fm)         Neutron       29.46       1.20       0.67       7.11       2.26       1.28       0.54       4.34       1.02       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26          1.02       0.59         Proton       e       1.25       0.65       1.26           4.34       1.02       0.59         SiFe(n,d) <sup>57</sup> Mn:         r       a'       New       We       We       We       fm)       fm)       (fm)       fm)	Proton	е	1.25	0.65	1.26							
Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       rso       aso         (MeV)       (fm)       (fm)       (fm)       (fm)       (MeV)       (fm)	<sup>57</sup> Fe(n,d) <sup>56</sup>	Mn										
(MeV)         (fm)         (fm)         (fm)         (MeV)         (fm)         (fm)         (MeV)         (fm)	Particle	v	r	a	rc	$\mathbf{W}_{\mathbf{v}}$	Ws	$\mathbf{r}'$	a'	Vso	r <sub>so</sub>	a <sub>so</sub>
Neutron       29.46       1.20       0.67       7.11       2.26       1.28       0.54       4.34       1.02       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       -		(MeV)	(fm)	(fm)	(fm)	(MeV)	(MeV)	(fm)	(fm)	(MeV)	(fm)	(fm)
Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26	Neutron	29.46	1.20	0.67		7.11	2.26	1.28	0.54	4.34	1.02	0.59
Proton         e         1.25         0.65         1.26 <sup>58</sup> Fe(n,d) <sup>57</sup> Mn:         58         Fe(n,d) <sup>57</sup> Mn:         r'         a'         V <sub>so</sub> rso         aso           (MeV)         (fm)         (fm)         (fm)         (fm)         (MeV)         (MeV)         (MeV)         (fm)         (fm) <td>Deuteron</td> <td>а</td> <td>1.20</td> <td>0.67</td> <td>1.26</td> <td>b</td> <td>С</td> <td>1.28</td> <td>0.54</td> <td>d</td> <td>1.02</td> <td>0.59</td>	Deuteron	а	1.20	0.67	1.26	b	С	1.28	0.54	d	1.02	0.59
5%Fe(n,d) <sup>57</sup> Mn:         Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       rso       aso         (MeV)       (fm)       (fm)       (fm)       (fm)       (MeV)       (MeV)       (MeV)       (fm)       (fm) <th< td=""><td>Proton</td><td>е</td><td>1.25</td><td>0.65</td><td>1.26</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th<>	Proton	е	1.25	0.65	1.26							
Particle       V       r       a       rc       Wv       Ws       r'       a'       Vso       rso       aso         (MeV)       (fm)       (fm)       (fm)       (fm)       (MeV)       (MeV)       (fm)	58Fe(n,d)57	Mn:										
(MeV)       (fm)       (fm)       (MeV)       (MeV)       (fm)       (fm)       (MeV)       (fm)	Particle	v	r	a	Гc	$W_{v}$	Ws	r'	a'	Vso	Г <sub>SO</sub>	a <sub>so</sub>
Neutron       29.28       1.20       0.67       7.11       2.22       1.28       0.54       4.34       1.02       0.59         Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26       c       1.28       0.621       c       1.02       1.02       0.621         Neutron       0.85fm       0.621       0.621       c       c       1.02		(MeV)	(fm)	(fm)	(fm)	(MeV)	(MeV)	(fm)	(fm)	(MeV)	(fm)	(fm)
Deuteron       a       1.20       0.67       1.26       b       c       1.28       0.54       d       1.02       0.59         Proton       e       1.25       0.65       1.26         Nonlocality parameters       Finite-range parameter       = 25         Proton       0.85fm       0.621         Neutron       0.85fm       0.621         Deuteron       0.54fm <sup>a</sup> V = V(proton)+V(neutron), See ref. [13] for V(proton) and V(neutron). <sup>b</sup> W <sub>v</sub> = W <sub>v</sub> (proton)+ W <sub>v</sub> (neutron), See ref. [13] for W <sub>v</sub> (proton) and W <sub>v</sub> (neutron). <sup>c</sup> W <sub>s</sub> = W <sub>s</sub> (proton)+ W <sub>s</sub> (neutron), See ref. [13] for W <sub>s</sub> (proton) and W <sub>s</sub> (neutron). <sup>d</sup> V <sub>soo</sub> V <sub>so</sub> (proton)+ V <sub>so</sub> (neutron), See ref. [13] for V <sub>so</sub> (proton) and V <sub>so</sub> (neutron). <sup>e</sup> Well depth adjusted to fit the separation energy.	Neutron	29.28	1.20	0.67		7.11	2.22	1.28	0.54	4.34	1.02	0.59
Proton         e         1.25         0.65         1.26           Nonlocality parameters         Finite-range parameter         = 25           Proton         0.85fm         0.621           Neutron         0.85fm         0.621           Deuteron         0.54fm         0.621           aV = V(proton)+V(neutron), See ref. [13] for V(proton) and V(neutron).         bWv = Wv (proton)+ Wv (neutron), See ref. [13] for Wv (proton) and Wv (neutron).           bWv = Wv (proton)+ Ws (neutron), See ref. [13] for Ws (proton) and Ws (neutron).         cWs = Ws (proton)+ Vso (neutron), See ref. [13] for Vso (proton) and Vso (neutron).           dVsoe Vso(proton)+ Vso (neutron), See ref. [13] for Vso (proton) and Vso (neutron).         e           well depth adjusted to fit the separation energy.         e	Deuteron	a	1.20	0.67	1.26	b	C	1.28	0.54	d	1.02	0.59
Nonlocality parametersFinite-range parameter= 25Proton0.85fm0.621Neutron0.85fm0.621Deuteron0.54fm*V = V(proton)+V(neutron), See ref. [13] for V(proton) and V(neutron).*Wv = Wv (proton)+ Wv (neutron), See ref. [13] for Wv (proton) and Wv (neutron).*Wv = Ws (proton)+ Vs (neutron), See ref. [13] for Ws (proton) and Ws (neutron).*Ws = Vso(proton)+ Vso (neutron), See ref. [13] for Vso (proton) and Vso (neutron).*Well depth adjusted to fit the separation energy.	Proton	е	1.25	0.65	1.26							
Proton       0.85fm       0.621         Neutron       0.54fm       0.621         Deuteron       0.54fm		Nonloca	lity pa	ramet	ers l	Finite-ra	nge par	ameter	• =	= 25		
Neutron0.85fm0.621Deuteron0.54fm $aV = V(proton) + V(neutron), See ref. [13] for V(proton) and V(neutron).bW_v = W_v (proton) + W_v (neutron), See ref. [13] for W_v (proton) and W_v (neutron).cW_s = W_s (proton) + W_s (neutron), See ref. [13] for W_s (proton) and W_s (neutron).cW_{so} = V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (neutron), See ref. [13] for V_{so} (proton) and V_{so} (neutron).dV_{so-} V_{so}(proton) + V_{so} (proton) + V_{so} (p$	Proton	0.85fm 0.621										
Deuteron0.54fmaV = V(proton)+V(neutron), See ref. [13] for V(proton) and V(neutron).bWv = Wv (proton)+ Wv (neutron), See ref. [13] for Wv (proton) and Wv (neutron).cWs = Ws (proton)+ Ws (neutron), See ref. [13] for Ws (proton) and Ws (neutron).dVso= Vso(proton)+ Vso (neutron), See ref. [13] for Vso (proton) and Vso (neutron).e Well depth adjusted to fit the separation energy.	Neutron	0	.85fm			0.621						
<sup>a</sup> V = V(proton)+V(neutron), See ref. [13] for V(proton) and V(neutron). <sup>b</sup> W <sub>v</sub> = W <sub>v</sub> (proton)+ W <sub>v</sub> (neutron), See ref. [13] for W <sub>v</sub> (proton) and W <sub>v</sub> (neutron). <sup>c</sup> W <sub>s</sub> = W <sub>s</sub> (proton)+ W <sub>s</sub> (neutron), See ref. [13] for W <sub>s</sub> (proton) and W <sub>s</sub> (neutron). <sup>d</sup> V <sub>so=</sub> V <sub>so</sub> (proton)+ V <sub>so</sub> (neutron), See ref. [13] for V <sub>so</sub> (proton) and V <sub>so</sub> (neutron). <sup>e</sup> Well depth adjusted to fit the separation energy.	Deuteron	0	.54fm			5.						
v = v (proton) + v (neutron), See ref. [13] for V (proton) and V (neutron). $^{b}W_{v} = W_{v} (proton) + W_{v} (neutron)$ , See ref. [13] for $W_{v} (proton)$ and $W_{v} (neutron)$ . $^{c}W_{s} = W_{s} (proton) + W_{s} (neutron)$ , See ref. [13] for $W_{s} (proton)$ and $W_{s} (neutron)$ . $^{d}V_{so=} V_{so}(proton) + V_{so} (neutron)$ , See ref. [13] for $V_{so} (proton)$ and $V_{so} (neutron)$ . $^{e}$ Well depth adjusted to fit the separation energy.	N/ N/	••••••••••••••••••••••••••••••••••••••				01 6 374		1.57				
${}^{b}W_{v} = W_{v} \text{ (proton)} + W_{v} \text{ (neutron)}, See ref. [13] for W_{v} (proton) and W_{v} (neutron).$ ${}^{c}W_{s} = W_{s} \text{ (proton)} + W_{s} \text{ (neutron)}, See ref. [13] for W_{s} (proton) and W_{s} (neutron).$ ${}^{d}V_{so=} V_{so} \text{ (proton)} + V_{so} \text{ (neutron)}, See ref. [13] for V_{so} (proton) and V_{so} (neutron).$ ${}^{e} \text{ Well depth adjusted to fit the separation energy.}$	aV = V(pro)	ton)+V(n	eutror	ı), See	rei. [1]	3] 10r V(j	proton) a	and V(I	neutro	n).		
<sup>c</sup> W <sub>s =</sub> W <sub>s</sub> (proton)+ W <sub>s</sub> (neutron), See ref. [13] for W <sub>s</sub> (proton) and W <sub>s</sub> (neutron). <sup>d</sup> V <sub>so=</sub> V <sub>so</sub> (proton)+ V <sub>so</sub> (neutron), See ref. [13] for V <sub>so</sub> (proton) and V <sub>so</sub> (neutron). <sup>e</sup> Well depth adjusted to fit the separation energy.	$^{\mathbf{b}}\mathbf{W}_{\mathbf{v}} = \mathbf{W}_{\mathbf{v}}$ (	proton)+	W <sub>v</sub> (ne	eutron	), See 1	ref. [13] f	for W <sub>v</sub> (p	roton)	and W	/v (neutr	on).	
<sup>d</sup> V <sub>so=</sub> V <sub>so</sub> (proton)+ V <sub>so</sub> (neutron), See ref. [13] for V <sub>so</sub> (proton) and V <sub>so</sub> (neutron). <sup>e</sup> Well depth adjusted to fit the separation energy.	<sup>c</sup> W <sub>s =</sub> W <sub>s</sub> (p	roton)+ \	₩s (neu	utron),	See re	ef. [13] fo	or Ws (pr	oton) a	nd Ws	(neutro	n).	
<sup>e</sup> Well depth adjusted to fit the separation energy.	<sup>d</sup> Vso= Vso(pr	oton)+ V	so (neu	itron),	See re	f. [13] fo	r V <sub>so</sub> (pr	oton) a	nd V <sub>so</sub>	(neutro	n).	
the appen adjusted to in the separation energy.	e Well dent	h adjust	ed to f	it the e	enara	tion ener	vov					
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be calculated by using an empirical formula given in [9]. The sums of spectroscopic factors and the centroid energies  $(E_{l,j})$  for  $J = l \pm \frac{1}{2}$  shell orbits have been estimated by using BCS calculations. In these calculations, single particle energies required to calculate the centroid energy are calculated by the prescription of Bohr and Motelson [10]. Spreading width ( $\Gamma$ ) is expressed by a function proposed by Brown and Rho [11] and by Mahaux and Sartor [8], as,

$$\Gamma(E) = \frac{\varepsilon_0 (E - E_F)^2}{(E - E_F)^2 + E_0^2} + \frac{\varepsilon_1 (E - E_F)^2}{(E - E_F)^2 + E_1^2}$$

where  $\varepsilon_0$ ,  $\varepsilon_1$ , E<sub>0</sub> and E<sub>1</sub> are constants which express the determined as, effects of nuclear damping in the nucleus [6]. The estimated parameters [6] are

$$\varepsilon_0 = 19.4$$
 (MeV),  $E_0 = 18.4$  (MeV)  
 $\varepsilon_1 = 1.40$  (MeV),  $E_1 = 1.60$  (MeV).

The sum rule of the spectroscopic factors of nucleon orbits for  $T \pm \frac{1}{2}$  isospin states are estimated with a simple shell model prescription [12]

$$\sum c^2 s_{l,j} = \begin{cases} n_n(l,j) - \frac{n_p(l,j)}{2T+1} & \text{for } T_{<} = T - \frac{1}{2} \\ \frac{n_p(l,j)}{2T+1} & \text{for } T_{>} = T + \frac{1}{2} \end{cases}$$

where  $n_n(l, j)$  and  $n_p(l, j)$  are the numbers of neutrons and protons respectively for each l, j orbit and T is the isospin of the target nucleus.

This sum rule of each orbit is suitable for (p,d) reaction but for (n,d) reaction we consider no contribution for  $n_n(l, j)$  i.e. no contribution for IAS in the spectrum. So we apply 100% contribution for the spectra only for  $n_p(l, j)$  and do some modification of the above sum rule equation i.e.

$$C^2 S_{l,j} = \frac{n_{p(l,j)}}{2T+1}$$

# Discussions

Experimental and Theoretical double differential cross-sections for the <sup>58</sup>Ni(p,d)<sup>57</sup>Ni and the <sup>nat</sup>Fe(n,d)Mn reactions at 68 MeV and 75 MeV, respectively are shown in Fig I. Table I shows the optical model parameters used in the DWBA calculations for the <sup>58</sup>Ni(p,d)<sup>57</sup>Ni and <sup>nat</sup>Fe(n,d) <sup>nat</sup>Mn reactions. In Fig. I, histograms represent the experimental spectra and solid lines the theoretical ones. The calculated spectra of both the (p,d) and (n,d) reactions obtained from the same method of calculation are in good agreement with the experimental ones in the higher energy region. To compensate the experimental energy resolutions for the (p,d) and (n,d) reactions, a convolution integration was applied to the theoretical cross-section with experimental resolution.



# Conclusion

The <sup>58</sup>Ni(p,d)<sup>57</sup>Ni and <sup>nat</sup>Fe(n,d)<sup>nat</sup>Mn reactions data have been studied here with the same method of calculations.

The theoretical calculations can reproduce well experimental spectra of forward angles  $(25^{0}, 45^{0})$ , at high outgoing energies. But for the spectra at backward angles  $(60^{0} \text{ for } {}^{58}\text{Ni} \text{ and } 65^{0} \text{ for } {}^{nat}\text{Fe})$ , the calculated results are somewhat underestimated. It is thus possible that for the backward angles there may be some contribution from the pre-equilibrium reaction process.

As a whole, a fairly good overall agreement is found between the theoretical and experimental spectra in both the magnitude and shape of double-differential cross-section. So from all the above consideration, we can conclude that this theoretical method is suitable not only for the (p,d) but also for (n,d) reactions.

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