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Dr. MacDonald

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ABSTRACT

Particle decay widths and energy shifts due to virtual transitions to the continuum are calculated for the five $J = 1^-$, $T = 1$ particle-hole states of O^{16}. Single particle $1d_{3/2}$ width contributions are found to be non-negligible for the 17.7 and 25.1 MeV levels. The energy shifts are significant and may be as large as -1.40 MeV.

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Session V: Nuclear Models

Effects of the Continuum on the O^{16} $J = 1^-$, $T = 1$ Levels

W. P. Beres and W. M. MacDonald

It is well known that the dipole states ($J = 1^-$, $T = 1$) of O^{16} are adequately described in terms of a particle-hole basis consisting of $p^{-1}_{1/2}\, s_{1/2}$, $p^{-1}_{1/2}\, d_{3/2}$, $p^{-1}_{3/2}\, s_{1/2}$, $p^{-1}_{3/2}\, d_{3/2}$ and $p^{-1}_{3/2}\, d_{5/2}$. A difficulty has always been the handling of the $1d_{3/2}$ state which is unbound in O^{17} and F^{17}. In the present calculation the exact nuclear reaction amplitude for a nucleon incident on a mass 15 system is written in terms of the states of a model Hamiltonian H_o[1]. This consists of a Woods-Saxon potential with spin-orbit coupling and the Coulomb potential of a uniform sphere of charge. Neutrons and protons with the same set of quantum numbers thus have different radially dependent wave functions.

The effective interaction $\hat{\tau}$ consists of two parts,

$$\hat{\tau} = \hat{\tau}_{p.h.} + \hat{\tau}_{1d_{3/2}} \tag{1}$$

The latter is a one-body interaction which exists only for the $1d_{3/2}$ state. This state is treated as an intermediate bound state which is pushed up into the continuum by $\hat{\tau}_{1d_{3/2}}$[2]. The former is the effective particle-hole interaction. Each term of (1) has the form

$$\hat{\tau} = \upsilon + \upsilon\,(\epsilon^+ - H_o)^{-1}\,\Pi_c\,\hat{\tau}\ , \tag{2}$$

where Π_c projects into the continuum of H_o, thereby removing the sharp energy dependence near resonances. For $\hat{\tau}_{p.h.}$ the first term of eq. (2) is the residual particle-hole interaction and for $\hat{\tau}_{1d_{3/2}}$ it is the amount by which the Woods-Saxon well must be dropped to bind the state.

Matrix elements of eq. (2) may be written as

$$\langle X_\mu | H_o + \hat{\tau} | X_\mu \rangle = \langle X_\mu | H_o + \hat{\tau}_{corr.} | X_\mu \rangle + \frac{1}{2\Pi} P \int_o^\lambda \frac{\Gamma_\mu (E') \, dE'}{E - E'} , \qquad (3)$$

where $\hat{\tau}_{corr.}$ is the energy independent effective interaction arising from high momentum components. The second term is the level shift due to virtual transitions from the compound nuclear state X_μ to the continuum and back expressed in terms of the width function $\Gamma_\mu(E')$. This energy shift is in addition to the damping shift caused by the imaginary part of $\hat{\tau}$. In ref. 3) this latter effect is found to be negligible. The width is given by

$$\Gamma_\mu (E') = 2\Pi \left| \langle X_\mu | \hat{\tau}_{corr.} | \chi^{(+)}(E') \rangle \right|^2 , \qquad (4)$$

where $\chi^{(+)}(E')$ is the continuum state. The particle-hole diagonalization is performed by replacing $(\hat{\tau}_{corr.})_{p.h.}$ by a phenomenological spin dependent residual interaction with delta function radial dependence using the Soper mixture.

In the present calculation the high energy limit λ in the second term of eq. (3) is arbitrarily chosen as 65 MeV which corresponds to a characteristic particle separation of the order of .5f. Energies above this are associated with short range correlations generated by the repulsive core and are included in $\tau_{corr.}$

The well parameters are obtained by fitting the O^{17} and F^{17} single particle levels and are indicated in Fig. 1. In table 1 are the partial widths eq. (4) for all decay channels at the five compound nuclear energies. Two broad levels are predicted in the 22 and 25 MeV regions; in addition two narrow levels at

13.7 and 20.1 MeV and a level at 17.7 MeV are obtained. The $1d_{3/2}$ single particle widths of the 17.7 and 25.1 MeV levels are a significant part of the total widths of these states. The energy shifts are presented in table 2. It is seen that these are negative and as large as 1.40 MeV. This significantly lowers the theoretical energy predictions.

1) W. M. MacDonald, Nuclear Physics 56, 636 (1964)

2) L. Garside and W. M. MacDonald, Phys. Rev. 138, B582 (1965)

3) W. M MacDonald, Phys. Rev. 137, B1438 (1965)

TABLE I

O^{16} T = 1, J = 1^- PARTICLE DECAY WIDTHS IN MEV

Partial Widths (neutrons)

Energy	$p_{\frac{1}{2}}^{-1} s_{\frac{1}{2}}$	$p_{\frac{1}{2}}^{-1} d_{3/2}$	$p_{\frac{1}{2}}^{-1}$	$p_{3/2}^{-1} s_{\frac{1}{2}}$	$p_{3/2}^{-1} d_{3/2}$	$p_{3/2}^{-1} d_{5/2}$	$p_{3/2}^{-1}$	$s_{\frac{1}{2}}$	$d_{3/2}$	$d_{5/2}$	Γ_n	
13.7	0	0	0	0	0	0	0	0	0	0	0	
17.7	.000976	.177	.178	0	0	0	0	.000976	.177	0	.178	
20.1	.0119	.00236	.0142	0	0	0	0	.0119	.00236	0	.0142	
22.6	.0638	.327	.391	.0146	.000947	.0208	.0363	.0784	.328	.0208	.427	
25.1	.000345	.415	.416	.0243	.573	.00724	.605	.0246	.989	.00724	1.02	

Partial Widths (Protons)

											Γ_p	$\Gamma_n + \Gamma_p$
13.7	.122	.0000	.122	0	0	0	0	.122	.000	0	.122	.122
17.7	.00117	.701	.702	0	0	0	0	.00117	.701	0	.702	.880
20.1	.00837	.00907	.0174	.210	.000335	.000716	.211	.218	.00941	.000716	.228	.242
22.6	.0567	.458	.514	.0197	.0129	.347	.380	.0764	.471	.347	.894	1.32
25.1	.000395	.597	.597	.0209	1.33	.0146	1.37	.0213	1.93	.0146	1.96	2.98

TABLE II

ENERGY SHIFTS (in MeV) OF THE O^{16} $T = 1$, $J = 1^-$ STATES DUE TO VIRTUAL TRANSITIONS TO THE CONTINUUM

Energy (Theory)	Energy (Exp.)	Neutron Shift	Proton Shift	Total Shift
25.1	24.5[a]	-.133	-.917	-1.05
22.6	22.4[a]	-.628	-.773	-1.40
20.1	(20.45)[b]	-.111	-.123	-.234
17.7	17.3[a]	-.143	-.413	-.556
13.7	13.1[a]	-.062	-.053	-.115

a) N.W. Tanner, G. C. Thomas, and E. D. Earle, Proc. Rutherford Conf., Manchester, England (1961), Nuclear Physics 52, 45 (1964).

b) K. N. Geller and E. G. Muirhead, Phys. Rev. Lett. 11 (1963) 371.

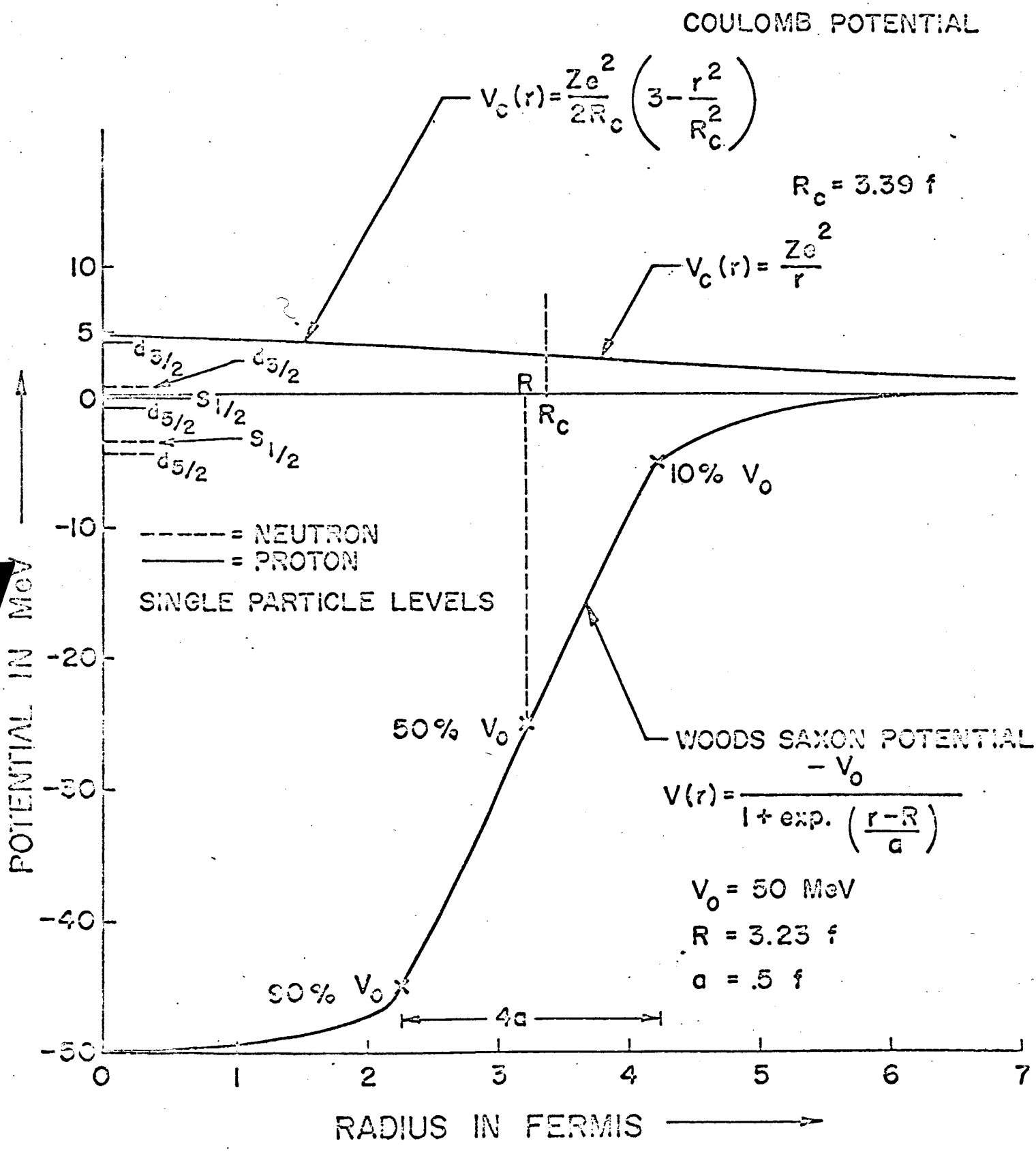
COULOMB POTENTIAL
$V_c(r) = \frac{Ze^2}{2R_c}\left(3 - \frac{r^2}{R_c^2}\right)$
$R_c = 3.39$ f
$V_c(r) = \frac{Ze^2}{r}$
$d_{5/2}$
$d_{3/2}$
$s_{1/2}$
$d_{5/2}$
$s_{1/2}$
$d_{5/2}$
R
R_c
10% V_o
= NEUTRON
= PROTON
SINGLE PARTICLE LEVELS
50% V_o
WOODS SAXON POTENTIAL
$V(r) = \frac{-V_o}{1 + \exp.\left(\frac{r-R}{a}\right)}$
$V_o = 50$ MeV
R = 3.23 f
a = .5 f
90% V_o
4a
POTENTIAL IN MeV
RADIUS IN FERMIS
10
5
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7

Fig. 1