DENSJT
Statistical Shell-Model Level Density
Computer Code Description and User's
Manual

Bill Dalton

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$2.25

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration/United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Contract No. W-7405-eng-26

PHYSICS DIVISION

DENSJT

Statistical Shell-Model Level Density Computer Code

Description and User's Manual

Bill Dalton

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

JULY 1976

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. LEVEL DENSITY FORMULA	2
III. FIXED-J AVERAGING	3
IV. FIXED-T DIMENSION	4
V. REDUCTION FORMULA AND BASIC INPUTS	5
VI. PROGRAM DESCRIPTION	6
VII. INPUT DATA	11
VIII. DESCRIPTION OF OUTPUT	12
IX. TEST ON CODE DENSJT	14
APPENDIX I: BASIC INPUTS	17
APPENDIX II: BASIC SUMS	23
REFERENCES AND FOOTNOTES	27

I. INTRODUCTION

Detailed calculations¹⁻³ have demonstrated that the shell model level density is approximately Gaussian in shape. Consequently, these level densities can be described by calculating the first few low moments of the Hamiltonian. In many cases such as in Hauser-Feshbach calculations, where details of individual levels are not needed, the statistical method is simpler and more economical than solving the shell-model problem exactly. This is especially true when the number of active nucleons becomes larger than two.

The FORTRAN code DENSJT described here is constructed to calculate the appropriate moments and dimensions needed in describing the Gaussian level density for fixed values of the total angular momentum (J) and isobaric spin ($T = T_0$). The input for this code is the same as in the usual shell model codes, namely, the single particle orbital properties ($n_\alpha, \ell_\alpha, j_\alpha, E_\alpha$) and the antisymmetric two-body matrix elements $W_{\alpha\beta\mu\nu}^{JT}$. To calculate the moments for fixed values of the angular momentum (J) we use the method described by Ginocchio.⁴ The averages of operators over the entire configuration space are calculated by using the reduction formula of Ayik and Ginocchio.⁵⁻⁷ In this formula, all of the terms ("basic inputs" as defined by these authors) can be expressed in terms of the usual shell model input mentioned above. Ginocchio, with Ayik^{7,8} and Yen^{3,9} demonstrate the usefulness of this reduction formula, but unfortunately their "basic inputs" were derived for restricted sets of orbitals, namely those sets for which all of the j_α values differ.

For use in the present code we have derived all of the "basic inputs" needed in the reduction formula but without any restrictions on the orbitals.

These "basic inputs" were first derived using the directed-diagram method of Ayik and Ginocchio⁶ to obtain the contractions. To verify that contributing diagrams had not been omitted, we wrote a symbolic code DIGRAM¹⁰ which was used to form the contractions, find the phase, count the number of left contractions, count the duplications due to operator symmetries and appropriately label the operator indices.

In the following pages the formulae used in DENSJT are described. The basic inputs are listed in convenient tables. A block flow chart showing the general structure and the specific function of each subroutine is included. All necessary information for the input and output of this code is described in Sections VII and VIII.

II. LEVEL DENSITY FORMULA

In recent literature^{3,4,6} it has been demonstrated that the Gaussian distribution

$$S(J,E) = \frac{(2J+1)\eta(J)}{(2\pi)^{1/2} \sigma_J} \exp\left(\frac{-(E-\bar{\epsilon}_J)^2}{2 \sigma_J^2}\right) \quad (1)$$

gives a reasonable description of the fixed-J shell model level density. In these calculations, the dimension $\eta(J)$ the centroid $\bar{\epsilon}_J$ and the width σ_J are calculated from the same truncated single particle basis used in the exact shell model calculation.

The total number of states at a fixed-J value is the product $(2J+1)\eta(J)$. The factor $(2J+1)$ represents the magnetic degeneracy. The factor $\eta(J)$ represents the number of states at a fixed-J value not counting the $2J+1$ magnetic degeneracy. That is, $\eta(J)$ is the fixed-J, fixed-M state density at each M, in the interval $[-J, J]$. The function $\eta(J)$ is given by the following

formula

$$\eta(J) = D(M=J) - D(M=J+1). \quad (2)$$

Here, $D(M)$ is the total number of states with magnetic projection M . Comparisons³⁻⁹ with exact calculations have demonstrated that the following Gaussian formula with excess correction (fourth moment) gives a good description of the state distribution over the magnetic projection (assuming that the configurations are symmetric about $M = 0$).

$$D(M) = \frac{d}{\sqrt{2\pi} \lambda} e^{-\frac{Z^2}{2}} \left[1 + \frac{\gamma}{24} (Z^4 - 6Z^2 + 3) \right]. \quad (3)$$

The normalized variable (Z), the width (λ) and excess (γ) are given by the following formulae:

$$Z = M/\lambda, \quad \lambda^2 = \langle J_Z^2 \rangle, \quad \gamma = \frac{\langle J_Z^4 \rangle}{\lambda^4} - 3. \quad (4)$$

Here $\langle \rangle$ means average over all states.

III. FIXED-J AVERAGING

Using a perturbed distribution method, Ginocchio⁴ obtained the following low moment expansion formula for finding the fixed-J average of an operator K .

$$\langle K \rangle^J = \langle K \rangle \left[1 + \alpha \frac{D_1(\chi)}{1 + \frac{1}{24} \gamma D_2(\chi)} \right]. \quad (5)$$

Here, D_1 , D_2 , and α are given by the following formulae

$$\chi = \frac{2J+1}{2\lambda}, \quad \alpha = \frac{1}{2} \left[\frac{\langle J_Z^2 K \rangle}{\lambda^2 \langle K \rangle} - 1 \right] \quad (6)$$

$$D_1(\chi) = \chi^3 - 3, \quad D_2(\chi) = \chi^4 - 10\chi^2 + 15. \quad (7)$$

The fixed-J moments ϵ_J and σ_J^2 appearing in (1) are obtained by setting $K = H$

and $K = (H - \epsilon_J)^2$ respectively in (5) and (6). For these calculations, the following operator averages over all states are needed

$$\langle J_Z^2 \rangle, \langle H \rangle, \langle H^2 \rangle, \langle J_Z^2 H \rangle, \\ \langle J_Z^2 H^2 \rangle \text{ and } \langle J_Z^4 \rangle.$$

The reduction formula used to calculate these averages is described in Section V.

IV. FIXED-T DIMENSION

The dimension (d) appearing in (3) depends upon the isobaric spin specification. With m_p and m_n representing the number of active protons and neutrons, we define T_0 and m by the formulae

$$M = M_p + M_n, T_0 = \frac{M - M_n}{2} \quad (8)$$

with inverses

$$M_p(T_0) = \frac{M}{2} + T_0, M_n(T_0) = \frac{M}{2} - T_0. \quad (9)$$

The dimension of states with $T_z = T_0$ resulting from all states with $T \geq T_0$ is given by

$$d(T_0) = \begin{pmatrix} N \\ M_p(T_0) \end{pmatrix} \begin{pmatrix} N \\ M_n(T_0) \end{pmatrix} \quad (10)$$

Here, N represents the number of single particle states. The dimension with fixed $T = T_z = T_0$ is given by

$$d = d(T_0) - d(T_0 + 1). \quad (11)$$

With the assumption that the matrix elements of the Hamiltonian are independent of T_z one can derive the following relationship

$$\langle H \rangle_{T_z=T_0}^{T=T_0} = d^{-1} [d(T_0) \langle H \rangle_{T_z=T_0} - d(T_0 + 1) \langle H \rangle_{T_z=T_0+1}]. \quad (12)$$

In order to calculate the level density difference for neighboring $T = T_z$ nuclei, one can run the code DENSJT with $T = T_z = T_0$ and then with $T = T_z = T_0 + 1$.

V. REDUCTION FORMULA AND BASIC INPUTS

From the work of Ginocchio and Ayik⁶ we have the following two-configuration reduction formula for the average of an operator K

$$\langle K \rangle_{M_p, M_n}^{M_p, M_n} = \begin{pmatrix} N_p \\ M_p \end{pmatrix}^{-1} \begin{pmatrix} N_n \\ M_n \end{pmatrix}^{-1} \sum_{t_p=0}^{P_p} \sum_{t_n=0}^{P_n} D_{t_p t_n}^{P_p P_n} \begin{pmatrix} N_p - P_p \\ M_p - t_p \end{pmatrix} \begin{pmatrix} N_n - P_n \\ M_n - t_n \end{pmatrix} \quad (13)$$

In this formula the indices n and p indicate the neutron and proton configurations. The neutron and proton single particle states are assumed to be the same so that $N_p = N_n = N$. The quantities $D_{t_p t_n}^{P_p P_n}$ are the "basic inputs" as defined by Ginocchio and Ayik.⁶ Here P_p and t_p indicate the particle rank of the operator and the left contraction count in the proton space.

The basic inputs for the isobaric spin basis were derived by Ginocchio, Ayik and Yin^{8,9} for the case where the single particle orbitals all differed in their j -values. This restriction amounts to replacing the delta function $\delta(j_\alpha, j_\beta)$ by $\delta(\alpha, \beta)$ in the basic inputs where α represents the entire orbital; that is, $\alpha \equiv (j_\alpha, l_\alpha, N_\alpha)$. To count and categorize the contractions for each operator, these authors used a directed-diagram method.⁶

In the present work, we used the directed-diagram method to derive the basic inputs needed in (13) without the above-mentioned restrictions on the orbitals. As a check on these formulae, we wrote a computer program DIGRAM which uses a permutation algorithm to systematically exhaust all possible contractions and count duplications due to the operator symmetries.

The basic input formulae for operators through $H_z^2 J_z^2$ are listed in Appendix I. These inputs are expressed in terms of an array function $U(N)$, each element of which is defined in Appendix II. To simplify the expressions in this table, we use the following definitions:

$$V_{\alpha\beta\mu\nu}^J \equiv W_{\alpha\beta\mu\nu}^{J,1} \mathcal{E}_{\alpha\beta} \mathcal{E}_{\mu\nu} \quad (14)$$

$$W_{\alpha\beta\mu\nu}^J \equiv \frac{\mathcal{E}_{\alpha\beta} \mathcal{E}_{\mu\nu}}{2} [W_{\alpha\beta\mu\nu}^{J,1} + W_{\alpha\beta\mu\nu}^{J,0}] \quad (15)$$

$$\mathcal{E}_{\alpha\beta} = \sqrt{1 + \delta(\alpha, \beta)} \quad (16)$$

The $W_{\alpha\beta\mu\nu}^{JT}$ are the usual antisymmetric two-body matrix elements with symmetry properties

$$W_{\alpha\beta\mu\nu}^{JT} = (-1)^{j_\alpha + j_\beta - J - T} W_{\beta\alpha\nu\mu}^{JT} = W_{\mu\nu\alpha\beta}^{JT} \quad (17)$$

VI. PROGRAM DESCRIPTION

The entire program is in the FORTRAN IV language. The different parts of the computation are made in separate subroutines. The main routine serves only to direct control in calling the subroutines in sequence. All input data are read in subroutine PUTIN and all output information is written from subroutine ALLOUT. The Block Flow Chart shows the general structure of DENSJT and indicates the purpose of each subroutine. Calculations of those Basic Sums with one index are grouped together in subroutine USUM1, those involving two indices are grouped together in subroutine USUM2, etc.

Because of the antisymmetric and Hermitian properties (17) of the two-body matrix elements $W_{\alpha_1\alpha_2\alpha_3\alpha_4}^{J,T}$, it is only necessary to have a table of the

unique ones. It is assumed that input data at least contains the unique subset of matrix elements $W_{\alpha_1 \alpha_2 \alpha_3 \alpha_4}^{J,T}$ which satisfy the following conditions (where each α_i can range over the set of single particle orbitals)

$$\alpha_1 \leq \alpha_2, \alpha_3 \leq \alpha_4 \quad (18)$$

$$\alpha_1 \leq \alpha_3, \text{ If } \alpha_1 = \alpha_3, \alpha_2 \leq \alpha_4. \quad (19)$$

The subroutine CHEK checks to see if the called matrix element satisfies conditions (18) and (19). If these conditions are not satisfied, then the anti-symmetric and Hermitian properties in (17) are used to express this matrix element in terms of one that does satisfy (18) and (19).

After the above checks, the appropriate matrix element is looked up in the input table. The index (K) which locates the matrix element in this table is computed by the formula

$$K = \alpha_1 2^{25} + \alpha_2 2^{20} + \alpha_3 2^{15} + \alpha_4 2^{10} + 2J2^2 + 2T. \quad (20)$$

This same formula is used in the subroutine PUTIN which makes the table. Our reason for using this packing formula is that it makes it possible to establish the index uniquely using a thirty-two bit computer word.

We emphasize here that the input table may contain matrix elements in addition to those satisfying (18) and (19). These additional ones will not be used in the computation, however, as they are not needed. Their inclusion will simply make the data table larger and consequently increase the look-up time.

To look up the matrix element corresponding to the index K, a binary search method is used in subroutine GETIND. This method consists of determining if the index K is in the upper or lower half of the table. If it is in the upper half, the lower limit on the table is changed to the mid-point. This process

is then repeated on the upper half of the table until the search converges to the location of the index K. This look-up method, of course, assumes that the matrix element table has been constructed such that the indices computed according to (20) appear in increasing order.

There are two limits on this computer code. The first is the dimensions of the arrays. The present dimensions are adequate to handle a table index K through 5000. The dimensions on the single-particle orbitals are adequate for 20 different orbitals.

The second limit on this code is the particular packing formula in (20). The indices α_i must be less than $32 = 2^5$ if this formula is to be used. Consequently, this packing formula cannot be used for cases where the number of single-particle orbitals exceeds 31. The Block Flow Chart for DENSJT is given on the following pages.

Block Flowchart for DENSJT

VII. INPUT DATA

All input read statements are in subroutine PUTIN. The data card organization is given as follows. The format for each card is also given.

<u>Card 1</u>	<u>Format (3I3)</u>
Col. 1-3	NBAR = isobaric spin $T_o = (M_p - M_n)/2$
Col. 4-6	NUCL = number of active nucleons = $M_p + M_n$.
Col. 7-9	NSPJ = number of single-particle orbitals.
<u>Card 2</u> - - -	<u>NSPJ+1, Format (3I3,11X,1D20.8)</u>
Col. 1-3	NR(K) = radial quantum number for the Kth orbit.
Col. 4-6	NL(K) = orbital angular momentum for the Kth orbit.
Col. 7-9	NJ(K) = twice the angular momentum value ($\ell \pm \frac{1}{2}$) for the Kth orbit.
Col. 21-41	EN(K) = single-particle energy of Kth orbit.
<u>Card NSPJ+2</u> - - -	<u>Format (10X,6I5,5X,E20.8)</u>
Col. 1-5	LA, (LA, LB, LC, are
Col. 6-10	LB, the left-to-right
Col. 11-15	LC, single-particle orbital
Col. 16-20	LD, indices on the two-body matrix elements, each may range from 1 through NSPJ.)
Col. 21-25	LJ = twice the total angular momentum value of the two-body matrix element.
Col. 26-30	LT = twice the total isobaric spin ($T = 0$ or 1) for the two-body matrix element.
Col. 36-56	W = value of the two-body matrix element.

Using the packing formula in (20), an index $KODE(N)$ is calculated from

LA, LB, LC, LD, LJ, and LT. The N-th matrix element is stored in array TMAT(N). The matrix element table is described then by arrays KODE(N) and TMAT(N) where $N = 1 \text{---} \text{Kount}$. Kount is the total number of two-body matrix elements read in. Kount is found by accumulation on the index N and needs not be read in as separate data.

The matrix element table may include all of the two-body matrix elements for the orbitals involved. However, the look-up procedure described in VI selects out only those matrix elements which satisfy conditions described in (18) and (19). It is thus only necessary that the table include those matrix elements which satisfy these conditions. The order on the matrix element table is important. The search procedure assumes that the index Kode(N) is larger than the index Kode (N-1). A convenient way to guarantee that one has this increasing order is to construct the input data in the usual odometer order on the indices. This is the order presently used in most matrix element codes at ORNL.

VIII. DESCRIPTION OF OUTPUT

All output statements are described in subroutine ALLOUT. The averages of operators needed to calculate the dimension D(M) centroid J and width σ_J are calculated before ALLOUT is called and stored in the following names:

$$\text{ZLAM} = \lambda^2 = \langle J_z^2 \rangle$$

$$\text{SZLAM} = \langle J_z^4 \rangle$$

$$\text{EHM} = \langle H \rangle$$

$$\text{EHMZ} = \langle J_z^2 H \rangle$$

$$\text{EHMS} = \langle H^2 \rangle$$

$$\text{EHMSZ} = \langle J_z^2 H^2 \rangle$$

$$\text{DIMITZ} = d = d(T_0) - d(T_0 + 1)$$

In subroutine ALLOUT the following quantities are computed and stored in the indicated names

$$\text{WIDM} = \lambda = [\langle J_z^2 \rangle]^{1/2} = \text{M-space width}$$

$$\text{EXCS} = \gamma = \langle J_z^4 \rangle / \lambda^4 - 3 = \text{M-space excess}$$

$$\text{ALPE} = \frac{1}{2} [\langle J_z^2 H \rangle / \lambda^2 \langle H \rangle - 1] = \alpha \text{ for centroid}$$

$$\text{ALPWD} = \frac{1}{2} [\langle J_z^2 (H - \langle H \rangle)^2 \rangle / \lambda^2 \langle (H - \langle H \rangle)^2 \rangle - 1] = \alpha \text{ for width}$$

$$\text{ECTALL} = \langle H \rangle = \text{scalar energy centroid (all J included)}$$

$$\text{EWDALL} = [\langle (H - \langle H \rangle)^2 \rangle]^{1/2} = \text{scalar energy width (all J included)}$$

The above five quantities along with the dimension DMTZ, the isobaric spin value and the nucleon number are printed out.

The dimension D(M) in Eq. (3) is computed in integer steps in the range $0 \leq M \leq 4\lambda$ in array DIMM(N+1). Notice that $D(0) = \text{DIMM}(1)$. The program prints out the following quantities J, $\eta(J)$, ϵ_J , σ_J for integer values of J in the range $0 \leq J \leq 4\lambda$. If the output is punched as data for another program, it is best to calculate S(J,E) using Eq. (1) in that program. We again emphasize that $\eta(J)$ here does not include the 2J+1 magnetic projection count.

IX. TEST ON CODE DENSJT

The first test we made on the code DENSJT was to calculate by hand the basic sums for a simple but non-trivial case. We used two orbitals $j = 1/2$ and $j = 3/2$. The single-particle energies and two-body matrix elements for the unique subset were set equal to one. The remaining matrix elements were obtained from these using the symmetry relations. The 46 basic sums with the exception of $U(36)$ and $U(46)$ were calculated by hand and used to validate the computer results for these sums. $U(41)$, $U(36)$, and $U(46)$ are calculated together in subroutine FORSIX. The same loops and look-up values for the matrix elements were used to calculate all three. Because of the length of these sums (involving 6 indices) only $U(41)$ was calculated by hand. The basic sums validated using this hand check are listed as follows.

Basic Sums for Hand Check

1	15.00	24	58.00
2	36.00	25	198.00
3	6.00	26	198.00
4	6.00	27	330.00
5	30.00	28	330.00
6	36.00	29	165.00
7	27.00	30	165.00
8	150.00	31	165.00
9	216.00	32	-66.00
10	180.00	33	0.00
11	5.50	34	27.50
12	66.00	35	-55.00
13	5.50	36	47.71
14	-5.50	37	8.47
15	33.00	38	10.38
16	27.50	39	0.00
17	137.50	40	-9.0
18	137.50	41	40.71
19	5.50	42	0.00
20	-8.50	43	0.00
21	50.50	44	14.56
22	27.50	45	30.50
23	-5.50	46	42.00

The second test on the program as well as on the basic inputs is a

comparison we made with the calculations of Ginocchio⁴ for ^{20}Ne . In both calculations, the standard 63 Kuo matrix elements for the s-d shell were used. The orbitals are $0d_{5/2}$ (-4.15), $1s_{1/2}$ (-3.28), and $0d_{3/2}$ (+.93). The fixed-J, fixed-T dimension, centroid, and width are given below, where, for comparison, the excess was set equal to zero. When plotted on the same scale, these three curves coincide with the dashed curves in the plots of Ginocchio.

Results for ^{20}Ne Comparisons ($\gamma \equiv 0.0$)

<u>J</u>	<u>Dimension</u>	<u>Energy Centroid (MeV)</u>	<u>Energy Width (MeV)</u>
0	.161D+02	-.170D+02	.76D+01
1	.423D+02	-.172D+02	.76D+01
2	.542D+02	-.175D+02	.75D+01
3	.511D+02	-.180D+02	.74D+01
4	.388D+02	-.186D+02	.71D+01
5	.245D+02	-.194D+02	.67D+01
6	.131D+02	-.204D+02	.61D+01
7	.603D+01	-.215D+02	.50D+01
8	.238D+01	-.228D+02	.29D+01

In the present version of DENSJT, the excess is calculated and generally differs from zero. In order to double check copies of the computer code, the following results with calculated excess are included.

^{20}Ne Check Results Using Kuo Matrix Elements

<u>J</u>	<u>Dimension</u>	<u>Energy Centroid (MeV)</u>	<u>Energy Width (MeV)</u>
0	.136D+02	-.167D+02	.77D+01
1	.370D+02	-.170D+02	.76D+01
2	.500D+02	-.174D+02	.75D+01
3	.503D+02	-.180D+02	.74D+01
4	.406D+02	-.186D+02	.71D+01
5	.268D+02	-.194D+02	.68D+01
6	.144D+02	-.203D+02	.62D+01
7	.629D+01	-.214D+02	.51D+01
8	.212D+01	-.233D+02	.76D+00

The following CPU run times on the CDC Cyber-70 computer were obtained:

3 orbitals in the s-d shell: CPU = 1 second.

10 orbitals in the s-d-f-p shells: CPU = 97 seconds.

APPENDIX I: BASIC INPUTS

for $\langle J_Z^2 \rangle$, $\langle H \rangle$, $\langle J_Z^2 \rangle$, $\langle H^2 \rangle$, and $\langle J_Z^2 H^2 \rangle$ $\langle J_Z^2 \rangle$

$$1) \quad D_{01}^{02}(J_{Zn}^2) = U(11)$$

 $\langle H \rangle$

$$2) \quad D_{01}^{01}(H_n) = U(3)$$

$$3) \quad D_{02}^{02}(V_n) = U(1)$$

$$4) \quad D_{11}^{11}(W) = U(2)$$

 $\langle J_Z^2 H \rangle$

$$5) \quad D_{01}^{03}(J_{Zn}^2 H_n) = U(13)$$

$$6) \quad D_{02}^{03}(J_{Zn}^2 H_n) = U(3) \quad U(11) - U(13)$$

$$7) \quad D_{11}^{12}(J_{Zn}^2 H_p) = U(11) \quad U(3)$$

$$8) \quad D_{21}^{22}(J_{Zn}^2 V_p) = U(11) \quad U(1)$$

$$9) \quad D_{02}^{04}(J_{Zn}^2 V_n) = U(14) + U(16)$$

$$10) \quad D_{03}^{04}(J_{Zn}^2 V_n) = U(1) \quad U(11) - U(16)$$

$$11) \quad D_{11}^{13}(J_{Zn}^2 W) = U(15)$$

$$12) \quad D_{12}^{13}(J_{Zn}^2 W) = U(11) \quad U(2) - U(15)$$

$$13) \quad D_{11}^{22}(J_{Zn} J_{Zp} W) = U(33)$$

 $\langle H^2 \rangle$

$$14) \quad D_{01}^{02}(H_n^2) = U(4)$$

$$15) \quad D_{02}^{02}(H_n^2) = U(3) \ U(3)$$

$$16) \quad D_{11}^{11}(H_n H_p) = U(3) \ U(3)$$

$$17) \quad D_{02}^{03}(H_n V_n) = U(5)$$

$$18) \quad D_{03}^{03}(H_n V_n) = U(3) \ U(1)$$

$$19) \quad D_{21}^{21}(H_n V_p) = U(3) \ U(1)$$

$$20) \quad D_{02}^{04}(V_n^2) = U(7)$$

$$21) \quad D_{03}^{04}(V_n^2) = U(8)$$

$$22) \quad D_{04}^{04}(V_n^2) = U(1) \ U(1)$$

$$23) \quad D_{22}^{22}(V_n V_p) = U(1) \ U(1)$$

$$24) \quad D_{11}^{22}(W^2) = U(12)$$

$$25) \quad D_{12}^{22}(W^2) = U(9) = D_{21}^{22}(W^2)$$

$$26) \quad D_{22}^{22}(W^2) = U(2) \ U(2)$$

$$27) \quad D_{11}^{12}(H_n W) = U(6)$$

$$28) \quad D_{12}^{12}(H_n W) = U(3) \ U(2)$$

$$29) \quad D_{12}^{13}(V_n W) = U(10)$$

$$30) \quad D_{13}^{13}(V_n W) = U(1) \ U(2)$$

$$\underline{\langle J_Z^2 H^2 \rangle}$$

$$31) \quad D_{11}^{22}(J_{Zn}^2 H_p^2) = U(11) \ U(4)$$

$$32) \quad D_{21}^{22}(J_{Zn}^2 H_p^2) = U(11) \ U(3) \ U(3)$$

$$33) \quad D_{21}^{42}(J_{Zn}^2 V_p^2) = U(11) \quad U(7)$$

$$34) \quad D_{31}^{42}(J_{Zn}^2 V_p^2) = U(11) \quad U(8)$$

$$35) \quad D_{41}^{42}(J_{Zn}^2 V_p^2) = U(11) \quad U(1) \quad U(1)$$

$$36) \quad D_{21}^{32}(J_{Zn}^2 H_p V_p) = U(11) \quad U(5)$$

$$37) \quad D_{31}^{32}(J_{Zn}^2 H_p V_p) = U(11) \quad U(3) \quad U(1)$$

$$38) \quad D_{11}^{13}(J_{Zn}^2 H_n H_p) = U(13) \quad U(3)$$

$$39) \quad D_{12}^{13}(J_{Zn}^2 H_n H_p) = [U(3) \quad U(11) - U(13)] \quad U(3)$$

$$40) \quad D_{12}^{14}(J_{Zn}^2 V_n H_p) = [U(14) + U(16)] \quad U(3)$$

$$41) \quad D_{13}^{14}(J_{Zn}^2 V_n H_p) = [U(1) \quad U(11) - U(16)] \quad U(3)$$

$$42) \quad D_{21}^{23}(J_{Zn}^2 H_n V_p) = U(13) \quad U(1)$$

$$43) \quad D_{22}^{23}(J_{Zn}^2 H_n V_p) = [U(3) \quad U(11) - U(13)] \quad U(1)$$

$$44) \quad D_{22}^{24}(J_{Zn}^2 V_n V_p) = [U(14) + U(16)] \quad U(1)$$

$$45) \quad D_{23}^{24}(J_{Zn}^2 V_n V_p) = [U(1) \quad U(11) - U(16)] \quad U(1)$$

$$46) \quad D_{01}^{04}(J_{Zn}^2 H_n^2) = U(19)$$

$$47) \quad D_{02}^{04}(J_{Zn}^2 H_n^2) = U(11) \quad U(4) + 2U(13) \quad U(3) - 4U(19)$$

$$48) \quad D_{03}^{04}(J_{Zn}^2 H_n^2) = U(11) \quad U(3) \quad U(3) + U(19) - 2U(13) \quad U(3)$$

$$49) \quad D_{02}^{06}(J_{Zn}^2 V_n^2) = U(20) + U(21)$$

$$50) \quad D_{03}^{06}(J_{Zn}^2 V_n^2) = U(18) + 2U(17) + 2U(45) + 2U(35) + U(7) \quad U(11) \\ - 2U(46) - 2U(21)$$

- $$\begin{aligned}
51) \quad D_{04}^{06}(J_{Zn}^2 V_n^2) &= 2[U(14) + U(16)] U(1) + U(11) U(8) \\
&\quad + U(20) + U(21) - 4U(18) - 2U(17) - 2U(35) \\
52) \quad D_{05}^{06}(J_{Zn}^2 V_n^2) &= U(11) U(1) U(1) + U(18) - 2U(16) U(1) \\
53) \quad D_{02}^{05}(J_{Zn}^2 H_n V_n) &= U(22) + U(34) + 2U(23) \\
54) \quad D_{03}^{05}(J_{Zn}^2 H_n V_n) &= U(13) U(1) + U(11) U(5) + U(3) U(14) \\
&\quad + U(3) U(16) - 4U(22) - 2U(23) - U(34) \\
55) \quad D_{04}^{05}(J_{Zn}^2 H_n V_n) &= U(1) U(3) U(11) + U(22) - U(13) U(1) - U(3) U(16) \\
56) \quad D_{11}^{24}(J_{Zn}^2 W^2) &= U(24) \\
57) \quad D_{21}^{24}(J_{Zn}^2 W^2) &= U(25) \\
58) \quad D_{12}^{24}(J_{Zn}^2 W^2) &= U(11) U(12) + 2U(26) + 2U(37) - 2U(24) - 2U(36) \\
59) \quad D_{22}^{24}(J_{Zn}^2 W^2) &= U(11) U(9) + 2U(15) U(2) - 4U(25) \\
60) \quad D_{13}^{24}(J_{Zn}^2 W^2) &= U(11) U(9) + U(24) - 2U(26) \\
61) \quad D_{23}^{24}(J_{Zn}^2 W^2) &= U(11) U(2) U(2) + U(25) - 2U(15) U(2) \\
62) \quad D_{11}^{23}(J_{Zn}^2 W_{H_p}) &= U(27) \\
63) \quad D_{21}^{23}(J_{Zn}^2 W_{H_p}) &= U(3) U(15) \\
64) \quad D_{12}^{23}(J_{Zn}^2 W_{H_p}) &= U(11) U(6) - U(27) \\
65) \quad D_{22}^{23}(J_{Zn}^2 W_{H_p}) &= U(11) U(3) U(2) - U(3) U(15) \\
66) \quad D_{11}^{14}(J_{Zn}^2 H_n W) &= U(28) \\
67) \quad D_{12}^{14}(J_{Zn}^2 H_n W) &= U(11) U(6) + U(13) U(2) + U(3) U(15) - 4U(28)
\end{aligned}$$

$$68) \quad D_{13}^{14}(J_{Zn}^2 H_n W) = U(11) \quad U(3) \quad U(2) + U(28) - U(3) \quad U(15) - U(13) \quad U(2)$$

$$69) \quad D_{21}^{33}(J_{Zn}^2 W V_p) = U(29)$$

$$70) \quad D_{22}^{33}(J_{Zn}^2 W V_p) = U(11) \quad U(10) - U(29)$$

$$71) \quad D_{31}^{33}(J_{Zn}^2 W V_p) = U(1) \quad U(15)$$

$$72) \quad D_{32}^{33}(J_{Zn}^2 W V_p) = U(1) \quad U(11) \quad U(2) - U(1) \quad U(15)$$

$$73) \quad D_{12}^{15}(J_{Zn}^2 W V_n) = U(31) + U(30) + U(32)$$

$$74) \quad D_{13}^{15}(J_{Zn}^2 V_n W) = U(11) \quad U(10) + U(16) \quad U(2) + U(14)U(2) + U(1)U(15) \\ - 4U(30) - U(31) - U(32)$$

$$75) \quad D_{14}^{15}(J_{Zn}^2 V_n W) = U(11) \quad U(1) \quad U(2) + U(30) - U(16) \quad U(2) - U(1) \quad U(15)$$

$$76) \quad D_{11}^{33}(J_{Zn} J_{Zp} W^2) = U(40)$$

$$77) \quad D_{21}^{33}(J_{Zn} J_{Zp} W^2) = 2U(39) - U(41) = D_{12}^{33}(J_{Zn} J_{Zp} W^2)$$

$$78) \quad D_{22}^{33}(J_{Zn} J_{Zp} W^2) = 2U(33) \quad U(2) + U(40) - 4U(39)$$

$$79) \quad D_{11}^{32}(J_{Zn} J_{Zp} H_p W) = U(42)$$

$$80) \quad D_{21}^{32}(J_{Zn} J_{Zp} H_p W) = U(3) \quad U(33) - U(42)$$

$$81) \quad D_{21}^{42}(J_{Zn} J_{Zp} V_p W) = U(43) + U(44)$$

$$82) \quad D_{31}^{42}(J_{Zn} J_{Zp} V_p W) = U(1) \quad U(33) - U(43)$$

$$\underline{\langle J_Z^4 \rangle}$$

$$83) \quad D_{01}^{04}(J_{Zn}^4) = U(38)$$

$$84) \quad D_{02}^{04}(J_{Zn}^4) = 3U(11) \quad U(11) - 4U(38)$$

$$85) \quad D_{03}^{04}(J_{Zn}^4) = U(38)$$

$$86) \quad D_{11}^{22}(J_{Zn}^2 J_{Zp}^2) = U(11) \ U(11)$$

APPENDIX II: BASIC SUMS

$$U(1) = \frac{1}{2} \sum (2J+1) V_{\alpha\beta\alpha\beta}^J$$

$$U(2) = \sum (2J+1) W_{\alpha\beta\alpha\beta}^J$$

$$U(3) = \sum (2j_{\alpha}+1) E_{\alpha}$$

$$U(4) = \sum (2j_{\alpha}+1) E_{\alpha}^2$$

$$U(5) = \sum (2J+1) E_{\alpha} V_{\alpha\beta\alpha\beta}^J$$

$$U(6) = \sum (2J+1) E_{\alpha} W_{\alpha\beta\alpha\beta}^J$$

$$U(7) = \frac{1}{4} \sum (2J+1) [V_{\alpha\beta\mu\nu}^J]^2$$

$$U(8) = \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} [V(\alpha, \beta)]^2$$

$$V(\alpha, \beta) = \sum_{\mu, J} (2J+1) V_{\alpha\mu\beta\mu}^J$$

$$U(9) = \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} [W(\alpha, \beta)]^2$$

$$W(\alpha, \beta) = \sum_{\mu, J} (2J+1) W_{\alpha\mu\beta\mu}^J$$

$$U(10) = \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} V(\alpha, \beta) W(\alpha, \beta)$$

$$U(11) = \frac{1}{3} \sum (2j_{\alpha}+1) j_{\alpha} (j_{\alpha}+1)$$

$$U(12) = \sum (2J+1) [W_{\alpha\beta\mu\nu}^J]^2$$

$$U(13) = \frac{1}{3} \sum (2J+1) E_{\alpha} (2j_{\alpha}+1) j_{\alpha} (j_{\alpha}+1)$$

$$U(14) = \frac{1}{6} \sum (2J+1) V_{\alpha\beta\alpha\beta}^J D(J, \alpha, \beta)$$

$$D(J, \alpha, \beta) = [J(J+1) - j_{\alpha}(j_{\alpha}+1) - j_{\beta}(j_{\beta}+1)]$$

$$U(15) = \frac{1}{3} \sum (2J+1) j_{\alpha}(j_{\alpha}+1) W_{\alpha\beta\alpha\beta}^J$$

$$U(16) = \frac{1}{3} \sum (2J+1) j_{\alpha}(j_{\alpha}+1) V_{\alpha\beta\alpha\beta}^J$$

$$U(17) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} Q(\alpha, \beta) V(\alpha, \beta)$$

$$Q(\alpha, \beta) = \sum_{\mu, J} (2J+1) j_{\mu}(j_{\mu}+1) V_{\mu\alpha\mu\beta}^J$$

$$U(18) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} j_{\alpha}(j_{\alpha}+1) [V(\alpha, \beta)]^2$$

$$U(19) = \frac{1}{3} \sum (2j_{\alpha}+1) j_{\alpha}(j_{\alpha}+1) E_{\alpha}^2$$

$$U(20) = \frac{1}{12} \sum (2J+1) [V_{\alpha\beta\mu\nu}^J]^2 D(J, \alpha, \beta)$$

$$U(21) = \frac{1}{6} \sum (2J+1) j_{\alpha}(j_{\alpha}+1) [V_{\alpha\beta\mu\nu}^J]^2$$

$$U(22) = \frac{1}{3} \sum (2J+1) j_{\alpha}(j_{\alpha}+1) E_{\alpha} V_{\alpha\beta\alpha\beta}^J$$

$$U(23) = \frac{1}{6} \sum (2J+1) E_{\alpha} V_{\alpha\beta\alpha\beta}^J D(J, \alpha, \beta)$$

$$U(24) = \frac{1}{3} \sum (2J+1) j_{\beta}(j_{\beta}+1) [W_{\alpha\beta\mu\nu}^J]^2$$

$$U(25) = \frac{1}{3} \sum \frac{\delta(j_{\alpha}, j_{\beta})}{(2j_{\alpha}+1)} j_{\alpha}(j_{\alpha}+1) [W(\alpha, \beta)]^2$$

$$U(26) = \frac{1}{3} \sum \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} R(\alpha, \beta) W(\alpha, \beta)$$

$$R(\alpha, \beta) = \sum_{\mu, J} (2J+1) j_{\mu}(j_{\mu}+1) W_{\alpha\mu\beta\mu}^J$$

$$U(27) = \frac{1}{3} \sum (2J+1) j_{\beta}(j_{\beta}+1) E_{\alpha} W_{\alpha\beta\alpha\beta}^J$$

$$U(28) = \frac{1}{3} \sum (2J+1) j_{\alpha}(j_{\alpha}+1) E_{\alpha} W_{\alpha\beta\alpha\beta}^J$$

$$U(29) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} R(\alpha, \beta) V(\alpha, \beta)$$

$$U(30) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} j_{\alpha}(j_{\alpha}+1) V(\alpha, \beta) W(\alpha, \beta)$$

$$U(31) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{(2j_{\alpha}+1)} Q(\alpha, \beta) W(\alpha, \beta)$$

$$U(32) = \frac{1}{3} \sum_{\alpha, \beta} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} W(\alpha, \beta) S(\alpha, \beta)$$

$$S(\alpha, \beta) = \sum_{\mu, J} (2J+1) V_{\alpha\mu\beta\mu}^J D(J, \beta, \mu)$$

$$U(33) = \frac{1}{6} \sum (2J+1) W_{\alpha\beta\alpha\beta}^J D(J, \alpha, \beta)$$

$$U(34) = \frac{1}{3} \sum (2J+1) j_{\beta}(j_{\beta}+1) E_{\alpha} V_{\alpha\beta\alpha\beta}^J$$

$$U(35) = \frac{1}{3} \sum \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} V(\alpha, \beta) S(\alpha, \beta)$$

$$U(36) = \frac{1}{3} \sum W_{\alpha\beta\mu\nu}^J W_{\alpha\beta\mu\nu}^{J'} (2J+1) (2J'+1) g(\nu) g(\beta)$$

$$(-1)^{j_{\nu}+j_{\mu}+J' + j_{\beta}+j_{\alpha}+J'} \begin{Bmatrix} JJ'1 \\ j_{\nu} j_{\nu} j_{\mu} \end{Bmatrix} \begin{Bmatrix} JJ'1 \\ j_{\beta} j_{\beta} j_{\alpha} \end{Bmatrix}$$

$$U(37) = \frac{1}{3} \sum_{\alpha, \beta} [Z(\alpha, \beta)]^2$$

$$Z(\alpha, \beta) = \sum_{\mu, J} W_{\alpha\mu\beta\mu}^J (2J+1) g(\mu) \begin{Bmatrix} j_{\alpha} j_{\beta} 1 \\ j_{\mu} j_{\mu} J \end{Bmatrix} (-1)^{j_{\mu}+j_{\beta}+J}$$

$$U(38) = \frac{1}{15} \sum_{\alpha} (2j_{\alpha}+1) j_{\alpha}(j_{\alpha}+1) [3j_{\alpha}(j_{\alpha}+1) - 1]$$

$$U(39) = \frac{1}{6} \sum_{\alpha} \frac{\delta(j_{\alpha} j_{\beta})}{2j_{\alpha}+1} W(\alpha, \beta) T(\alpha, \beta)$$

$$T(\alpha, \beta) = \sum_{\mu, J} W_{\mu\alpha\mu\beta}^J (2J+1) D(J, \mu, \alpha)$$

$$U(40) = \frac{1}{6} \sum_{\alpha} [W_{\alpha\beta\mu\nu}^J]^2 (2J+1) D(J, \alpha, \beta)$$

$$U(41) = \frac{1}{3} \sum_{\alpha\beta\mu\nu} W_{\alpha\beta\mu\nu}^J W_{\alpha\beta\mu\nu}^J (2J+1) (2J'+1) g(\alpha) g(\nu)$$

$$(-1)^{j_{\alpha}+j_{\beta}+j_{\mu}+j_{\nu}+2J'} \begin{Bmatrix} JJ'1 \\ j_{\alpha} j_{\alpha} j_{\beta} \end{Bmatrix} \begin{Bmatrix} JJ'1 \\ j_{\nu} j_{\nu} j_{\mu} \end{Bmatrix}$$

$$g(\alpha) = \left[\frac{(2j_{\alpha}+2)(2j_{\alpha}+1) 2j_{\alpha}}{4} \right]^{1/2}$$

$$U(42) = \frac{1}{6} \sum_{\alpha} (2J+1) W_{\alpha\beta\alpha\beta}^J E_{\alpha} D(J, \alpha, \beta)$$

$$U(43) = \frac{1}{6} \sum_{\alpha} \frac{\delta(j_{\alpha}, j_{\beta})}{2j_{\alpha}+1} V(\alpha, \beta) T(\alpha, \beta)$$

$$U(44) = \frac{1}{3} \sum_{\alpha, \beta} Z(\alpha, \beta) X(\alpha, \beta)$$

$$X(\alpha, \beta) = \sum_{\mu, J} V_{\alpha\mu\beta\mu}^J (2J+1) g(\mu) \begin{Bmatrix} j_{\alpha} j_{\beta} 1 \\ j_{\mu} j_{\mu} J \end{Bmatrix} (-1)^{j_{\mu}+j_{\beta}+J}$$

$$U(45) = \frac{1}{3} \sum_{\alpha, \beta} [X(\alpha, \beta)]^2$$

$$U(46) = \frac{1}{3} \sum_{\alpha\beta\mu\nu} V_{\alpha\beta\mu\nu}^J V_{\alpha\beta\mu\nu}^{J'} (2J+1) (2J'+1) g(\nu) g(\beta)$$

$$(-1)^{j_{\alpha}+j_{\beta}+j_{\mu}+j_{\nu}+2J'} \begin{Bmatrix} JJ'1 \\ j_{\nu} j_{\nu} j_{\mu} \end{Bmatrix} \begin{Bmatrix} JJ'1 \\ j_{\beta} j_{\alpha} \end{Bmatrix}$$

REFERENCES AND FOOTNOTES

1. F. S. Chang, J. B. French and T. H. Thio, Ann. Phys. (N.Y.) 66 (1971) 137
2. F. S. Chang and A. Zuker, Nucl. Phys. A198 (1972) 417
3. J. N. Ginocchio and M. M. Yen, Nucl. Phys. A239 (1975) 365
4. J. N. Ginocchio, Phys. Rev. Lett. 31 (1973) 1260
5. J. N. Ginocchio, Phys. Rev. C8 (1973) 135
6. S. Ayik and J. N. Ginocchio, Nucl. Phys. A221 (1974) 285
7. S. Ayik and J. N. Ginocchio, Nucl. Phys. A234 (1974) 13
8. S. Ayik, Ph.D thesis, Yale University, 1974
9. M. M. Yen, Ph.D thesis, Yale University, 1974
10. This code is available on request from the authors.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

INTERNAL DISTRIBUTION

1. R. L. Becker	11. R. G. Stokstad
2. K. T. R. Davies	12. K. L. Vander Sluis
3. H. T. Feldmeier	13. T. A. Welton
4. E. C. Halbert	14. C. Y. Wong
5. J. A. Maruhn	15. V. Maruhn (consultant)
6. J. B. McGrory	16. Laboratory Records - RC
7. C. W. Nestor, Jr.	17-26. Laboratory Records
8. L. D. Rickertsen	27-28. Central Research Library
9. G. R. Satchler	29. Document Reference Section
10. H. C. Schweinler	30. ORNL Patent Section

EXTERNAL DISTRIBUTION

31. D. Robson, Dept. of Physics, Florida State Univ., Tallahassee, FL 32306
32. R. J. Philpott, Dept. of Physics, Florida State Univ., Tallahassee, FL 32306
33. S. A. Williams, Dept. of Physics, Iowa State Univ., Ames, IA 50010
34. J. P. Vary, Dept. of Physics, Iowa State Univ., Ames, IA 50010
35. W. J. Thompson, Dept. of Physics, Univ. of North Carolina, Chapel Hill, NC 27514
36. C. Fred Moore, Center for Nuclear Studies, 143 Eng. Sci. Bldg., Univ. of Texas, Austin, TX 78712
37. H. T. Fortune, Dept. of Physics, Univ. of Pennsylvania, Philadelphia, PA 19174
38. S. S. M. Wong, Dept. of Physics, Univ. of Toronto, Toronto, Ontario M5S 1A7 CANADA
39. B. Wybourne, Dept. of Physics, Univ. of Canterbury, Christchurch, NEW ZEALAND
40. S. Ayik, Institut für Theoretische Physik, der Universität, Abteilung Kernphysik, 69 Heidelberg, Philosophenweg 19, WEST GERMANY
41. J. B. French, Dept. of Physics, Univ. of Rochester, Rochester, NY 14627
42. M. M. Yen, National Chiao Tung University, Hsinchu, Taiwan, REPUBLIC OF CHINA
43. J. N. Ginocchio, T5, MS-454, Los Alamos Scientific Lab., P. O. Box 1663, Los Alamos, New Mexico 87545
44. S. M. Grimes, Lawrence Livermore Lab., P. O. Box 808, Livermore, CA 94550
45. R. D. Koshel, Dept. of Physics, Ohio Univ., Athens, OH 45701
46. S. E. Edwards, Dept. of Physics, Florida State Univ., Tallahassee, FL 32306
47. K. Ruedenberg, Dept. of Chemistry, Iowa State Univ., Ames, IA 50010
48. R. Y. Cusson, Dept. of Physics, Duke Univ., Durham, NC 27706
49. A. L. Merts, T4, Los Alamos Scientific Lab., P. O. Box 1663, Los Alamos, New Mexico 87545
50. J. E. Purcell, Dept. of Physics, Georgia State Univ., Atlanta, GA 30303
- 51-60. B. J. Dalton, Dept. of Physics, Iowa State Univ., Ames, Iowa 50011
61. W. G. Love, Dept. of Physics, Univ. of Georgia, Athens, GA 30601
62. K. W. McVoy, Dept. of Physics, Univ. of Wisconsin, Madison, WI 53706
63. J. G. Belinfante, Georgia Inst. of Technology, Atlanta, GA 30332
64. T. L. Talley, Los Alamos Scientific Lab., P. O. Box 1663, Los Alamos, NM 87545
65. T. Tamura, Center for Nuclear Studies, Univ. of Texas, Austin, TX 78712
- 66-92. Technical Information Center, Oak Ridge, TN 37830