NATIONAL NUCLEAR DATA CENTER
Bldg. 197D
Brookhaven National Laboratory
P. O. Box 5000
Upton, NY 11973-5000 U.S.A.

(*Internet*) "NNDC@BNL.GOV
(*Hepnet*) BNL::NNDC

Telephone: (516)344-2902
FAX: (516)344-2806

Memo CP-C/230

DATE: May 6, 1997

TO: Distribution

FROM: V.McLane

SUBJECT: Update to Memo CP-C/228 on Polarization: Dictionary additions, LEXFOR writeup.

Attached is the proposed new LEXFOR entry for polarization.

The following is a list of codes associated with polarization. I have included codes from memo CP-C/222 for the sake of completeness.

<u>Add to Dictionary 24</u> (Data headings)

KQ	Indicis for tensor analyzing power

<u>Add to Dictionary 31</u> (Branch)

LL	Beam and target spins parallel to beam direction in scattering plane (= zz)
LON	Longitudinally polarized
LS	Target spin perpendicular, to beam direction in scattering plane
NN	Beam and target spins normal to scattering plane (= yy)
SL	Beam spin perpendicular, target spin parallel, to beam direction in scattering plane
SS	Target and beam spins perpendicular to beam
TRS	Transversely polarized

<u>Modify in Dictionary 34</u> (Modifiers)

ANA	Vector analyzing power, A(y), for incident beam
AYY	Tensor analyzing power, incident projectile spin normal to scattering plane
AZZ	Tensor analyzing power, incident projectile spin parallel to beam direction in scattering plane

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NNDC (3)
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cc: Arcilla
Lammer
Muir
Oblozinsky
Schwerer
Wienke

Add to Dictionary 34 (Modifiers)

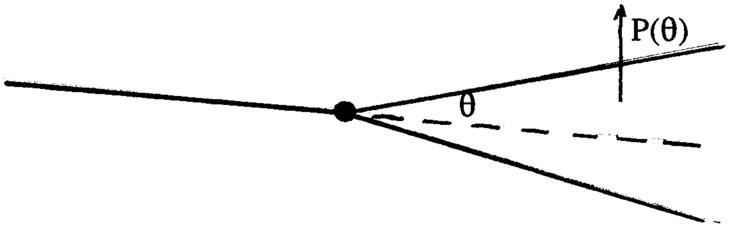
C	Spin-Correlation Parameter
DSP	Difference for spins parallel - antiparallel
K	Spin-Transfer Parameter
SF	Spin Flip
SRF	Spin rotation function
SS	Difference for spins parallel - antiparallel
TAP	Tensor analyzing power, spherical coordinates
VAP	Vector analyzing power, spherical coordinates

Add to Dictionary 36 (Quantities)

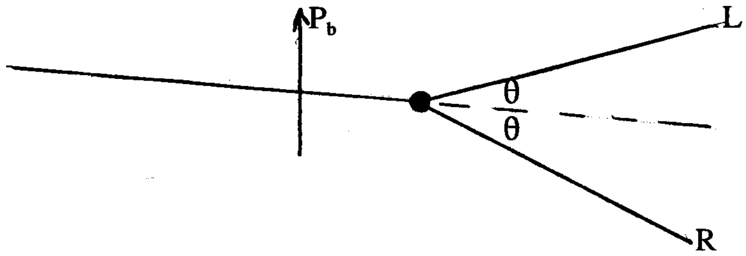
,POL/DA,,ANA	Normal analyzing power, A(y)
,POL/DA,N,ANA	Normal analyzing power of neutrons, A(y)
,POL/DA,,SF	Spin-flip probability, S(nn)
,POL/DA,,SRF	Spin Rotation Function, Q
,POL/DA,,TAP	Tensor analyzing power, T(kq), spherical coordinates
,POL/DA,,VAP	Tensor analyzing power, iT(11), spherical coordinates
,SIG,,SF	Spin-flip cross section
LL,POL/DA,,C	Spin correlation function, C(LL)
LL,POL/DA,,K	Spin-transfer parameter, K(LL)
LL/PAR,POL/DA,,K	Spin-transfer parameter, K(LL), partl reaction
LON,SIG,,DSP	Cross section difference, longitudinal spins, parallel - anti parallel
LS,POL/DA,,C	Spin correl. function, C(LS)
LS,POL/DA,,K	Spin-transfer parameter, K(LS)
LS/PAR,POL/DA,,K	Spin-transfer parameter, K(LS), partl reaction
NN,POL/DA,,C	Spin correl. function, C(NN)
NN,POL/DA,,K	Spin-transfer parameter, K(NN)
NN/PAR,POL/DA,,K	Spin-transfer parameter, K(NN), partl reaction
NN/PAR,POL/DA,RCL,K	Spin-transfer param,recoil nucl, K(NN), partl reaction
PAR,POL/DA,,TAP	Tensor analyzing power, T(kq) for partial reaction, spherical coord.
PAR,POL/DA,,VAP	Vector analyzing power, iT(11) for partial reaction, spherical coord.
SL,POL/DA,,C	Spin correl. function, C(SL)
SL,POL/DA,,K	Spin-transfer parameter, K(SL)
SL/PAR,POL/DA,,K	Spin-transfer parameter, K(SL), partl reaction
SS,POL/DA,,C	Spin correlation function, C(SS)
SS,POL/DA,,K	Spin-transfer parameter, K(SS)
SS/PAR,POL/DA,,K	Spin-transfer parameter, K(SS), partl reaction
TRS,POL/DA,,ANA	Transverse vector analyzing power, A(x)
TRS,SIG,,DSP	Cross section difference, transverse spins, parallel - anti parallel

Polarization

Under the influence of a spin-orbit force, an unpolarized beam of particles becomes at least partially polarized upon scattering from a target.



The inverse of this situation is the asymmetric scattering of a polarized beam of particles. The degree of polarization of such a beam may be determined by measuring the left-rright asymmetry upon scattering from a target nucleus which plays the role of an analyzer.



Conventions

All terms are given following the Madison Convention [2]. The following conventions are used.

1. In the expression for a nuclear reaction A(b,c)D, an arrow placed over the symbol denotes a particle in a polarized state.

   Example: $A(\vec{b},\vec{c})D$

2. The following notations are used to describe polarization and analyzing power.

Coordinate system	Polarization	Analyzing Power	
Spherical	t_{kq}	T_{kq}	$\lvert q \rvert \leq k$
Cartesian	P_i, P_{ij}	A_i, A_{ij}	$i,j = x,y,z$

3. Polarization is referred to a right-handed coordinate system in which the positive z-axis is along the direction of momentum of the incident particles, and the positive y-axis along $\vec{k}_{in} \times \vec{k}_{out}$ (scattering plane).

4. Analyzing power is referred to a right-handed coordinate system in which the positive z-axis is along the direction of of the incident beam ($\vec{k}_{in}$), and the positive y-axis along $\vec{k}_{in} \times \vec{k}_{out}$

Quantities given in Cartesian Coordinates

The following subscripts are defined:

- ***b*** refers to the incident beam polarization
- ***t*** refers to the target polarization
- N = y = normal to the scattering plane
- ***L*** = z = longitudinal, *i.e.*, parallel to beam direction in scattering plane
- ***S*** = x = ***N×L*** (sideways), *i.e.*, perpendicular to beam direction in scattering plane
- $\uparrow$ = spin up
- $\downarrow$ = spin down

Y is the normalized yield

σ_0 = differential cross section for an unpolarized (spin-averaged) beam

The differential cross section for a reaction initiated by a beam of particles with spin-1 may be written as

$$\sigma = \sigma_0 \left[1 + \tfrac{3}{2} p_y A_y + \tfrac{1}{2} p_{zz} A_{zz} + \tfrac{2}{3}(p_{xz} A_{xz} + \tfrac{1}{6}(p_{xx} - p_{yy})\,(A_{xx} - A_{yy})\right]$$

Polarization: $A(b,\vec{c})D$

P(θ), the polarization of the outgoing particle beam as a function of angle.

$$\sigma_P = \sigma_0\, P(\theta)$$

REACTION Coding: `,POL/DA`

Asymmetry: $A(\vec{b},c)D$

$$\epsilon = \frac{L-R}{L+R} = P_b A_y$$

where ϵ = left-right asymmetry
P_b = incident beam polarization
A_y = analyzing power of target
L,R = intensity of particles scattered left and right in the same plane under the same angle.

A_y, the difference in the number of particles scattered to the right and to the left in the reaction plane.

REACTION Coding: `,POL/DA,,ASY`

The principle of *Polarization-Asymmetry Equality* states that, for time-reversal invariant reactions, the polarization induced in a previously completely unpolarized beam by elastic scattering from a spin-zero nucleus is identically equal to the asymmetry ensuing from the scattering of a perfectly polarized beam under the same conditions.

For polarized beam:

$$\epsilon_b = \frac{Y_{\uparrow\uparrow} - Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} - Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$

For polarized target:

$$\epsilon_t = \frac{Y_{\uparrow\uparrow} - Y_{\downarrow\downarrow} - Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$

Polarized beam and target (spin-correlation asymmetry):

$$\epsilon_{bt} = \frac{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} - Y_{\uparrow\downarrow} - Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$

- **Analyzing Power**: relative difference in cross sections for the corresponding spin up vs. spin down.

Vector Analyzing Power:

$$A_y = \frac{\epsilon}{P_b P_t}$$

REACTION Coding Examples:

`,POL/DA,,ANA`	A_{y0}, incident projectile analyzing power, unpolarized target, incident projectile spin normal to scattering plane
`,POL/DA,*,ANA`	A_{0y}, target analyzing power, unpolarized target, incident projectile spin normal to scattering plane, where * refers to the nuclide code (*e.g.*, 6-C-12).

Tensor Analyzing Power: A_{ij}

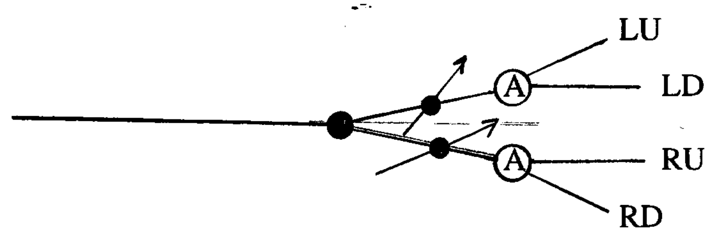
- **REACTION Coding Examples:**

`,POL/DA,,AYY`	A_{yy}, Tensor analyzing power, incident projectile spin normal to scattering plane

Spin-Correlation Parameter: $\vec{A}(\vec{b},c)D$ and $A(b,\vec{c})\vec{D}$; cross section is measured.

$$C_{it} = \frac{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} - d\sigma/d\Omega_{\uparrow\downarrow} - d\sigma/d\Omega_{\downarrow\uparrow}}{d\sigma/d\Omega_{\uparrow\uparrow} + d\sigma/d\Omega_{\downarrow\downarrow} + d\sigma/d\Omega_{\uparrow\downarrow} + d\sigma/d\Omega_{\downarrow\uparrow}} = \frac{1}{P_i P_t} \frac{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} - Y_{\uparrow\downarrow} - Y_{\downarrow\uparrow}}{Y_{\uparrow\uparrow} + Y_{\downarrow\downarrow} + Y_{\uparrow\downarrow} + Y_{\downarrow\uparrow}}$$

where i refers to the i^{th} component of the incident beam.



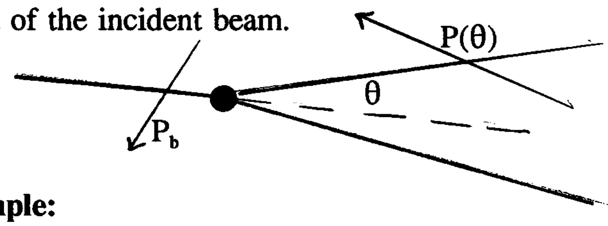
REACTION Coding Example:

`NN,POL/DA,,C` C_{NN}, polarized target and beam; target and beam spins parallel to beam direction in scattering plane; outgoing particles scattered right and left analyzed[1].

Spin-Transfer Parameter: $A(\vec{b},\vec{c})D$; polarization is measured[2].

$$K_{it} = \frac{P_t}{B_i}$$

where B_i is the i component of the incident beam.



REACTION Coding Example:

`NN,POL/DA,,K` K_{NN}, spin transfer parameter, target and beam spins normal to scattering plane

Spin Rotation Function (SRF or Q) gives the coupling between the longitudinal component of the beam polarization and the component of the outgoing particle spin perpendicular to the beam direction.

$$Q = \sqrt{1-P^2}\sin\beta$$

where β is the angle through which the projection of the polarization upon the scattering plane is rotated.

Spin-Flip Probability (S_{nn}) is related to the Spin-Transfer Parameter by:

$$S_{nn} = \frac{1}{2}(1-K_{nn})$$

REACTION Coding: `POL/DA,,SF`

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[1] Sometimes referred to as A_{YY}.

[2] Sometimes referred to as the Spin-Rotation Parameter, D_{ij}.

Quantities given in Spherical Coordinates

The following subscripts are defined:
- k refers to rank
- q refers to projection

The differential cross section for a reaction initiated by a beam with tensor components t_{kq} is given by

$$\sigma = \sigma_0 \left(\sum_{k,q} t_{kq} T_{kq}^* \right)$$

where σ_0 is the cross section for unpolarized particles.

The definitions given, following, refer to spin-1 particles.

If parity is conserved, $T_{10} = 0$, T_{11} = pure imaginary, and T_{2q} = pure real, the cross section may be written as

$$\sigma = \sigma_0 \left[1 + 2iT_{11}\mathrm{Re}(it_{11}) + T_{20}t_{20} + 2T_{21}\mathrm{Re}(t_{21}) + 2T_{22}\mathrm{Re}(t_{22})\right]$$

Analyzing Power

Vector Analyzing Power, iT_{11}.

REACTION Coding: ,,POL/DA,,VAP

Tensor Analyzing Power, T_{20}, T_{21}, T_{22}.

REACTION Coding: TAP in REACTION SF3, T_{kq}

k and q given under data heading KQ with units NO-DIM.

Coding Example:

```
REACTION    (6-C-12(3-LI-6,EL)6-C-12,,POL/DA,,TAP)
 ------
DATA
KQ          ANG         DATA        DATA-ERR
NO-DIM      ADEG        NO-DIM      NO-DIM
 20.         10.0        0.XXXX      0.XXXX
 20.         20.0        0.XXXX      0.XXXX
 20.         30.0        0.XXXX      0.XXXX
 21.         10.0        0.XXXX      0.XXXX
 21.         20.0        0.XXXX      0.XXXX
 21.         30.0        0.XXXX      0.XXXX
 ------
ENDDATA
```

Polarized beam specification

For a polarized incident neutron beam, enter the code POLNS under the keyword INC-SOURCE; for a polarized ion beam, enter POL-IS. If the incident source is known, it should follow in the same set of parenthesis.

Example; `INC-SOURCE (POLNS,D-T)`

Atomic beam and Lamb-shift sources are entered using the codes ATOMI and LAMB, respectively.

The polarization of the incident beam should be given in the data table, if known, using the data heading POL-BM. The numerical uncertainties are entered using the heading POL-BM-ERR, with an explanation in free text under ERR-ANALYS (see EXFOR 8.E.2).

Polarized target specification

For a polarized target, enter the code POLTR under the keyword INC-SOURCE.

The polarization of the incident target should be given in the data table, if known, using the data heading POL-TR. The numerical uncertainties are entered using the heading POL-TR-ERR, with an explanation in free text under ERR-ANALYS (see EXFOR 8.E.2).

REFERENCES

1. *Proceedings of the International Symposium on Polarization Phenomena of Nucleons*, P.Huber and K.P.Meyer, eds., ***Helvetica Phys.Acta***, Suppl. VI (1960).
2. ***Polarization Phenomena in Nuclear Reactions***, page xxv, H.H.Barschall and W.Haeberli, eds. (The University of Wisconsin Press, Madison, WI, 1971).
3. ***Polarization Phenomena in Nuclear Physics - 1980***, G.G.Ohlsen, R.E.Brown, N.Jarmie, W.W.McNaughton, G.M.Hale, eds. (American Institute of Physics, 1981).
4. G. G. Ohlsen, *Polarization transfer and spin correlation measurements in nuclear physics*, ***Rep. Prog. Phys.*** **35**, 717 (1972)
5. L.Wolfenstein, *Polarization of Fast Neutrons*, ***Annual Review of Nuclear Science*** **6**, 43 (Annual Reviews, Inc., Palo Alto, CA, 1956).
6. P. W. Keaton, Jr., J. L. Gammel, and G. G. Ohlsen, ***Annals of Phys.*** **85**, 152 (1974)