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Memo CP-C/271

DATE: 28 August 2000

TO: Distribution

FROM: V. McLane

SUBJECT: Polarization LEXFOR entry

Attached is the proposed new version of the LEXFOR entry on polarization. If accepted, it will involve some new codes and changes to already existing codes. I have checked our library, and there exists only one entry outside of our area for which updates will be needed.

A memo on the dictionary updates will be sent shortly, after everyone has had a chance to look at the LEXFOR entry.
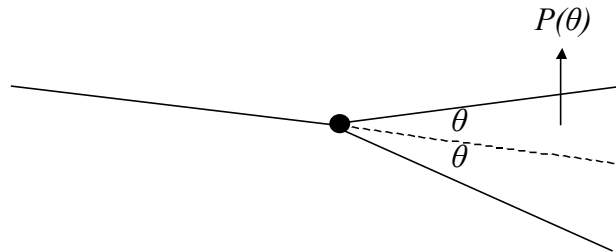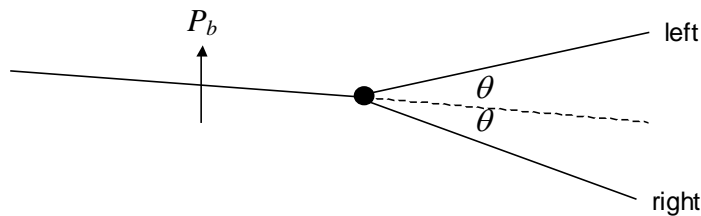
Polarization[1]

If the spins of a assembly of particles, either stationary or in a beam, are oriented in all directions with equal probability, the assembly is said to be unpolarized. If the spins are predominantly oriented in one direction, the assembly is said to be polarized.

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

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-right <u>asymmetry</u> upon scattering from a target nucleus which plays the role of an <u>analyzer</u>.

<u>For elastic scattering from a spin-0 nucleus</u>: the principle of *Polarization-Asymmetry Equality* states that, for time-reversal invariant reactions, the polarization induced in a previously completely unpolarized beam is identically equal to the asymmetry ensuing from the scattering of a perfectly polarized beam under the same conditions.

Conventions for quantities given in Cartesian coordinates

<u>Basel Convention for spin-½ particles[2]</u>

In nuclear reactions, the positive polarization of spin-½ particles is taken in the direction of the vector product $\vec{k}_{in} \times \vec{k}_{out}$ where $\vec{k}_{in}$ and $\vec{k}_{out}$ are the circular wave vectors of the incoming and outgoing particles.

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[1] See [1970Ma].
[2] See [1960Hu].

Madison Convention for spin-1 particles; quantities given in Cartesian coordinates[3]

1. *Polarization (P)*, the state of spin orientation of an assembly of particles, 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 $\vec{k}_{in} \times \vec{k}_{out}$ (perpendicular to the beam direction in the reaction plane) for the nuclear reaction which the polarized particles initiate, or from which they emerge.

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

   The cross section for a reaction initiated by polarized particles with spin-1 may be written in terms of Cartesian tensors as:

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

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

Additional conventions

1. The following subscripts are defined:
   - *b* beam
   - *t* target
   - ↑ spin up ↓ spin down
   - i i^{th} component for beam k k^{th} component for scattered particle
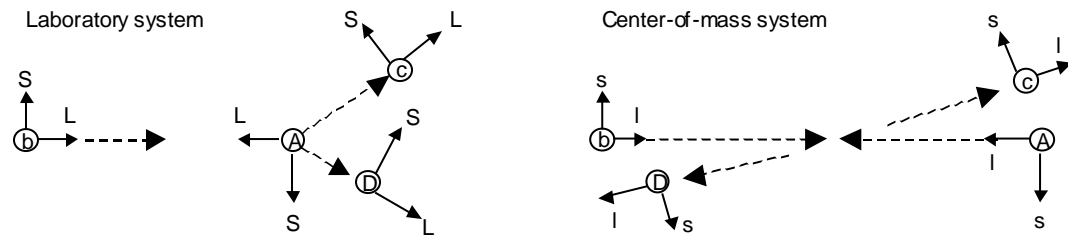   - j j^{th} component for target p p^{th} component for recoil nucleus
   - N=n=y normal to the scattering plane
   - L=l=z longitudinal, *i.e.*, parallel to incident particle momentum in scattering plane
   - S=s=x N⊔L (sideways), *i.e.*, perpendicular to particle momentum in scattering plane

$\overline{N}$ and $\vec{n}$ are identical with direction out of page for all particles.

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[3] See [1971Sa].

Occasionally, a 4-index notation is used; the order of the subscript in a 4-index notation is (i,j;k,p). A zero in a field denotes unpolarized or polarization not measured.

2. **Y** is the normalized yield.

3. σ_0 is the differential cross section for an unpolarized (spin-averaged) beam.

Quantities given in Cartesian coordinates and compiled in EXFOR

Polarization:refers to the degree of polarization of a single particle or ensemble.

$P_s(\theta)$ is the polarization of the outgoing particle beam as a function of angle.

where $\qquad \sigma_P = \sigma_0 P(\theta)$

REACTION Coding: `,POL/DA`

Asymmetry: Asymmetry is the relative difference between:

   a.) the number of particles scattered to the right and to the left in the reaction plane**.**

$$\varepsilon = (L - R)/(L + R) = P_b A_y$$

where $\quad \varepsilon =$ 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.

REACTION coding: `POL/DA,,ASY`

   b.) the angular distribution for incident projectiles with their polarization vectors perpendicular and parallel to the reaction plane.

$$\varepsilon = \left(d\sigma_\perp - d\sigma_\parallel \right) / \left(d\sigma_\parallel + d\sigma_\perp \right)$$

Where $\parallel$ refers to the parallel component,
        $\perp$ refers to perpendicular component.

REACTION coding: `,POL/DA,,ASY/PP`

If data are given as $(d\sigma_\parallel - d\sigma_\perp)/(d\sigma_\parallel + d\sigma_\perp)$, the negative of the value given is coded.

   c.) the angular distribution for forward and backward scattered particles.

$$\varepsilon = \left(d\sigma_F - d\sigma_B \right) / \left(d\sigma_F + d\sigma_B \right)$$

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

The angles are given as ANG1 and ANG2.

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

Vector analyzing power (A_i or $A_{i,0;0,0}$ and A_j or $A_{0,j;0,0}$):

Coding: Modifier ANA in SF8**.**

    *Example***:**

        `,POL/DA,,ANA`   Analyzing power, A_n, incident projectile spin normal to scattering plane.

Tensor analyzing power (A_{ij} or $A_{i,j,0,0}$): initial spin state correlation parameters.[4]

$$A_{yy} = A_{NN} = \frac{\varepsilon}{\left|P_b\right|\left|P_t\right|}$$

Coding: Modifier A in SF8, branch code in SF5 giving components of beam and target spin
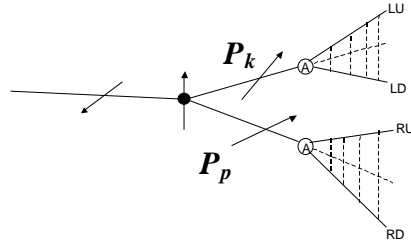
    *Example***:**

        `NN,POL/DA,,ANA`   Tensor analyzing power, A_{NN}, incident projectile and target spins normal to scattering plane.

Spin-Correlation Parameter (C_{kp} or $C_{0,0,k,p}$): final spin state correlation parameters.

For spins in the scattering plane:

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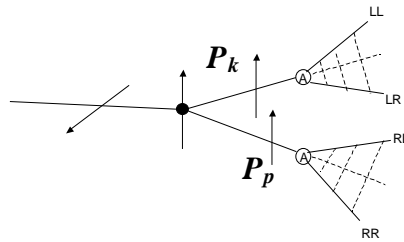

where:
    L = left
    R = right
    D = down
    U = up

For spins normal to the scattering plane:

$$C_{NN} = \frac{1}{p_b P_t}\frac{(LL)(RL) + (LR)(RR) - (LL)(RR) - (LR)(RL)}{(LL)(RL) + (LR)(RR) + (LL)(RR) + (LR)(RL)}$$

where:
    L = left
    R = right

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[4] May be referred to in the literature as spin correlation parameter.

REACTION Coding: Modifier `C` in SF8, branch code in SF5 giving components of beam and target spin.
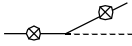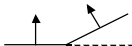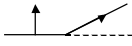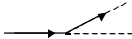
> ***Example:*** `LL,POL/DA,,C` C_{LL}, spin correlation function, outgoing particle and recoil nucleus spins parallel to beam direction in scattering plane

If time reversal holds: $C_{NN} = A_{NN}$

Spin-Rotation-Depolarization Parameters (D_{ik} or $D_{i,0,k,0}$ for incident beam and D_{jp} or $D_{0,j,0,p}$ for target)

The spin-rotation parameter is a measure of the rotation of the spin of the scattered beam. The three orthogonal components of the outgoing particle polarization are related to the components of the incident particle polarization through the set of spin-rotation parameters.

These parameters are related to the Wolfensein [1956Wo] parameters as follows:

	Wolfenstein Parameter	Representation
$D_{NN} =$	D	$\otimes$ signifies normal to the scattering plane
$D_{SS} =$	R	
$D_{LS} =$	R′	
$D_{SL} =$	A	
$D_{LL} =$	A′	

D_{NN} is also known as the **Spin-Depolarization Parameter**

REACTION Coding: Modifier `D` in SF8, branch code in SF5 giving components of beam and target spin.

> ***Example:***
>
> `LL,POL/DA,,D`   Spin-Rotation Parameter D_{LL}, beam and scattered particle spins parallel to beam direction in scattering plane.
>
> `LL,POL/DA,*,D`   Spin-Rotation Parameter D_{LL}, target and recoil nucleus spins parallel to beam direction in scattering plane.

Spin-flip probability (S_{nn})

REACTION coding: `POL/DA,,SF`

The Spin-Flip Probability is related to the spin depolarization parameter by: $S_{flip} = \frac{1}{2}(1 - D_{NN})$.

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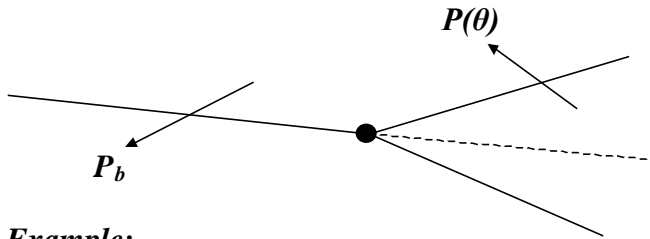
$$Q = \sqrt{1 - P^2}\, \sin\beta$$

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

For spin-0 particles:

$$Q = A\cos\theta_{lab} + R\sin\theta_{lab} = D_{SL}\cos\theta_{lab} + D_{SS}\cos\theta_{lab}$$

REACTION coding: `POL/DA,,SRF`

Spin-Transfer Parameter (K_{ip} for incident beam and K_{jk} for target)

Coding Example:

`NN,POL/DA,,K`   **K_{NN},** spin transfer parameter, incoming particle and recoil nucleus spins normal to scattering plane

`LL,POL/DA,*,K`   **K_{NN},** spin transfer parameter, target nucleus and outgoing particle spins longitudinal in scattering plane

The spin-transfer parameter is related to the spin-rotation parameter by:.

$$D_{ij}(\theta) = K_{ij}(\pi - \theta)$$

Conventions for quantities given in Spherical Coordinates

The following subscripts are defined:

k refers to the rank

q refers to the projection

Madison convention for spin-1 particles quantities given in spherical coordinates[5]

For particles of spin ≥ 1, the polarization may be described in terms of tensor quantities of integer rank $k \geq 2i$: $0 \leq |q| \leq k$.

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

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

where T_{kq} = analyzing power components.

For spin-1 particles, if parity is conserved, $T_{10}=0$, T_{11} is pure imaginary, and T_{2q} is pure real; the cross section may be written as

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

Quantities given in Cartesian coordinates and compiled in EXFOR

Analyzing Power (T_{kq})

Vector analyzing power (iT_{11})

Coding: quantity code VAP in SF6

Example: POL/DA,,VAP

Tensor analyzing power (T_{20}, T_{21}, T_{22})

Coding: quantity code TAP in SF6; k and q are specified under the branch field using the codes 20, 21, and 22.

Example: 20,POL/DA,,TAP

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[5] See [1971Sa].

Associated Information

Polarized beam specitifcation

For a polarized incident neutron beam, enter the code POLNS under the keyword INC-SOURCE; for a polarized ion beam, enter POLIS. 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.

Polarized target specification

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

The polarization of the incident beam and target should be given in the data table, if known, using the data headings POL-BM and POL-TR, respectively. The numerical uncertainties are entered using the headings POL-BM-ERR and POL-TR-ERR; an explanation may be given in free text under ERR-ANALYS (see EXFOR 8.10).

REFERENCES

1956Wo L. Wolfenstein, *Polarization of fast nucleons*, ***Ann. Rev. Nucl. Sci. 6***, (1956) 43-47.

1960Hu *Proceedings of the International Symposium on Polarization Phenomena of Nucleons*, P.Huber and K. P. Meyer, eds., ***Helv. Phys.Acta***, Suppl. VI (1960) end of volume.

1970Ma P. Marmier and E. Sheldon, ***Physics of Nuclei and Particles,*** (Academic Press, NY, 1970) Vol. II, Ch. 13.

1971Sa G. R. Satchler et al., ***Polarization Phenomena in Nuclear Reactions*** (University of Wisconsin Press, Madison, WI, 1971) pp. xxv-xxix; also S. E. Darden, pp. 39-56.

For more information, see also the following references.

T. A. Welton, *The theory of polarization in reactions and scattering*, ***Fast Neutron Physics***, Part II (Interscience Publishers, 1963) 1317-1377.

G. G. Ohlsen, *Polarization transfer and spin correlation experiments in nuclear physics*, ***Rev. Prog. Phys. 35***,(1972) pp. 717-801.

J. Ashkin et al., *Convention for spin parameters in high energy scattering experiments*, ***Higher Energy Polarized Proton Beams*** (American Institute of Physics, 1978) pp. 142-146.

D. Crabb, *Spin correlation measurements in nucleon-nucleon scattering at high* energy, ***Polarization Phenomena in Nuclear Physics - 1980***, (American Institute of Physics, 1981) pp. 11-30.