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Notations for Spin Observables in NN Scattering

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This gives a comparison table of notations for spin parameters used in experimental reports on NN scattering, aiming at a quick identification of symbols we want to know by comparison with familiar ones. Relations to symbols used in reports on other processes than NN, $1/2+0 \to 1/2+0$, $1/2+1 \to 1/2+1$, etc. will be noted briefly. For details of each system of notations, see, e.g., review articles: HOS-68, ASH-77, BYS-78, YOK-80. See also OHL-72 for nuclear reactions and BOU-80 for hadron reactions.

Spin parameters are defined as those involving spin projections on basis vectors. The basis is defined in LAB or in CM and is chosen differently for different particles. As NN experiments are with fixed targets, we will concentrate on spin observables defined in LAB. Consider the reaction A+B → C+D with particle B at rest and particle C fast. Figures 1(a)-(c), 2 and 3 show a variety of definitions and notations of spin polarization directions. The coordinate system of Fig. 1 has been mainly used. The choice of Fig. 2 (ASH-77) or Fig. 3 (BOU-80) was proposed as more logical.

Table I gives notations for various spin parameters currently used in experimental reports. For historical reasons, we first cite the symbols introduced by Wolfenstein et al. (column HOS-68). They are compared with the notation of Ann Arbor (column ASH-77), symbols employed by experimenters at SACLAY (after SATURNE-II), SIN, etc. (column BYS-78), notations used by ANL group (column YOK-80) and by experimentalists working on the LAMPF accelerator (column HOL-84). Column headed by "OHL-72 and others" represents the corresponding symbols used in nuclear reactions (OHL-72) and other miscellaneous notations (DRE-73, HIG-79, LAP-85 and STA-83). In order to identify each symbol definitely, we list the 4-index notation in the last column, which reads (Beam, Target; Scattered, Recoil). 0 denotes unpolarized or polarization unmeasured. Letters N, L, S indicate the directions of polarization referring to the coordinate system of Fig. 1(c) (YOK-80) or Fig. 2 (ASH-77). Concretely, the 4-index parameter is defined by

$$(\alpha,\beta;\mu,\nu) = \left(\frac{d\sigma}{d\Omega}\right)^{-1} \frac{1}{4}\mathrm{Tr}(M\sigma_\alpha^A\sigma_\beta^B M^+\sigma_\mu^C\sigma_\nu^D)$$

with normalization $(0,0;0,0) = 1$. Here, $d\sigma/d\Omega$ is the differential cross section, and M is the scattering matrix in spin space. σ_α^A is the α-component of the Pauli spin operator for nucleon A and $\sigma_0^A = 1$, etc.

The symbols for spin observables as listed in Table I for NN scattering are very often used for reactions other than NN, $1/2+0 \to 1/2+0$, $1/2+1 \to 1/2+1$, etc. Their physical meaning is common to the NN case, but with few exceptions. We note that $A_{\alpha\beta}$ for the initial spin correlation parameters should be distinguished from $A_{\alpha\beta}$ for the tensor analyzing powers for reactions involving polarized deuterons. Example: A_{zz} for $\vec{p}\vec{p} \to \pi d$ is the spin correlation parameter (z,z;0,0), but A_{zz} for $\vec{d}+{}^3\mathrm{He} \to p+{}^4\mathrm{He}$ is the tensor analyzing power (zz,0;0,0), which is frequently written in terms of the spherical tensor $T_{20}(=A_{zz}/\sqrt{2})$ (MAD-71). For the use of spherical tensors, see SIM-74. The symbol A is often used for various asymmetries with subscripts such as A_{LR} for the left-right asymmetry or without suffix. In photoreactions, $\gamma+B \to C+D$, it is customary to follow the notation developed for $\gamma N \to \pi N$: Σ for the linearly polarized photon asymmetry, T for the polarized target asymmetry, P for the polarization of the scattered particles, etc. (MOO-74). In $\pi N \to \pi N$, the symbols R and A are applied to R_{recoil} and A_{recoil}, i.e., to (0,S;0,S) and (0,L;0,S) of YOK-80, respectively (LES-72 and HOH-79).

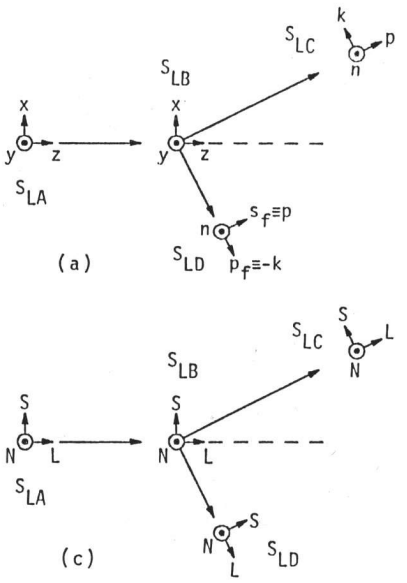

Fig. 1. Description of spin directions in LAB for A+B → C+D.
S_{LA}: Coordinate system for A, etc.
⊙•: Upward out of the paper.
(a) HOS-68. (b) BYS-78. (c) YOK-80.

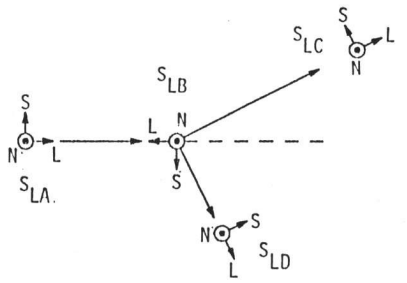

Fig. 2. Ann Arbor description of spin directions in LAB. (ASH-77).

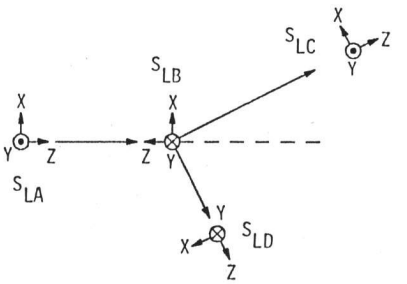

Fig. 3. Description of spin directions in LAB. (BOU-80).

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Table I
Comparison of notations for spin parameters.[a)]

Type	HOS-68	ASH-77	BYS-78	YOK-80	HOL-84	OHL-72 & others	YOK-80# ASH-77*
	Fig.1a	Fig.2	Fig.1b O_{SRBT}	Fig.1c	Fig.1c		(B,T;S,R)
Total cross sections							
A+B→ anything			σ_{0tot}	σ^{Tot}		σ_{tot}	
$\vec{A}+\vec{B}$→ anything		$\Delta\sigma_T$ $\Delta\sigma_L$	$-2\sigma_{1tot}$ $\Delta\sigma_L$	$\Delta\sigma_T{}^{Tot}$ $\Delta\sigma_L{}^{Tot}$		$\Delta\sigma_T$ 1) $\Delta\sigma_L$ 1)	
Note: $\Delta\sigma_T = \sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}$ $\quad \Delta\sigma_L = \sigma_{\rightarrow\atop\leftarrow} - \sigma_{\rightarrow\atop\rightarrow}$							
Differential cross section							
A+B→C+D	I_0	$d\sigma/dt$	I_{0000}	σ		I_0	(0,0;0,0)
Note: $d\sigma/dt = \pi\lambda\!\!\!^{-2}\, d\sigma/d\Omega = \pi\lambda\!\!\!^{-2} I_0$ Normalization: (0,0;0,0) = 1							
Analyzing powers							
$\vec{A}$+B→C+D	P	A^a	A_{00n0}	P	A A_y	A_y A_{y0} 2)	(N,0;0,0)
A+$\vec{B}$→C+D	P	A^b	A_{000n}	P	A A_y	A_y^T A_{0y} 2)	(0,N;0,0)
Polarizing powers or polarizations							
A+B→$\vec{C}$+D	P	P^c	P_{n000}	P	P	$P_{y'}$	(0,0;N,0)
A+B→C+$\vec{D}$	P	P^d	P_{0n00}	P	P		(0,0;0,N)
Initial state correlation of polarizations							
$\vec{A}+\vec{B}$→C+D	A_{yy}	A_{NN}	A_{00nn}	C_{NN}	A_{NN} A_{nn}	$C_{y,y}$	(N,N;0,0)
	A_{zz}	$-A_{LL}$	A_{00kk}	C_{LL}	A_{LL} 3,4)	$C_{z,z}$	(L,L;0,0)# -(L,L;0,0)*
	A_{xx}	$-A_{SS}$	A_{00ss}	C_{SS}		$C_{x,x}$	(S,S;0,0)# -(S,S;0,0)*
	A_{xz}	$-A_{SL}$	A_{00sk}	C_{SL}	A_{SL} 4)	$C_{x,z}$	(S,L;0,0)# -(S,L;0,0)*
	A_{zx}	$-A_{LS}$	A_{00ks}	C_{LS}		$C_{z,x}$	(L,S;0,0)# -(L,S;0,0)*
Note: $A_{zx} = A_{xz}$							
Final state correlation of polarizations							
A+B→$\vec{C}$+$\vec{D}$	C_{nn}	C_{NN}	C_{nn00}			$C_{n,n}$	(0,0;N,N)
	C_{kp}	C_{SS}	$C_{s's''00}$			$C_{p,p}$	(0,0;S,S)
	C_{pp}	C_{LS}	$C_{k's''00}$			$C_{k,p}$	(0,0;L,S)
	$-C_{kk}$	C_{SL}	$C_{s'k''00}$			$C_{p,k}$	(0,0;S,L)

a) Arrow in the column headed "Type" indicates the particle whose spin polarization is known or measured. Suffices in O_{SRBT} and letters in (B,T;S,R) are as follows. B:beam, T:target, S:scattered, R:recoil. 0:unpolarized or polarization unmeasured. N,L,S: spin directions referred to Fig. 1(c) (YOK-80) or Fig. 2 (ASH-77). (B,T;S,R) without * and # is common to ASH-77 and YOK-80.
1) STA-83,YOK-80. 2) LAP-85. 3)GAZ-85. 4) CHA-85.

Type	HOS-68	ASH-77	BYS-78	YOK-80	HOL-84	OHL-72 & others	YOK-80# ASH-77*
Polarization transfer or Wolfenstein parameters							
$\vec{A}+B\to\vec{C}+D$	D	D^{a}_{NN}	D_{n0n0}		D_{NN}	$K_{y}^{y'}$	(N,0;N,0)
	R	D^{a}_{SS}	$D_{s'0s0}$		D_{SS}	$K_{x}^{x'}$	(S,0;S,0)
	A	D^{a}_{LS}	$D_{s'0k0}$		D_{LS}	$K_{z}^{x'}$	(L,0;S,0)
	R'	D^{a}_{SL}	$D_{k'0s0}$		D_{SL}	$K_{x}^{z'}$	(S,0;L,0)
	A'	D^{a}_{LL}	$D_{k'0k0}$		D_{LL}	$K_{z}^{z'}$	(L,0;L,0)
		Note: D=1-2S, S being spin-flip probabilities.					
$\vec{A}+B\to C+\vec{D}$	D_t	K^{a}_{NN}	K_{0nn0}	K_{NN}	K_{NN}		(N,0;0,N)
	R_t	K^{a}_{SS}	$K_{0s"s0}$	K_{SS}	K_{SS}		(S,0;0,S)
	A_t	K^{a}_{LS}	$K_{0s"k0}$	K_{LS}	K_{LS}		(L,0;0,S)
	$-R_t'$	K^{a}_{SL}	$K_{0k"s0}$	K_{SL}	K_{SL}		(S,0;0,L)
	$-A_t'$	K^{a}_{LL}	$K_{0k"k0}$	K_{LL}	K_{LL}		(L,0;0,L)
		Note: $K_{ij}(\theta_{CM})=D_{ij}(\pi-\theta_{CM})$ for p+p→p+p.					
$A+\vec{B}\to C+\vec{D}$		D^{b}_{NN}	D_{0n0n}	D_{NN}			(0,N;0,N)
		$-D^{b}_{SS}$	$D_{0s"0s}$	D_{SS}		R [5] R_r [6]	(0,S;0,S)# -(0,S;0,S)*
		$-D^{b}_{LS}$	$D_{0s"0k}$	D_{LS}			(0,L;0,S)# -(0,L;0,S)*
		$-D^{b}_{SL}$	$D_{0k"0s}$	D_{SL}		$-R'_r$ [6]	(0,S;0,L)# -(0,S;0,L)*
		$-D^{b}_{LL}$	$D_{0k"0k}$	D_{LL}			(0,L;0,L)# -(0,L;0,L)*
$A+\vec{B}\to\vec{C}+D$		K^{b}_{NN}	K_{n00n}				(0,N;N,0)
		$-K^{b}_{SS}$	$K_{s'00s}$				(0,S;S,0)# -(0,S;S,0)*
		$-K^{b}_{LS}$	$K_{s'00k}$				(0,L;S,0)# -(0,L;S,0)*
		$-K^{b}_{SL}$	$K_{k'00s}$				(0,S;L,0)# -(0,S;L,0)*
		$-K^{b}_{LL}$	$K_{k'00k}$				(0,L;L,0)# -(0,L;L,0)*
Three spin observables							
$\vec{A}+\vec{B}\to\vec{C}+D$			$M_{\mu'0\alpha\beta}$				±(α,β;μ,0) [7]
$\vec{A}+\vec{B}\to C+\vec{D}$			$N_{0\nu"\alpha\beta}$	$H_{\alpha\beta\nu}$			±(α,β;0,ν) [7]
$\vec{A}+B\to\vec{C}+\vec{D}$	$C^{\alpha}_{\mu\nu}$		$C_{\mu'\nu"\alpha0}$				(α,0;μ,ν)
$A+\vec{B}\to\vec{C}+\vec{D}$	$C'^{\beta}_{\mu\nu}$		$C_{\mu'\nu"0\beta}$				±(0,β;μ,ν) [7]
Four spin observables							
$\vec{A}+\vec{B}\to\vec{C}+\vec{D}$			$C_{\mu'\nu"\alpha\beta}$				±(α,β;μ,ν) [7]

5) DRE-73. 6) HIG-79. 7) The minus sign is for ASH-77 with β=L or S.