Differential data and Angular correlations

The following recent memos on this topic were exchanged (in reverse chronological order): CP-E/051Rev., CP-D/409, C/350, E/049, C/348,346.
Latest comprehensive proposal by NNDC is in CP-C/350, to which minor modifications are proposed in CP/E-051 and CP-D/409.
This WP contains: CP-E/051 (proposed corrections), CP-D/409 with modified complete proposed LEXFOR entry of CP-C/350, and the covering page of CP-C/350.
The older memos on the topic are not reproduced here.

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Memo CP-E/051 (Revised)

Date: August 30, 2004
To: Distribution
From: OTSUKA Naohiko
Subject: Differential data (Definition of mean energy and mean linear momentum)
Reference: CP-C/346, 348, 350, CP-D/409, CP-E/049

I appreciate the revision of LEXFOR entry in CP-C/350 and CP-D/409.

- Non-coplanar angular correlations:

Unit type of angular correlation function $W(\theta_a, \theta_b, \phi)$ should be `ARB-UNITS` rather than `NO-DIM`.

- Energy distribution for a correlated pair:

"The angle is given …" should be "The energy is given…".

What is the definition of *mean energy* E_m given under `E-MN-CM`? Does it mean "energy of relative motion of correlated pair" (= center-of-mass energy) E_{rel}?

$$E_{rel} = \boldsymbol{p}_{rel}^2/2\mu^2$$
$$= \boldsymbol{p}_a^2/2m_a + \boldsymbol{p}_b^2/2m_b \qquad \text{(in c.m.s. of correlated pair)} \qquad (1)$$

, where momentum of relative motion $\boldsymbol{p}_{rel}$ and reduced mass μ of correlated pair are defined as

$$\boldsymbol{p}_{rel} = (m_b\, \boldsymbol{p}_a - m_a\, \boldsymbol{p}_b) / (m_a + m_b)$$
$$= \boldsymbol{p}_a = -\boldsymbol{p}_b \qquad \text{(in c.m.s. of correlated pair)} \qquad (2)$$

$$\mu = m_a m_b / (m_a + m_b) \quad (3)$$

If so, alternative heading codes would be `E-RL` etc. We must avoid the confusion with "energy of outgoing particle given in center-of-mass system" (e.g. `E-CM`). c.f. CP-A/121. Examples o f this energy distribution can be found in E1748.020-045. Note that E_{rel} is Galilei invariant.

Concerning WP2002-5, I try to check the definition of "`,ECO`" (Energy correlation). However I cannot find any entries of "`,ECO`" in our database.

<u>- Linear momentum for a correlated pair:</u>

"distribution" is needed between "momentum" and "for" in the title.

Unit type should be `DP` rather than `DA`.

What is the definition of *mean linear momentum* p_m? Does it mean "momentum of relative motion" ($|\boldsymbol{p}^{rel}|$ given in Eq. (2)), or "momentum difference between two particles" $|\boldsymbol{p}_a - \boldsymbol{p}_b|$? There would be alternative heading codes, e.g. `MOM-SEC-RL` for $|\boldsymbol{p}^{rel}|$.

Concerning WP2002-5, I study the possibility of replacing `MCO` (Linear momentum correlation) by "`DP,a+b`". Two subsections, M0035.022 and M0054.002, use this code:

- M0035.022:
  Data shown in Fig.4 of main reference gives counts as a function of momentum difference between proton and neutron $|\boldsymbol{p}_p - \boldsymbol{p}_n|$ for ^{4}He(γ,p+n)^{2}H (we can find the definition in p.934 of the article). We could code M0035.002 using "`,DP,N+P,REL`" as a function of momentum difference given under appropriate data heading.

- M0054.002 (I check the English translation Sov. J. Nucl. Phys.**34** (1981) 789):
  Data shown in Fig.1 of main reference gives counts as a function of $|\boldsymbol{p}_d| = |\boldsymbol{p'}_p + \boldsymbol{p'}_n - \boldsymbol{p}_\gamma|$ for ^{12}C(γ,p+n)^{10}B, where $\boldsymbol{p'}_p$ and $\boldsymbol{p'}_n$ are the momenta of proton and neutron in ^{12}C. These momenta are obtained by applying final state interaction correction to measured momenta $\boldsymbol{p}_p$ and $\boldsymbol{p}_n$ (authors are interested in the momentum of quasi-deuterons in ^{12}C). We could code M0054.002 using "`,DP,D,REL`" or "`,DP,N+P,REL`" as a function of momentum of quasi-deuterons $|\boldsymbol{p}_d|$ given under `MOM-SEC`. In this case, the definition of this quasi-deuteron's momentum should be clarified under information identifier `MOM-SEC`.

Additional remark on M0054.002 :

Fig.1 considers the correction of momenta due to final state interaction by assuming various average depth for proton and neutron. In current compilation, heading `E1` is assigned for this potential depth and `PAR` is used in SF5. This is probably incorrect. Average depths should be given under `MISC`, and `PAR` in SF5 should be removed.

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Memo CP-D/409

Date: 24 August 2004
To: Distribution
From: O. Schwerer

Subject: Angular distribution data
Re: Memo CP-C/350, CP-C/346, CP-C/348, CP-E/049

1) I agree with the proposed new coding rules for angular distributions, provided that correction of existing entries is taken care of. In particular I appreciate the removal of the code DA/CRL and the new clear definition of angular correlations, now to be coded as DA/DA.

2) I have only the following small changes to propose to the draft LEXFOR entry of CP-C/350 and **I append a revised version of it**, with the following modifications:

- An additional sentence in the introduction about the nomenclature (differential cross sections vs. angular distributions)

- Editorial / typographical corrections for the definitions of ,DA,,RS and ,LP,DP

- I think double-, triple- and quadruple-differential cross sections should consistently be written as $d^2\sigma/$…., $d^3\sigma/$…, and $d^4\sigma/$….

3) The proposed and agreed new CINDA quantity COR for correlation is now no longer meaningful and appropriate changes in all affected dictionaries (not only dictionary 36/236) will be needed.

4) The existing LEXFOR entry "Correlations" should now consist only of a cross reference to the new page on "Differential Data" and some remark or cross-reference to the reamining other correlations (EMC and MCO).

Differential Data

(See also **Fitting Coefficients**, **Angle, Polarization**).

Definitions

Reaction plane: The plane defined by the incident beam direction and the outgoing particle direction. For the following discussions plane *A* is defined by the incident beam direction and the outgoing particle *a* direction

Differential data refers, in general, to:

- the particle given in the REACTION string SF3,
- for production or fission, the product given in SF4 or in the data table
- the particle defined in the REACTION string SF7.

A particle must be specified in SF7 (particle considered) if:

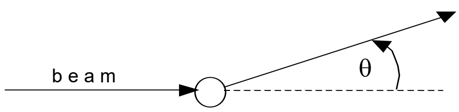
- there is more than one particle given in SF3,
- the data refers to a different particle or nuclide than those specified above,
- or the data refers to more than one outgoing particle.

Nomenclature

In the literature, usually data given in units of cross sections (millibarns/sterad, barns/MeV etc.) are called differential (double-differential, triple-differential, quadruple-differential) **cross sections**, while data given in dimensionless units are called angular, energy, or angle/energy **distributions**. However, these names are often used interchangeably. In this chapter we call them all "distributions" because the independent variables can be more easily added to the name (as in angle/energy distributions).

Angular Distributions

1. Angular distribution: probability for a particle to be emitted into an area of solid angle dΩ lying at a mean angle of θ to the incident beam direction in the reaction plane; given as $\sigma(\theta) = d\sigma/d\Omega$. The data are given in units of cross section per unit solid angle (*e.g.*, mb/sr).



REACTION coding: DA in SF6.
Unit type: DA (*e.g.*, B/SR)

2. Relative angular distributions

a.) The shape of the angular distribution W(θ); the data are dimensionless, and are most often normalized to W(90°) = 1.

REACTION coding: DA in SF6; modifier REL in SF8.
Units: ARB-UNITS.

b. Ratio to 90°

REACTION coding: DA in SF6; modifier RSD in SF8.
Units: NO-DIM

c. Ratio to 0°

REACTION coding: DA in SF6; modifier RS0 in SF8.
Units: NO-DIM

d. Ratio to average value from 0° - 180°: $d\sigma/d\Omega\,/\,\sigma/4\pi$

REACTION coding: DA in SF6; modifier RS in SF8.
Units: NO-DIM

e. Ratio to the value at another angle: $\frac{d\sigma}{d\Omega}(\theta_1) \Big/ \frac{d\sigma}{d\Omega}(\theta_2)$

Code as a ratio using the separator //, see **Ratios**.

f. Ratios to the integrated cross section:

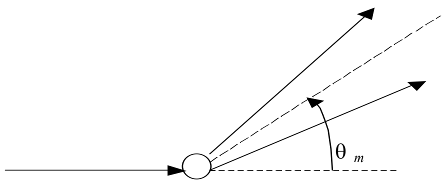
Code as a ratio with the separator /, see **Ratios**.

g. Ratio to Rutherford or Mott scattering

REACTION coding: DA in SF6; modifier RTH (Rutherford) or MOT (Mott) in SF8.
Units: NO-DIM

3. Angular distribution for a correlated pair

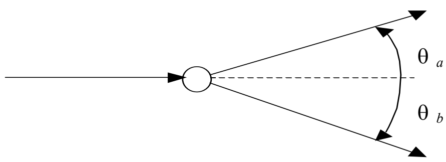
Probability that a particle *a* and a particle *b* will be emitted at a mean angle θ_m to the incident beam, $d\sigma/d\Omega$ for θ_m:



REACTION coding: DA in SF6; particles in SF7 as *a*+*b* (*e.g.*, P+A).
Unit type: DA (*e.g.*, B/SR)

The angle is given under the heading ANG-MN

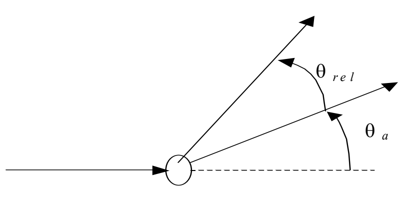
3. Angular correlation: probability that, if a particle *a* in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane, particle *b* will be emitted at a mean angle of θ_b to the incident beam direction in the same plane (coplanar); given as $d^2\sigma/d\Omega_a d\Omega_b$. The data are given in units of cross section per unit solid angle squared (*e.g.*, mb/sr^2).



REACTION coding: DA/DA in SF6; particles in SF7 as *a*/*b* (*e.g.*, P/D).
Unit type: DA2 (*e.g.*, MB/SR2)

The angles θ_a and θ_b are coded under the headings ANG1 and ANG2, in the same order as the particles appear in SF7. If the particles are measured on opposite sides of the beam direction, the angles will be given as, for example, 30. and –30.

Alternately, the angle of particle *b*, θ_b, may be given with the angle between the two emitted particles θ_{rel}.



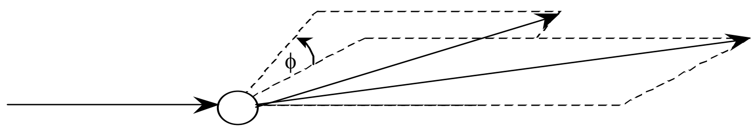
REACTION coding: DA/DA in SF6; particles in SF7 (*e.g.*, P/P+A).
Unit type: DA2 (*e.g.*, MB/SR2)

The angles are given as ANG1 and ANG-RL.

The angular correlation is often given as an angular correlation function $W(\theta_a,\theta_b)$; the data are dimensionless.

REACTION coding: DA/DA in SF6; particles in SF7, REL in SF8.
Units: ARB-UNITS.

4. Non-coplanar angular correlations: The more general situation is for particle *a* and particle *b* not in the same reaction plane. Then θ_a is the angle of particle *a* relative to the beam direction in plane *A*, θ_b is the angle of particle *b* relative to the beam direction in plane *B*, and a third angle ϕ is defined as the angle between the *A* and *B* reaction planes (azimuthal angle).



REACTION coding: DA/DA in SF6; particles in SF7 as *a*/*b* (*e.g.*, N/P) ; NCP in SF8.
Unit type: DA2 (*e.g.*, `MB/SR2`).

The angles θ_a and θ_b are coded under the headings ANG1 and ANG2, in the same order as the particles appear in SF7. The azimuthal angle is coded under the heading ANG-AZ-RL.

The angular correlation function is then given as $W(\theta_a,\theta_b,\phi)$.

REACTION coding: DA/DA in SF6; particles in SF7; NCP/REL in SF8.
Units: NO-DIM

<u>Secondary Energy Distributions</u>

1. Energy distribution: probability for a particle to be emitted with a given energy E′ or in a given energy range E_{min} to E_{max}; given as $\sigma(E') = d\sigma/dE$. The data are given in units of cross section per unit of secondary energy (*e.g.*, mb/MeV).

REACTION coding: DE in SF6.
Unit type: DE (*e.g.*, B/MEV)

2. Energy distribution for a correlated pair: Probability that a particle *a* and a particle *b* will be emitted at a mean energy E_m or in a given energy range, dσ/dE, usually given for the center-of-mass energy of the emitted particles:

REACTION coding: DE in SF6; particles in SF7 as *a*+*b* (*e.g.*, P+A).
Unit type: DE (*e.g.*, B/MEV)

The angle is given under the data heading E-MN-CM

3. Linear momentum distribution: probability for a particle to be emitted with a given momentum p′; given as σ(p′) = dσ/dp. The data are given in units of cross section per unit of secondary linear momentum (*e.g.*, mb/MeV/c).

REACTION coding: DP in SF6.
Unit type: ~~DA~~ DP (*e.g.*, MB/MEV/C)

Example:
(……(N,X)……,LP,DP) longitudinal momentum distribution of emitted particles.

The linear momentum is given under the data heading MOM-SEC.

4. Linear momentum for a correlated pair: Probability that a particle *a* and a particle *b* will be emitted at a mean linear momentum p_m.

REACTION coding: DP in SF6; particles in SF7 as *a*+*b* (*e.g.*, P+A).
Unit type: DA (*e.g.*, MB/MEV/C)

The linear momentum is given under the heading MOM-SEC-MN.

Angle/Energy Distributions

1. Angle/energy distribution: probability for a particle to be emitted at a given energy E′ and into an area of solid angle Ω lying at a mean angle of θ to the incident beam direction in the reaction plane; given as $\sigma(\theta) = d^2\sigma/d\Omega/dE$. The data are given in units of cross section per unit solid angle per unit of energy (*e.g.*, mb/sr/MeV).

REACTION coding: DA/DE in SF6.
Unit type: DAE (*e.g.*, B/SR/MEV)

The energy is given under the data heading E or E-MIN and E-MAX.

2. Angle/energy correlations:

a.) probability that, if a particle *a* in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E′, particle *b* will be emitted at a mean angle of θ_b to the incident beam direction in the same plane (coplanar); given as $d^{\cancel{2}3}\sigma/d\Omega_a d\Omega_b dE_a$. The data are given in units of cross section per unit solid angle squared per unit energy (*e.g.*, mb/sr^2/MeV).

REACTION coding: DA/DA/DE in SF6, . particles in SF7 as *a*/*b*/*a* (*e.g.*, P/A/P)
Unit type: D3A (*e.g.*, MB/SR2/MEV)

The angles θ_a and θ_b are coded under the headings ANG1 and ANG2 in the same order as the particles appear in SF7; the energy is coded under the heading E1 or E2 to correlate the energy with the angle of the same particle.

b.) probability that, if a particle *a* in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E_a, particle *b* will be emitted at an energy E_b; given as $d^{\cancel{2}3}\sigma/d\Omega_a dE_a/dE_b$. The data are given in units of cross section per unit solid angle per unit energy squared (*e.g.*, mb/sr/MeV^2).

REACTION coding: DA/DE/DE in SF6, . particles in SF7 as *a*/*b*/*a* (*e.g.*, P/A/P)
Unit type: D3 (*e.g.*, MB/SR/MEV2)

The energies are coded under the data heading E1 and E2 in the same order as the particles appear in SF7; the angle θ_a is coded under ANG1 or ANG2 to correlate with the energy of the same particle.

c.) probability that, if a particle *a* in emitted at a mean angle of θ_a to the incident beam direction in the reaction plane and an energy E_a, particle *b* will be emitted at a mean angle of θ_b to the incident beam direction in the reaction plane and an energy E_b; given as $d^{\cancel{2}4}\sigma/d\Omega_a d\Omega_b/dE_a/dE_b$. The data are given in units of cross section per unit solid angle per unit energy squared (*e.g.*, mb/sr^2/MeV^2).

REACTION coding: DA2/DE2 in SF6, . particles in SF7 as *a*/*b* (*e.g.*, P/A)
Unit type: D4A (*e.g.*, MB/SR2MEV2)
The angles θ_a and θ_b are coded under the headings ANG1 and ANG2 in the same order as the particles appear in SF7; the energies are, similarly, coded under the headings E1 and E2.

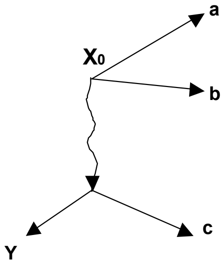
d.) <u>Angle/linear momentum distribution</u>: probability for a particle to be emitted with a given momentum p′ and angle θ; given as $\sigma(\theta,p') = d\sigma/d\Omega dp$. The data are given in units of cross section per unit of solid angle per unit of secondary linear momentum (*e.g.*, mb/MeV/c).

REACTION coding: DA/DP in SF6.
Unit type: DAP (*e.g.*, MUB/SRMEVC)

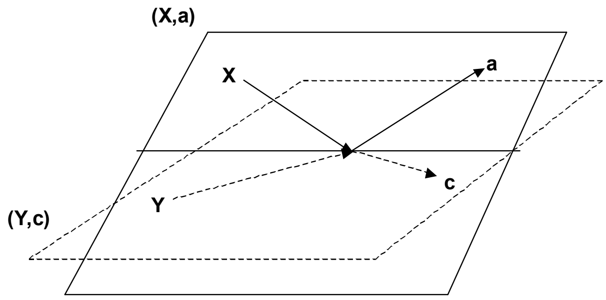
The linear momentum is given under the data heading MOM-SEC.

Treiman-Yang Angular Distribution

Definition: The angular distribution measured as a function of the angle between two reaction planes for three-particle final states in the anti-laboratory system (*i.e.*, *X* is at rest). That is, for the reaction between particles *X* and *Y* producing particles *a, b, c* (see diagram below), the angle between the planes (*X,a,b*) and (*Y,c*). Data are given in the center-of-mass system.



For photonuclear reactions in the center-of-mass system, it is the angle between the (*X,a*) and (*Y,b*) or (*Y,c*) planes, where *X* is the incident gamma, *Y* is the target nucleus.



See Shapiro[1] for more information.

The reaction planes are defined as:
- Plane 1: defined by target (SF1) and residual nucleus (SF4)
- Plane 2: defined by incident projectile (SF2) and particle designator (SF7)

REACTION coding: parameter code TYA in SF6, outgoing particle in SF7.

Example:

`REACTION (2-HE-4(G,N+P)1-H-2,,DA/TYA,P)` distribution over Treman-Yang angle between (^{4}He,^{2}H) and (γ,p) planes

The data headings ANG-CM and DATA-CM should be used in the data table.

Reference System

An indication that the differential cross section, the angle, or the energy is given in center-of-mass system is given in the data headings; see **Center-of-Mass System**.

1 I. S. Shapiro et al., ***Nucl.Phys.*** **61**, 353 (1965)

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Memo CP-C/350

DATE: August 20, 2004
TO: Distribution
FROM: V. McLane
SUBJECT: Angular distribution data
Re: Memo CP-C/346, CP-C/348, CP-E/049.

This memo is meant to consolidate the proposals of the above three memos.

Regarding the points made in Memo CP-E/049:

1. I agree that it's best to be consistent, and propose the addition of ANG-AZ-RL to Dictionary 24. The heading ANG-AZ will be reserved for possible future use.
2. I agree that ARB-UNITS should be used, and have updated to LEXFOR entry.
3. I agree; I have discussed this same point in Memo CP-C/348. I believe the code CRL is not necessary; the data are fully defined by the use of SF7.

To clarify some points brought up in comments by Naohiko Otsuka on the corrected entries that I sent, I am now suggesting (as stated, but not emphasized, in the new LEXFOR entry) that, for all reactions for which the quantity measured is a function of more than one outgoing particle, the particles must be specified in SF7. This is an extension of the rule currently in place for triple-differential data.

I have also looked at the other differential data and updated the LEXFOR entry accordingly.

Add to Dictionary 24 (Data headings)

ANG-AZ-RL	Azimuthal angle between two reaction planes.
MOM-SEC-MN	Mean secondary linear momentum of correlated particle pair.

Attached is a complete updated LEXFOR entry for Differential data.
(See CP-D/409 above, with minor changes by O.S.)