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Nuclear Data Section
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Memo CP-D/622

Date: 11 March 2010
To: Distribution
From: N. Otsuka, V. McLane, O. Schwerer, S. Dunaeva
Subject: **Reaction Coding (SF1-SF2)**
Reference: Memo CP-D/607

Below is update of the EXFOR Formats Manual and LEXFOR entries "Center-of-Mass System" and "Incident-Projectile Energy" We plan to follow up shortly with a memo on Reaction Coding (SF3-SF4).

1) Proposed revision of the EXFOR Formats Manual 6:

Reaction field

…

Notes on SF1 and SF2

Target is given in SF1 and the incident projectile is given in SF2. If the incident energy is given in center-of-mass energy (EN-CM) or laboratory incident energy per nucleon (MEV/A, *etc.*), and reversing the order of the target and the projectile does not change the numerical data, the REACTION is coded using the tautology formalism. See LEXFOR **Incident Particles** for use of the tautology formalism for inverse kinematics. When such a tautology is given, an explanation about the sample and incident particle beam must be given under SAMPLE and INC-SOURCE.

Example:

```
REACTION     ((1-H-2(9-F-19,P)9-F-20,,SIG)=
             (9-F-19(1-H-2,P)9-F-20,,SIG))
```

(Cross section for ^{2}H(^{19}F,p)^{20}F given with incident energy in center-of-mass)

2) Proposed revision of LEXFOR "Center-of-Mass System":

Center-of-Mass System

…

Note: Only one representation (*i.e.*, either laboratory or center-of-mass) for each parameter may be coded as a variable in the data table. The other representation may be added under the data heading MISC if considered desirable by the compiler. In case of doubt, the laboratory system is preferred.

Centre-of-Mass Energy and Incident Energy per Nucleon

Note that the centre-of-mass energy (EN-CM) is defined as

$$E_{cm} = E_{\text{proj,lab}} M_{\text{targ}} / \left(M_{\text{proj}} + M_{\text{targ}}\right) = E_{\text{proj,cm}} + E_{\text{targ,cm}} = Mc^2 - \left(M_{\text{proj}} + M_{\text{targ}}\right) c^2$$

(M: invariant mass in relativistic kinematics). It is clear from the 3nd and 4th term that the centre-of-mass is invariant under exchange of the incident projectile and the target. Because the numerator of the 2nd term can be rewritten as ($E_{\text{proj,lab}}$/ M_{proj}) M_{proj} M_{targ} , the incident energy in laboratory system per projectile mass (number) (MeV/A, *etc.*) is also invariant under this exchange. This invariance is not valid when the Debye effect (shielding of the nuclear Coulomb field by bound atomic electrons) enhances the cross section. This is observed in several reactions such as ^{3}He(d,p)^{4}He, ^{6}Li(p,α)^{3}He, ^{6}Li(d,α)^{4}He and ^{6}Li(p,α)^{4}He at low energy.

3) Proposed revision of LEXFOR "Incident-Projectile Energy (to be renamed)":

Incident Particles

In general, the incident projectile is coded in REACTION SF2 and the target is given in SF1. (Particles resulting from the REACTION to be defined are given in SF3 and SF4, see Outgoing **Particles**[1]).

Incident-Projectile Energy

(See also **Spectrum Average**.)

The energy of the incident projectile is entered in the COMMON or DATA section under the appropriate data heading (*i.e.*, a data heading from Dictionary 24 having an A in column 66).

…

Information on the **characteristics of the resolution and the spectrum** of the incident-projectile beam is entered in free text under the keyword INC-SPECT. (See EXFOR Exchange Formats Manual Chapter 7: INC-SPECT).

Inverse kinematics

If the incident energy is given in center-of-mass energy (EN-CM) or laboratory incident energy per nucleon (MEV/A etc.), $A_{\text{targ}} \leq 4$ and $A_{\text{proj}} \geq 5$ in the experiment, and reversing the order of the target and the projectile does not change the numerical data, REACTION must be coded using the tautology formalism. This helps users when inverse kinematics technique is applied. The target and projectile used in the experiment should be in the left hand side of REACTION.

Examples:

[1] [1] LEXFOR entry to follow in memo on REACTION SF3-SF4.

```
REACTION     ((1-H-2(9-F-19,P)9-F-20,,SIG)=
             (9-F-19(1-H-2,P)9-F-20,,SIG))
```

(Cross section for $^{2}H(^{19}F,p)^{20}F$ given with center-of-mass energy)

```
REACTION     ((1-H-1(9-F-19,EL)1-H-1,,DA,P)=
             (9-F-19(P,EL)9-F-19,,DA,RSD))
```

(Proton angular distribution for $^{1}H(^{19}F,p)^{19}F$ given with center-of-mass energy and centre-of-mass angle.)

See also, **Center-of-Mass System.**

Nuclear Quantities

…

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Memo CP-D/607

Date: 31 January 2010
To: Distribution
From: N. Otsuka, S. Dunaeva, O.Schwerer, V.McLane

Subject: **REACTION for heavy-ion scattering by light element target**

To provide reaction rate table to nuclear synthesis study in the light mass region, resonance structures of light unstable nuclei have been investigated by using compound elastic scattering reaction where resonance structure of the compound nucleus is measured with unstable nucleus beam on light nucleus target (e.g. ^{1}H). The R-matrix analysis can be performed to the excitation function of the angular differential cross section at a fixed angle.

Example (EXFOR C1724.002 [1] in compilation, similar data are in E2107.006 [2])
Resonance structure of ^{22}Mg is studied by detection of protons in ^{1}H(^{21}Na,p)^{21}Na$_{g.s.}$

LEXFOR defines elastic and inelastic scattering as follows:

Scattering:
Two-body interaction with only one particle, which is the same as the incident particle, in the exit channel;

Elastic scattering:
Scattering without excitation of the scattering nucleus (Q = O).

Inelastic scattering:
Two-body interaction in which the incident projectile re-emerges with an energy less than its' initial energy by the amount of energy deposited in the target nucleus (Q<O). The residual nucleus is left in an excited state which then decays, primarily, by γ-ray emission.

Therefore the data set C1724.002 is classified to elastic scattering data in EXFOR, too. What is the right REACTION code?

1. `1-H-1(11-NA-21,P)11-NA-21,,DA`
2. `1-H-1(11-NA-21,EL)1-H-1,,DA,P`

1. Because of LEXFOR ask compilers to use `EL` in SF3, the 1st option should be excluded. We may add the underlined part to the EXFOR Formats Manual Chapter 7 as an item of "Notes on SF3" to clarify this rule as follows:
   3) For coding of SF3 in the case of scattering, an appropriate process code (e.g., `EL`, `INL`, `SCT`) is used. See **LEXFOR, Scattering**.

2.–To clarify the coding rule for scattering data measured by inverse kinematics, addition of an item of the exceptional case in the EXFOR Formats Manual Chapter 7 is proposed:
   f) For scattering, nuclide code in SF1 is also coded in SF4 except for the isomer

code, which can be different for (de-)excitation of the isomeric state.

Note that `P` should be coded in SF7 of E2107.002-003 and 005-006 if data are for proton angle.

Definition of elastic and inelastic scattering

Revision of definition is proposed below for elastic and inelastic scattering.

1. Elastic scattering

Because projectile nucleus also can be excited in heavy-ion induced reaction, the following new definition is proposed:

"Scattering without excitation of both the projectile and target nucleus (Q = O)."

2. Inelastic scattering

Some EXFOR data give de-excitation of the metastable states ("inelastic neutron acceleration", see EXFOR 10465, 20295, 41381).

Example (EXFOR 22950.008):

```
(71-LU-177-M(N,INL)71-LU-177-G,,SIG,,MXW)
```

In order to allow use of INL for Q>0 scattering case, revision of the current definition (See the 1st page of this memo) is proposed:

"Scattering with (de-)excitation of the projectile and/or target nucleus ($Q \neq 0$)."

References

[1] J. J. He *et al*., Phys. Rev. C **80**(2009)015801
(EXFOR C1724, in compilation)

[2] J. J. He et al., Euro. Phys. J. A **36**(2008)1
(EXFOR E2107)