ANALYTICAL METHODS FOR ANALYSIS OF NEUTRON CROSS-SECTIONS OF AMINO ACIDS AND PROTEINS

**Dante L.Voi¹, Francisco de O. Ferreira¹,
Hélio F. da Rocha², Rogerio Chaffin Nunes¹ and Luciana Carvalheira¹**

¹ Instituto de Engenharia Nuclear (IEN / CNEN - RJ)
Caixa Postal 68550
21945-970 Rio de Janeiro, RJ
dante@ien.gov.br
fferreira@ien.gov.br
Chaffin@ien.gov.br
luciana@ien.gov.br

² Instituto de Pediatria IPPMG –UFRJ-RJ
Av. Brigadeiro Trompowski,s/n
21941-970-Rio de Janeiro-RJ
helionutro@gmail.com.br

ABSTRACT

Two unpublished analytical processes were developed at IEN-CNEN-RJ for the analysis of neutron cross-sections of chemical compounds and complex molecules, the method of data parceling and grouping (P&G) and the method of data equivalence and similarity (E&S) of cross-sections. The former allows the division of a complex compound or molecule so that the parts can be manipulated to construct a value of neutron cross-section for the compound or the entire molecule. The second method allows by comparison obtain values of neutron cross-sections of specific parts of the compound or molecule, as the amino acid radicals or its parts. The processes were tested for the determination of neutron cross-sections of the 20 human amino acids and a small database was built for future use in the construction of neutron cross-sections of proteins and other components of the human being cells, also in other industrial applications.

Keywords: amino acids and proteins, analytical methods, neutron cross-sections analysis

1. INTRODUCTION

One of the nuclear techniques that uses neutron beams of reactors to analyze the chemical composition of materials is the technique of neutron cross-section measurements and was developed in the Laboratório de Medidas Nucleares (LMN) of the Argonauta reactor (IEN-CNEN-RJ) [1,2]. The technique arose from the need to control biological materials marketed with hospitals, originating from imports and national suppliers. Amino acids used in hospitals, for enteral and parenteral administration in patients, require routine quality analyzes depending on the different origins [3]. The technique was applied in the analysis of synthetic amino acid compositions supplied by the former Nutri-Ente-BioRio-UFRJ at the beginning of the millennium [4,5,6]. As a result, a database of neutron cross-sections of essential and non-essential amino acids was constructed through laboratory measurements, and data from the literature of their radicals and molecular groups were also collected in

order to generate data for the purpose of comparative calculations [7]. The results are important for the choice of hospital providers and for the good health of the patients.

1.1. The Nuclear Analytical Techniques Developed at IEN-CNEN-RJ

Conventional techniques used for the analysis of compositions of chemical compounds and large molecules are: mass spectrometry, ultrasound, infrared, nuclear magnetic resonance, X-ray techniques, etc. The techniques with applications of neutrons are complementary to those mentioned and can highlight the presence and movement of hydrogen atoms, linked to carbon, oxygen, nitrogen and sulfur atoms, elements typical of the constitution of living beings.

Amino acids are characterized by the radicals attached to the major chain formed by the amine and carboxylic acid groups, with the exception of proline and glutamine having slightly different structures. Clusters of atoms of the type CH, CH₂, CH₃, OH, SH, rings formed by C's, N's and H's, and also NH and NH₂ groups are special to be studied in detail for their vibration, rotation and librations movements. A specific database of neutron cross-sections was constructed at IEN-CNEN-RJ to treat amino acids since their values are not found in the conventional literature [7].

The data of neutron cross-sections in the manuals of chemical elements and their isotopes are presented in publications called "barnbook" of the Brookhaven National Laboratory (BNL-USA) [8,9,10], among which the publication BNL- 325 presents data in the form of graphs and tables and is very useful for the various areas of science.

However, to deal with molecules and molecular groups, the analytical method of parceling & grouping (P&G) of neutron cross-sections was created in the IEN to solve the problem of the chemical bonds of H's with the other elements [2]. The result is a considerable increase of the cross-sections by the action of the degrees of freedom of movement of the H's.

The Nelkin model [11] theoretically explains the water molecule through a mathematical formalism using tensors, to represent the incidence of the neutron on the water molecule under different directions. An atypical curiosity is to attempt to explain the value of 80b of the water cross-section in the thermal energy of neutrons, with the addition of the individual cross-sections of the H's (30b each) and the oxygen (4,7b) resulting 64b. The movements of, translation, free rotation and rotation hampered by the neighboring molecules, and the vibration motions between the OH bonds, all do part of a complicated analysis to generate the value of the theoretical neutron cross-section of the water.

1.2. The Parceling & Grouping (P&G) Method of Neutron Cross-Sections

A recent theory of physics shows that protons and neutrons are no longer elementary particles because they are formed by three quarks each, and a new particle, the gluon, serves to join quarks in the atomic nucleus [12,13] and the prediction is one will work in the near future, no longer with neutron or proton cross-sections, but with quark sections for quarks as soon as they are isolated. The quark cross-sections will be a deeper and more accurate parameter to explain the composition of matter.

However for some time still, the practical way is to continue using the neutron as an entity to deal with the cross-sections of an atomic nucleus, even neutron formed by three quarks, connected by gluons.

The P&G method for the cross-sections is a practical way of manipulating a molecule, large or small, either formed of neutrons and protons or by their quarks. Whether it is nuclear or atomic, the fact remains that it is still inexplicable, but the P&G helps to get around the problem of, "why the neutron cross-section increases when two or more H atoms are close to form a molecule, a molecular group or a radical ". It is possible that in its time, quarks and gluons can explain this paradigm.

This no longer occurs with the isotope of hydrogen, deuterium. Its absorption neutron cross-section is the lowest value of all neutron moderators, even if its mass number is added to 1.01 u.m.a. by the neutron that matches the proton.

2. RESULTS AND DISCUSSIONS

2.1. The Experimental and Calculated Neutron Cross- Sections

The experimental measurements of the amino acids neutron cross-sections were obtained in this millennium using the crystal spectrometer installed in the irradiation channel J-9 of the reactor Argonauta (IEN-CNEN-RJ) [3,4,5,6,7] and are shown in table 1.

Table 1 – Amino Acids Neutron Cross-Sections.

Sample	$\sigma_T(0,05\text{eV})$ (barn) measured	$\sigma_T(0,05\text{eV})$ (barn) calculated	$\Delta\sigma/\sigma \times 100$ (%) deviation
Treonine	378±17	377±3	1
Cisteine	252±12	253±3	1
Tirosine	512±24	500±3	2
Phenilalanine	453±21	452±3	1
Serine	276±15	286±5	3
Methionine	467±20	472±9	1
Thriptophane	552±35	547±10	5
Glicine	188±21	170±3	10
Alanine	257±15	275±6	6
Proline	486±25	454±20	7
Glutamine	503±25	458±20	9
Lysine	660±35	605±30	8
Arginine	672±35	625±30	7
Histidine	406±20	405±15	0
Glutamic Acid	429±20	404±20	6
Valine	475±20	440±10	8
Methionine	511±20	484±10	5
Leucine	470±20	539±10	15
Isoleucine	565±20	538±10	5
Aspartic Acid	316±20	294±10	7

With the help of the P&G method it was also possible to construct a small database of neutron cross-sections of auxiliary molecular groups (table 2). The method allows obtaining the calculated cross-sections of Table 1 and whose comparisons result in deviations recorded.

The lack of values of cross-sections of appropriate molecular groups in the literature, forced the use of values taken from other molecules with different functions and characteristics of the amino acid molecules.

These values were obtained in the majority of measurements made in the 1960s and 1970s on acetates and methyl compounds by IPEN-CNEN researchers [14,15,16]. The knowledge of neutron spectrometry and the technique of measurements of shock sections was brought to the IEN by the researcher Roberto Stasiulevicius when it was transferred from IPEN in 1970 [17].

Not that neutron cross-section data are inaccurate, as many of these and other data have been published by the International Atomic Energy Agency (IAEA), and in the manuals or barnbooks of the Brookhaven National Laboratory (BNL-325). But in all the previous works a forced use of these was made, due to the lack of data for the comparison of the values of measured and calculated cross-sections.

Table 2. Auxiliary Database of Molecular Group Cross-Sections

Energia (eV)	0,0035	0,0050	0,0350	0,0400	0,0450	0,0500	0,0550	0,0600
CH	85*		51,8*	49,5*	47*	45*	43	42
CH ₂	176,5*		107	103*	99*	98	45,6** 95	93
CH ₃	278,1* 275,0#	243,2*	150	142	138	135	131	128
OH			56	54	52	48,2*	47	46
NH			60,3*	59	55	53	51	49
SH			53,1	49,5	47	45,3	43	41
BENS			380	370	360	350	340	
S			1,4	1,5	1,4	1,4	1,4	
C	4,2	3,8	4,3	4,5	4,9	4,8	4,7	
H			33	32	31	30	29	
N	22	19	12,5	12	12	12	12	
O	7	6	6,9	4	4	4	4	

* S. B. Herdade, Tese de Doutorado, UNICAMP 1969.

** CH₂ with restricted degree of freedom.

Mean of five values from Herdade paper.

A new, more accurate method for obtaining auxiliary neutron cross-sections of molecular groups or amino acid radicals has been developed in the IEN and can be extended to other molecules or chemical compounds: the Equivalence & Similarity (E&S) method of neutron cross-sections.

2.2. The Equivalence & Similarity (E&S) Method for the Calculation of Neutron Cross-Sections

The main and repetitive amino acid moiety formed by the amine and carboxylic acid groups makes it possible to compare two or more amino acid structures to give the cross-section of an entire radical or its components. The degrees of freedom of movement of these groups give better values of neutron cross-sections when compared with the values shown in Table 2.

A useful and illustrative comparison is to obtain the value of the cross-section of the hydroxyl group hanging on the benzene ring of the tyrosine which by direct subtraction of the phenylalanine cross-section results in 59 barns. This value compared to the 48.2 barns of Table 2 results in a deviation of around 20%.

Another comparison is the cross-section of the serine when subtracted from the tyrosine, results 236 barns. The comparison with the cross-section of the benzene ring obtained in Table 2 results in a deviation of around 30%.

Another useful example is obtained for the cross-section of the CH₂ group, from the subtraction between the isoleucine and valine cross-sections, which results in 90 barns. Compared to the 98 barns obtained in Table 2, it results in a deviation of about 10%, and it is well evidenced that the degree of freedom of movement, more is for the side of a more restricted movement.

Through these three examples we can say that by manipulating the experimental cross-sections of Table 1, the results are more accurate and are on the side of using the E&S method. Moreover, the molecular groups OH, the benzene ring and the CH₂ group of these examples, and others which are to be obtained by the same process, have functions and characteristics specific to molecular groups originating from the amino acids.

On the other hand, the rings that appear in the structures of tryptophan, proline and histidine are a little more difficult, but possible to be treated and with more precision than the old procedure.

It was the construction of the library of amino acid neutron cross-sections using the P&G method that made possible the development of the S&E method. And with it a new and more precise auxiliary library for cross-sections can be obtained and consequently a more accurate library also for all amino acids.

3. CONCLUSIONS

A new table of molecular or radical groups also should be constructed from data obtained by the E&S method by performing the appropriate operations on the experimentally obtained amino acid neutron cross-sections shown in Table I. However, well controlled samples of the most reliable amino acids and manufacturers should be used for the new measures.

The equivalence & similarity (E&S) method of neutron cross-sections gives a radical changing on the procedures used so far in the manipulation of neutron cross-section data for the study of molecular structures.

It is useful for applications, in addition to proteins and other components of the living cell, and also in other areas, as an example in the oil industry, in molecular structures of polycyclic aromatic hydrocarbons.

REFERENCES

1. Voi, D. L., “*Medidas de Seções de Choque para Nêutrons com o Espectrometro de Cristal do IEN*”, Tese de Mestrado, COPPE-PEN, UFRJ, Dezembro de 1978
2. Voi, D. L. , “*Estudos da Estrutura e Dinâmica Moleculares da Baquelite Através de Medidas de Seções de Choque para Nêutrons*”, Tese de Doutorado, COPPE-UFRJ, 1990.
3. Voi, D.L, Ferreira, F. de O. and Rocha, H.F. “*Análise de Aminoácidos Através de Medidas de Seções de Choque para Nêutrons*”, INAC 2002, Rio de Janeiro, 2002
4. Voi, D.L, Ferreira, F. de O. and Rocha, H.F. “ *Análise de Aminoácidos Através de Determinações de Seções de Choque para Nêutrons-Parte II*”, INAC 2005, Santos, SP, 2005
5. Voi, D.L, Ferreira, F. de O. and Rocha, H.F. “ *Análise de Aminoácidos Através de Determinações de Seções de Choque para Nêutrons-Parte III*”, INAC 2007, Santos, SP, 2007.
6. Voi, D.L, Ferreira, F. de O. and Rocha, H.F. “ *Análise de Aminoácidos Através de Determinações de Seções de Choque para Nêutrons-Parte IV*”, INAC 2009, Belo Horizonte, MG, 2009
7. Voi, D.L., Ferreira, F. de O. and Rocha , H.F., “*Total Neutron Cross-Sections Database for Amino Acids and Proteins*”, Encontro Nacional de Aplicações Nucleares, INAC 2013, Recife-Pe, 2013.
8. Hughes, D. J.and Harvey, J.A. “*Neutron Cross Sections*”, BNL-325, Upton, N.York, July 1955.
9. Mughabghab, S.F. and Garber, D.L. “*Neutron Cross Sections*”, Vol. I e II, BNL- 325, 1973.
10. Mughabghab, S.F. “*Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross-Sections-Z= 1-100*”, National Nuclear Data Center, Brookhaven National Laboratory, Upton, USA, 2006.
11. Rosa, L.P. “*Estudos do Espalhamento de Nêutrons Térmicos na Água*” Tese de Mestrado, COPPE-PEN-UFRJ, Rio de Janeiro, Novembro (1969).

12. Endler, A.M.F. “*Introdução a Física de Partículas*” ,CBPF (Centro Brasileiro de Pesquisas Físicas), Editora Livraria da Física, 2010.
13. Caruso, F., Oguri V. e Santoro, A. (editores), “*Partículas Elementares: 100 Anos de Descobertas*” Livraria da Física, Rio de Janeiro, Abril de 2012.
14. Zimmerman, R.L., Amaral, L.Q., Fulfaro, R., Matos, M.C. Abreu, M.A.N. and Stasiulevicius, R. “*Neutron Cross Section of PR, Yb, Lu, Er, Ho and Tm*” Proceedings of Nuclear Data for Reactors Conference, Paper CN 23/129, IAEA, Viena Austria, pp. 53-59 (1967).
15. S.B. Herdade, “Espalhamento de Nêutrons Lentos na Água, Polietileno e Compostos Metálicos”, *Tese de Doutorado, Universidade de Campinas, São Paulo, 1969.*
16. Amaral, L.Q. do, “*Estudo dos Movimentos Atômicos do t-Butanol por Espalhamento de Nêutrons Lentos*”, Tese de Doutorado, I. Física-USP (1972)
17. Stasiulevicius, R. “*Desenvolvimento de Técnicas de Medidas de Seções de Choque Total para Nêutrons com Espectrômetro de Cristal*”,