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Calculation the Fast Neutrons Interaction Parameters for Several Carbohydrates

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ABSTRACT

The investigation of fast neutron removal cross section $\sum_R$ and mean free path have been studied in this work for some carbohydrates which affected on the living cells. The carbohydrates included (Arabinose, Ribose, Glucose, Mannose, Fructose, Maltose, Sucrose, Lactose, Lactose monohydrate, Melezitose and Raffinose) have different densities so, they have different removal cross section. The study was implemented by the mass removal cross section $\sum_R/\rho$ data for carbohydrate composition. $\sum_R$ and $\sum_R/\rho$ have been calculated by using empirical equations program with python 3.10.11 language for all carbohydrates. The calculation results, show that Ribose has the minimum value removal cross section, while Fructose has the maximum value of removal cross section, and all the results are in reasonable corresponding.

***Keywords*-** Removal cross section, neutron, mean free path, carbohydrate.

I. INTRODUCTION

Neutron is one of the ionization radiations that is hazardous for human body and causes the damage to cells and tissue [1]. Therefore, it is important to assess the risks when expose to neutrons, and improving the types of materials used as a shield to protect against it, where neutron shielding can be achieved by the interactions of elastic and inelastic scattering with the material until they are absorbable [2,3]. In elastic scattering the interaction between the neutrons and nucleus will be stable which is subject to the laws of conservation of momentum and energy, while in the inelastic scattering interactions the nucleus remains in the excited state after reaction then back the excited nucleus to the ground state, through the emission of gamma rays, so the nucleus is converted into an unstable radioactive nucleus when the neutron is absorbed and captured by the atomic nucleus [4].

Interactions of neutron with matter happen only inside the nuclei, due to that, their stoppage is quite difficult to imagine and are capable of travelling long distances through the majority of materials except for the effects of scattering and absorption processes. This in turn leads us to realize that the neutrons have high penetrability, which makes them unsafe both in terms of material or radiation [5,6]. The effective removal cross section $\sum_R$, mass removal cross section $\sum_R/\rho$, half value layer χ and mean free path τ are the parameters that illustrated the interaction of neutrons with the materials [7]. In our paper, $\sum_R$ has been calculated for Carbon, Hydrogen and oxygen which make up carbohydrates. As we all know carbohydrates are organic compounds are essential according to many aspects, additionally neutrons have been employed within living cells to accomplish a variety of physiological tasks. And, are broadly used in biological, chemical, medical, food, nuclear power and textile industries etc. In addition, starch and sugar are made of carbohydrates are the two main parts of the caloric supply for both humans and animals [8]. Many of studies and different types of materials are tested for neutrons shielding [1,2,3,5,7,8,11 and 13].

II. CALCULATION'S

The SAZ software, which was built in Python 3.10.11, was used to calculate the parameters of neutron attenuation. In the current study the fast neutron interaction parameter such as $\sum_R$, $\sum_R/\rho$, half value layer χ and mean free path τ have been calculated by using empirical equations written by python program.

a. Macroscopic effective removal cross section for fast neutrons ($\sum_R$)

The probability of the first collision, due to which neutrons are removed from the non- interacting beam of fast neutrons called the removal cross section, and this fast neutron is obeyed elastic scattering [9].

$$\Sigma_R\ (\mathrm{cm}^{-1}) = \sum \rho_i (\sum_R/\rho)_i \qquad (1)$$

Where ρ_i represented the partial density in (g/cm^3), and $\sum_R/\rho$ is the mass removal cross section of the (ith) limiting element and the unit of it is (cm^2/g).

$\Sigma_R/\rho(cm^2/g)$ is the mass removal cross section of elements have been compiled from NCRP (National Council on Radiation protection), and can be calculated by: [10]

$$\Sigma_R/\rho(cm^2/g) = 0.206A^{-1/3}z^{-0.294} \qquad (2)$$

A is the atomic weight and Z is the atomic number, and the number 0.206 is fitting coefficient.

b. Half value layer χ

The thickness of the materials required to attenuate the incident neutrons to its half initial value I_0 is called half value layer χ. The idea of the value χ is advantageous during creating rapid and approximate shielding calculations. The thickness of a layer of a material reduces the intensity of a radiation to half of its initial value, and two layers of a half thickness of materials can reduce the intensity to a quarter of its original value and three layers will reduce the intensity one of the eight of its original value and so on [11].

$$\chi = \ln 2/\sum_R = 0.693/\sum_R \qquad (3)$$

While tenth value layer is defined as:

$$\mathrm{TVL} = \ln 10/\sum_R \qquad (4)$$

c. Mean free path τ

The Mean free path is defined as the distance that the neutron travel without interaction during two successive collisions of the fast neutron inside materials [12].

$$\tau\ (\mathrm{cm}) = 1/\sum_R \qquad (5)$$

(τ) is mean free path and $\sum_R$ is removal cross section of fast neutron in cm^{-1}.

III. RESULTS AND DISCUSSION

Employing a Python program based on the James and Zoller equations for different carbohydrates (arabinose, ribose, glucose, mannose, fructose, maltose, sucrose, lactose, lactose monohydrate, melezitose, raffinose), the effective removal cross section ($\sum_R$) and the mass removal cross section ($\sum_R/\rho$) were calculated for fast neutrons. The investigation results show in (table/figure 1) that the carbohydrate's partial density and the removal cross-section value ($\sum_R$) are directly related [13]. A partial density of 0.800 g/cm^3 for ribose indicates the lowest value of $\sum_R$, and a partial density of 1.665 g/cm^3 for fructose indicates the highest value of $\sum_R$. This means that ribose is less dense than other carbohydrates, fast neutrons can penetrate it much deeper. Other carbohydrates, with the exception of ribose, have almost identical values in terms of cross-sectional efficiency. As illustrates in tables 1,2 and 3 there is a good agreement for the results of carbohydrates component, only hydrogen has different result compare to the (reference result [8]), this discrepancy results in variances in the cross-sectional area values needed for neutron removal, which can be traced to variations in the approved database that was used to formulate different empirical equations for the removal cross section ($\sum_R$) of hydrogen. These variations additionally yield particular values for optional arbitrary constant and distinct rules regulating the exponential relationship in the two used equations between the mass (A) and atomic (Z) numbers of each element in a substance with respect to the target material.

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Table 1: The comparison mass removal cross section $\sum_R/\rho$ and removal cross section $\sum_R$ of carbohydrates as a function of photon energy ρ_p.

C.hydrate	F.W%		$\rho_p(g/cm^3)$	$\sum_R/\rho(cm^2/g)$ (James)	$\sum_R/\rho(cm^2/g)$ (Zoller)	$\sum_R/\rho(cm^2/g)$ [8]	$\sum_R(cm^{-1})$ (James)	$\sum_R(cm^{-1})$ (Zoller)	$\sum_R(cm^{-1})$ [8]
Arabinose $C_5H_{10}O_5$	H	0.06713	0.10641214	0.206	0.19	0.602	0.0219209	0.020218	0.06381
	C	0.40001	0.63402536	0.053132918	0.0501865	0.051	0.0336876	0.0318	0.03233
	O	0.53284	0.8445625	0.044359377	0.0405282	0.041	0.0374643	0.034229	0.03464
Total	1		1.585	0.303492295	0.2807148	0.694	0.0930728	0.086267	0.13079
Ribose $C_5H_{10}O_5$	H	0.06713	0.0537096	0.206	0.19	0.602	0.0110642	0.010205	0.03250
	C	0.40001	0.3200128	0.053132918	0.0501865	0.051	0.0170032	0.016060	0.01632
	O	0.532847	0.4262776	0.044359377	0.0405282	0.041	0.0189094	0.017276	0.01746
Total	1		0.8	0.303492295	0.2807148	0.694	0.046977	0.043541	0.06629
Glucose $C_6H_{12}O_6$	H	0.06713	0.10486799	0.206	0.19	0.602	0.0216028	0.019925	0.06321
	C	0.40001	0.62482499	0.053132918	0.0501865	0.051	0.0331988	0.031358	0.03187
	O	0.53284	0.83230701	0.044359377	0.0405282	0.041	0.0369101	0.033722	0.03411
Total	1		1.562	0.303492295	0.2807148	0.694	0.0917117	0.085005	0.12919
Mannose $C_6H_{12}O_6$	H	0.06713	0.10332384	0.206	0.19	0.602	0.0212847	0.019632	0.06200
	C	0.40001	0.61562462	0.053132918	0.0501865	0.051	0.0327099	0.030896	0.03141
	O	0.53284	0.82005153	0.044359377	0.0405282	0.041	0.036377	0.033235	0.03362
Total	1		1.539	0.303492295	0.2807148	0.694	0.0903716	0.083763	0.127
Fructose $C_6H_{12}O_6$	H	0.06713	0.11178310	0.206	0.19	0.602	0.0230273	0.021239	0.06742
	C	0.40001	0.66602664	0.053132918	0.0501865	0.051	0.0353879	0.033426	0.03396
	O	0.53284	0.88719025	0.044359377	0.0405282	0.041	0.0393552	0.035956	0.03636
Total	1		1.665	0.303492295	0.2807148	0.694	0.0977705	0.090621	0.13775
Maltose $C_{12}H_{22}O_{11}$	H	0.06478	0.10015142	0.206	0.19	0.602	0.0206312	0.019029	0.0602
	C	0.42106	0.65097267	0.053132918	0.0501865	0.051	0.0345881	0.032670	0.03320
	O	0.51414	0.79487435	0.044359377	0.0405282	0.041	0.0352601	0.032215	0.03259
Total	1		1.546	0.303492295	0.2807148	0.694	0.0904794	0.083914	0.12599
Sucrose $C_{12}H_{22}O_{11}$	H	0.06479	0.10241876	0.206	0.19	0.602	0.0210983	0.01946	0.06140
	C	0.42107	0.66571008	0.053132918	0.0501865	0.051	0.0353711	0.03341	0.03391
	O	0.51414	0.81286956	0.044359377	0.0405282	0.041	0.0360584	0.032944	0.03333
Total	1		1.581	0.303492295	0.2807148	0.694	0.0925278	0.085814	0.12865
Lactose $C_{12}H_{22}O_{11}$	H	0.06478	0.1030018	0.206	0.19	0.602	0.0212184	0.019571	0.06200
	C	0.42106	0.6694997	0.053132918	0.0501865	0.051	0.0355725	0.0336	0.03411
	O	0.51415	0.8174969	0.044359377	0.0405282	0.041	0.0362637	0.033132	0.03353
Total	1		1.590	0.303492295	0.2807148	0.694	0.0930545	0.086302	0.12966
Lac. monohydrate $C_{12}H_{24}O_{12}$	H	0.06713	0.10386093	0.206	0.19	0.602	0.0213954	0.019734	0.06260
	C	0.40001	0.61882475	0.053132918	0.0501865	0.051	0.03288	0.031057	0.03156
	O	0.53284	0.82431430	0.044359377	0.0405282	0.041	0.0365661	0.033408	0.03378
Total	1		1.547	0.303492295	0.2807148	0.694	0.0908414	0.084198	0.128
Melezitose $C_{18}H_{32}O_{16}$	H	0.06394	0.09891518	0.206	0.19	0.602	0.0203765	0.018794	0.0602
	C	0.42858	0.66302563	0.053132918	0.0501865	0.051	0.0352285	0.03328	0.03401
	O	0.50747	0.78505918	0.044359377	0.0405282	0.041	0.0348247	0.03182	0.03239

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Total		1	1.547	0.303492295	0.2807148	0.694	0.0904298	0.083886	0.126
Raffinose $C_{18}H_{32}O_{16}$	H	0.06394	0.0936721	0.206	0.19	0.602	0.0192965	0.017798	0.05658
	C	0.42858	0.62788142	0.053132918	0.0501865	0.051	0.0333612	0.031511	0.03202
	O	0.50747	0.74344648	0.044359377	0.0405282	0.041	0.0329788	0.030131	0.03046
Total		1	1.465	0.303492295	0.2807148	0.694	0.0856364	0.07944	0.119

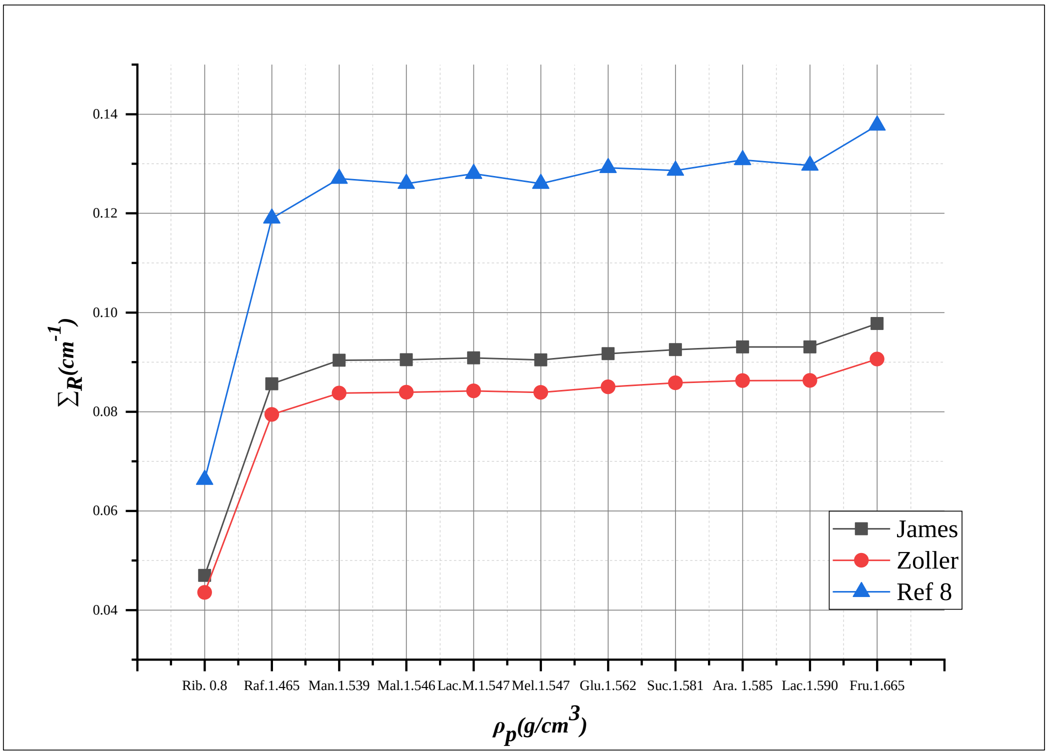

Figure 1: comparison between removal cross section of carbohydrates compounds with partial density by using (James, Zoller) equations and Ref [8].

Figure 2 and figure 3, illustrates that the partial density is inversely proportional with the mean free path τ and half value layer χ. So, Ribose has the lowest value of partial density and highest value of mean free path and half value layer. Also, the two are is inversely proportional with the magnitude of removal cross section.

Table 2: The comparison between mean free path of (James, Zoller) equations and Ref [8] with partial density.

C.hydrate	ρ_p(g/cm^3)	τ(cm)James	τ (cm) Zoller	τ (cm) [8]
Arabinose $C_5H_{10}O_5$	1.585	10.7442799	11.59199	7.64578602
Ribose $C_5H_{10}O_5$	0.800	21.2871034	22.96663	15.0843213
Glucose $C_6H_{12}O_6$	1.562	10.9037353	11.76401	7.74011780
Mannose $C_6H_{12}O_6$	1.539	11.0654207	11.93847	7.87141260
Fructose $C_6H_{12}O_6$	1.665	10.2280382	11.03502	7.25915924
Maltose $C_{12}H_{22}O_{11}$	1.546	11.0522395	11.91701	7.93675989
Sucrose $C_{12}H_{22}O_{11}$	1.581	10.8075662	11.65319	7.77290675
Lactose $C_{12}H_{22}O_{11}$	1.590	10.7463917	11.58723	7.71230034
Lactose. monohydrate $C_{12}H_{24}O_{12}$	1.547	11.0081991	11.87673	7.81488109
Melezitose $C_{18}H_{32}O_{16}$	1.547	11.0583076	11.92095	7.89845743
Raffinose $C_{18}H_{32}O_{16}$	1.465	11.6772719	12.5882	8.39778634

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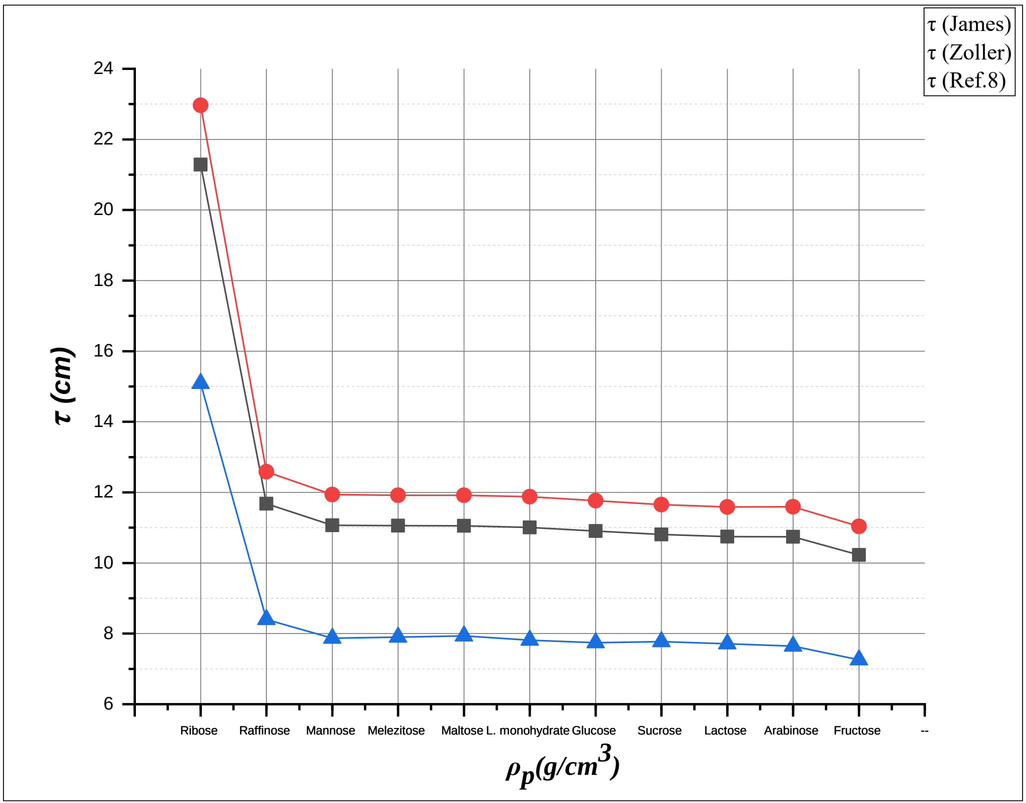

Figure 2: The comparison between mean free path of (James, Zoller) equations and Ref. [8] with partial density.

Table 3: The comparison between half value layer χ of (James, Zoller) equations and Ref. [8] with partial density.

C.hydrate	ρ_p(g/cm^3)	χ (cm)James	χ (cm) Zoller	χ (cm) [8]
Arabinose $C_5H_{10}O_5$	1.585	7.445792	8.033249	5.29857
Ribose $C_5H_{10}O_5$	0.800	14.75196	15.91588	10.45407
Glucose $C_6H_{12}O_6$	1.562	7.556296	8.152457	5.364192
Mannose $C_6H_{12}O_6$	1.539	7.668338	8.273358	5.454889
Fructose $C_6H_{12}O_6$	1.665	7.088035	7.647267	5.030597
Maltose $C_{12}H_{22}O_{11}$	1.546	7.659202	8.258486	5.500175
Sucrose $C_{12}H_{22}O_{11}$	1.581	7.489649	8.07566	5.386624
Lactose $C_{12}H_{22}O_{11}$	1.590	7.447249	8.029949	5.344624
Lactose. monohydrate $C_{12}H_{24}O_{12}$	1.547	7.628689	8.230575	5.415713
Melezitose $C_{18}H_{32}O_{16}$	1.547	7.663411	8.261221	5.473631
Raffinose $C_{18}H_{32}O_{16}$	1.465	7.445792	8.033249	5.29857

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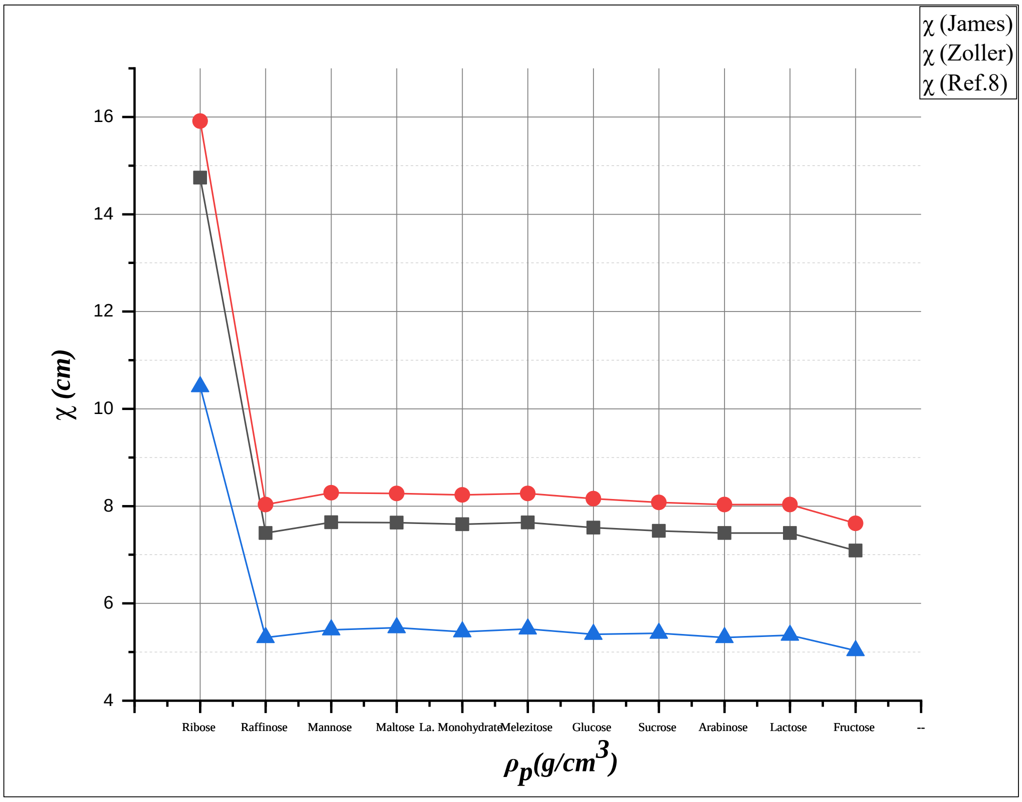

Figure 3: The comparison between partial density and half value layer of (James, Zoller) equations and Ref. [8] with partial density.

IV. CONCLUSIONS

In this study the effective fast removal cross section $\sum_R$, mass removal cross section $\sum_R/\rho$, mean free path τ and half value layer χ have been calculated for eleven essential carbohydrates contains Carbon, Hydrogen and Oxygen, where the results show that ribose has the minimum value of effective removal cross section and the maximum value of mean free path and half value layer, while fructose has the maximum value of effective removal cross section and the minimum value of mean free path and half value layer. From this we can see that the elements with smallest partial density have smallest removal cross section with higher mean free path as well as half value layer, but the elements with higher partial density have higher removal cross section in additional to lower mean free path and half value layer.

Therefore, we can infer that fructose is the most effective carbohydrate for neutralizing harmful neutrons within our body, as it demonstrates superior capability in minimizing neutron penetration compared to other carbohydrates.

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