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Calculation the Cross Sections and Stopping Power of I-131(p,2n)Xe-130 Reaction

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Abstract:

In this study, we calculated the cross-section of the $^{131}I(p,2n)^{130}Xe$ reaction by using standard data from the International nuclear energy Agency (IAEA) and plotting them with the mat-lap program, and calculate the stopping power by (SRIM Program) then plotting them by mat-lap, these calculations with the energy range (1×10^7 - 3×10^7 eV), we get a general mathematical formula for both (Cross-Section and Stopping Power) to use it in the determination of cross-section or stopping-power or energy in several fields, we get the whole stopping power by sum the electrical and nuclear stopping power.

Keyword: Cross-Section, Stopping-Power, Iodine, Xe, Nuclear reaction.

حساب المقطع العرضي
وقدرة الايقاف للتفاعل النووي I-131 (p,2n) Xe-130

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الخلاصة :

في هذه الدراسة، تم حساب المقطع العرضي للتفاعل النووي $I^{131}(p،2n)\ Xe^{130}$ من خلال استخدام البيانات القياسية من الوكالة الدولية للطاقة النووية (IAEA)، ورسمها باستخدام برنامج (Mat-Lap) وحساب طاقة الايقاف باستخدام برنامج (SRIM) وايضا رسها باستخدام برنامج (Mat-Lap)، هذه الحسابات كانت ضمن مدى طاقة (1×10^7 to 3×10^7 eV)، ولقد حصلنا على صيغة رياضية عامة لكل من المقطع العرضي وقدرة الايقاف لاستخدامها في تحديد وحساب المقطع العرضي وطاقة الايقاف والطاقة النووية في مجالات متعددة. تم حساب قدرة الايقاف الكلية من خلال جمع قدرة الايقاف الالكترونية وقدرة الايقاف النووية.

الكلمات المفتاحية: المقطع العرضي، قدرة الايقاف، اليود، الزينون، التفاعل النووي .

1. Introduction:

If two charged nuclei approached each other Exceeding limits of Coulomb repulsion, the constitute of nucleus rearrangement in atoms in a chemical reaction. Nuclear reaction arises from the bombardment of the target nucleus with nuclear projectile (n-p-d-α-β-... etc.) [1].

Generally, the nuclear reaction described as:

Projectile(P)+Target(T) → emitted particle (X) + residual nucleus (R)

T (P, X) R, the total number of (neutrons - protons) on the left and right sides of the equations must be equal. In our study, we have ^{131}I as a target, proton as Projectile, ^{130}Xe as a residual nucleus, and tow neutrons as an emitted particle (131I(p,2n)130Xe). We will calculate First, the cross-section of this reaction and then the stopping-power with the energy range (1×10^7 - 3×10^7 eV) by the mat-lap program.

2. Cross-section

In general, the cross-section is the probability of nuclear reaction to happen, for more accuracy, we should talk about its as follows:

a. Nuclear Cross-Section (σ)

It is the probability of the projectile to interact with the target, and it is associate with the concept of an area that's mean a large area leads to the large cross-section, also it is not necessarily identical to the geometric area of the target. The symbol of nuclear Cross-Section is (σ) with Barn unit, which equals to 10–28 m² or 10–24 cm², and the mathematical relation is:

σ = π × r2 .... (1)

where r is the nuclei radius, and as the typical in order 10^{-12} m, therefore, it equal to 10^{-28} m² (i.e. 1 barn).

Cross-Sections varying massively as observed and for example:

- The (n, {\displaystyle \gamma }) reaction has a cross-section of 1000 barn.
- The transmutations by gamma-ray absorption cross-section is 0.001 barn

Such cross-sections can be used to characterize any type of nuclear reaction. [2]

b. Microscopic Cross Section (σ)

It represents the effective target that one nucleus presents to a bombarding particle, where the incident nuclei and target nuclei might be visualized as classical, and would quite naturally correspond to the cross-sectional area given by each of the target nuclei to the beam. Particles, also measured with (barn) the geometrical interpretation of a nuclear cross-section can frequently be misleading since σ are often larger (or smaller) than the geometrical cross-section of the nucleus because of the resonance effects which, in turn, are a consequence of the quantum mechanical nature of the neutron and therefore, the nucleus, for instance, the absorption cross-section of $_{54}Xe^{135}$ for slow neutrons is nearly a million times larger than its geometrical cross-section. The mathematical formula of a microscopic cross-section is:

$$\sigma = \frac{Number\ of\ reactions/nucleus/sec}{Number\ of\ incident\ neutrons/cm\ /sec}$$

$$= \frac{R/Na}{I} \ .... (2)$$

R is the number of reaction per unite time per nucleus.

Na is a number of target atoms per unit area (cm^{-2}).

I is the intensity (in units of a number of neutrons/cm^2-sec).[3]

c. Macroscopic Cross Section (∑)

It is a quantity that embodies the whole target area estimated by all nuclei in a unit volume, i.e. it represents the overall cross-section for a medium containing N targets per unit volume, symbolized (∑) as below :

$\sum = N\sigma$ .... (3)

where σ is the microscopic cross-section

and that means, the macroscopic cross-section is the entirety of the microscopic cross-sections of all targets per unit volume (i.e. represents the effective target area that is presented by all the nuclei contained in 1 cm^3 of the material), and can be thought of as the probability of interaction per unit distance, in the same manner, the decay constant λ has dimensions of inverse time and Macroscopic Cross Section has dimensions of the inverse distance then we can derive the exponential formula of attenuation

$I = I_0 \exp(-\sum x)$ .... (4)

I_0 is the intensity of a narrow beam of radiation incident on the material of thickness x

I is the intensity of the radiation that succeeds in penetrating the material.[4]

Nuclear Total Cross-Section (σ_T)

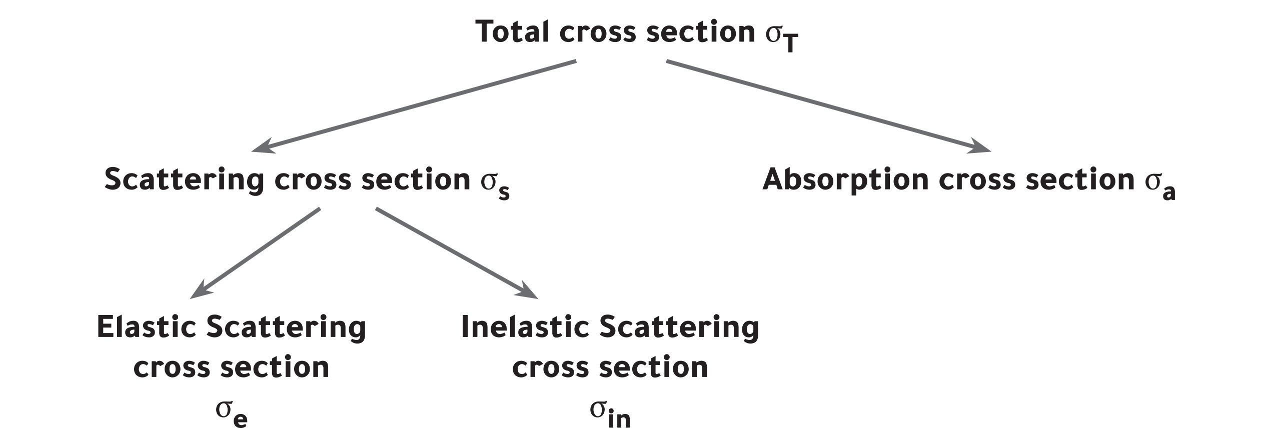
It is the cross-sections of all possible interactions. For each type of interaction, or for a group of interactions, one can define a separate cross-section as:

$\sigma_T = \sigma_s + \sigma_{abs}$ .... **(5)**

σ_s is the scattering cross-section include (elastic and inelastic)

σ_{abs} absorption cross-section

for example, neutron total cross-section is: [3]



Schematic diagram of the Neutron cross section hierarchy

3. Stopping Power

Stopping power is the parameter interested with charged particles used to define the gradual loss of energy, it plays an important role in radiation dosimetry and its dependence on the properties of the charged particle (mass - charge - velocity - energy) and to the properties of the absorbing medium (density - atomic number) [5].

When charged particles pass through an absorbing medium is exposed to a large number of interactions before their kinetic energy is consumed, In each interaction, the charged particles path may be changed (elastic or inelastic scattering) and it may lose some of its kinetic energy that will be transferred to the medium (collision loss) or photons (radiation loss) and each of these probable interactions among the charged particle and orbital electrons or the nucleus of the absorber atoms is categorized by a specific cross-section (probability) σ for the specific interaction [6].

linear stopping power is the simplest form of stopping power it is the rate of energy loss (E) per unit of path length(x) by a charged particle in an absorbing medium gives by ($-\frac{dE}{dx}$), the minus sign makes stopping power positively. Another is mass stopping (S) we get it from Dividing the linear stopping power by the density (ρ) of the absorber. Results in the mass stopping power (S) are given in units (MeV. cm^2. g–1).

In general, the average energy loss per unit path length ($-dE/dx$) experienced by the heavy particle is calculated by multiplying the cross-section for a given energy loss σ_{ni} by the energy loss ΔE_{ni} and a summation over all possible individual collisions (i)

$$-dE/dx = N_i \, \Delta E_{ni} \, \sigma_{ni} \quad \text{.............................. (6)}$$

Where *Ni* is the density of atoms i.

There are two types of stopping power are known:

a. Radiation stopping power (also named nuclear stopping power) resultant from charged particle Coulomb interaction with the nuclei of the absorber. Only light charged particles (electrons and positrons) experience ratable energy loss through these interactions that are usually denoted to as bremsstrahlung interactions. For heavy charged particles (protons, *α* particles, etc.) the radiation (bremsstrahlung) loss is negligible in comparison with the collision loss.
b. Collision stopping power (also called ionization or electronic stopping power) resulting from charged particle Coulomb interactions with orbital electrons of the absorber. Together with heavy and light charged particles go through these interactions that result in energy transfer from the charged particle to orbital electrons through impact excitation and ionization of absorber atoms.

The total stopping power in general terms expressed as the following sum:[7]

$$S_{tot} = S_{rad} + S_{col} \quad \text{.............................. (7)}$$

$$S_{col} = S^{col.}_{soft} + S^{col.}_{hard} \quad \text{.............................. (8)}$$

$$S_{tot} = S_{rad} + S^{col.}_{soft} + S^{col.}_{hard} \quad \text{.................... (9)}$$

Where S_{rad} is radiation stopping power, S_{col} is collision stopping power, $S^{col.}_{soft}$ is soft collision stopping power and $S^{col.}_{hard}$ is hard collision stopping power.

The stopping power mathematical calculated from (Bethe-Bloch equation) (Bethe and Ashkin 1953; Leo 1987; Bichsel et al. 2002):

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}\right] \quad \text{..... (10)}$$

T_{max}: the maximum kinetic energy which the incident particle can impart to a free electron in a collision

C/Z: The shell correction.

δ : Density effect correction.

β = u/c: Relative speed of the incident particle.

γ : Relativistic factor.

K : Constant in stopping power = 0.307075 MeV cm^2.

Z: Atomic number of absorbers.

I: Mean (electronic) excitation energy of an element.

Surface density is used in place of thickness to make the stopping power formulation valid to both gases and condensed media but to correct the density effect and the correct shell and neglected, the effective ionization energy should approximate the above formula to be: [8]

$$-\frac{dE}{dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\ln\frac{2m_e c^2\beta^2}{I(1-\beta^2)} - \beta^2\right] \quad \text{.........} (11)$$

a. Nuclear Stopping Power (S_n) :

The stopping power belongs to the charged particle, now is the beam of charged particle interact with material those charged particles interact first with electrons in outer atom-shell then with the nuclei inside atom as the range of particle energy allow and generate Electric Stopping Power with nuclear Stopping Power. If the medium is gas, the nuclear stopping power is neglect because the ratio of the energy loss in interaction with atomic electrons(S_e) to the energy loss in interaction with atomic nuclei(S_n) is given as [9]

$$\frac{Se}{Sn} \cong \frac{2mp}{me} \cong 4\times 10^3 \quad \text{.................} (12)$$

Therefore in the situation of gas, the Electric Stopping power is Dominant and nuclear stopping power is neglect. If the medium is solid (i.e. give thickness equal to neutron width) we get more nuclear interaction and the Electric stopping power is comparable with nuclear stopping power. The Nuclear stopping power (S_n) of an alpha particle with different ranges of energy is calculated with Ziegler Formula: [10,12,14]

$$S_n = 1.593\sqrt{\varepsilon} \quad \text{......................} (13)$$

$$\text{when} \quad \varepsilon < 0.01\, Mev$$

$$S_n = 1.7\sqrt{\varepsilon} \times \frac{\ln(\varepsilon + exp1)}{1+68\varepsilon+3.4\varepsilon^{\frac{3}{2}}} \quad \text{..........} (14)$$

$$\text{when} \quad 0.01 \le \varepsilon \le 10 \text{ Mev}$$

$$S_n = \frac{(\ln 0.74\,\varepsilon)}{2\varepsilon} \quad \text{......................} (15)$$

$$\text{when} \quad \varepsilon > 10 \text{ Mev}$$

Where ε is the reduced ion energy which is given by :

$$\varepsilon = \frac{32.53\times M_2\times E}{Z_1\times Z_2\times(M_1+M_2)\times \sqrt[2]{Z_1^{\frac{2}{3}}+Z_2^{\frac{2}{3}}}} \quad \text{..........} (16)$$

E = ion Energy.
M_1 = mass projectile in amu.
M_2 = mass of target in amu.
Z_1= atomic number of projectile.
Z_2 = atomic number of the target.

b. Electronic Stopping Power (S_e)

It is the stopping power from interacting the incident charged particle of electrons in atoms of medium until particle rises to thermal equilibrium with their surroundings, and it is calculated by Ziegler formula:

$$\frac{1}{S_e} = \frac{1}{S_{low}} + \frac{1}{S_{High}} \quad \text{............................} (17)$$

$$S_{low} = A_1\, E^{A2} \quad \text{..............................} (18)$$

$$S_{High} = \frac{A3}{E/1000} + \ln\left(\frac{A4}{E/1000} + \frac{A5E}{1000}\right) \quad \text{........} (19)$$

A_i is coefficients given by Zeigler; these expressions are valid for Energy range (10 to 140) keV. [11,13]

4. Results and Discussion :

The assessed cross-sections as a function of proton energy are listed in the table (1) from Evaluated Nuclear Data File (ENDF) and plotted in fig (1) by use matlab program we get mathematical formula representing the cross-sections distribution of the indicated range of proton energy as follows:

y = 6.7e-70*x^{10} - 1.4e-61*x^{9} + 1.2e-53*x^{8} - 6.5e-46*x^{7} + 2.2e-38*x^{6} - 5.1e-31*x^{5} + 7.9e-24*x^{4} - 8.3e-17*x^{3} + 5.6e-10*x^{2} - 0.0022*x + 3.8e+03

where y represents the cross-section with (barn) unite and x represents an energy with (eV) unite. The Cross-Section increase in range of energy (1×10^{7} to 1.6×10^{7}) with maximum cross-Section points (1.04 barn) then decrease smoothly, that's mean at the point (1.6×10^{7} eV - 1.04 barn) we get a maximum probability of reaction occurs and by using the formula we can calculate any cross-section of (^{131}I (p,2n)^{130}Xe) with any available energy.

In table (2) the Electronic stopping power and table (3) the Nuclear stopping power we calculated them by Srim-Program we chose Hydrogen in ion box and Iodine in target box and put (130.9061246 amu) in weight box with Energy Range (1×10^{7} - 3×10^{7} eV) and click on calculate table, we get the electronic and nuclear stopping power, then we sum them to get the total stopping power in the table (4) and plotted in fig(2) by a mat-lab program, we get mathematical formula as:

y = 1.4e-31*x^{4} - 1.2e-23*x^{3} + 3.8e-16*x^{2} - 6.2e-09*x + 0.055

Where y represented the stopping power with uniting (eV/mg.cm^{2}) and x represent energy with unite (eV). The stopping power be at maximum value at first energy value (1×10^{7} eV - 0.02117 (eV/mg.cm^{2})) then decrease gradually. Mat-lab program is this report used for plotting and get a mathematic formula, srim-program is used to calculate stopping power.

Table (1): The cross section of ^{131}I (p, 2n) ^{130}Xe as a function of proton energy.[15]

Proton energy (eV)	Cross-section (barn)	Proton energy (eV)	Cross-section (barn)	Proton energy (eV)	Cross-section (barn)
1.00E+07	4.34E-01	1.68E+07	1.03E+00	2.36E+07	2.26E-01
1.02E+07	4.69E-01	1.70E+07	1.03E+00	2.38E+07	2.16E-01
1.04E+07	5.04E-01	1.72E+07	1.00E+00	2.40E+07	2.06E-01
1.06E+07	5.40E-01	1.74E+07	9.77E-01	2.42E+07	2.02E-01
1.08E+07	5.75E-01	1.76E+07	9.53E-01	2.44E+07	1.98E-01
1.10E+07	6.10E-01	1.78E+07	9.28E-01	2.46E+07	1.94E-01
1.12E+07	6.38E-01	1.80E+07	9.04E-01	2.48E+07	1.89E-01
1.14E+07	6.65E-01	1.82E+07	8.69E-01	2.50E+07	1.85E-01
1.16E+07	6.93E-01	1.84E+07	8.34E-01	2.52E+07	1.81E-01
1.18E+07	7.20E-01	1.86E+07	7.99E-01	2.54E+07	1.77E-01
1.20E+07	7.48E-01	1.88E+07	7.65E-01	2.56E+07	1.72E-01
1.22E+07	7.68E-01	1.90E+07	7.30E-01	2.58E+07	1.68E-01
1.24E+07	7.89E-01	1.92E+07	6.94E-01	2.60E+07	1.64E-01
1.26E+07	8.09E-01	1.94E+07	6.58E-01	2.62E+07	1.62E-01
1.28E+07	8.30E-01	1.96E+07	6.22E-01	2.64E+07	1.60E-01
1.30E+07	8.50E-01	1.98E+07	5.86E-01	2.66E+07	1.58E-01
1.32E+07	8.66E-01	2.00E+07	5.50E-01	2.68E+07	1.56E-01
1.34E+07	8.81E-01	2.02E+07	5.26E-01	2.70E+07	1.53E-01
1.36E+07	8.97E-01	2.04E+07	5.02E-01	2.72E+07	1.51E-01
1.38E+07	9.12E-01	2.06E+07	4.77E-01	2.74E+07	1.49E-01
1.40E+07	9.28E-01	2.08E+07	4.53E-01	2.76E+07	1.47E-01
1.42E+07	9.40E-01	2.10E+07	4.29E-01	2.78E+07	1.45E-01
1.44E+07	9.52E-01	2.12E+07	4.04E-01	2.80E+07	1.43E-01
1.46E+07	9.65E-01	2.14E+07	3.80E-01	2.82E+07	1.42E-01
1.48E+07	9.77E-01	2.16E+07	3.56E-01	2.84E+07	1.40E-01
1.50E+07	9.90E-01	2.18E+07	3.31E-01	2.86E+07	1.39E-01
1.52E+07	1.00E+00	2.20E+07	3.07E-01	2.88E+07	1.38E-01
1.54E+07	1.01E+00	2.22E+07	2.97E-01	2.90E+07	1.37E-01
1.56E+07	1.02E+00	2.24E+07	2.87E-01	2.92E+07	1.35E-01
1.58E+07	1.03E+00	2.26E+07	2.77E-01	2.94E+07	1.34E-01
1.60E+07	1.04E+00	2.28E+07	2.67E-01	2.96E+07	1.33E-01
1.62E+07	1.04E+00	2.30E+07	2.57E-01	2.98E+07	1.31E-01
1.64E+07	1.03E+00	2.32E+07	2.47E-01	3.00E+07	1.30E-01
1.66E+07	1.03E+00	2.34E+07	2.37E-01	-----	------

Table (2): I-131 Electronic stopping power as a function of proton energy with energy range (10 to 30) MeV.[16]

Energy (eV)	Stopping power (eV/mg.cm²)	Energy (eV)	Stopping power (eV/mg.cm²)	Energy (eV)	Stopping power (eV/mg.cm²)
1.00E+07	2.1160E-02	1.68E+07	1.4690E-02	2.36E+07	1.1503E-02
1.02E+07	2.0890E-02	1.70E+07	1.4560E-02	2.38E+07	1.1432E-02
1.04E+07	2.0620E-02	1.72E+07	1.4444E-02	2.40E+07	1.1362E-02
1.06E+07	2.0350E-02	1.74E+07	1.4328E-02	2.42E+07	1.1292E-02
1.08E+07	2.0080E-02	1.76E+07	1.4212E-02	2.44E+07	1.1221E-02
1.10E+07	1.9810E-02	1.78E+07	1.4096E-02	2.46E+07	1.1151E-02
1.12E+07	1.9576E-02	1.80E+07	1.3980E-02	2.48E+07	1.1080E-02
1.14E+07	1.9342E-02	1.82E+07	1.3877E-02	2.50E+07	1.1010E-02
1.16E+07	1.9108E-02	1.84E+07	1.3774E-02	2.52E+07	1.0951E-02
1.18E+07	1.8874E-02	1.86E+07	1.3671E-02	2.54E+07	1.0892E-02
1.20E+07	1.8640E-02	1.88E+07	1.3568E-02	2.56E+07	1.0832E-02
1.22E+07	1.8438E-02	1.90E+07	1.3465E-02	2.58E+07	1.0773E-02
1.24E+07	1.8236E-02	1.92E+07	1.3362E-02	2.60E+07	1.0714E-02
1.26E+07	1.8034E-02	1.94E+07	1.3259E-02	2.62E+07	1.0655E-02
1.28E+07	1.7832E-02	1.96E+07	1.3156E-02	2.64E+07	1.0596E-02
1.30E+07	1.7630E-02	1.98E+07	1.3053E-02	2.66E+07	1.0536E-02
1.32E+07	1.7450E-02	2.00E+07	1.2950E-02	2.68E+07	1.0477E-02
1.34E+07	1.7270E-02	2.02E+07	1.2865E-02	2.70E+07	1.0418E-02
1.36E+07	1.7090E-02	2.04E+07	1.2780E-02	2.72E+07	1.0359E-02
1.38E+07	1.6910E-02	2.06E+07	1.2696E-02	2.74E+07	1.0300E-02
1.40E+07	1.6730E-02	2.08E+07	1.2611E-02	2.76E+07	1.0282E-02
1.42E+07	1.6570E-02	2.10E+07	1.2526E-02	2.78E+07	1.0307E-02
1.44E+07	1.6410E-02	2.12E+07	1.2441E-02	2.80E+07	1.0331E-02
1.46E+07	1.6250E-02	2.14E+07	1.2356E-02	2.82E+07	1.0356E-02
1.48E+07	1.6090E-02	2.16E+07	1.2272E-02	2.84E+07	1.0380E-02
1.50E+07	1.5930E-02	2.18E+07	1.2187E-02	2.86E+07	1.0405E-02
1.52E+07	1.5786E-02	2.20E+07	1.2102E-02	2.88E+07	1.0429E-02
1.54E+07	1.5642E-02	2.22E+07	1.2017E-02	2.90E+07	1.0454E-02
1.56E+07	1.5498E-02	2.24E+07	1.1932E-02	2.92E+07	1.0478E-02
1.58E+07	1.5354E-02	2.26E+07	1.1855E-02	2.94E+07	1.0503E-02
1.60E+07	1.5210E-02	2.28E+07	1.1784E-02	2.96E+07	1.0528E-02
1.62E+07	1.5080E-02	2.30E+07	1.1714E-02	2.98E+07	1.0552E-02
1.64E+07	1.4950E-02	2.32E+07	1.1644E-02	3.00E+07	1.0577E-02
1.66E+07	1.4820E-02	2.34E+07	1.1573E-02		

Table (3): I-131 Nuclear stopping power with energy range (10 to 30) MeV.[16]

Energy (eV)	Stopping power (eV/mg.cm^2)	Energy (eV)	Stopping power (eV/mg.cm^2)	Energy (eV)	Stopping power (eV/mg.cm^2)
1.00E+07	9.8000E-06	1.68E+07	6.2414E-06	2.36E+07	4.6401E-06
1.02E+07	9.6446E-06	1.70E+07	6.1740E-06	2.38E+07	4.6060E-06
1.04E+07	9.4892E-06	1.72E+07	6.1138E-06	2.40E+07	4.5718E-06
1.06E+07	9.3338E-06	1.74E+07	6.0536E-06	2.42E+07	4.5376E-06
1.08E+07	9.1784E-06	1.76E+07	5.9934E-06	2.44E+07	4.5035E-06
1.10E+07	9.0230E-06	1.78E+07	5.9332E-06	2.46E+07	4.4693E-06
1.12E+07	8.8916E-06	1.80E+07	5.8730E-06	2.48E+07	4.4352E-06
1.14E+07	8.7602E-06	1.82E+07	5.8212E-06	2.50E+07	4.4010E-06
1.16E+07	8.6288E-06	1.84E+07	5.7694E-06	2.52E+07	4.3726E-06
1.18E+07	8.4974E-06	1.86E+07	5.7176E-06	2.54E+07	4.3442E-06
1.20E+07	8.3660E-06	1.88E+07	5.6658E-06	2.56E+07	4.3158E-06
1.22E+07	8.2534E-06	1.90E+07	5.6140E-06	2.58E+07	4.2874E-06
1.24E+07	8.1408E-06	1.92E+07	5.5622E-06	2.60E+07	4.2590E-06
1.26E+07	8.0282E-06	1.94E+07	5.5104E-06	2.62E+07	4.2306E-06
1.28E+07	7.9156E-06	1.96E+07	5.4586E-06	2.64E+07	4.2022E-06
1.30E+07	7.8030E-06	1.98E+07	5.4068E-06	2.66E+07	4.1738E-06
1.32E+07	7.7056E-06	2.00E+07	5.3550E-06	2.68E+07	4.1454E-06
1.34E+07	7.6082E-06	2.02E+07	5.3128E-06	2.70E+07	4.1170E-06
1.36E+07	7.5108E-06	2.04E+07	5.2707E-06	2.72E+07	4.0886E-06
1.38E+07	7.4134E-06	2.06E+07	5.2285E-06	2.74E+07	4.0602E-06
1.40E+07	7.3160E-06	2.08E+07	5.1864E-06	2.76E+07	4.0460E-06
1.42E+07	7.2304E-06	2.10E+07	5.1442E-06	2.78E+07	4.0459E-06
1.44E+07	7.1448E-06	2.12E+07	5.1020E-06	2.80E+07	4.0458E-06
1.46E+07	7.0592E-06	2.14E+07	5.0599E-06	2.82E+07	4.0457E-06
1.48E+07	6.9736E-06	2.16E+07	5.0177E-06	2.84E+07	4.0456E-06
1.50E+07	6.8880E-06	2.18E+07	4.9756E-06	2.86E+07	4.0455E-06
1.52E+07	6.8126E-06	2.20E+07	4.9334E-06	2.88E+07	4.0454E-06
1.54E+07	6.7372E-06	2.22E+07	4.8912E-06	2.90E+07	4.0454E-06
1.56E+07	6.6618E-06	2.24E+07	4.8491E-06	2.92E+07	4.0453E-06
1.58E+07	6.5864E-06	2.26E+07	4.8109E-06	2.94E+07	4.0452E-06
1.60E+07	6.5110E-06	2.28E+07	4.7768E-06	2.96E+07	4.0451E-06
1.62E+07	6.4436E-06	2.30E+07	4.7426E-06	2.98E+07	4.0450E-06
1.64E+07	6.3762E-06	2.32E+07	4.7084E-06	3.00E+07	4.0449E-06
1.66E+07	6.3088E-06	2.34E+07	4.6743E-06	-----	-----

Table (4): I-131 total stopping power with energy range (10 to 30) MeV.[16]

Energy (eV)	Stopping power (eV/mg.cm^2)	Energy (eV)	Stopping power (eV/mg.cm^2)	Energy (eV)	Stopping power (eV/mg.cm^2)
1.00E+07	2.116980E-02	1.68E+07	1.469624E-02	2.36E+07	1.150744E-02
1.02E+07	2.089964E-02	1.70E+07	1.456617E-02	2.38E+07	1.143701E-02
1.04E+07	2.062949E-02	1.72E+07	1.445011E-02	2.40E+07	1.136657E-02
1.06E+07	2.035933E-02	1.74E+07	1.433405E-02	2.42E+07	1.129614E-02
1.08E+07	2.008918E-02	1.76E+07	1.421799E-02	2.44E+07	1.122570E-02
1.10E+07	1.981902E-02	1.78E+07	1.410193E-02	2.46E+07	1.115527E-02
1.12E+07	1.958489E-02	1.80E+07	1.398587E-02	2.48E+07	1.108484E-02
1.14E+07	1.935076E-02	1.82E+07	1.388282E-02	2.50E+07	1.101440E-02
1.16E+07	1.911663E-02	1.84E+07	1.377977E-02	2.52E+07	1.095517E-02
1.18E+07	1.888250E-02	1.86E+07	1.367672E-02	2.54E+07	1.089594E-02
1.20E+07	1.864837E-02	1.88E+07	1.357367E-02	2.56E+07	1.083672E-02
1.22E+07	1.844625E-02	1.90E+07	1.347061E-02	2.58E+07	1.077749E-02
1.24E+07	1.824414E-02	1.92E+07	1.336756E-02	2.60E+07	1.071826E-02
1.26E+07	1.804203E-02	1.94E+07	1.326451E-02	2.62E+07	1.065903E-02
1.28E+07	1.783992E-02	1.96E+07	1.316146E-02	2.64E+07	1.059980E-02
1.30E+07	1.763780E-02	1.98E+07	1.305841E-02	2.66E+07	1.054057E-02
1.32E+07	1.745771E-02	2.00E+07	1.295536E-02	2.68E+07	1.048135E-02
1.34E+07	1.727761E-02	2.02E+07	1.287051E-02	2.70E+07	1.042212E-02
1.36E+07	1.709751E-02	2.04E+07	1.278567E-02	2.72E+07	1.036289E-02
1.38E+07	1.691741E-02	2.06E+07	1.270083E-02	2.74E+07	1.030366E-02
1.40E+07	1.673732E-02	2.08E+07	1.261599E-02	2.76E+07	1.028631E-02
1.42E+07	1.657723E-02	2.10E+07	1.253114E-02	2.78E+07	1.031083E-02
1.44E+07	1.641714E-02	2.12E+07	1.244630E-02	2.80E+07	1.033536E-02
1.46E+07	1.625706E-02	2.14E+07	1.236146E-02	2.82E+07	1.035988E-02
1.48E+07	1.609697E-02	2.16E+07	1.227662E-02	2.84E+07	1.038441E-02
1.50E+07	1.593689E-02	2.18E+07	1.219178E-02	2.86E+07	1.040893E-02
1.52E+07	1.579281E-02	2.20E+07	1.210693E-02	2.88E+07	1.043346E-02
1.54E+07	1.564874E-02	2.22E+07	1.202209E-02	2.90E+07	1.045798E-02
1.56E+07	1.550466E-02	2.24E+07	1.193725E-02	2.92E+07	1.048251E-02
1.58E+07	1.536059E-02	2.26E+07	1.185961E-02	2.94E+07	1.050703E-02
1.60E+07	1.521651E-02	2.28E+07	1.178918E-02	2.96E+07	1.053156E-02
1.62E+07	1.508644E-02	2.30E+07	1.171874E-02	2.98E+07	1.055608E-02
1.64E+07	1.495638E-02	2.32E+07	1.164831E-02	3.00E+07	1.058061E-02
1.66E+07	1.482631E-02	2.34E+07	1.157787E-02		

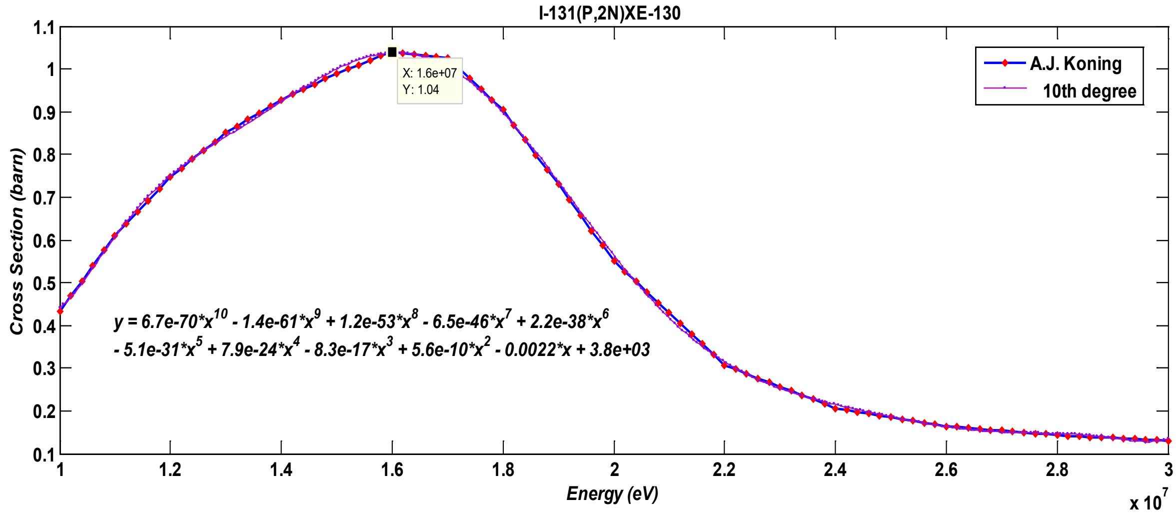


Fig.(1):
The cross section of I-131(p,2n)Xe-130 as a function of Proton energy

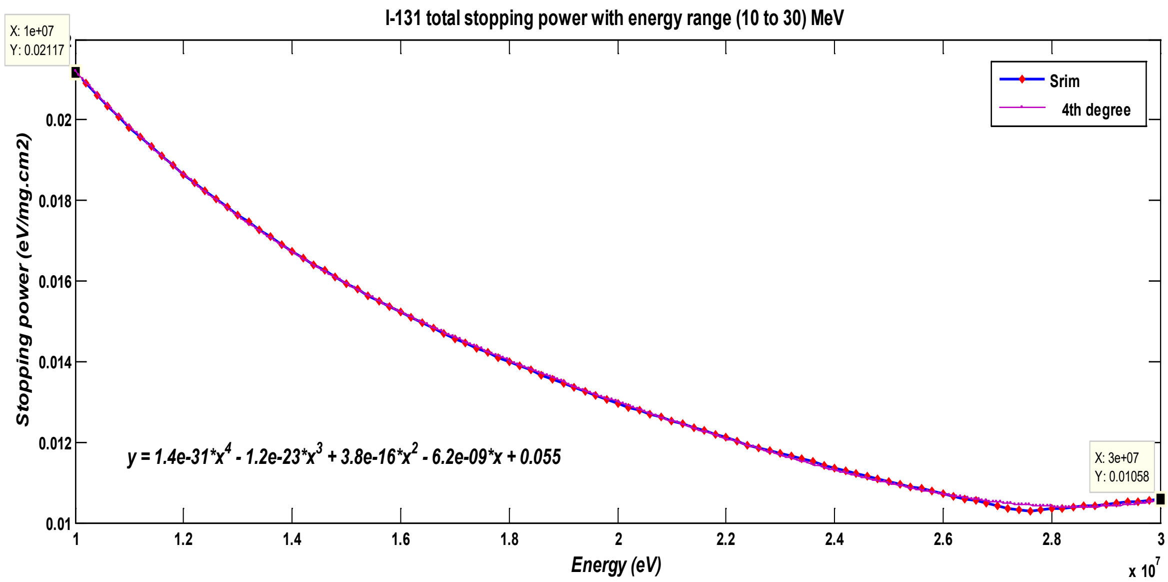


Fig.(2):
Total Stopping – Power with energy range (10-30 MeV)

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