Photo-disintegration of N=Z light nuclei using SRC-based approach

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SRCs : An Ubiquitous Phenomena in Nuclei

- ✓ Photodisintegration by energetic photons Eγ > 40 MeV onward: Observation of kinematically correlated neuteron-proton pair
  - -The quasi-deuteron model (QDM) by Levinger[1] in 1951
  - - $\sigma(\gamma, np) = L \frac{N Z}{A} \sigma_d(\gamma, \text{np})$
  - L =Levinger Constant (~6.4), $\sigma_d(\gamma, \text{np})$ is photo-disintegration cross-section of deuteron
  - - Well-tested by extensive set of experiments[2,3]
- ✓ Pion absorption in nuclei through Quasi-free 2N absorption model[4]
  - - Pion absorption proceed mainly through absorption by n-p/quasideuterons
  - - As high as 70% of pion absorption events may be through np-absorption
- ✓ Direct (Inclusive and exclusive measurements) using few GeV e$^-$/p probes[5,6] -
  - - Extensive measurements at Jlab and BNL
  - - For ejected nucleon momentum > 250MeV/c, 92^{+8}_{-18}% of times ejected p$^+$ is accompanied with kinematically correlated n ejection
  - - Nucleons in SRCs have high relative momenta and low c.m. momenta
  - - Dominance of n-p SRCs observed (about 94% of all SRCs)
- ✓ Direct confirmation of quasi-deuteron like structures by (p,pd) reactions since 1960s, see for example Sutter *et al.* and much recent work at RIKEN[7]
- ✓ SRCs are also considered as cause of EMC effect[5]
- ✓ Their presence has been recognized through many other type of nuclear reactions (a comprehensive review of these processes is in pipeline)

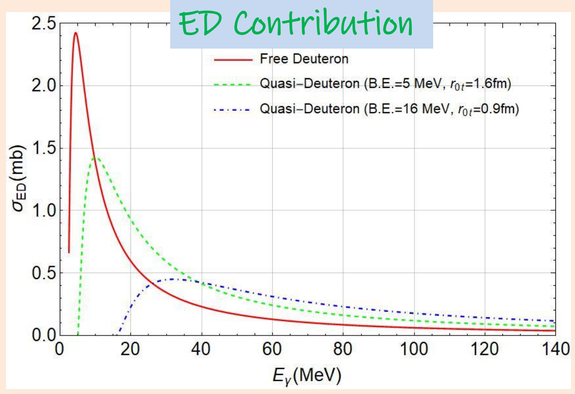
Model & Photo-disintegration for N=Z nuclei

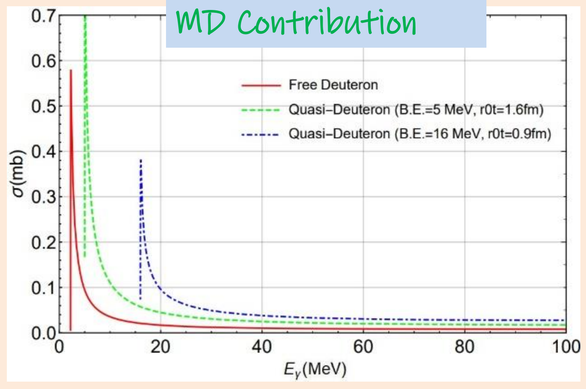
- ✓ In N=Z nuclei, n/p are in same orbitals => Form np SRCs/quasi-deuterons
- ✓ Major fraction of nuclear B.E. may be contributed by the two-body interaction in these n-p SRCs/quasi-deuterons as suggested by Gomes, Walecka & Weisskopf[8] (Independent PAir Model or IPAM)
- ✓ These quasi-deuterons are paired to form quasi-α structures

The photo-disintegration of N=Z nuclei is due to the photo-dis. of quasi-deuteron/n-p SRC degree of freedom and quasi-α degree of freedom

- ➢ The QD photo-disintegration $\sigma_{qd}(\gamma, np)$ can be inferred from well-known form of $\sigma_d(\gamma, np)$ for free deuteron[9] using appropriate value of effective n-p separation (B.E.) energy & effective range r_{0t} values
- ➢ Both ED and MD contributions can be evaluated
  - - The r_{0t} value is scaled with n-p separation energy of quasi-deuteron
  - - Tightly bound n-p system would have smaller effective separation
  - - The r_{0t}=1.75fm is used for free deuteron & r_{0t}~0.8fm is used for n-p separation energy of ~26MeV for quasi-deuteron in ^{4}He, intermediate r_{0t} values are used intermediate n-p separation energy
- ➢ The α-photodisintegration $\sigma_\alpha(\gamma, n)$ & $\sigma_\alpha(\gamma, p)$ can be computed by Gunn-Irving[10] approach using exponential wavefunction
  - - Properly optimized size parameters are used

Photo-disintegration of Quasi-deuteron(QD)





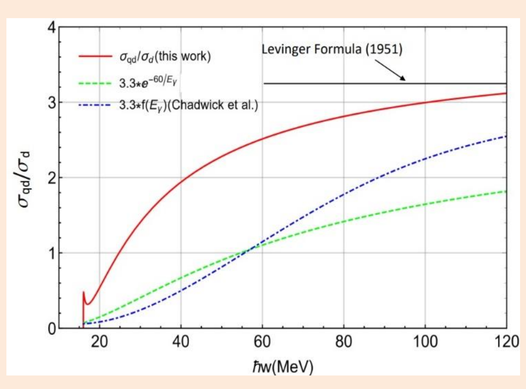
The initial $\sigma_{ED}(\gamma, np)$ peak shifts & decreases with n-p separation/B.E. of quasi-deuteron

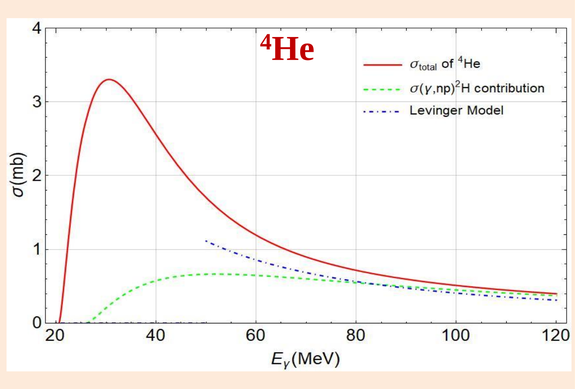
- ➢ $\sigma_{ED}(\gamma, np)$ contribution starts just after it is allowed energetically and peaks few MeV after that
- ➢ In QD region, $\sigma_{ED}(\gamma, np)$ contribution decreases with E_γ at much slower rate as expected
- ➢ For E_γ~100MeV; $\sigma_{ED}(\gamma, np)$ of QD ~ 3 times Free Deuteron

A sharp peak in $\sigma_{MD}(\gamma, np)$ curve is observed just after it is allowed energetically

- ➢ For E_γ>40MeV, $\sigma_{MD}(\gamma, np)$ changes quite slowly
- ➢ The $\sigma_{MD}(\gamma, np)$ for quasi-deuterons at higher E_γ ~100MeV is much higher compared to that of free deuteron (~3 times)
- ➢ The $\sigma_{MD}(\gamma, np)$ contribution is ~10% of $\sigma_{total}(\gamma, np)$ for E_γ~100MeV.
- ➢ MD contribution is neglected in further plots.

Photo-dis. of Quasi-deuteron & ^{4}He





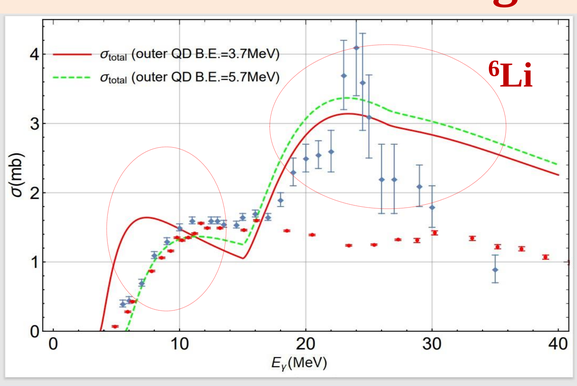
$\sigma_{total}(\gamma, np)$ ratio of quasideuteron (with n-p separation energy of 16 MeV) to that of a free deuteron (by our model), obtained using Levinger formula containing damping factor of $\exp(-D/E_\gamma)$ and obtained using Chadwick's Pauli-blocking factor.

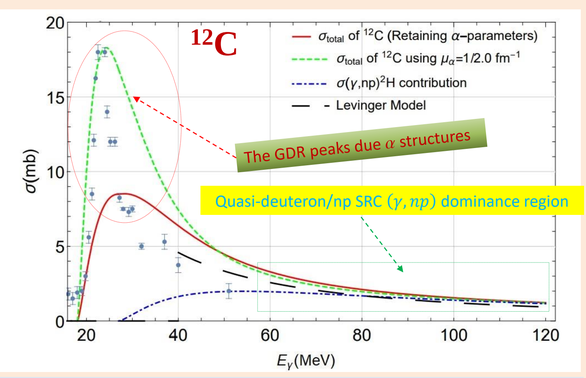
An insightful derivation of Levinger formula with damping

Total photo-dis. cross-section of ^{4}He is sum of $\sigma_{qd}(\gamma, np)$ due to two quasi-deuterons + $[\sigma(\gamma, p) + \sigma(\gamma, n)]$ of α (calculated by Gunn-Irving approach using $\mu_\alpha = \frac{1}{1.7}$fm^{-1}, $\mu_t = \frac{1}{4.5}$fm^{-1}). Quasi-deuteron contribution $\sigma_{qd}(\gamma, np)$ & Levinger model are shown separately also.

- ➢ σ_{tot} vs E_γ plot have a prominent peak in GDR region (mainly due to $\sigma(\gamma, N)$ contribution)
- ➢ The QD contribution dominates for E_γ>50MeV
- ➢ The QD contribution is quite similar to Levinger model prediction (L= 6.4) for E_γ>60MeV
- ➢ Excellent agreement with measurements[11]

Photo-disintegration of ^{6}Li and ^{12}C





^{6}Li is considered as loosely bounded outer quasi-deuteron attached with core-α (as demonstrated in numerous expt. studies). The np separation energy for outer QD is taken as 3.7 & 5.7 MeV (an effective n-p separation energy of ~5MeV has been measured)while core-α calculation are done similar to ^{4}He

- ➢ Two peak structure in photo-disintegration curve!! *Agree with the experimental trends[12]*
- ➢ The first peak is due to loosely bound outer quasi-deuteron (γ, np) & 2nd peak due photo-dis. of core-alpha mainly due to $(\gamma, p) + (\gamma, n)$ channels
- ➢ The double peak structure was not reproduced by recent microscopic ab-initio calculations[13]

$\sigma_{total} = \sigma_{qd}(\gamma, np)$ due to six quasideuterons + $\sigma(\gamma, N)$due to 3quasi-α by using the size parameters of free-α (red curve) and using $\mu_\alpha = \frac{1}{2.0}$ fm^{-1} (green curve). Quasi-deuteron contribution by $\sigma_{qd}(\gamma, np)$ & Levinger equation are shown separately too

- ➢ The experimental GDR peak can be reproduced using slightly larger size for quasi-alpha structures compared to free alpha nucleus.
- ➢ The QD contribution dominates for E_γ>50MeV
- ➢ The calculated cross sections agree very nicely with Levinger QDM (using L= 6.4) for E_γ>60MeV

Excellent agreement with measurements[12].

Summary and Future Outlook

- ❖ Photo-disintegration cross section $\sigma_{\gamma,tot}$ for N=Z light nuclei is calculated
  - - Assuming neutrons/protons in np SRCs/QD which pair off to form quasi-α structures.
  - - Photo-dis. cross section is the sum of individual SRCs/QD and quasi- α photo-dis.
- ❖ The QD photo-dis. $\sigma_{qd}(\gamma, np)$ is calculated from well-known ED & MD contributions for free ^{2}H using appropriate n-p separation energy and r_{0t}
- ❖ The photo-disintegration $\sigma_\alpha(\gamma, N)$ for quasi- α degree of freedom is inferred from Gunn-Irving approach for ^{4}He
  - - The size parameters are inferred by comparing the calculated cross-section values with experimental results for ^{4}He
- ❖ The $\sigma_{\gamma,tot}$ vs E_γ curve for ^{6}Li nucleus results in double-peak structure in accordance to the measurements
  - The contribution of outer loosely bound QD and that of core-α are nicely separated!!
- ❖ The GDR peak in ^{12}C can be reproduced using slightly larger quasi-α size
- ❖ For E_γ betwen 60-120MeV, calculated photo-dis cross-section value agree nicely with the phenomenological model of Levinger without any additional assumption.
- ❖ Present approach can be very useful tool for SRCs/quasi-α investigation
- ❖ Proposed approach has been extended for N≠Z nuclei.

You are welcome for further discussion on details and its implications!!

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