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Three-Body Calculation of the ^{4}He(^{3}H,γ)^{7}Li and ^{4}He(^{3}He,γ)^{7}Be Reactions and Structure of the ^{7}Li and ^{7}Be at Solar Energies *

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The two ^{3}H+^{4}He and ^{3}He+^{4}He fusion reactions at low energies are usually viewed as an approximate external capture process. We study the ^{4}He(^{3}H,γ)^{7}Li and ^{4}He(^{3}He,γ)^{7}Be reactions in a cluster model, which can take into account two- and three-body electromagnetic currents, using minimal substitution in the explicit momentum dependence of the two- and three-cluster interactions. Our main goal is to explore how the cross section of the low-energy ^{3}H+^{4}He or ^{3}He+^{4}He capture reactions depends on energy. The astrophysical S-factors for these reactions are calculated at very low energies. We construct the conserved realistic Argonne v_{18} for two nucleons and Urbana IX or Tucson-Melbourne three-cluster interactions, which are considered for calculation. We also calculate the binding energies and the structural properties of ^{3}H+^{4}He or ^{3}He+^{4}He systems. The binding energies are found to be -37.72 (-36.32) MeV and -39.35 (-37.43) MeV, with (without) three-body interactions for ^{7}Be and ^{7}Li, in satisfactory agreement with other theoretical results and experimental data, respectively.

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The ^{4}He(^{3}He,γ)^{7}Be reaction plays a major role in the solar proton-proton chain in hydrogen burning, from which the ^{7}Be and ^{8}B neutrinos are generated. It is also a fundamental reaction in Big-Bang nucleosynthesis (BBN) and significantly important in the verification of the standard solar model. The experimental situation regarding the capture cross section has been unclear for a long time, due to conflicting experimental results.[1−9] The aim of these experiments were, therefore, to provide high precision data obtained simultaneously using different methods. A cross section of the ^{4}He(^{3}He,γ)^{7}Be reaction has been remeasured by Weizmann,[9] the LUNA collaboration,[3] the Seattle group,[1] and the ERNA collaboration[4] now providing consistent, high precision data. Furthermore, it is still impossible to reach the low energies relevant in nuclear burning.

In theoretical frameworks, some groups are studying the radiative capture cross section for ^{4}He(^{3}He,γ)^{7}Be reaction. For such reactions, solving the many-body problem with realistic interactions is hard and consistent *ab initio* reaction calculations have been possible only for single nucleon projectiles.[10,11] Up to now, no calculation has been successful in describing the energy dependence of the capture cross section data. Neff has consistently investigated the bound state properties and the scattering phase shifts, as well as the normalization and energy dependence of this capture cross section.[11]

Recently, we have calculated the astrophysical S-factor for ^{4}He–^{3}He (^{4}He–^{3}H) radiative capture process at very low energies.[11] We construct conserved two- and three-body electromagnetic currents, using minimal substitution in the explicit momentum dependence of the two- and three-cluster interactions. The zero energy S-factor is calculated to be $S(0) = 0.563(0.581)$ keV·b, with(without) three-body interactions, in satisfactory agreement with other theoretical results and experimental data.

It is the purpose of the present study to present the calculation of the binding energy and multipole transitions of the two ^{3}H+^{4}He or ^{3}He+^{4}He fusion reactions at low energies, usually viewed as an approximate external capture process. The emphasis is on constructing three-body currents corresponding to two- and three-cluster interactions, and on comparing our results with those of other theoretical methods and experimental data.

Firstly, we present a brief review of the nuclear electromagnetic current operator) and the Faddeev integral equation with respect to the above symmetry principles of fundamental interactions for calculating of ^{4}He-^{3}He radiative capture and vice versa at thermal energies (for more details, see Refs. [11,12].

The nuclear electromagnetic charge and current operators is given by

$$\rho(\boldsymbol{q}) = \sum_i \rho_i(\boldsymbol{q}) + \sum_{i<j} \rho_{ij}(\boldsymbol{q}) + \sum_{i<j<k} \rho_{ijk}(\boldsymbol{q}) \cdots,$$
$$\boldsymbol{J}(\boldsymbol{q}) = \sum_i \boldsymbol{J}_i(\boldsymbol{q}) + \sum_{i<j} \boldsymbol{J}_{ij}(\boldsymbol{q}) + \sum_{i<j<k} \boldsymbol{J}_{ijk}(\boldsymbol{q}) \cdots, \quad (1)$$

where $\rho_i(\boldsymbol{q})$ and $\boldsymbol{J}_i(\boldsymbol{q})$ are one-body operators derived from the non-relativistic reduction of the covariant single-nucleon current; $\rho_{ij}(\boldsymbol{q})$ ($\rho_{ijk}(\boldsymbol{q})$) and $\boldsymbol{J}_{ij}(\boldsymbol{q})$ ($\rho_{ijk}(\boldsymbol{q})$) are also two-body (three-body) terms

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that operate on the cluster degrees of freedom, the one-body charge operator in configuration space is given by

$$\rho_i(\boldsymbol{q}) = \rho_{i,\mathrm{NR}}(\boldsymbol{q}) + \rho_{i,\mathrm{RC}}(\boldsymbol{q}), \quad \rho_{i,\mathrm{NR}}(\boldsymbol{q}) = \epsilon_i e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}_i}, \quad (2)$$

where $\epsilon_i = \frac{1}{2}[G_E^S(q_\mu^2) + G_E^V(q_\mu^2)\tau_{i,z}]$; $G_E^S(q_\mu^2)$ and $G_E^V(q_\mu^2)$ are the isoscalar and isovector combinations of the nucleon electric Sachs form factors, respectively, which are evaluated at the four-momentum transfer q_μ^2.[8] The relativistic correction term $\rho_{i,\mathrm{RC}}(\boldsymbol{q})$ is proportional to $1/m^2$.

A conserved current can then be derived by considering an infinitesimal gauge transformation. By performing minimal substitution and keeping only terms linear in the vector potential $\boldsymbol{A}$, the associated current is found to be[8]

$$\begin{aligned}\boldsymbol{J}_{ij}(\boldsymbol{q};b\tau) = {}& \frac{1}{4}v_{b\tau}(r)\boldsymbol{S}\times\boldsymbol{r}_{ij}\left(\eta_j e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}_i} - \eta_i e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{r}_j}\right) \\ & + \frac{1}{2}v_{b\tau}(r)G_E^V(q_\mu^2)(\boldsymbol{\tau}_i\times\tau_j)_z \\ & \cdot\left(\boldsymbol{L}\cdot\boldsymbol{S}\int_{\gamma_{ij}} d\boldsymbol{s}e^{\mathrm{i}\boldsymbol{q}\cdot\mathbf{s}} + \int_{\gamma_{ij}} d\boldsymbol{s}e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{s}}\boldsymbol{L}\cdot\boldsymbol{S}\right), \end{aligned} \quad (3)$$

where

$$\eta_i = G_E^S(q_\mu^2)\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j + G_E^V(q_\mu^2)\tau_{i,z}.$$

The Urbana-type of the three-body interaction is written as a sum of a short-range spin- and isospin-independent term and a term involving the excitation of an intermediate Δ. The central term is ignored and the Δ-excitation term is given by[8]

$$\begin{aligned} V_{ijk} = \sum_{\text{cyclic } ijk} A_{2\pi}\Big(&\{X_{ij},\, X_{jk}\}\,\{\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j,\, \boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k\} \\ & + \frac{1}{4}\,[X_{ij},\, X_{jk}]\,[\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j,\, \boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k]\,\Big), \end{aligned} \quad (4)$$

with

$$\begin{aligned} &\{\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j,\, \boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k\} = 2\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_k, \\ &X_{ij} = v_{\sigma\tau}^{\mathrm{II}}(r)\sigma_i\cdot\sigma_j + v_{t\tau}^{\mathrm{II}}(r)S_{ij}, \end{aligned}$$

where $v_{\sigma\tau}^{\mathrm{II}}(r)$ and $v_{t\tau}^{\mathrm{II}}(r)$ are the standard spin-isospin and tensor-isospin functions occurring in the one-pion-exchange interaction. The parameter $A_{2\pi}$ is determined by reproducing the triton binding energy in an approximate hypernetted-chain variational calculation. Consider the isospin dependence of the three-Body interaction. Gauging the gradient operators and retaining only linear terms in the vector potential (in the same way of two-body interaction) leads to the following current $\boldsymbol{J}_{j;ki}^C(\boldsymbol{q})$ from the commutator term of the three-body interaction:[8]

$$\begin{aligned} &\boldsymbol{J}_{j;ki}(\boldsymbol{q}) = \boldsymbol{J}_{j;ki}^A(\boldsymbol{q}) + \boldsymbol{J}_{j;ki}^C(\boldsymbol{q}) \\ &= 2A_{2\pi}\,G_E^V(q_\mu^2)\,\{X_{ij},\, X_{jk}\}\,(\boldsymbol{\tau}_i\times\boldsymbol{\tau}_k)_z\int d\boldsymbol{s}e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{s}} \\ &\quad + \frac{\mathrm{i}}{4}A_{2\pi}G_E^V(q_\mu^2)[X_{ij}, X_{jk}]\Big[(\tau_{i,z}\,\boldsymbol{\tau}_j\cdot\boldsymbol{\tau}_k - \tau_{j,z}\,\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_k) \\ &\quad \cdot\int d\boldsymbol{s}e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{s}} + (\tau_{k,z}\,\boldsymbol{\tau}_i\cdot\boldsymbol{\tau}_j - \tau_{j,z}\boldsymbol{\tau}_i\cdot\tau_k)\int d\boldsymbol{s}e^{\mathrm{i}\boldsymbol{q}\cdot\boldsymbol{s}}\Big]. \end{aligned} \quad (5)$$

In photonuclear processes, photodisintegration or radiative capture in threshold, the photon can be characterized by the smallest value of j. Thus, the basic formulas for the construction of the matrix elements for electromagnetic processes from the corresponding combinations of polarization $\boldsymbol{\epsilon}$ and unit vector $\hat{\boldsymbol{k}}$ are given by

$$\begin{aligned} &\boldsymbol{e}\to E_1, \\ &\boldsymbol{e}\times\hat{\boldsymbol{k}}\to M_1, \\ &e_a\hat{\boldsymbol{k}}_b + e_b\hat{\boldsymbol{k}}_a\to E_2. \end{aligned} \quad (6)$$

The degree of this three-vector $\hat{\boldsymbol{k}}$ is directly related to the value of the orbital angular momentum of colliding particles or the multiplicity of the photon.

The radiative capture, corresponding to each multipole transition, can then be expressed as

$$\begin{aligned} &T_{JM}^E(q) \simeq \frac{1}{i}\sqrt{\frac{J+1}{J}}\frac{q^{J-1}}{(2J+1)!!}\int d\boldsymbol{x}x^J Y_{JM}(\hat{\boldsymbol{x}})\nabla\cdot j(\boldsymbol{x}), \\ &T_{JM}^M(q) \simeq -\frac{1}{i}\sqrt{\frac{2J+1}{4\pi}}\sqrt{\frac{J+1}{J}}\frac{q^J}{(2J+1)!!}\mu_{JM}, \\ &\mu_{JM} \equiv \sqrt{\frac{4\pi}{2J+1}}\frac{1}{J+1}\int d\boldsymbol{x}[\boldsymbol{x}\times j(\boldsymbol{x})]\cdot\nabla[x^J Y_{JM}(\hat{\boldsymbol{x}})]. \end{aligned} \quad (7)$$

The description of the (Helium-4 and triton) three-body system, with the Argonne V18 two-body and UIX/Tucson-Melbourne three-body forces, is quite successful at low energies. The methods based on the Faddeev equation are applied. We describe the scattering process in a system of three clusters interacting with short-range, strong interactions v_α, $\alpha = 1, 2, 3$; where v_1 is the potential between clusters αp, pd and αd.[5,6] In the framework of non-relativistic quantum mechanics, the center-of-mass (c.m.) and the internal motion can be separated by introducing Jacobi momenta

$$\begin{aligned} \boldsymbol{p}_\alpha &= \frac{m_\gamma\boldsymbol{k}_\beta - m_\beta\boldsymbol{k}_\gamma}{m_\beta + m_\gamma}, \\ \boldsymbol{q}_\alpha &= \frac{m_\alpha(\boldsymbol{k}_\beta + \boldsymbol{k}_\gamma) - (m_\beta + m_\gamma)\boldsymbol{k}_\alpha}{m_\alpha + m_\beta + m_\gamma}, \end{aligned} \quad (8)$$

where $(\alpha\beta\gamma)$, $\boldsymbol{k}_\alpha$ and m_α are the cyclic permutations of (123), the individual cluster momenta and the

masses, respectively. We now consider the particle or cluster β scattering from the pair β that is bound with energy ϵ_β. The initial channel state $|b_\beta \boldsymbol{q}_\beta\rangle$ is the product of the bound state wave function $|b_\beta\rangle$ for the pair β and a plane wave with the relative particle-pair β momentum $\boldsymbol{q}_\beta$. The dependence on the discrete quantum numbers is suppressed in our notation.

We start from the triad of Lippmann–Schwinger equations[5] acting on a three-cluster initial state given by

$$\Phi_\beta^{(c)} = |\boldsymbol{p}_\beta\rangle^{(c)}|\boldsymbol{q}_\beta\rangle, \tag{9}$$

where $|\boldsymbol{p}_\beta\rangle^{(c)}$ is a two-cluster state and the index $\beta = 1, 2, 3$ indicates the three choices of pairs characterized by the third particle or cluster. The final channel state is the particle-pair state in the same or different configuration $|b_\alpha \boldsymbol{q}_\alpha\rangle$ in the case of elastic and rearrangement scattering or, in the case of breakup, it is the state of three free particles; that is, $|\boldsymbol{p}_\gamma \boldsymbol{q}_\gamma\rangle$ with the same energy $E = p_\gamma^2/2\mu_\gamma + q_\gamma^2/2M_\gamma$ and pair γ reduced mass $\mu_\gamma = m_\alpha m_\gamma/(m_\alpha + m_\gamma)$; any set of Jacobi momenta can be used equally well for the breakup state. Furthermore, $U^\beta = \sum_{\gamma\neq\beta} U_\gamma$, where U_γ ($\gamma = 1, 2, 3$) are the pair forces. Three-body forces can also be incorporated in a straightforward fashion. The LS equations are given by

$$\Psi_0^{(c)} = \Phi_\beta^{(c)} + G_\beta U^\beta \Psi_0^{(c)}, \tag{10}$$

where $G_\beta^{-1} = (E + i\varepsilon - H_0 - U_\beta)^{-1}$ is Green's function. By using standard Jacobi momenta $\boldsymbol{p}_\alpha$ and $\boldsymbol{q}_\alpha$, Eq. (8) and suitable multiplication of the three equations in the triad from the left by V_γ, one obtains the transition operators $V_{\beta 0} \equiv (U_\gamma + U_\theta)\Psi_0^{(c)}$, with $\gamma \neq \beta, \beta \neq \theta$, which fulfill the set of equations

$$V_{\beta 0} = \sum_{\gamma\neq\beta} t_\gamma \Phi_0 + \sum_{\gamma\neq\beta} t_\gamma G_0 U_{\gamma 0}, \tag{11}$$

where $\Phi_0 = |\boldsymbol{p}\rangle|\boldsymbol{q}\rangle$ is the three-cluster state. We consider the system of three-clusters with charges z_β of equal sign interacting via pairwise strong short-range and screened Coulomb potentials $V_\beta + W_{\beta R}$ with β being 1, 2, or 3. The corresponding two-particle transition matrices are calculated with the full channel interaction, see Ref. [5],

$$T_\beta^{(R)} = (V_\beta + W_{\beta R}) + (V_\beta + W_{\beta R}) G_0 T_\beta^{(R)}. \tag{12}$$

For the three-body break-up operator, one can generate the multiple scattering series directly by decomposing V_{00} as

$$V_{00} \equiv \sum_\theta V_\theta, \tag{13}$$

where V_θ is the coupled set of Faddeev equations

$$V_\theta = T_\theta + T_\theta G_0 \sum_{\alpha\neq\theta} V_\beta. \tag{14}$$

Iterating Eq. (16) and inserting the result into Eq. (15) leads exactly to the multiple scattering series. Thus, we have a set of three coupled equations,[7]

$$\begin{aligned} V_1 &= T_1 + T_1 G_0 (V_2 + V_3), \\ V_2 &= T_2 + T_2 G_0 (V_3 + V_1), \\ V_3 &= T_3 + T_3 G_0 (V_1 + V_2). \end{aligned} \tag{15}$$

The matrix element for the ^{4}He+^{3}He$\rightarrow^7$Be+γ and ^{4}He+^{3}H$\rightarrow^7$Li+γ processes is simply related to the time reversed photo disintegration processes of ^{7}Be and ^{7}Li, into three free clusters. It is necessary that one can formulate photodisintegration of ^{7}Be and ^{7}Li based on an four-particle picture. Let O be the photon absorption operator and $|\Psi_{^7A}\rangle$ the ^{7}Be or ^{7}Li ground state. The break-up amplitude into n+nn+^{4}He can then be written as an infinite series of processes:

$$\begin{aligned} \langle \Phi_{0,a}|V_0|\Psi_{^7A}\rangle = \langle \Phi_{0,a}|O|\Psi_{^7A}\rangle + \sum_i \langle \Phi_{0,a}|U_i G_0 O|\Psi_{^7A}\rangle \\ + \sum_{ij} \langle \Phi_{0,a}|U_i G_0 U_j G_0 O|\Psi_{^7A}\rangle + \cdots, \end{aligned} \tag{16}$$

where U_i are the pair forces among the ^{4}He–nucleon, ^{4}He–deuteron, and ^{4}He–^{3}He (^{4}He–^{3}H) particles. This infinite series in terms of pair forces represents the final state interactions. The first term is the direct break-up process generated by O. By defining

$$\langle \Phi_{0,a}|V_0|\Psi_{^7A}\rangle = \langle \Phi_{0,a}|O|\Psi_{^7A}\rangle + \sum_i \langle \Phi_{0,a}|V_{0i}|\Psi_{^7A}\rangle, \tag{17}$$

one can obtain the T-matrix T_i, which leads to three coupled Faddeev equations ($i = 1, 2, 3$),[7]

$$V_{0i}|\Psi_{^7A}\rangle = T_i G_0 O|\Psi_{^7A}\rangle + T_i G_0 \sum_{j\neq i} V_{0j}|\Psi_{^7A}\rangle, \tag{18}$$

and the complete break-up amplitude

$$\begin{aligned} \langle \Phi_{0,a}|U_0|\Psi_{^7A}\rangle = \langle \Phi_{0,a}|O|\Psi_{^7A}\rangle + \langle \Phi_{0,a}|U_{01}|\Psi_{^7A}\rangle \\ + \langle \Phi_{0,a}|(1 - P_{23})U_{02}|\Psi_{^7A}\rangle. \end{aligned} \tag{19}$$

We employ the two- and three-body subsystem interactions and single particle currents, two-body currents because these coupled equations can be solved by standard techniques.[6] We derived two coupled Faddeev equations for the three-cluster scattering amplitudes, see Ref. [13]. We derived the results of three-body Faddeev-type calculations for systems of three-particles interacting through short-range nuclear plus the long-range Coulomb potentials and two- and three-body currents. In the present proton-deuteron-^{4}He, three-body system, it is absolutely necessary that any sub-cluster systems composed of the one, two, or

three constituent particles are reasonably described by taking the two- and three-body interactions among these systems, as discussed above. We provided Faddeev equations for the ^{3}He(^{3}H)+^{4}He radiative capture process to the ^{7}Be(^{7}Li) ground state. We have numerically solved the Faddeev integral equation. The energy of ^{7}Be and ^{7}Li ground states calculated with our method and the calculated ground state energies using the SRG-N3LO NN potential,[10] in comparison with the experimental values, are summarized in Table 1 (for more detail of our calculations see Ref. [13]).

Table 1. Our calculated ground state energies of ^{7}Be and ^{7}Li and the obtained results using the SRG-N3LO NN potential[10] in comparison with the experimental values.

Energy (MeV)	^{7}Be	Error	^{7}Li	Error
Calculation[10]	−37.82	<1%	−39.42	<1%
This work(Two-body)	−36.32	3%	−37.43	5%
This work(Two-&three-body)	−37.73	<1%	−39.35	<1%
Experiment	−37.60		−39.24	

In this model, we can also calculate structure properties of ^{7}Be and ^{7}Li. We have calculated all of the contributions of multipole transitions, including the states that are not allowed by Wildermuth's rule. The results are listed in Table 2. For magnetic dipole interaction, we consider the virtual state $0p_{1/2}$, the first excited state $1p_{1/2}$ and the continuum $p_{1/2}$. In Table 2, we compare our results with the values obtained from the other model. The M_1 contribution is comparable with the E_1 contribution but it is much smaller than the E_2 contribution.

Table 2. Comparison between the obtained result in Ref. [14] and our calculation for ^{7}Be and ^{7}Li. Dic=Di-cluster, TWB=two-body and TWhB=two- & three-body results.

$E_{M\lambda}$	^{7}Be			^{7}Li		
	Dic	TWB	TWhB	Dic	TWB	TWhB
E_1 (MeV^{2}fm^3)	1.00	1.02	1.01	1.01	1.02	1.01
M_1 (μ_N^2MeV)	0.82	0.85	0.83	1.20	1.31	1.25
E_2 (MeV^{2}fm^5)	639	1123	1421	482	1450	1120

In this respect, the study of radiative capture process is a particularly important reaction for two reasons: firstly, it is most important due to the fact that the one-, two- and three-body current contributions are comparable in magnitude and different signs;[3] and, secondly, many-body axial currents, specifically conserved current, can then be derived by considering an infinitesimal gauge transformation as a procedure of Marcucci *et al.*[8] in the two- and three-body current operators in the minimal-substitution scheme.

In this study, the destructive interference between one- and many-body currents occurs, although there are leading components of the many-body currents (model independent), which give a much larger contribution than that associated with the one-body current. The cancelation between the one and many-body matrix elements of transition amplitudes has the effect of enhancing the importance of P-wave capture channels. The contribution due to P-waves has only considered the long-wavelength form of the multipole transition amplitudes; namely, their $q = 0$ limit. In P capture, only the multipole transition amplitudes survive in this limit and the corresponding $S(0)$-factor is calculated, including two- and three-body contributions. The suppressed one-body contribution also comes mostly from transitions involving the D-state components of the ^{3}He(^{3}H) and ^{4}He wave functions, while the many-body contributions are predominantly due to transitions connecting the S state in ^{3}He(^{3}H) to the D state in ^{4}He, or vice versa.

Table 3. A comparison between different theoretical and experimental results for the $S(0)$-factor values of ^{4}He(^{3}He,γ)^{7}Be reaction, obtained from this work in comparison with a weighted average of the $S(0)$-factor values from the activation measurements[1,15] and the prompt measurements.[1] The last row shows our three-body interactions results.

	Year	$S(0)$-factor (keV·b)
Experiment		
Alexander *et al.*	1984	0.47±0.04
Brown *et al.*	2007	0.59±0.01
Theory		
Cyburt *et al.*	2008	0.58(0)
Neff	2011	0.59(3)
Two- & three-body[13]	2013	0.56(3)

Table 4. A comparison between different theoretical and experimental results for the $S(0)$-factor values of ^{3}H(α,γ)^{7}Li reaction, obtained from this work in comparison with an extrapolating of the $S(0)$-factor values from recent measurements[12] and theoretical method.[11] The last two rows show our results of two- and three-body interactions.[13]

	Year	$S(0)$-factor (keV·b)
Experiment		
Brune *et al.*	1994	0.101±0.006
Theory		
Neff	2011	0.11(8)
Two- & three-body[13]	2013	0.10(7)

In order to compare the $S(0)$-factor values, following Tables 3 and 4, it is instructive to list the extrapolated $S(0)$-factor values for the different theoretical and experimental studies together with their quoted uncertainty at different years. The calculated data are shown in better agreement with the experimental data based on activation studies. The extrapolated S-factor at astrophysical energies obtained for ^{4}He(^{3}He,γ)^{7}Be(^{4}He(^{3}H,γ)^{7}Li), $S(0) = 0.56(0.10)$ keV·b, from the three-body interactions, is in good agreement with that obtained in the calculation based on Fermionic molecular dynamics, $S(0) = 0.59(0.11)$ keV·b.[11]

Three-body currents give small but significant contributions to the astrophysical S-factor in the ^{4}He(^{3}He,γ)^{7}Be or ^{4}He(^{3}H,γ)^{7}Li reaction at low energies. Carlson *et al.* found a small astrophysical S factor because of sensitive cancelations in the wave

function and destructive interference between the one- and many-body current contributions.[2] These studies showed that inferring the S-factor from the measured cross section can be misleading because of the large contributions associated with the many-body components of the electro weak current operator and also because of their destructive interference with the one-body current contributions.

We focus on the photonuclear process, and study a reaction, namely the ^{4}He(^{3}He,γ)^{7}Be and ^{4}He(^{3}H,γ)^{7}Li reactions; that is, the object of much interest as modern topics of nuclear astrophysics research. We have considered bound and scattering states starting from the realistic modern nucleon-nucleon Argonne v18(AV18) two- and Urbana IX three-body interactions, which reproduces the astrophysical S-factor. These theoretical tools turn out to be in agreement with the basic assumptions of our model; namely, we can describe ^{7}Be and ^{7}Li as formed by the clusters in which all the electromagnetic strength arises from excitation of the relative motion.

The range of applications of this theoretical framework developed is then expanded to include nuclear radiative capture processes. After computing the reduced matrix elements for E_1, E_2 and M_1 transitions, we have calculated the cross section for photodissociation and radiative capture processes because of their astrophysical interest. Finally we have pointed out two aspects related to this calculation. Firstly, the M_1 contribution is comparable with the E_1 contribution, but they are much smaller than the E_2 contribution. Secondly, properly including the nuclear three-body interactions in evaluating the observations is of importance. Then, we have compared our results with experimental measurements of the $S(0)$-factor. The agreement is found to be quite good, as discussed in the text.

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