

Many-channel microscopic cluster model of ^8Be : S factors

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We investigate low-energy astrophysical S factors for reactions proceeding through the ^8Be compound system with entrance channels $p + ^7\text{Li}$, $n + ^7\text{Be}$, and $d + ^6\text{Li}$. Using the same microscopic many-channel three-cluster framework as in our previous study of the high-lying ^8Be spectrum, we calculate $S(E)$ for $^7\text{Li}(p, \alpha)^4\text{He}$, $^7\text{Be}(n, \alpha)^4\text{He}$, $^7\text{Be}(n, p)^7\text{Li}$, $^6\text{Li}(d, \alpha)^4\text{He}$, $^6\text{Li}(d, p)^7\text{Li}$, and $^6\text{Li}(d, n)^7\text{Be}$ in the energy range relevant for primordial and stellar nucleosynthesis. For the mirror reactions $^7\text{Li}(p, \alpha)^4\text{He}$ and $^7\text{Be}(n, \alpha)^4\text{He}$, as well as for $^7\text{Be}(n, p)^7\text{Li}$ the calculated S factors reproduce both the absolute scale and the low-energy trends of the experimental data within their quoted uncertainties, whereas the absolute S factors for the deuteron-induced channels on ^6Li are underestimated at low energy, consistent with the shifted $^6\text{Li} + d$ threshold and the absence of a broad subthreshold 2^+ structure in the present implementation. A partial-wave analysis identifies the dominant J^π contributions in each channel and relates them to specific ^8Be resonances, while demonstrating that cluster polarization, previously shown to be crucial for the ^8Be spectrum, is likewise essential for the normalization and energy dependence of several S factors. Evaluating $S(E)$ at appropriate Gamow energies, we obtain a hierarchy of reaction channels that quantifies the relative importance of neutron- and deuteron-induced processes for the production and destruction of ^7Li and ^7Be .

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I. INTRODUCTION

Reactions that proceed through the compound nucleus ^8Be at low entrance-channel energies (tens to a few hundred keV) are key inputs for astrophysical reaction rates. They also provide a stringent test of cluster models because multiple binary partitions couple through ^8Be and there exists a broad set of low-energy cross-section and S -factor data, while a unified microscopic description of these observables is still lacking. Among these, reactions involving ^7Li and ^7Be enter standard calculations of light-element nucleosynthesis and are directly relevant to the long-standing cosmological lithium problem.

In our previous work [1] (hereafter Paper I), we analyzed high-excitation resonances of ^8Be within a microscopic three-cluster model, including the configurations

$$\begin{aligned} &^4\text{He} + ^3\text{H} + p, \quad ^4\text{He} + ^3\text{He} + n, \\ &^4\text{He} + d + d, \quad ^4\text{He} + 2p + 2n, \end{aligned}$$

which embed all binary rearrangement channels

$$\begin{aligned} &^4\text{He} + ^4\text{He}, \quad ^7\text{Li} + p, \quad ^3\text{He} + ^5\text{Li}, \quad ^7\text{Be} + n, \\ &^3\text{He} + ^5\text{He}, \quad d + ^6\text{Li}, \quad 2n + ^6\text{Be}, \quad 2p + ^6\text{He}. \end{aligned}$$

That study established the rich spectrum of ^8Be near the $p + ^7\text{Li}$, $n + ^7\text{Be}$, and $d + ^6\text{Li}$ thresholds, and demonstrated that cluster polarization in the $A = 5, 6$, and 7 subsystems is decisive for the formation and properties of the twin 1^+ , 2^+ , 3^+ , and 4^+ resonance doublets.

Here we apply the same microscopic many-channel three-cluster framework to reactions at low entrance-channel energies in the $p + ^7\text{Li}$, $n + ^7\text{Be}$, and $d + ^6\text{Li}$ channels, and focus on the astrophysical S factors for

$$\begin{aligned} &^7\text{Li}(p, \alpha)^4\text{He}, \quad ^7\text{Be}(n, \alpha)^4\text{He}, \quad ^7\text{Be}(n, p)^7\text{Li}, \\ &^6\text{Li}(d, \alpha)^4\text{He}, \quad ^6\text{Li}(d, p)^7\text{Li}, \quad ^6\text{Li}(d, n)^7\text{Be}. \end{aligned} \quad (1)$$

Our goal is a unified microscopic description of the six reactions in Eq. (1) that (i) predicts low-energy $S(E)$ from explicit cluster structure and intercluster dynamics, (ii) identifies the dominant J^π contributions to each S factor and links them to specific ^8Be resonances found in Paper I, and (iii) quantifies how cluster polarization controls the absolute scale and energy dependence of $S(E)$ in the astrophysical regime.

The ^8Be spectrum is rich: many states lie above the $p + ^7\text{Li}$ threshold ($E_x \gtrsim 17$ MeV), while the 0^+ ground state is a very narrow resonance just above the $^4\text{He} + ^4\text{He}$ threshold. Because several open and near-threshold partitions are coupled through ^8Be , the reactions in Eq. (1) have attracted

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sustained experimental effort. Cross sections and S factors have been measured with improving precision down to tens of keV, and low-energy extrapolations commonly use linear or low-order polynomial parametrizations of $S(E)$. A reasonably consistent picture emerges across different experiments and techniques. Appendix summarizes the experimental datasets, within the energy range considered in this work, that are used in our S -factor comparisons for the six reactions listed above.

By contrast, modern microscopic calculations of these S factors remain comparatively sparse and reaction-specific. Descouvemont and Baye treated ${}^7\text{Li}(p, \alpha){}^4\text{He}$, ${}^7\text{Be}(p, n){}^7\text{Li}$, and ${}^7\text{Li}(p, \gamma){}^8\text{Be}$ in a generator-coordinate three-cluster model [2]. While total cross sections were described over a broad energy range, only the S factor for $p + {}^7\text{Li} \rightarrow \alpha + \alpha$ was analyzed in the astrophysical limit; the calculation overestimates both the absolute scale and the low-energy slope, predicting a pronounced rise of $S(E)$ as $E \rightarrow 0$ driven by the twin 2^+ subthreshold states of ${}^8\text{Be}$ just below the $p + {}^7\text{Li}$ threshold, whereas the experimental $S(E)$ is almost flat with at most a weak upward trend.

A microscopic many-cluster calculation for ${}^7\text{Li}(p, \gamma){}^8\text{Be}$ yields $S(E)$ for radiative capture [3], while analyses using the distorted-wave Born approximation (DWBA) have been performed for ${}^7\text{Li}(p, \alpha){}^4\text{He}$ [4,5] and ${}^6\text{Li}(d, \alpha){}^4\text{He}$ [6]. In particular, Ref. [5] showed that finite-range DWBA with direct+exchange amplitudes can reproduce low-energy angular distributions and provide an $S(E)$ curve consistent with existing data, and Ref. [6] emphasized the importance of coherently combining direct and resonant amplitudes near threshold, driven by interference with a subthreshold 2^+ resonance in ${}^8\text{Be}$. These studies reinforce the conclusion that low-energy observables in these systems are highly sensitive to near-threshold structure and benefit from models with explicit cluster dynamics.

Complementary to these structure-based approaches, global R -matrix evaluations of the ${}^8\text{Be}$ system provide a phenomenological, data-driven description. An early multichannel analysis by Page and collaborators fitted a broad set of scattering and reaction data and yielded differential and integrated cross sections for many of the channels listed in Eq. (1) [7,8]. More recently, Paneru *et al.* carried out a comprehensive Bayesian R -matrix analysis using the AZURE2 code [9], assimilating new datasets (in particular for deuteron-induced reactions on ${}^6\text{Li}$), quantifying uncertainties for level and channel parameters, and providing evaluated cross sections for several of the reactions in Eq. (1). As a phenomenological framework, the R -matrix approach is well suited to interpolation, extrapolation, and reaction-rate evaluations; however, it does not by itself resolve the underlying cluster dynamics or the role of subthreshold structure across all entrance and exit channels.

Thus, the gap we address here is a unified, microscopic, and multichannel description of the six reactions in Eq. (1) that simultaneously connects to the high-lying ${}^8\text{Be}$ resonances identified in Paper I and predicts low-energy $S(E)$ in the astrophysical entrance-channel regime.

The paper is organized as follows: In Sec. II we summarize the many-channel microscopic three-cluster model for ${}^8\text{Be}$ and its implementation for the relevant binary partitions,

including the definition of the astrophysically relevant Gamow windows for the reactions of interest. Section III presents the calculated astrophysical S factors and compares them with available experimental data, highlighting the role of Coulomb effects in mirror channels, the low-energy behavior and analytical approximations to $S(E)$, and the resulting reaction hierarchy at representative Gamow energies. Our main findings and their astrophysical implications are summarized in Sec. IV, and Appendix lists the experimental datasets used in our S -factor comparisons.

II. MANY-CHANNEL MICROSCOPIC MODEL

A. Cluster configurations and nucleon-nucleon interaction

To study nuclear reactions proceeding through the compound nucleus ${}^8\text{Be}$, we employ the same microscopic three-cluster model as in Ref. [1], previously used to describe high-energy resonance states of ${}^8\text{Be}$. This model explicitly includes all eight binary partitions of ${}^8\text{Be}$:

$$\begin{aligned} &{}^4\text{He} + {}^4\text{He}, \quad p + {}^7\text{Li}, \quad n + {}^7\text{Be}, \quad d + {}^6\text{Li}, \quad 2n + {}^6\text{Be}, \\ &2p + {}^6\text{He}, \quad t + {}^5\text{Li}, \quad {}^3\text{He} + {}^5\text{He}. \end{aligned}$$

Consequently, the total wave function of a continuum state of ${}^8\text{Be}$ is written as a superposition of eight channel wave functions, each describing one of these binary partitions.

The wave function of ${}^8\text{Be}$ in a given three-cluster configuration can be represented as

$$\begin{aligned} \Psi^{(E,J)} = \sum_{\alpha} \hat{\mathcal{A}} \{ &\Phi_{\alpha}(A_{\alpha}, S_{\alpha}) \psi_{\alpha}(\mathcal{E}_{\alpha}, A_{\beta} + A_{\gamma}, j_2) \\ &\times \varphi_{E-\mathcal{E}_{\alpha}, l_1, j_1}(\mathbf{y}_{\alpha}) \} J, \end{aligned} \quad (2)$$

where $\Psi^{(E,J)}$ denotes the wave function of ${}^8\text{Be}$ with total energy E and total angular momentum J . The index α labels the three clusters in a given three-cluster configuration, with (α, β, γ) running over all permutations of the three constituents. Thus, for a fixed three-cluster configuration the sum over α represents the three binary channels $A_{\alpha} + (A_{\beta} + A_{\gamma})$, each term describing the scattering of the cluster with index α on a bound or pseudo-bound two-cluster state formed by the clusters β and γ .

The function $\Phi_{\alpha}(A_{\alpha}, S_{\alpha})$ is the many-particle shell-model wave function that describes the internal structure of the “projectile” cluster A_{α} , with intrinsic spin S_{α} . In the present model, the projectiles are the proton, neutron, deuteron, $2n$, $2p$, triton, ${}^3\text{He}$, and the ${}^4\text{He}$ cluster. They are treated microscopically as composites of nucleons but, in contrast with the target nuclei, are not themselves described as two-cluster subsystems. Instead, we use a translationally invariant shell-model description and assume them to be nonpolarizable in the present implementation; $2n$ and $2p$ are restricted to the ${}^1S_0$ configuration ($S_{\alpha} = 0, l = 0$), while d is taken in the ${}^3S_1$ configuration ($S_{\alpha} = 1, l = 0$).

The function $\psi_{\alpha}(\mathcal{E}_{\alpha}, A_{\beta} + A_{\gamma}, j_2)$ describes the internal structure of the “target” nucleus, i.e., a two-cluster system $(\alpha + n, \alpha + p, \alpha + d, \alpha + 2n, \alpha + 2p, \alpha + t, \alpha + {}^3\text{He})$ corresponding to ${}^5\text{He}, {}^5\text{Li}, {}^6\text{Li}, {}^6\text{He}, {}^6\text{Be}, {}^7\text{Li}$, and ${}^7\text{Be}$. Here $\mathcal{E}_{\alpha}$ is the internal energy of this two-cluster subsystem, and j_2 is

TABLE I. Energies of bound and pseudobound states in the dominant two-cluster subsystems used in the present microscopic model. The first column lists the two-cluster subsystem (identified by the composite nucleus and j_2^π), and the second column gives its cluster partition. The energies $\mathcal{E}_{\text{calc}}$ and $\mathcal{E}_{\text{expt}}$ are given with respect to the corresponding two-cluster thresholds for the partition shown. The theoretical results are obtained with the Hasegawa–Nagata NN potential using Majorana parameter $m = -0.008$, spin-orbit strength $f_{LS} = 0.30$, and oscillator length $b = 1.362$ fm. Experimental energies are taken from Ref. [11].

Two-cluster subsystem (j_2^π)	Cluster partition	$\mathcal{E}_{\text{calc}}$ (MeV)	$\mathcal{E}_{\text{expt}}$ (MeV)
${}^7\text{Li}(3/2^-)$	${}^4\text{He} + {}^3\text{H}$	-2.447	-2.467
${}^7\text{Li}(1/2^-)$	${}^4\text{He} + {}^3\text{H}$	-1.974	-1.989
${}^7\text{Be}(3/2^-)$	${}^4\text{He} + {}^3\text{He}$	-1.597	-1.587
${}^7\text{Be}(1/2^-)$	${}^4\text{He} + {}^3\text{He}$	-1.150	-1.158
${}^6\text{Li}(1^+)$	${}^4\text{He} + d$	-1.656	-1.474
${}^5\text{He}(3/2^-)$	${}^4\text{He} + n$	1.065	0.798
${}^5\text{He}(1/2^-)$	${}^4\text{He} + n$	1.492	2.068
${}^5\text{Li}(3/2^-)$	${}^4\text{He} + p$	1.692	1.69
${}^5\text{Li}(1/2^-)$	${}^4\text{He} + p$	2.016	3.18
${}^6\text{He}(0^+)$	${}^4\text{He} + 2n$	-2.892	-0.973
${}^6\text{Be}(0^+)$	${}^4\text{He} + 2p$	-1.085	1.371

its total angular momentum. In particular, the ${}^6\text{Li}$ subsystem is treated in the $\alpha + d$ clustering with the deuteron taken as an isosinglet ($T_d = 0$), so that the corresponding ${}^6\text{Li}$ basis in the present channel space is restricted to total isospin $T = 0$. This is consistent with the predominance of the $T = 0$ $\alpha + d$ component in ${}^6\text{Li}$ at low excitation energies.

For each binary partition α entering Eq. (2), the internal states of the corresponding two-cluster target subsystem are obtained by solving the microscopic two-cluster Schrödinger equation with full intercluster antisymmetrization. The resulting subsystem wave functions $\psi_\alpha(\mathcal{E}_\alpha, A_\beta + A_\gamma, j_2)$ are represented as antisymmetrized products of the internal wave functions of the two clusters and a relative-motion amplitude depending on their intercluster coordinate. In the numerical implementation, this relative-motion amplitude is expanded in a Gaussian basis. We used four Gaussian basis functions to describe the binary subsystems. As shown in our earlier works (see, for example, Ref. [10]), this number of Gaussian functions provides sufficiently accurate energies and wave functions for bound two-cluster systems. Subsystem polarization is taken into account by retaining, for each α , not only the lowest (ground) subsystem state but also additional discretized-continuum (pseudobound) eigenstates.

Energies of bound and pseudobound states in the dominant two-cluster subsystems are listed in Table I. For ${}^7\text{Li}$, ${}^7\text{Be}$, ${}^6\text{Li}$, and ${}^6\text{He}$ the diagonalization yields bound states. For ${}^5\text{He}$ and ${}^5\text{Li}$, which have no bound states and appear as resonances, it yields pseudobound states. Recall that a pseudobound state is a square-integrable eigenstate associated with the continuum that emerges from the diagonalization procedure. As seen from Table I, our model reproduces well the bound-state energies of ${}^7\text{Li}$ and ${}^7\text{Be}$ and slightly overbinds the ${}^6\text{Li}$ ground state. The pseudobound states in ${}^5\text{He}$ and ${}^5\text{Li}$ are in satisfactory agreement with the corresponding resonance energies.

TABLE II. Threshold energies for the entrance and exit channels relevant to the considered reactions: calculated (E_{calc}) and experimental (E_{expt}) values [15], measured relative to the ${}^7\text{Li}(3/2^-) + p$ threshold. $W_{T=0}$ (in percent) is the weight of the total-isospin $T = 0$ component for each channel.

Channel	$W_{T=0}$ (%)	E_{calc} (MeV)	E_{expt} (MeV)
${}^4\text{He} + {}^4\text{He}$	100	-19.925	-17.347
${}^7\text{Li}(3/2^-) + p$	50	0.00	0.00
${}^7\text{Li}(1/2^-) + p$	50	0.473	0.478
${}^7\text{Be}(3/2^-) + n$	50	1.693	1.644
${}^7\text{Be}(1/2^-) + n$	50	2.140	2.073
${}^6\text{Li}(1^+) + d$	100	7.992	5.025

At first glance, our model noticeably overbinds ${}^6\text{He}$ and ${}^6\text{Be}$ when they are represented as the two-cluster configurations ${}^4\text{He} + 2n$ and ${}^4\text{He} + 2p$. However, the experimental ground-state energies of ${}^6\text{He}$ and ${}^6\text{Be}$ are quoted with respect to the three-body thresholds ${}^4\text{He} + n + n$ and ${}^4\text{He} + p + p$, respectively, whereas our theoretical values are defined with respect to the corresponding two-cluster thresholds ${}^4\text{He} + 2n$ and ${}^4\text{He} + 2p$. Moreover, in the present model, the effective $2n$ and $2p$ clusters carry a positive internal energy.

The relative-motion function $\varphi_{E-\mathcal{E}_\alpha, l_1, j_1}(\mathbf{y}_\alpha)$ describes the motion of the projectile A_α with respect to the center of mass of the pair $A_\beta + A_\gamma$. The vector $\mathbf{y}_\alpha$ is the corresponding Jacobi coordinate, l_1 is the orbital angular momentum associated with this relative motion, and j_1 is the total angular momentum obtained by coupling l_1 to the channel spin.

The intercluster relative-motion wave functions $\varphi_{E-\mathcal{E}_\alpha, l_1, j_1}(\mathbf{y}_\alpha)$ in Eq. (2) are expanded in an oscillator basis for each partial wave, and the multichannel S matrix is extracted from the asymptotic behavior of the resulting coupled-channel solutions [see Eq. (17) of Ref. [12]. The wave function $\Psi^{(E, J)}$ of ${}^8\text{Be}$ is thus obtained as a solution of the corresponding Schrödinger equation with appropriate boundary conditions. Further details of the microscopic many-channel model can be found in Refs. [1, 12].

The astrophysical S factors for reactions in the compound nucleus ${}^8\text{Be}$ are calculated using the Hasegawa–Nagata nucleon-nucleon potential [13, 14]. We adopt the same potential and input parameters as in Paper I [1], where the Majorana parameter was slightly adjusted to reproduce the energies of the ground ($3/2^-$) and first excited ($1/2^-$) states of ${}^7\text{Li}$ and ${}^7\text{Be}$, and thereby the correct relative positions of the $p + {}^7\text{Li}$ and $n + {}^7\text{Be}$ thresholds. Because these nuclei and their low-lying states play a central role in reactions of astrophysical interest, particular care was taken to describe their structure accurately. With this choice, however, the $d + {}^6\text{Li}$ threshold cannot be reproduced simultaneously with the $p + {}^7\text{Li}$ and $n + {}^7\text{Be}$ thresholds; the implications of this limitation for deuteron-induced reactions on ${}^6\text{Li}$ will be discussed below.

The relative positions of the main binary breakup thresholds of ${}^8\text{Be}$ are shown in Fig. 1. Table II lists the calculated and experimental threshold energies for the entrance and exit channels discussed in the present S -factor analysis. For each channel, we also indicate the weight $W_{T=0}$ of the total-isospin $T = 0$ component.

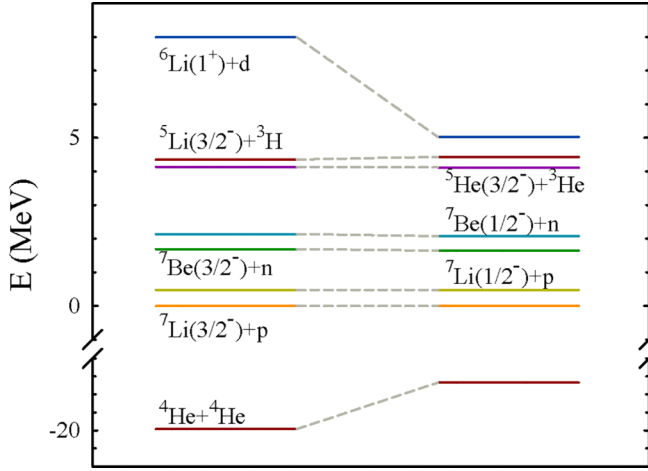


FIG. 1. Relative positions of the main binary breakup thresholds in ${}^8\text{Be}$. Calculated thresholds are shown on the left and experimental ones, taken from Ref. [15], on the right. Energies are measured relative to the ${}^7\text{Li}(3/2^-) + p$ threshold. Dashed lines connect corresponding thresholds.

B. Astrophysical Gamow energies and reaction windows

The energy range most relevant for thermonuclear reactions is defined by the Gamow window, which identifies the region where the product of the Maxwell–Boltzmann distribution and the tunneling probability is maximized [16]. This concept provides a practical criterion for estimating the energies at which charged-particle-induced reactions predominantly occur in astrophysical environments.

In Table III, we present the Gamow peak energy E_0 and the corresponding width ΔE_0 for all entrance channels associated with the reactions considered in this work. Following the approach adopted in our previous studies [12,17], these parameters are evaluated for a typical astrophysical temperature of $T_9 = 0.8$, where T_9 denotes the temperature in units of 10^9 K.

For reactions involving charged particles or clusters, we employ the standard analytic expressions for the Gamow peak and width:

$$E_0 = 0.122 \left(Z_1^2 Z_2^2 \frac{A_1 A_2}{A_1 + A_2} T_9^2 \right)^{1/3} \text{ MeV}, \quad (3)$$

$$\Delta E_0 = 0.2368 \left(Z_1^2 Z_2^2 \frac{A_1 A_2}{A_1 + A_2} T_9^5 \right)^{1/6} \text{ MeV}, \quad (4)$$

where A_1 and Z_1 are the mass number and charge of the first interacting nucleus, and A_2 and Z_2 are those of the second.

TABLE III. Gamow peak energy E_0 and width ΔE_0 for the reaction entrance channels, calculated at $T = 0.8$ GK.

Channel	E_0 , keV	ΔE_0 , keV
$p + {}^7\text{Li}$	209	277
$d + {}^6\text{Li}$	250	303
${}^3\text{He} + {}^5\text{He}$	327	347
$n + {}^7\text{Be}$	103	95

For reactions induced by neutron-nucleus interactions, an analog of the Gamow window can be used, referred to as the effective-energy window. As defined in Ref. [18], the effective-energy window is given by $E_0 \pm \frac{1}{2} \Delta E_0$, where

$$E_0 = 0.086 \left(l + \frac{1}{2} \right) T_9, \quad (5)$$

$$\Delta E_0 = 0.097 \left(l + \frac{1}{2} \right)^{1/2} T_9, \quad (6)$$

and l is the orbital angular momentum of the relative motion between the interacting nuclei.

The cross sections of the ${}^7\text{Be}(n, \alpha){}^4\text{He}$ reaction for p -wave neutrons were experimentally determined for the first time in Ref. [19], at $E_{\text{c.m.}} = 0.20\text{--}0.81$ MeV, slightly above the effective-energy window, by applying the principle of detailed balance to the time-reverse reaction.

In all subsequent figures, the Gamow (effective-energy) window is shown as a dashed band in the astrophysical S -factor plots for each reaction. For the calculation of the effective-energy window parameters E_0 and ΔE_0 for the reaction induced by the $n + {}^7\text{Be}$ interaction, the orbital angular momentum was taken as $l = 1$, corresponding to the dominant partial wave in the entrance channel at low energies.

III. ASTROPHYSICAL S FACTORS AND COMPARISON WITH EXPERIMENT

In this section, we present the astrophysical S factors obtained with the many-channel microscopic model of Sec. II and compare them with available experimental data. We first discuss reactions on $A = 7$ nuclei, beginning with the α -emission mirror pair ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, \alpha){}^4\text{He}$, which share the same $\alpha + \alpha$ exit channel and therefore involve only even- J , positive-parity states, and then turn to the charge-exchange reaction ${}^7\text{Be}(n, p){}^7\text{Li}$. We then consider the deuteron-induced reactions on ${}^6\text{Li}$. Global systematics, including Coulomb effects in the charged entrance channels, low-energy approximations to $S(E)$, and the reaction hierarchy at the Gamow energies defined in Sec. II, are discussed in the subsequent subsections.

A. α -emission reactions: ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, \alpha){}^4\text{He}$

Because the exit channel is $\alpha + \alpha$ with identical bosons, only states with even total angular momentum and positive parity ($J^\pi = 0^+, 2^+, 4^+, \dots$) can contribute to the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, \alpha){}^4\text{He}$ reactions; odd- J and negative-parity states ($1^+, 3^+, 1^-, 2^-, \dots$) are excluded by symmetry. In Paper I, we found a twin 2^+ doublet located just below the $p + {}^7\text{Li}$ threshold, and an additional 2^+ resonance at $E \approx 1.27$ MeV above the ${}^7\text{Be} + n$ threshold, while no 0^+ resonance states appear near either of the $p + {}^7\text{Li}$ or ${}^7\text{Be} + n$ thresholds. The different positions of these 2^+ states relative to the two entrance thresholds, together with the presence or absence of Coulomb repulsion in the entrance channel, explain why the low-energy $S(E)$ behavior differs between the two mirror reactions. Figure 2 shows the astrophysical S factor for ${}^7\text{Li}(p, \alpha){}^4\text{He}$, calculated within the present model and compared with the experimental data summarized in

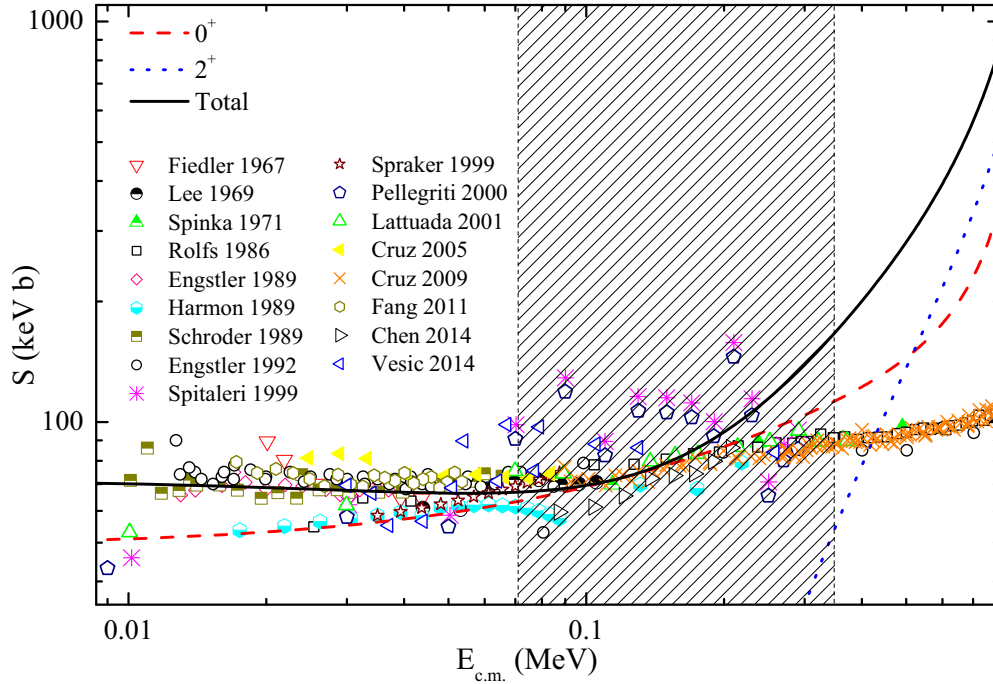


FIG. 2. Total and partial astrophysical S factors for the reaction ${}^7\text{Li}(p, \alpha){}^4\text{He}$ in the center-of-mass energy range $E_{\text{c.m.}} \lesssim 1$ MeV, calculated within the present model and compared with the experimental data listed in Table VI. The dashed and dotted curves denote the $J^\pi = 0^+$ and 2^+ contributions, respectively, and the solid curve shows their sum. The shaded area indicates the Gamow window.

Table VI. The dashed red, dotted blue, and solid black curves represent the 0^+ , 2^+ , and total contributions, respectively; the 4^+ contribution is negligible over the energy range displayed and is not shown. The 0^+ partial wave clearly dominates, while the 2^+ component provides a noticeable correction only at very low ($E_{\text{c.m.}} \lesssim 100$ keV) and relatively high ($E_{\text{c.m.}} \gtrsim 500$ keV) energies. In our microscopic spectrum, there are no 0^+ resonances close to the $p + {}^7\text{Li}$ threshold, and the only nearby structure is the upper member of the twin 2^+ states, located about 200 keV below that threshold. Consequently, the total $S(E)$ varies smoothly with energy and shows no narrow structures in the low-energy region: the 0^+ component sets the overall scale, while the subthreshold 2^+ resonance induces only a gentle curvature as $E \rightarrow 0$. The calculated S factor is in good agreement with the experimental data, particularly for $E_{\text{c.m.}} \lesssim 200$ keV.

The total and partial astrophysical S factors for ${}^7\text{Be}(n, \alpha){}^4\text{He}$ are shown in Fig. 3, together with the experimental data summarized in Table VII. Compared with the mirror ${}^7\text{Li}(p, \alpha){}^4\text{He}$ channel, the ${}^7\text{Be}(n, \alpha){}^4\text{He}$ reaction exhibits a different hierarchy of partial contributions: the 2^+ wave dominates over the whole energy range, followed by the 0^+ component. The 4^+ contribution is small over most of the range but becomes more visible than in the proton-induced reaction at higher energies, while remaining subdominant to the 2^+ and 0^+ parts. The absence of Coulomb repulsion in the entrance channel, together with the proximity of a higher 2^+ resonance located at $E \approx 1.27$ MeV above the ${}^7\text{Be} + n$ threshold (and thus closer to this threshold than to the $p + {}^7\text{Li}$ threshold), enhances the weight of the 2^+ partial wave and leads to a low-energy $S(E)$ that differs from the

almost flat behavior of the mirror $p + {}^7\text{Li}$ reaction. Overall, the calculated total S factor reproduces the magnitude and energy dependence of the experimental data for ${}^7\text{Be}(n, \alpha){}^4\text{He}$ within the quoted uncertainties.

Figure 4 further decomposes the calculated S factors into contributions from reactions with ${}^7\text{Be}$ in its ground ($3/2^-$) and first-excited ($1/2^-$) states. For the ${}^7\text{Be}(1/2^-)$ initial state, the 2^+ partial wave almost saturates the total S factor, so that the total curve nearly coincides with the 2^+ contribution. In contrast, for ${}^7\text{Be}(3/2^-)(n, \alpha){}^4\text{He}$ the 0^+ and 2^+ components are of comparable magnitude, and a pronounced enhancement due to the 2^+ resonance is clearly visible in the 2^+ curve. In our microscopic calculation, this 2^+ state appears at $E \approx 1.27$ MeV above the ${}^7\text{Be} + n$ threshold, in good agreement with the value adopted by Tilley *et al.* [15] and somewhat higher than the resonance energy $E \approx 0.99$ MeV reported by Hayakawa *et al.* [20]. Both analyses require enhanced 2^+ contribution in this region, and the energy dependence of our 2^+ component is qualitatively consistent with the behavior inferred from the data of Ref. [20].

As a consequence of this partial-wave pattern, our calculation predicts that the ${}^7\text{Be}(1/2^-)(n, \alpha){}^4\text{He}$ channel gives a larger contribution than the ${}^7\text{Be}(3/2^-)(n, \alpha){}^4\text{He}$ channel over most of the energy range. This trend is consistent with the state-resolved cross sections extracted by Kawabata *et al.* [19], whose data also indicate a larger cross section for reactions on the first-excited state (the points labeled “Kawabata2017*” and “Kawabata2017gs” in Fig. 4). The sum of the two initial-state contributions reproduces the total S factor shown in Fig. 3, in good agreement with the experimental data. In this sense, the relative weight of the ground and

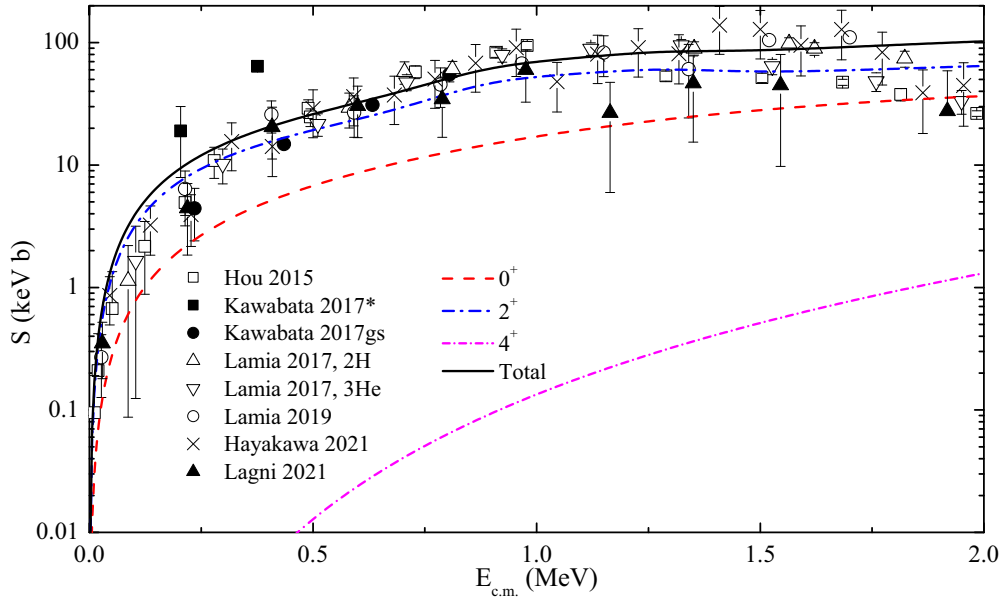


FIG. 3. Total and partial astrophysical S factors for the reaction ${}^7\text{Be}(n, \alpha){}^4\text{He}$, calculated within the present model and compared with the experimental data summarized in Table VII. All experimental datasets except those of Kawabata *et al.* correspond to reactions with ${}^7\text{Be}$ in its ground state; the points labeled Kawabata 2017gs and Kawabata 2017* represent reactions with the ground and first-excited states, respectively. The dashed curves show the $J^\pi = 0^+$, 2^+ , and 4^+ partial contributions, and the solid curve is their sum.

first-excited states of ${}^7\text{Be}$ emerges as a sensitive observable: the present microscopic model provides a definite prediction for this ratio, which can be further tested by future experiments with improved control over the ${}^7\text{Be}$ beam composition and state selectivity.

B. Charge-exchange reaction ${}^7\text{Be}(n, p){}^7\text{Li}$

The astrophysical S factors for ${}^7\text{Be}(n, p){}^7\text{Li}$, calculated within the present model with and without cluster polarization, are shown in Fig. 5 and compared with the experimental data summarized in Table VIII. The figure

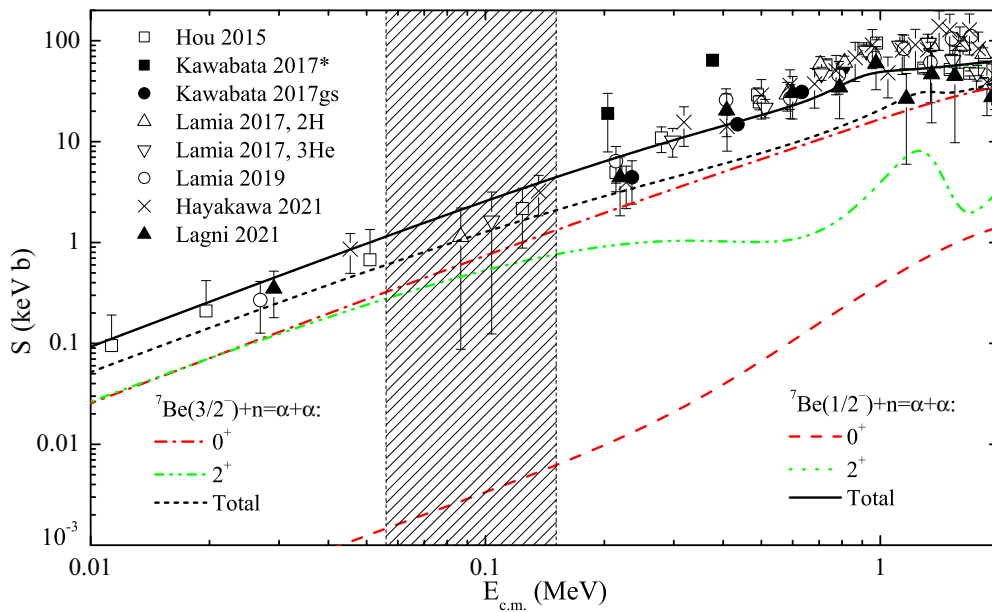


FIG. 4. Low-energy astrophysical S factors for the reaction ${}^7\text{Be}(n, \alpha){}^4\text{He}$, calculated within the present model separately for initial ${}^7\text{Be}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states and compared with the experimental data summarized in Table VII (all non-Kawabata points correspond to reactions on ${}^7\text{Be}$ in its ground state, while Kawabata 2017gs and Kawabata 2017* denote the ground and first-excited states, respectively). For each initial state, the red and green curves denote the 0^+ and 2^+ contributions, respectively, and the black curve gives their sum.

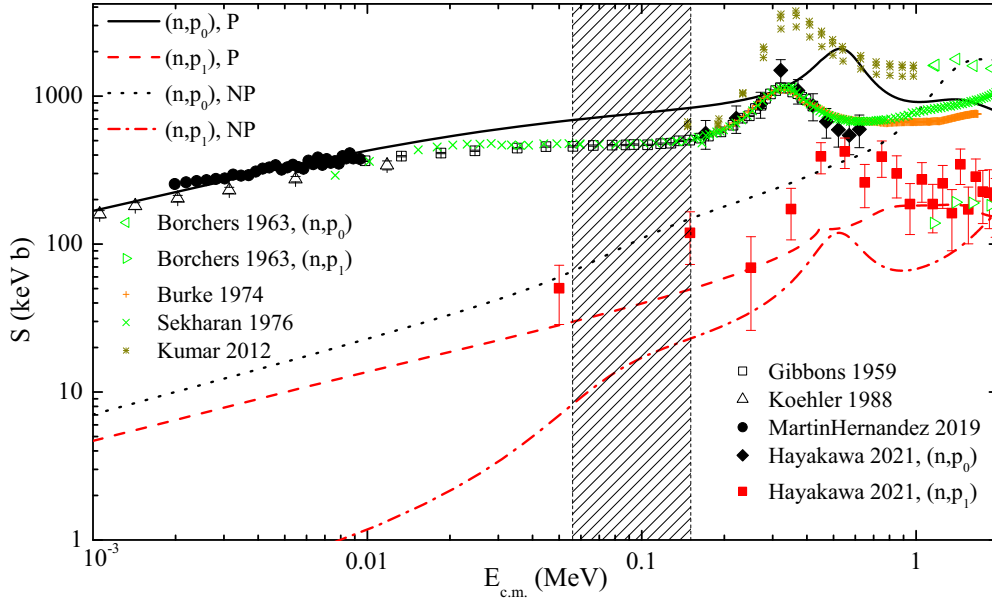


FIG. 5. Astrophysical S factors for the reaction ${}^7\text{Be}(n, p){}^7\text{Li}$, calculated within the present model and compared with experimental data summarized in Table VIII. The (n, p_0) and (n, p_1) channels correspond to ${}^7\text{Li}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively. The labels “P” and “NP” denote calculations with and without cluster polarization. All experimental datasets, except those of Borchers and Hayakawa, correspond to the (n, p_0) channel.

displays both ${}^7\text{Be}(n, p_0){}^7\text{Li}$ and ${}^7\text{Be}(n, p_1){}^7\text{Li}$ channels, each shown for calculations with (P) and without (NP) cluster polarization. Our results exhibit a pronounced enhancement in the ${}^7\text{Be}(n, p_0){}^7\text{Li}$ S factor near $E_{\text{c.m.}} \simeq 0.5$ MeV. This structure is generated by the higher member of the twin 3^+ resonance doublet, which in our model lies about 0.53 MeV above the ${}^7\text{Be} + n$ threshold. In the ${}^7\text{Be}(n, p_1){}^7\text{Li}$ channel, the peak just below 0.5 MeV is produced by a 1^- resonance located at $E \approx 0.45$ MeV. The experimental data show a similar pattern: both channels develop maxima in this energy region, but the peak in the measured S factor for ${}^7\text{Be}(n, p_0){}^7\text{Li}$ is slightly shifted toward lower energies, consistent with the fact that our calculation places the 3^+ resonance about 200 keV higher than the experimental value.

As demonstrated in Paper I, cluster polarization plays a critical role in the formation of the 1^+ , 2^+ , 3^+ , and 4^+ twin resonance states. Figure 5 confirms that it also has a substantial impact on the astrophysical S factor for ${}^7\text{Be}(n, p){}^7\text{Li}$, especially at low energies. Calculations without cluster polarization (NP) underestimate the S factor already at very low energies and throughout the Gamow window and place the (n, p_0) peak at too high an energy. Including cluster polarization (P) enhances the dynamical coupling between entrance and exit channels, increases the S factor at very low energies, and shifts the (n, p_0) maximum toward the experimental value, leading to good overall agreement with the data. Further insight into the charge-exchange mechanism is provided by the decomposition into total angular momentum J , shown in Fig. 6. As discussed above, the $\alpha + \alpha$ exit channel is restricted to even- J , positive-parity states. By contrast, ${}^7\text{Be}(n, p){}^7\text{Li}$ can proceed through both parities and a wider set of J values. In the ${}^7\text{Be}(n, p_0){}^7\text{Li}$ channel, the 3^+ resonance dominates the

peak region just above 0.5 MeV, whereas a 2^- state located very close to the ${}^7\text{Be} + n$ threshold governs the behavior at both lower and higher energies. In contrast, the ${}^7\text{Be}(n, p_1){}^7\text{Li}$ channel is dominated by the 1^- state over the entire energy range: the corresponding 1^- resonance at $E \approx 0.45$ MeV fixes the position of the peak in the (n, p_1) S factor and provides the main contribution away from the maximum.

A comparison of the astrophysical S factors for the two neutron-induced reactions with ${}^7\text{Be}$, ${}^7\text{Be}(n, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, p){}^7\text{Li}$, shows that in the low-energy region the charge-exchange channel ${}^7\text{Be}(n, p){}^7\text{Li}$ clearly dominates over the α -emission channel. Thus, at astrophysically relevant energies, neutron interactions with ${}^7\text{Be}$ predominantly lead to the production of ${}^7\text{Li}$.

C. Deuteron-induced reactions on ${}^6\text{Li}$

We now turn to deuteron-induced reactions on ${}^6\text{Li}$, where all three channels share a common sensitivity to the ${}^6\text{Li} + d$ threshold and to broad 2^+ resonance in ${}^8\text{Be}$ just below this threshold. As discussed in Paper I, the present model places the ${}^6\text{Li} + d$ threshold somewhat too high compared with experiment, which leads to a systematic underestimation of the calculated S factors for the ${}^6\text{Li}(d, \alpha){}^4\text{He}$, ${}^6\text{Li}(d, p){}^7\text{Li}$, and ${}^6\text{Li}(d, n){}^7\text{Be}$ reactions at low entrance-channel energies. Since all three exit channels originate from the same ${}^6\text{Li} + d$ entrance configuration, we therefore examine not only the total $S(E)$ but also the J^π decomposition in order to see which partial waves dominate the calculated S factors in each exit channel.

Figure 7 shows the astrophysical S factor for ${}^6\text{Li}(d, \alpha){}^4\text{He}$, calculated within the present model and compared with the

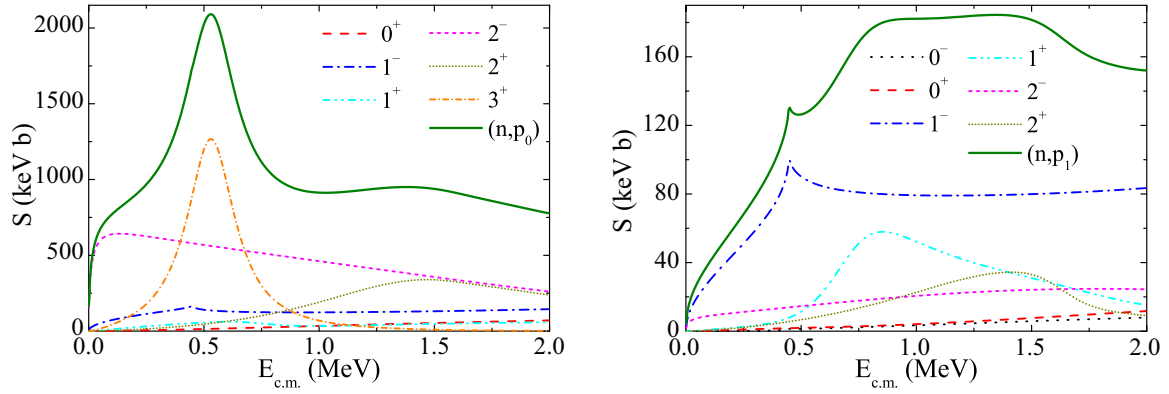


FIG. 6. Contribution of states with the different values of the total angular momentum J to the total astrophysical S -factor of the reaction ${}^7\text{Be}(n, p){}^7\text{Li}$. The (n, p_0) and (n, p_1) channels correspond to ${}^7\text{Li}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively.

experimental data summarized in Table IX of Appendix. Owing to the shifted position of the ${}^6\text{Li}+d$ threshold, the calculated S factor remains lower than most experimental values in the range $E_{\text{c.m.}} \lesssim 1$ MeV. Including cluster polarization increases the S factor and improves agreement with the data, although the enhancement is not sufficient to fully reproduce the experimental magnitudes. At higher energies, the theoretical results gradually converge toward the experimental trend.

The partial S factors shown in Fig. 8 indicate that the 0^+ state provides the dominant contribution to the total ${}^6\text{Li}(d, \alpha){}^4\text{He}$ S factor below $E_{\text{c.m.}} \approx 1.5$ MeV; above this energy, the 2^+ contribution becomes comparable, while the 4^+ component remains small over the entire range displayed. Thus, as in the α -emission reactions with $A = 7$ nuclei, the $\alpha + \alpha$ exit channel is governed primarily by 0^+ and 2^+ waves, with the missing broad 2^+ resonance near the ${}^6\text{Li}+d$ threshold in the present implementation largely responsible for the underestimated S factor at low energies.

The astrophysical S factors for the ${}^6\text{Li}(d, p){}^7\text{Li}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$ reactions are shown in Figs. 9 and 10, respectively, with the corresponding experimental data summarized in Tables X and XI. In Fig. 9, most experimental data for ${}^6\text{Li}(d, p_1){}^7\text{Li}$ lie very close to our calculated ${}^6\text{Li}(d, p_0){}^7\text{Li}$ curve, whereas the experimental S factors for ${}^6\text{Li}(d, p_0){}^7\text{Li}$ itself exceed the theoretical predictions for $E_{\text{c.m.}} \lesssim 1$ MeV. A similar pattern is seen for ${}^6\text{Li}(d, n){}^7\text{Be}$ in Fig. 10, where the calculated S factors reproduce the shapes of the data but underestimate their absolute scale at low energies.

As seen in Figs. 9 and 10, cluster polarization has little effect on the ${}^6\text{Li}(d, p){}^7\text{Li}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$ S factors, in contrast with the ${}^6\text{Li}(d, \alpha){}^4\text{He}$ and, especially, the ${}^7\text{Be}(n, p){}^7\text{Li}$ channels, where its impact is much more pronounced. In these deuteron-induced (d, p) and (d, n) channels, the remaining discrepancy with experiment at $E_{\text{c.m.}} \lesssim 1$ MeV is therefore mainly attributable to the misplaced ${}^6\text{Li}+d$ threshold rather than to the treatment of cluster polarization.

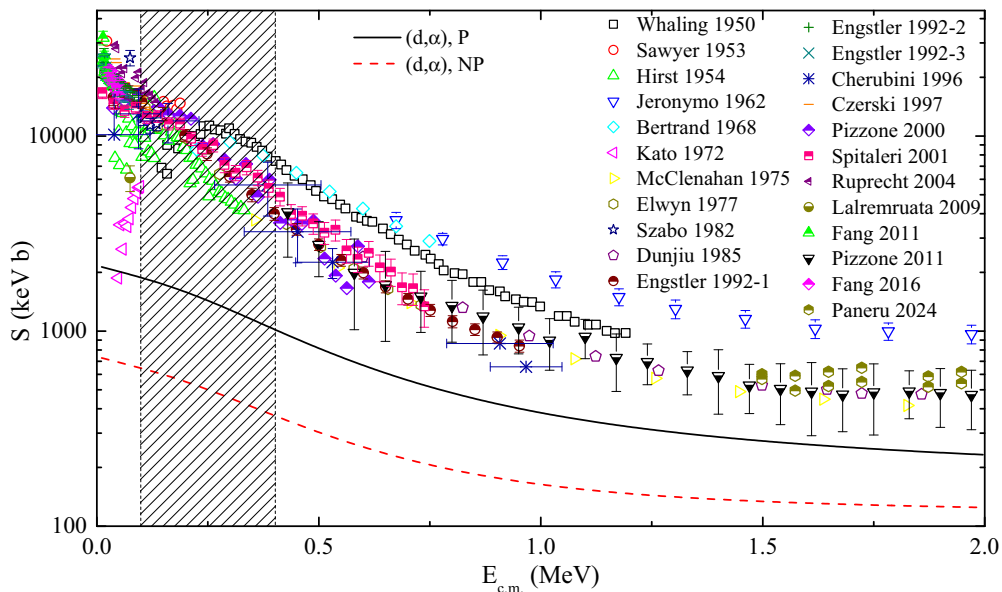


FIG. 7. Astrophysical S factor for the reaction ${}^6\text{Li}(d, \alpha){}^4\text{He}$ calculated within the present model (lines) and compared with experimental data summarized in Table IX. P and NP denote calculations with and without cluster polarization, respectively.

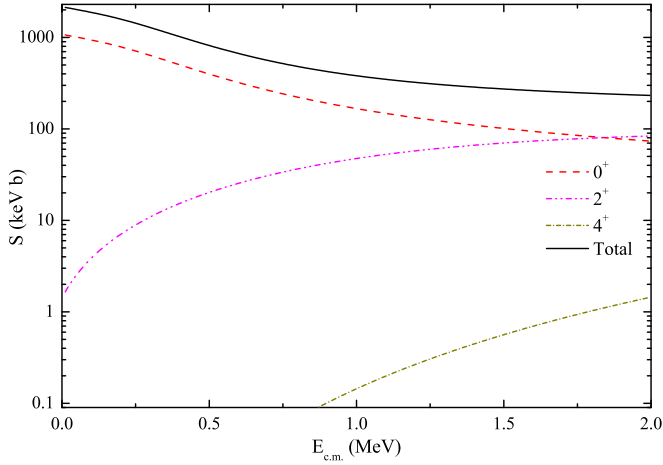


FIG. 8. Contributions of states with different total angular momenta J to the astrophysical S factor for the reaction ${}^6\text{Li}(d, \alpha){}^4\text{He}$, calculated within the present model.

The J^π decomposition provides additional insight into the structure of these charge-exchange channels. Figures 11 and 12 show the partial and total astrophysical S factors for ${}^6\text{Li}(d, p){}^7\text{Li}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$, respectively. In the ${}^6\text{Li}(d, p_0){}^7\text{Li}$ channel (left panel of Fig. 11), the 0^+ and 1^+ states dominate for $0 \leq E_{\text{c.m.}} \lesssim 0.5$ MeV, while at higher energies the 2^- state provides the largest contribution. For ${}^6\text{Li}(d, p_1){}^7\text{Li}$ (right panel), the 1^+ and 0^+ components dominate below $E_{\text{c.m.}} \lesssim 0.25$ MeV, whereas at higher energies the 1^- and 2^- states become dominant.

The pattern for ${}^6\text{Li}(d, n_0){}^7\text{Be}$ (left panel of Fig. 12) is similar: the 0^+ and 1^+ states dominate at low energies ($0 \leq E_{\text{c.m.}} \lesssim 0.4$ MeV), while at higher energies the negative-parity states become more important. The partial S factors for ${}^6\text{Li}(d, n_1){}^7\text{Be}$ (right panel) closely resemble those for ${}^6\text{Li}(d, p_1){}^7\text{Li}$, indicating that the same set of J^π states governs the population of the first-excited $1/2^-$ level in ${}^7\text{Li}$ and ${}^7\text{Be}$.

D. Coulomb effects in the charged entrance channels $p + {}^7\text{Li}$ and $d + {}^6\text{Li}$

Having analyzed the S factors for the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^6\text{Li}(d, \alpha){}^4\text{He}$ reactions separately, we now compare the impact of the Coulomb barrier in these charged entrance channels. This comparison quantifies how the different charges and reduced masses suppress the low-energy S factors relative to each other and helps disentangle Coulomb effects from structural enhancements associated with the ${}^8\text{Be}$ spectrum. Here we use “structural enhancement” to denote the residual contribution to $S(E)$ beyond the Gamow factor, governed primarily by the effective cluster-cluster interaction, entrance-exit channel coupling, and the subthreshold or near-threshold resonance pattern in ${}^8\text{Be}$.

Coulomb repulsion plays a central role in suppressing nuclear reactions involving charged particles at low center-of-mass energies. The strength of this suppression is

characterized by the Sommerfeld parameter

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar} \sqrt{\frac{\mu}{2E}},$$

where Z_1 and Z_2 are the charges of the interacting clusters, E is the center-of-mass energy, and μ is the reduced mass,

$$\mu = m \frac{A_1 A_2}{A_1 + A_2},$$

with A_1 and A_2 the mass numbers and m the nucleon mass. For the $p + {}^7\text{Li}$ and $d + {}^6\text{Li}$ systems one finds

$$\eta_d = \sqrt{\frac{12}{7}} \eta_p,$$

so that the Sommerfeld parameter for $d + {}^6\text{Li}$ is only slightly larger than for $p + {}^7\text{Li}$.

Despite this relatively small difference in η , the astrophysical S factors for the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^6\text{Li}(d, \alpha){}^4\text{He}$ reactions differ by more than two orders of magnitude. Experimentally, the S factor for ${}^6\text{Li}(d, \alpha){}^4\text{He}$ lies in the range 16.9–23 MeV b at zero energy, whereas that for ${}^7\text{Li}(p, \alpha){}^4\text{He}$ is $S(0) \approx 0.06$ MeV b, about 300 times smaller (see Tables IV and V for polynomial fits). This discrepancy cannot be attributed solely to the exponential Coulomb suppression encoded in the Gamow factor. While the S -factor formalism removes the leading tunneling probability, it retains residual Coulomb effects through the interference of Coulomb and nuclear interactions, and the remaining difference reflects primarily nuclear-structure effects: the details of the cluster-cluster interaction, the entrance-exit channel couplings, and the pattern of subthreshold and near-threshold ${}^8\text{Be}$ resonances.

Our microscopic calculations reproduce the S factor for $p + {}^7\text{Li}$ with good accuracy, yielding $S(0) \simeq 0.07$ MeV b, consistent with experiment. For the $d + {}^6\text{Li}$ reaction, the present model predicts $S(0) \simeq 2.16$ MeV b, roughly 30 times larger than the $p + {}^7\text{Li}$ value, but still an order of magnitude below the experimental $S(0)$ for $d + {}^6\text{Li}$. Thus, the model captures the main Coulomb effects and part of the structural enhancement, i.e., the residual contribution to $S(E)$ beyond the Gamow factor, generated by the coupled-channel dynamics in the present many-channel space (including subsystem polarization effects implemented for the relevant $A = 5, 6, 7$ two-cluster subsystems), which yields a much larger low-energy S factor for $d + {}^6\text{Li}$ than for $p + {}^7\text{Li}$. However, the calculated $d + {}^6\text{Li}$ S factor remains below experiment. This remaining deficit is consistent with (i) the shifted ${}^6\text{Li} + d$ threshold relative to the $\alpha + \alpha$ threshold in the present interaction tuning, which reduces the effective entrance-exit coupling in the near-threshold region, and (ii) the absence, in the present implementation, of a broad 2^+ resonance near the ${}^6\text{Li} + d$ threshold.

E. Low-energy approximations to experimental astrophysical S -factor data

To assess the behavior of astrophysical S factors predicted by our model at low energies, we compare them with a selection of empirical parametrizations that have been

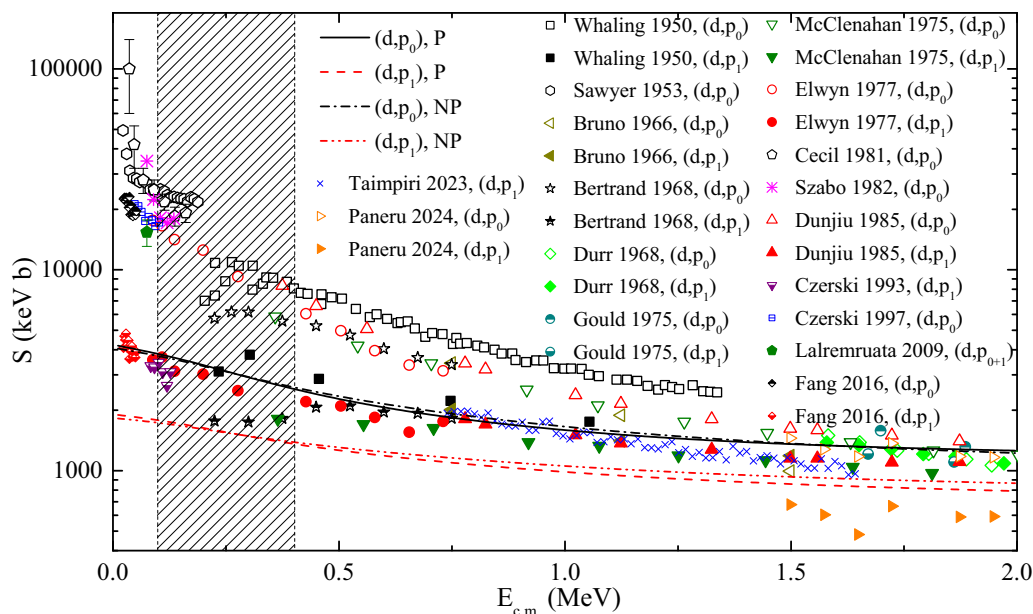


FIG. 9. Astrophysical S factors for the reaction ${}^6\text{Li}(d, p){}^7\text{Li}$ calculated within the present model (lines) and compared with experimental data summarized in Table X. The (d, p_0) and (d, p_1) channels correspond to population of ${}^7\text{Li}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively. The labels “P” and “NP” denote calculations with and without cluster polarization, respectively.

widely used in the literature. These low-energy fits are derived from experimental data, typically over sub-MeV energy ranges relevant to astrophysical processes. Although differing in functional form and fitted datasets, most aim to capture the smooth, nonresonant component of the S -factor near threshold. They are often employed in nuclear reaction-rate calculations due to their simplicity and computational convenience.

However, these parametrizations are purely empirical and lack a direct theoretical foundation; their extrapolation behavior outside the data range is not always controlled. As such, while comparisons with them offer useful insight into how our model aligns with the established data landscape, they must be interpreted with appropriate caution. Our many-channel microscopic cluster model provides a physically motivated description of the same reactions, and its agreement or deviation

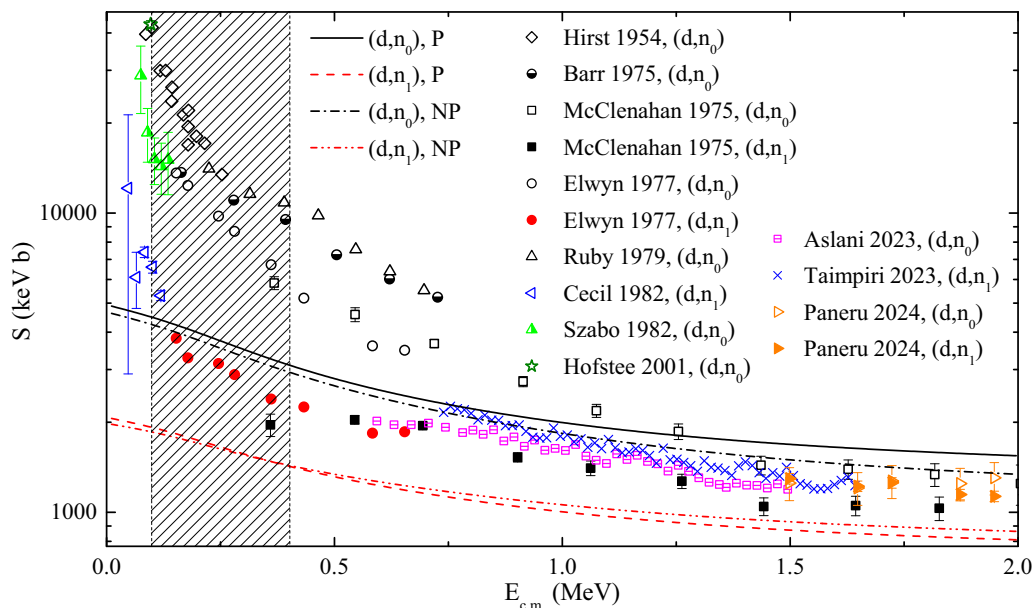


FIG. 10. Astrophysical S factors for the reaction ${}^6\text{Li}(d, n){}^7\text{Be}$ calculated within the present model (lines) and compared with experimental data summarized in Table XI. The (d, n_0) and (d, n_1) channels correspond to ${}^7\text{Be}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively. The labels “P” and “NP” denote calculations with and without cluster polarization, respectively.

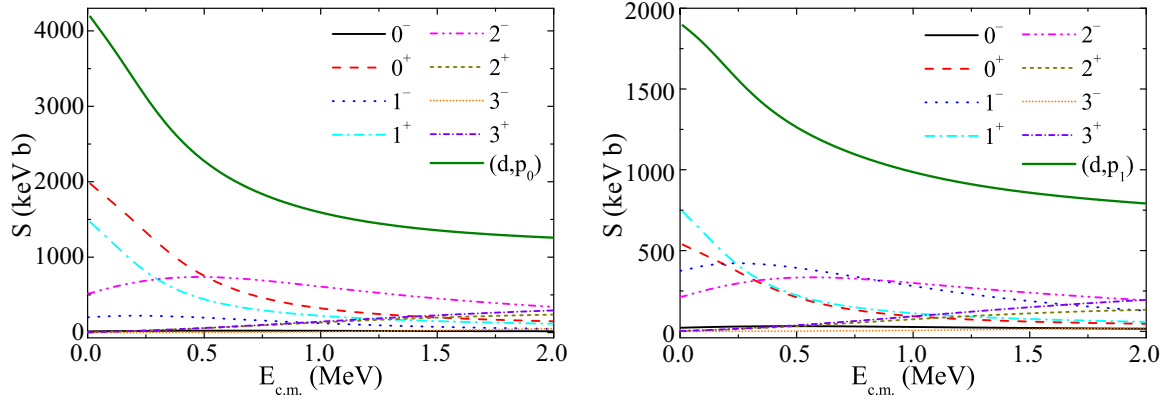


FIG. 11. Contributions of states with different total angular momenta J to the astrophysical S factor of the ${}^6\text{Li}(d, p){}^7\text{Li}$ reaction. The (d, p_0) and (d, p_1) channels correspond to ${}^7\text{Li}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively.

from these fits may help identify both the strengths and the limitations of empirical approaches.

Tables IV and V summarize several representative parametrizations of the experimental S -factor data for the reactions ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^6\text{Li}(d, \alpha){}^4\text{He}$ and include, for comparison, the corresponding low-energy expansions obtained from our model. We provide explicit tables only for these two channels because the literature contains a large number of competing polynomial fits for them, so collecting the most widely used parametrizations in one place is particularly useful; for the other reactions, where only a few reference fits exist, graphical comparisons in Figs. 14 and 15 are sufficient. The lines labeled “Our model” in Tables IV and V represent polynomial fits to the $S(E)$ values generated by our microscopic calculation, valid over the energy ranges indicated in the table captions.

Figure 13 shows the detailed low-energy behavior of the astrophysical S factor for the reaction ${}^7\text{Li}(p, \alpha){}^4\text{He}$ in the energy range $E \leq 250$ keV. The total S factor obtained within the present model exhibits a slow increase as the energy decreases below $E \lesssim 50$ keV. This trend originates from the subthreshold 2^+ resonance located about 0.2 MeV below the ${}^7\text{Li} + p$ threshold, which induces a parabolic shape of the S factor in this region. The predicted behavior is consistent

with low-energy analytical approximations to the experimental data shown in the figure.

Figure 14 shows a comparison of the low-energy behavior of the astrophysical S factor for the reaction ${}^7\text{Be}(n, p){}^7\text{Li}$, as calculated in the present microscopic model, with several representative results from the literature. The curve by Descouvemont *et al.* [33] is based on an R -matrix analysis of low-energy experimental data, while the parametrization by Meissner *et al.* [34] results from a fit with a nonrelativistic Breit–Wigner function and polynomials in $\sqrt{E}$ to the experimental measurements of Refs. [36,37]. The fit labeled “Iwasa2025” corresponds to an S factor extracted from the total cross section of the ${}^7\text{Be}(n, p_1){}^7\text{Li}$ reaction, as reported in [35]. The present model reproduces both the absolute value and the energy dependence of the S -factor for the ${}^7\text{Be}(n, p_0){}^7\text{Li}$ reaction very well in the low-energy region ($E < 0.02$ MeV), while the predicted S factor for the ${}^7\text{Be}(n, p_1){}^7\text{Li}$ channel exceeds the Iwasa2025 fit at the energies below 1 MeV.

Figure 15 shows the low-energy astrophysical S factors for the reactions ${}^6\text{Li}(d, p_0){}^7\text{Li}$ and ${}^6\text{Li}(d, p_1){}^7\text{Li}$, as calculated in the present model, compared with low-energy analytical fits to experimental data from Refs. [32,38,39]. The calculated S factor for the (d, p_1) channel is in reasonable agreement

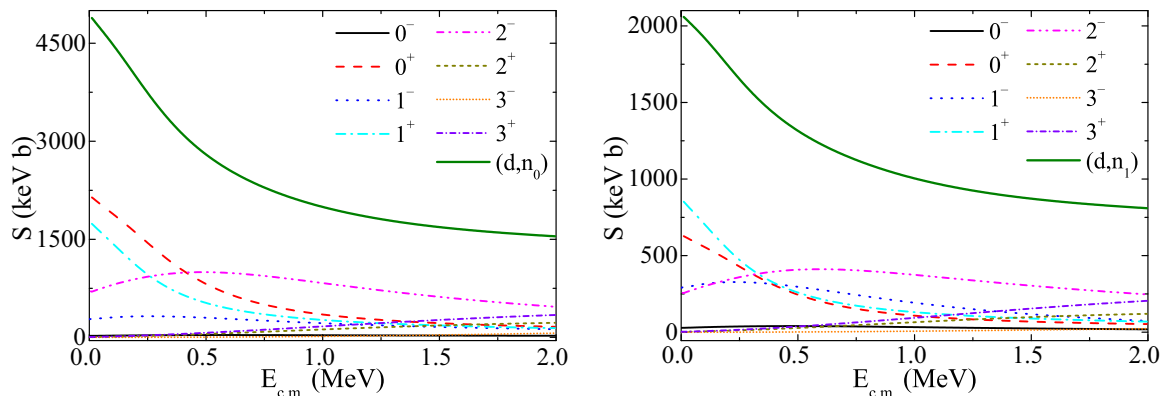


FIG. 12. Contributions of states with different total angular momenta J to the astrophysical S factor of the ${}^6\text{Li}(d, n){}^7\text{Be}$ reaction. The (d, n_0) and (d, n_1) channels correspond to ${}^7\text{Be}$ in the ground ($3/2^-$) and first-excited ($1/2^-$) states, respectively.

TABLE IV. The low-energy approximations to the experimental data of the astrophysical S factors of the reaction ${}^7\text{Li}(p, \alpha)\alpha$. Our model fit applies to the range 6–250 keV.

Our notation	Source	$S(E)$, MeV b
Engstler 1992	[21]	$0.0593 + 0.1929E - 0.3555E^2 + 0.2363E^3$
Smith 1993	[22]	$0.052 + 0.041[1 - \exp(-8.804E)]$
Yamashita 1995	[5]	$0.0565 + 0.1705E - 0.1986E^2$
Lattuada 2001	[23]	$0.055 + 0.210E - 0.310E^2$
Barker 2002	[24]	$0.0621 + 0.159E - 0.280E^2 + 0.186E^3$
Cybert 2004	[25]	$0.0607 + 0.1926E - 0.4603E^2 + 0.5181E^3 - 0.1951E^4$
Serpico 2004	[26]	$0.0609 + 0.173E - 0.319E^2 + 0.217E^3$
CruzDiss	[27]	$0.0594 + 0.141E - 0.223E^2 + 0.153E^3$
Kimura 2007	[28]	$0.062 + 0.15E - 0.24E^2 + 0.14E^3$
Wang 2012	[29]	$0.0616 + 0.162E - 0.284E^2 + 0.187E^3$
Our model	This article	$0.0721 - 0.2143E + 2.2294E^2 - 3.9083E^3 + 4.5481E^4$

with empirical approximations across the energy range shown, while for the (d, p_0) channel the model underestimates the low-energy enhancement, consistent with the overall underestimation of the ${}^6\text{Li}(d, \alpha){}^4\text{He}$ S factor discussed above. This enhancement is commonly attributed to the influence of a

broad subthreshold 2^+ resonance in ${}^8\text{Be}$, located approximately 80 keV below the reaction threshold [39]. Since this resonance is not included in our current model, the resulting S factor for the (d, p_0) channel aligns more closely with DWBA calculations containing only the direct component [38] (shown as “Ruprecht 2002, (d, p_0) , d.s.o.” in Fig. 15).

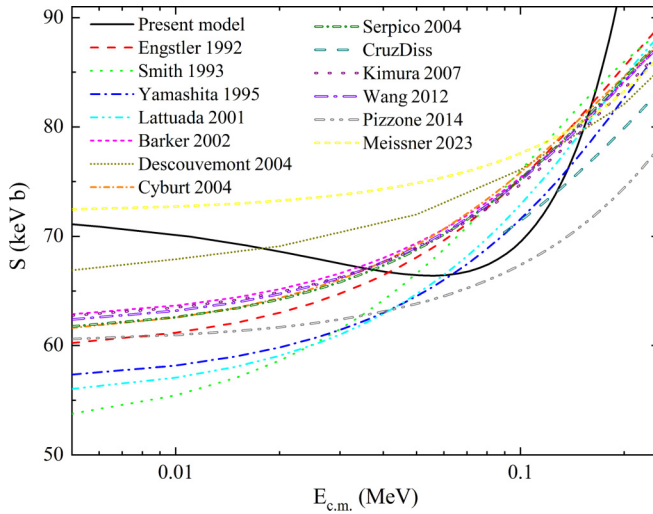


FIG. 13. Low-energy behavior of the astrophysical S factor for the reaction ${}^7\text{Li}(p, \alpha){}^4\text{He}$, calculated within the present model and compared with various low-energy analytical approximations derived from experimental data and listed in Table IV.

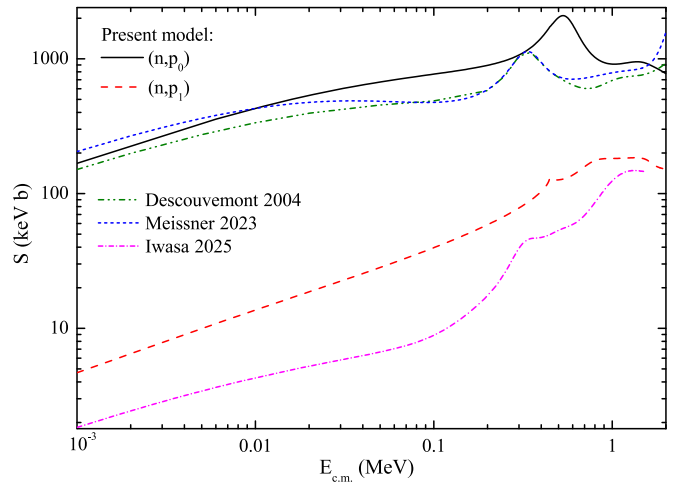


FIG. 14. Low-energy behavior of the astrophysical S factor for the reaction ${}^7\text{Be}(n, p){}^7\text{Li}$, calculated within the present model and compared with analytical approximations based on experimental data fits from Refs. [33–35].

TABLE V. The low-energy approximations to the experimental data of the astrophysical S factors of the reaction ${}^6\text{Li}(d, \alpha)\alpha$. Our model fit applies to the range 1–250 keV.

Our notation	Source	$S(E)$, MeV b
Engstler 1992	[21]	$18.79 - 58.54E + 66.64E^2 - 25.81E^3$
Czerski 1997	[30]	$23 \exp[-4.838E + 1.3586E^2]$
Musumarra 2001	[31]	$16.9 - 41.6E + 28.2E^2$
Barker 2002	[24]	$19.7 - 66.0E + 79.7E^2 - 33.0E^3$
Wang 2012	[29]	$20.5 - 70.6E + 88.5E^2 - 37.9E^3$
Fang 2016	[32]	$19.20 - 62.24E + 73.13E^2 - 29.51E^3$
Our model	This article	$2.16 - 2.87E + 0.53E^2 - 3.09E^3$

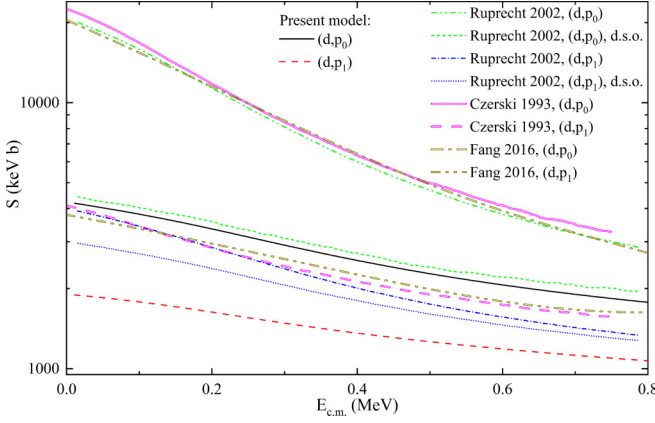


FIG. 15. Low-energy behavior of the astrophysical S factor for the reaction ${}^6\text{Li}(d, p){}^7\text{Li}$, shown separately for the (d, p_0) and (d, p_1) channels. Solid and dashed curves represent the present model, while colored lines show analytical approximations based on experimental data from Refs. [32,38,39]. For comparison, DWBA calculations including only direct contributions are also shown (Ruprecht2002, d.s.o.).

F. Hierarchy of reaction channels in the ${}^8\text{Be}$ compound system at Gamow energies

Figure 16 summarizes the hierarchy of deuteron-induced reactions on ${}^6\text{Li}$ at a stellar temperature $T = 0.8$ GK. The astrophysical S factors are evaluated at the corresponding Gamow energy, $E_0 = 250$ keV (see Table III). Within the present model, the ${}^6\text{Li}(d, n_0){}^7\text{Be}$ channel is dominant: its $S(E_0)$ exceeds those of ${}^6\text{Li}(d, \alpha){}^4\text{He}$, ${}^6\text{Li}(d, p_1){}^7\text{Li}$, and ${}^6\text{Li}(d, n_1){}^7\text{Be}$ by more than a factor of 2. The second most important reaction is ${}^6\text{Li}(d, p_0){}^7\text{Li}$, whose astrophysical S factor at the Gamow energy is about 83% of that of the dominant ${}^6\text{Li}(d, n_0){}^7\text{Be}$ reaction. The hierarchy of reactions induced by neutrons on ${}^7\text{Be}$, evaluated at the effective energy $E_0 = 103$ keV, is shown in Fig. 17. The S factor of the charge-exchange reaction ${}^7\text{Be}(n, p_0){}^7\text{Li}$ is about one order of magnitude larger than that of ${}^7\text{Be}(n, p_1){}^7\text{Li}$ (771 keV b compared with 40 keV b) and two orders of magnitude larger than that of ${}^7\text{Be}(n, \alpha){}^4\text{He}$ (≈ 4 keV b). Thus, at a stellar

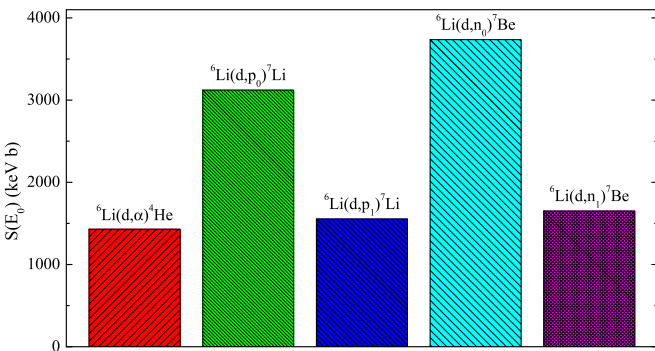


FIG. 16. Astrophysical S factors for reactions induced by deuterons on ${}^6\text{Li}$, evaluated at the Gamow energy $E_0 = 250$ keV. Here p_0 (n_0) and p_1 (n_1) denote the population of the ground ($3/2^-$) and first-excited ($1/2^-$) states in ${}^7\text{Li}$ (${}^7\text{Be}$), respectively.

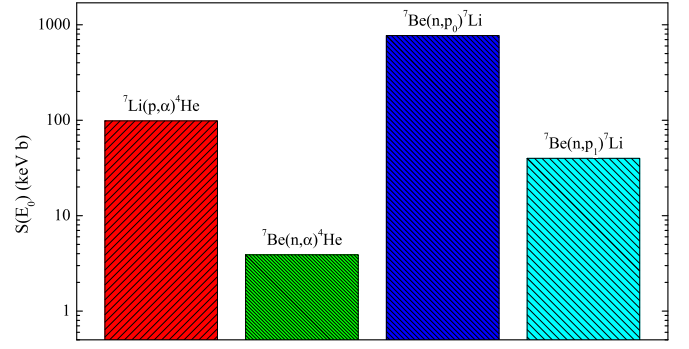


FIG. 17. Astrophysical S factors for reactions induced by neutrons on ${}^7\text{Be}$, evaluated at the Gamow energy $E_0 = 103$ keV, and for the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ reaction, evaluated at $E_0 = 209$ keV.

temperature of $T = 0.8$ GK, neutron interactions with ${}^7\text{Be}$ predominantly proceed through the ${}^7\text{Be}(n, p_0){}^7\text{Li}$ channel rather than through α emission. For comparison, Fig. 17 also includes the S factor of the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ reaction, evaluated at its Gamow energy $E_0 = 209$ keV, which is substantially smaller—by roughly a factor of eight—than that of the dominant ${}^7\text{Be}(n, p_0){}^7\text{Li}$ channel.

IV. CONCLUSIONS

In this second paper of our series on the ${}^8\text{Be}$ system, we extend the microscopic many-channel three-cluster framework used in Paper I [1] to low-energy reactions in the $p + {}^7\text{Li}$, $n + {}^7\text{Be}$, and $d + {}^6\text{Li}$ entrance channels. Within this unified model, which includes the ${}^4\text{He} + {}^3\text{H} + p$, ${}^4\text{He} + {}^3\text{He} + n$, ${}^4\text{He} + d + d$, and ${}^4\text{He} + 2p + 2n$ configurations and embeds all binary rearrangement channels with ground and excited states of ${}^7\text{Be}$, ${}^7\text{Li}$, ${}^5\text{Li}$, and ${}^5\text{He}$, we have calculated the astrophysical S factors for the reactions ${}^7\text{Li}(p, \alpha){}^4\text{He}$, ${}^7\text{Be}(n, \alpha){}^4\text{He}$, ${}^7\text{Be}(n, p){}^7\text{Li}$, ${}^6\text{Li}(d, \alpha){}^4\text{He}$, ${}^6\text{Li}(d, p){}^7\text{Li}$, and ${}^6\text{Li}(d, n){}^7\text{Be}$ in the energy range relevant for primordial and stellar nucleosynthesis. A dedicated scan of the low-energy region in all three entrance channels revealed no additional narrow or broad resonances close to the $p + {}^7\text{Li}$, $n + {}^7\text{Be}$, or $d + {}^6\text{Li}$ thresholds; within the present framework the often-invoked scenario of an unknown near-threshold resonance that could resolve the lithium problems is therefore not supported. This conclusion is consistent with the big-bang nucleosynthesis (BBN) response analysis of Ref. [40], which finds that the enhancement of the ${}^7\text{Be} + n$ destruction rate required to solve the lithium problem is incompatible with general nuclear-physics constraints on the relevant cross sections.

For the mirror reactions ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, \alpha){}^4\text{He}$, and for the charge-exchange channel ${}^7\text{Be}(n, p){}^7\text{Li}$, the calculated $S(E)$ curves reproduce both the absolute scale and the low-energy trends of the data within their quoted uncertainties. The partial-wave analysis connects these observables directly to the ${}^8\text{Be}$ spectrum obtained in Paper I: the low-energy ${}^7\text{Li}(p, \alpha){}^4\text{He}$ S factor is governed by the $J^\pi = 0^+$ component with curvature induced by subthreshold 2^+ strength, whereas ${}^7\text{Be}(n, \alpha){}^4\text{He}$ is dominated by the 2^+ wave,

TABLE VI. Experimental data for the reaction ${}^7\text{Li}(p,\alpha){}^4\text{He}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
(p, α)	$\sigma(E)$, mb	0.020–0.044	+	Fiedler 1967	[41]
(p, α)	$\sigma(E)$, mb	0.044–0.105	+	Lee 1969	[42]
(p, α)	$\sigma(E)$, mb	0.114–0.490	+	Spinka 1971	[43,44]
(p, α)	$S(E)$, keV b	0.025–0.873	–	Rolfs 1986	[45]
(p, α)	$S(E)$, MeV b	0.013–0.041	+	Engstler 1989	[46]
(p, α)	$\sigma(E)$, b	0.017–0.219	+	Harmon 1989	[47]
(p, α)	$S(E)$, keV b	0.010–0.065	+	Schroder 1989	[48]
(p, α)	$S(E)$, keV b	0.013–1.004	+	Engstler 1992	[21]
(p, α)	$S(E)$, keV b	0.010–0.290	+	Spitaleri 1999	[49]
(p, α)	$S(E)$, mb	0.035–0.087	+	Spraker 1999	[50]
(p, α)	$S(E)$, keV b	0.009–0.290	–	Pellegriti 2000	[51]
(p, α)	$S(E)$, keV b	0.010–0.371	+	Lattuada 2001	[23]
(p, α)	$S(E)$, keV b	0.025–0.083	+	Cruz 2005	[27,52]
(p, α)	$S(E)$, keV b	0.090–1.740	+	Cruz 2009	[27,53]
(p, α)	$S(E)$, MeV b	0.017–0.053	+	Fang 2011	[54]
(p, α)	$S(E)$, MeV b	0.087–0.207	–	Chen 2014	[55]
(p, α)	$S(E)$, keV b	0.030–0.258	–	Vesic 2014	[56]

with the 0^+ component remaining subdominant and the 4^+ contribution becoming noticeable only at higher energies. In the ${}^7\text{Be}(n, \alpha){}^4\text{He}$ channel, reactions on the first-excited $1/2^-$ state of ${}^7\text{Be}$ contribute more strongly than those on the ground $3/2^-$ state, in line with the state-resolved cross sections of Ref. [19]. For ${}^7\text{Be}(n, p){}^7\text{Li}$ the enhancement near $E_{\text{c.m.}} \approx 0.5$ MeV is generated by the 3^+ and 1^- resonances identified previously, and cluster polarization is essential to reproduce both the low-energy normalization and the correct position of the (n, p_0) peak. Thus, the same microscopic ingredients—specific J^π resonances and polarization of the binary subsystems—that were shown in Paper I to shape the high-lying ${}^8\text{Be}$ spectrum also control the astrophysical S factors at low entrance-channel energies near the $p + {}^7\text{Li}$, $n + {}^7\text{Be}$, and $d + {}^6\text{Li}$ thresholds.

For deuteron-induced reactions on ${}^6\text{Li}$, the model captures the qualitative hierarchy of exit channels and the dominant J^π components but underestimates the absolute S factors at $E_{\text{c.m.}} \lesssim 1$ MeV. This shortcoming can be traced to the position of the ${}^6\text{Li}+d$ threshold and to the absence, in the present implementation, of a broad subthreshold $J^\pi = 2^+$ structure in ${}^8\text{Be}$ very close to that threshold. Cluster polarization enhances the ${}^6\text{Li}(d, \alpha){}^4\text{He}$ S factor and improves agreement with experiment, while having a more modest effect on ${}^6\text{Li}(d, p){}^7\text{Li}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$. Despite this limitation, the J^π analysis remains physically transparent: 0^+ (and, at higher energies, 2^+) controls reactions with the $\alpha + \alpha$ exit channel, whereas combinations of 0^+ , 1^+ and negative-parity states ($1^-, 2^-$) govern the (d, p) and (d, n) transitions to the ground and first-excited states of ${}^7\text{Li}$ and ${}^7\text{Be}$. Comparisons with empirical low-energy fits confirm the microscopic description for ${}^7\text{Li}(p, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, p_0){}^7\text{Li}$ and isolate the missing subthreshold 2^+ strength as the main source of discrepancy in ${}^6\text{Li}(d, \alpha){}^4\text{He}$ and ${}^6\text{Li}(d, p_0){}^7\text{Li}$, while the ${}^6\text{Li}(d, p_1){}^7\text{Li}$ channel, where this strength is known to be much weaker, is reproduced more accurately.

Evaluating the S factors at Gamow energies characteristic of big bang and stellar conditions, we find that ${}^6\text{Li}(d, n_0){}^7\text{Be}$ and ${}^6\text{Li}(d, p_0){}^7\text{Li}$ dominate among the deuteron-induced channels on ${}^6\text{Li}$ at $T = 0.8$ GK, while ${}^7\text{Be}(n, p_0){}^7\text{Li}$ is by far the strongest neutron-induced channel on ${}^7\text{Be}$ and exceeds the ${}^7\text{Li}(p, \alpha){}^4\text{He}$ S factor evaluated at its Gamow energy. These hierarchies show that, at the relevant Gamow energies, neutron-induced reactions with ${}^7\text{Be}$ and deuteron-induced reactions with ${}^6\text{Li}$ provide significant pathways for the production and redistribution of ${}^7\text{Li}$ and ${}^7\text{Be}$. Taken together with the resonance analysis of Paper I, the present results demonstrate that a single microscopic, many-channel cluster approach can give a coherent and predictive description of both the ${}^8\text{Be}$ spectrum and reaction observables at low entrance-channel energies, and they highlight specific observables—such as the relative contributions of the ground and first-excited states in ${}^7\text{Be}(n, \alpha){}^4\text{He}$ and ${}^7\text{Be}(n, p){}^7\text{Li}$, as well as the hierarchy of $S(E_0)$ values at Gamow energies—as concrete targets for future high-precision measurements of lithium-related reaction channels.

ACKNOWLEDGMENTS

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DATA AVAILABILITY

The data that support the findings of this article are not publicly available. The data are available from the authors upon reasonable request.

TABLE VII. Experimental cross section of the reaction ${}^7\text{Be}(n, \alpha){}^4\text{He}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.011–5.754	—	Hou 2015	[57]
${}^7\text{Be}^*(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.204–0.376	+	Kawabata 2017*	[19]
${}^7\text{Be}_{\text{gs}}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.235–0.805	+	Kawabata 2017gs	[19]
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.087–4.048	—	Lamia 2017, 2H	[58]
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.104–5.252	—	Lamia 2017, 3He	[58]
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.027–1.700	+	Lamia 2019	[59]
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.045–1.955	+	Hayakawa 2021	[20]
${}^7\text{Be}(n, \alpha){}^4\text{He}$	$\sigma(E)$, mb	0.029–1.918	—	Lagni 2021	[60]

APPENDIX: EXPERIMENTAL RESULTS

In this Appendix, we compile the experimental data used for comparison with our theoretical results. The datasets are summarized in six tables: Tables VI–XI, which correspond to the reactions ${}^7\text{Li}(p, \alpha){}^4\text{He}$, ${}^7\text{Be}(n, \alpha){}^4\text{He}$, ${}^7\text{Be}(n, p){}^7\text{Li}$, ${}^6\text{Li}(d, \alpha){}^4\text{He}$, ${}^6\text{Li}(d, p){}^7\text{Li}$, and ${}^6\text{Li}(d, n){}^7\text{Be}$, respectively.

Each table lists the measured (or derived) quantity, its energy range, and the corresponding reference. The column “EXFOR source” indicates whether the numerical data were taken directly from the EXFOR database (“+”) or digitized from the original publication (“—”). Dataset labels given under “Our notation” are identical to those used in the figures. For recent experiments not yet included in EXFOR, we follow the same referencing format.

The conventions used in compiling the data and the specific features of individual experiments are outlined below.

Notes on experimental datasets and conventions

General conventions. All energies are quoted in the center-of-mass frame, $E_{\text{c.m.}}$. Reported quantities are the integrated cross section $\sigma(E)$, differential cross section $d\sigma/d\Omega$, or the astrophysical S factor $S(E)$ in the units given in the tables. When the literature reports S in MeV b, we convert to keV b for internal uniformity in plots; the tables preserve the authors’ original units. The EXFOR source column indicates whether numerical data were taken directly from EXFOR (+) or from the article/thesis tables or our digitization (—).

The “Our notation” column lists the short labels used in our figures.

Electron screening and indirect methods. At very low energies in charged-particle reactions, some direct measurements are affected by electron screening; we compare with the values as reported by the authors without applying additional screening corrections. Indirect determinations (e.g., Trojan-Horse or breakup methods) are largely free from atomic screening but may carry model dependence.

Practical implications for our comparisons. (i) No cross-experiment renormalization has been applied in the appendix tables; each dataset is shown as published (units and targets preserved). (ii) Forward-reverse conversions [for ${}^7\text{Be}(n, p)$] follow the specific relations used by the cited authors; we do not recompute these from raw reverse-channel data here.

a. Comments on ${}^7\text{Li}(p, \alpha){}^4\text{He}$ data

Spinka (1971) and Harmon (1989) report the number of α particles emitted per incident proton. Since $p + {}^7\text{Li} \rightarrow 2\alpha$ produces two α particles per event, the total reaction cross section is obtained by dividing the reported α yield by 2 before converting to $\sigma(E)$.

b. Comments on ${}^7\text{Be}(n, \alpha){}^4\text{He}$ data

State selection (Kawabata 2017). Separate cross sections are reported for reactions on ground state ${}^7\text{Be}$ and on the first-excited state ${}^7\text{Be}^*$ (0.429 MeV). We

TABLE VIII. Experimental data for the reaction ${}^7\text{Be}(n, p){}^7\text{Li}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
${}^7\text{Be}(n, p_0){}^7\text{Li}$	$\sigma(E) \times \sqrt{E}$, b MeV ^{1/2}	0.0098–0.421	—	Gibbons 1959	[61]
${}^7\text{Be}(n, p){}^7\text{Li}$	$\sigma(E)$, b	2.35×10^{-8} –0.012	+	Koehler 1988	[36]
${}^7\text{Be}(n, p_0){}^7\text{Li}$	$\sigma(E) \times \sqrt{E}$, b MeV ^{1/2}	0.0020–0.0094	—	MartinHernandez 2019	[61]
${}^7\text{Be}(n, p_0){}^7\text{Li}$	$\sigma(E)$, mb	0.171–0.621	+	Hayakawa 2021, (n, p_0)	[20]
${}^7\text{Be}(n, p_1){}^7\text{Li}$	$\sigma(E)$, mb	0.05–2.45	+	Hayakawa 2021, (n, p_1)	[20]
${}^7\text{Be}(n, p_0){}^7\text{Li}$	$S(E)$, keV b	1.168–7.058	—	Borchers 1963, (n, p_0)	[62]
${}^7\text{Be}(n, p_1){}^7\text{Li}$	$S(E)$, keV b	1.160–7.066	—	Borchers 1963, (n, p_1)	[62]
${}^7\text{Be}(n, p){}^7\text{Li}$	$S(E)$, keV b	0.183–1.678	—	Burke 1974	[63]
${}^7\text{Be}(n, p){}^7\text{Li}$	$S(E)$, keV b	0.0076–2.031	—	Sekharan 1976	[64]
${}^7\text{Be}(n, p){}^7\text{Li}$	$S(E)$, keV b	0.147–0.977	—	Kumar 2012	[65]

TABLE IX. Experimental data for the reaction ${}^6\text{Li}(d,\alpha){}^4\text{He}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
(d, α)	$\frac{d\sigma}{d\Omega}$, mb/sr	0.146–1.191	+	Whaling 1950	[66]
(d, α)	$\frac{d\sigma}{d\Omega}$, $\mu\text{b/sr}$	0.022–0.188	+	Sawyer 1953	[67]
(d, α)	$\frac{d\sigma}{d\Omega}$, mb/sr	0.041–0.332	+	Hirst 1954	[68]
(d, α)	$\sigma(E)$, mb	0.674–3.708	+	Jeronymo 1962	[69]
(d, α)	$\sigma(E)$, mb	0.225–0.749	+	Bertrand 1968	[70]
(d, α_0)	$\frac{d\sigma}{d\Omega}$, mb/sr	0.048–0.097	+	Kato 1972	[71]
(d, α)	$\sigma(E)$, mb	0.357–2.572	+	McClenahan 1975	[72]
(d, α)	$\sigma(E)$, mb	0.088–0.730	+	Elwyn 1977	[73]
(d, α)	$\sigma(E)$, mb	0.075–0.135	–	Szabo 1982	[74]
(d, α)	$\sigma(E)$, mb	0.375–1.858	+	Dunjiu 1985	[75]
(d, α)	$S(E)$, MeV b	0.037–0.952	+	Engstler 1992-1	[21]
(d, α)	$S(E)$, MeV b	0.016–0.090	+	Engstler 1992-2	[21]
(d, α)	$S(E)$, MeV b	0.014–0.073	+	Engstler 1992-3	[21]
(d, α)	$S(E)$, MeV b	0.039–0.967	–	Cherubini 1996	[76]
(d, α)	$S(E)$, MeV b	0.041–0.132	–	Czerski 1997	[30]
(d, α)	$S(E)$, MeV b	0.037–0.613	–	Pizzone 2000	[77]
(d, α)	$S(E)$, MeV b	0.012–0.737	+	Spitaleri 2001	[78]
(d, α)	$S(E)$, MeV b	0.041–0.132	–	Ruprecht 2004	[6]
(d, α)	$S(E)$, MeV b	0.075	+	Lalremruata 2009	[79]
(d, α)	$S(E)$, MeV b	0.014–0.039	+	Fang 2011	[54]
(d, α)	$\sigma(E)$, mb	0.430–4.963	+	Pizzone 2011	[80]
(d, α)	$S(E)$, MeV b	0.023–0.052	+	Fang 2016	[32]
(d, α)	$\frac{d\sigma}{d\Omega}$, mb/sr	1.498–7.491	+	Paneru 2024	[81]

list these datasets distinctly as Kawabata 2017gs and Kawabata 2017*.

Indirect extractions (Lamia 2017). The ${}^7\text{Be}(n, \alpha)$ cross section was derived using deuteron and ${}^3\text{He}$ breakup data (“2H” and “3He” rows), via detailed balance and reaction theory.

c. Comments on ${}^7\text{Be}(n, p){}^7\text{Li}$ data

Reverse-reaction mapping (Gibbons 1959 and Martin-Hernandez 2019). In Ref. [61], the quantities $\sigma(E)\sqrt{E}$

TABLE X. Experimental data for the reaction ${}^6\text{Li}(d, p){}^7\text{Li}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
$(d, p_{0,1})$	$\frac{d\sigma}{d\Omega}$, mb/sr	0.203–1.336; 0.234–1.054	+	Whaling 1950	[66]
(d, p)	$\frac{d\sigma}{d\Omega}$, $\mu\text{b/sr}$	0.022–0.188	+	Sawyer 1953	[67]
$(d, p_{0,1})$	$\sigma(E)$, mb	0.749–1.498	–	Bruno 1966	[72]
$(d, p_{0,1})$	$\sigma(E)$, mb	0.225–0.749	+	Bertrand 1968	[70]
$(d, p_{0,1})$	$\frac{d\sigma}{d\Omega}$, mb/sr	1.522–8.316; 1.563–8.166	+	Durr 1968	[82]
$(d, p_{0,1})$	$\sigma(E)$, mb	1.698–5.225; 1.671–4.501	+	Gould 1975	[83]
$(d, p_{0,1})$	$\sigma(E)$, mb	0.359–2.582; 0.365–2.566	+	McClenahan 1975	[72]
$(d, p_{0,1})$	$\sigma(E)$, mb	0.088–0.730	+	Elwyn 1977	[73]
(d, p)	$S(E)$, MeV b	0.036–0.161	–	Cecil 1981	[84]
(d, p)	$\sigma(E)$, mb	0.075–0.135	–	Szabo 1982	[74]
$(d, p_{0,1})$	$\sigma(E)$, mb	0.375–1.873; 0.779–1.873	+	Dunjiu 1985	[75]
(d, p_1)	$S(E)$, MeV b	0.083–0.127	+	Czerski 1993	[39]
(d, p_0)	$S(E)$, MeV b	0.048–0.102	+	Czerski 1997	[85]
(d, p_{0+1})	$S(E)$, MeV b	0.0749	+	Lalremruata 2009	[79]
$(d, p_{0,1})$	$S(E)$, MeV b	0.024–0.052; 0.023–0.052	+	Fang 2016	[32]
$(d, p'\gamma)$	$\frac{d\sigma}{d\Omega}$, mb/sr	0.739–1.642	+	Taimpiri 2023	[86]
$(d, p_{0,1})$	$\frac{d\sigma}{d\Omega}$, mb/sr	1.498–7.491	+	Paneru 2024	[81]

TABLE XI. Experimental data for the reaction ${}^6\text{Li}(d, n){}^7\text{Be}$.

Reaction	Quantity	$E_{\text{c.m.}}$, MeV	EXFOR source	Our notation	Ref.
(d, n)	$\sigma(E)$, mb	0.086–0.253	+	Hirst 1954	[68]
(d, n)	$\sigma(E)$, mb	0.164–0.726	+	Barr 1975	[88]
$(d, n_{0,1})$	$\sigma(E)$, mb	0.368–2.188; 0.360–2.197	+	McClenahan 1975	[72]
$(d, n_{0,1})$	$\sigma(E)$, mb	0.153–0.654	+	Elwyn 1977	[73]
(d, n)	$\sigma(E)$, mb	0.225–0.697	+	Ruby 1979	[88]
$(d, n_1\gamma)$	$S(E)$, MeV b	0.047–0.119	+	Cecil 1982	[90]
(d, n)	$\sigma(E)$, mb	0.075–0.135	–	Szabo 1982	[74]
(d, n)	$S(E)$, MeV b	0.0966	+	Hofstee 2001	[91]
$(d, n\gamma)$	$\frac{d\sigma}{d\Omega}$, mb/sr	0.593–1.495	+	Aslani 2023	[92]
$(d, n'\gamma)$	$\frac{d\sigma}{d\Omega}$, mb/sr	0.739–1.642	+	Taimpiri 2023	[86]
$(d, n_{0,1})$	$\sigma(E)$, mb	1.498–7.491	+	Paneru 2024	[81]

for ${}^7\text{Be}(n, p_0){}^7\text{Li}$ were inferred from the reverse reaction ${}^7\text{Li}(p, n){}^7\text{Be}$. We adopt the tabulated values from Tables A3 and A4 of Ref. [61] for the Gibbons (1959) and Martín-Hernández (2019) inputs.

Legacy S factors from reverse data. For Borchers (1963), Burke (1974), Sekharan (1976), and Kumar (2012) we list $S(E)$ values obtained via the reverse channel using the relations summarized in Ref. [61].

d. Comments on ${}^6\text{Li}(d, p){}^7\text{Li}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$ data

Reprinted data. Ref. [72] includes the Bruno (1966) data from Ref. [87].

The paper [88] reports the Barr (1975) data from Ref. [89].

Angular vs total cross sections. Taimpiri (2023) reported $d\sigma/d\Omega$ at several angles. We used the 0° data multiplied by 4π to obtain the total cross section for the S -factor evaluation.

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