Constraints on the ^{22}Ne(α,n)^{25}Mg s-process neutron source from analysis of ^{nat}Mg+n total and ^{25}Mg(n,γ) cross sections

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The ^{22}Ne(α,n)^{25}Mg reaction is thought to be the neutron source during the s process in massive and intermediate mass stars as well as a secondary neutron source during the s process in low-mass stars. Therefore, an accurate determination of this rate is important for a better understanding of the origin of nuclides heavier than iron as well as for improving s-process models. Also, the s process produces seed nuclides for a later p process in massive stars, so an accurate value for this rate is important for a better understanding of the p process. Because the lowest observed resonance in direct ^{22}Ne(α,n)^{25}Mg measurements is considerably above the most important energy range for s-process temperatures, the uncertainty in this rate is dominated by the poorly known properties of states in ^{26}Mg between this resonance and threshold. Neutron measurements can observe these states with much better sensitivity and determine their parameters (except Γ_α) much more accurately than direct ^{22}Ne(α,n)^{25}Mg measurements. I have analyzed previously reported ^{nat}Mg+n total and ^{25}Mg(n,γ) cross sections to obtain a much improved set of resonance parameters for states in ^{26}Mg between threshold and the lowest observed ^{22}Ne(α,n)^{25}Mg resonance, and an improved estimate of the uncertainty in the ^{22}Ne(α,n)^{25}Mg reaction rate. For example, definitely two, and very likely at least four, of the states in this region have natural parity and hence can contribute to the ^{22}Ne(α,n)^{25}Mg reaction, but two others definitely have non-natural parity and so can be eliminated from consideration. As a result, a recent evaluation in which it was assumed that only one of these states has natural parity has underestimated the reaction rate uncertainty by at least a factor of 10, whereas evaluations that assumed all these states could contribute probably have overestimated the uncertainty.

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I. INTRODUCTION

During helium-burning and, perhaps, carbon-burning phases in massive and intermediate mass stars, the ^{22}Ne(α,n)^{25}Mg reaction is thought to be the neutron source driving the synthesis of nuclides in the $A\approx60$–90 mass range during the slow-neutron-capture (s) process [1,2]. The s process in these stars also can modify the abundances of several lighter nuclides. The ^{22}Ne(α,n)^{25}Mg reaction also acts as a secondary neutron source during the s process in low-mass asymptotic giant branch (AGB) stars during which roughly half the abundances of nuclides in the $A\approx90$–209 range are thought to be synthesized [3]. Although the overall neutron exposure due to this reaction in AGB stars is much smaller than that due to ^{13}C(α,n)^{16}O, the neutron density as well as the temperature are much higher during the ^{22}Ne(α,n)^{25}Mg phase, resulting in important modifications to the final s-process abundances. Massive stars during their later burning stages are also the leading candidates for the production of the rare neutron-deficient isotopes of nuclides in the $A\gtrsim90$ mass range through the so-called p process. Because the s process in these stars produces seed nuclides for a later p process, the size of the ^{22}Ne(α,n)^{25}Mg reaction rate used in the stellar model can have a significant effect on the predicted abundances of the p isotopes [4].

There have been several attempts to determine the rate for this reaction either through direct ^{22}Ne(α,n)^{25}Mg measurements [5–9] or indirectly via ^{26}Mg(γ,n)^{25}Mg [10] or charged-particle transfer reactions [8]. However, direct measurements have suffered from relatively poor resolution as well as the fact that the cross section is extremely small at the lower energies corresponding to s-process temperatures. Indirect methods have also suffered from limited sensitivity and relatively poor resolution. This rate, in principle, could be determined via the inverse ^{25}Mg(n,α)^{22}Ne reaction, but the small size of the cross section in the relevant energy range makes these measurements exceedingly difficult, so no results have been reported. As a result, various evaluations [7,11–13] of this rate show considerable differences and all but the most recent [9] recommend uncertainties much larger than needed to adequately constrain astrophysical models. Because the lowest observed resonance ($E_\alpha=832$ keV, which corresponds to $E_n=235$ keV in the inverse reaction) in direct ^{22}Ne(α,n)^{25}Mg measurements is considerably above the most important energy range for s-process temperatures, the uncertainty in this rate is dominated by the poorly known properties of states in ^{26}Mg between this resonance and threshold. Because both ^{22}Ne and ^{4}He have $J^\pi=0^+$, only natural-parity ($0^+,1^-,2^+\ldots$) states in ^{26}Mg can participate in the ^{22}Ne(α,n)^{25}Mg reaction, so only a subset of ^{26}Mg states in the relevant energy range observed via neutron reactions can contribute to the reaction rate. Most evaluations have made the assumption that either all, or only one, of the known states [14,15] in this region can contribute to the reaction rate. For example, in the recent Nuclear Astrophysical Compilation of Reaction rates (NACRE) [13] evaluation, all known states in this region were considered when calculating the uncertainty whereas in the most recent report [9] only one state was assumed to

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have natural parity. As a result, the recommended uncertainties in the NACRE evaluation are much larger than those in Ref. [9]. For example, at $T=0.2$ GK, the NACRE uncertainty is approximately 300 times larger than that given in Ref. [9].

Much of the information about states in ^{26}Mg in the relevant energy region comes from neutron measurements [16–18]. In principle, the combination of neutron total and capture cross section measurements on ^{25}Mg can determine all of the relevant resonance parameters (E_r, J^{π}, Γ_n, and Γ_{γ}) except Γ_{α} with much better sensitivity and to greater precision than other techniques. Both high-resolution $^{\mathrm{nat}}\mathrm{Mg}+n$ total and $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ cross sections have been reported [18] and some resonance parameters were extracted from these data. However, the resonance analysis was rather limited and it is possible to extract much more information using current techniques. For example, resonance shapes and peak heights in the total cross section should allow the extraction of J^{π} values, but no definite assignments were made in Ref. [18] for states in ^{26}Mg. Also, it should be possible to determine the partial widths for many of the resonances, but only five Γ_n and no Γ_{γ} values were reported for the 17 $^{25}\mathrm{Mg}+n$ resonances reported in Ref. [18]. Partial width information can be particularly valuable in assessing the relative strengths of the competing $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ and $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reactions in stars, and hence the efficiency of the *s*-process neutron source.

I have analyzed previously reported [18] $^{\mathrm{nat}}\mathrm{Mg}+n$ total and $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ cross sections using the multilevel, multichannel $\mathcal{R}$-matrix code SAMMY [19] to obtain a much improved set of resonance parameters for states from threshold through the lowest observed $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ resonances. In the next section, I describe the data and analysis technique used. In Sec. III, I compare the new results to previous analyses of neutron data as well as resonance parameter information from $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$, $^{26}\mathrm{Mg}(\gamma,n)^{25}\mathrm{Mg}$, and $^{22}\mathrm{Ne}(^{6}\mathrm{Li},d)^{26}\mathrm{Mg}$ measurements. In Sec. IV, I use the new resonance parameters together with recently reported [9] upper limits for the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ cross section to compute the uncertainty in this rate at *s*-process temperatures. I conclude that the most recent report [9] of this reaction rate has underestimated the uncertainty by at least a factor of 10 and that high-resolution $^{25}\mathrm{Mg}+n$ total cross section measurements would be invaluable in further refining the uncertainty in this important reaction rate.

II. DATA AND $\mathcal{R}$-MATRIX ANALYSIS

The best data for the present purposes are those of Ref. [18]. The data consist of very high-resolution $^{\mathrm{nat}}\mathrm{Mg}+n$ total and high-resolution $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ cross sections measured using time-of-flight techniques at the white neutron source of the Oak Ridge Electron Linear Accelerator facility [20–22]. Total cross sections were measured using a relatively thick (0.2192 atoms/b) metallic Mg sample and a plastic scintillator detector on a 200-m flight path. The neutron capture measurements were made using a thin (0.030 atoms/b), 97.87% enriched sample on a 40-m flight path, and employed the pulse-height weighting technique using fluorocarbon scintillators to detect the γ rays. Although total cross section measurements have been reported [16] using an enriched ^{25}Mg sample, the data are of much lower resolution and precision than those of Ref. [18].

The original, unaveraged $^{\mathrm{nat}}\mathrm{Mg}+n$ transmission data were obtained [23] to preserve the best resolution so that the best possible parameters could be obtained from fitting the data. The data between resonances were averaged to speed up the fitting process. Only a subset of the $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data, corresponding to energy regions near the resonances reported in Ref. [18] and extending to only $E_n=275$ keV, could be located [24]. These data were corrected by a factor of 0.9325 as recommended in Ref. [25]. The $^{24,26}\mathrm{Mg}(n,\gamma)^{25,27}\mathrm{Mg}$ data of Ref. [18] could not be found.

The data were fitted with the $\mathcal{R}$-matrix code SAMMY [19] to extract resonance parameters. All three stable Mg isotopes were included in the analysis because the sample for the total cross section measurements was natural Mg (78.99% ^{24}Mg, 10.00% ^{25}Mg, and 11.01% ^{26}Mg). Orbital angular momenta up to and including *d* waves were considered. Radii of 4.9 fm were used in all $^{25}\mathrm{Mg}+n$ channels as well as the $^{24}\mathrm{Mg}+n$ *d*-wave channels, and a radius of 4.3 fm was used in all $^{26}\mathrm{Mg}+n$ channels. Because ^{24}Mg is the major isotope in natural Mg and because the *s*- and *p*-wave penetrabilities are considerably larger than *d* wave at these energies, the *s*- and *p*-wave radii for $^{24}\mathrm{Mg}+n$ were allowed to vary while fitting the total cross sections. The fitted radii were 5.88 fm and 4.17 fm for *s* and *p* waves, respectively, in $^{24}\mathrm{Mg}+n$. All resonances up to the highest energy given in Ref. [18] (1.754 MeV) were included in the $\mathcal{R}$ matrix although I did not attempt to fit the total cross section data above 500 keV because the unavailability of $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data above 275 keV made it increasingly difficult to assign $^{25}\mathrm{Mg}+n$ resonances at the higher energies. The parameters of Ref. [18], supplemented by those in Ref. [14] in some cases, were used as starting points in the fitting process.

The starting parameters required considerable adjustments in some cases to fit the data. Some of these differences probably can be ascribed to the Breit-Wigner fitting approach of Ref. [18]. The resulting parameters are given in Tables I–III. All parameters for all observed resonances are included in these tables, even those that are not well determined, so that the present results could be duplicated if necessary. The $^{\mathrm{nat}}\mathrm{Mg}+n$ and $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data of Ref. [18] and the SAMMY fits are shown in Figs. 1 and 2, respectively.

Although I did not have $^{24,26}\mathrm{Mg}(n,\gamma)^{25,27}\mathrm{Mg}$ data to fit, the gamma widths for the strong resonances and the neutron widths for the weak resonances presented herein were calculated to be consistent with the corrected [25] neutron capture data of Ref. [18]. For strong resonances that were clearly visible in the total cross section data, the Γ_{γ} values in Tables I and II were calculated to yield the corrected [25] capture kernels ($g\Gamma_n\Gamma_{\gamma}/\Gamma$) given in Ref. [18]. Because $\Gamma_n \gg \Gamma_{\gamma}$ for these resonances, the choice of Γ_{γ} has a negligible effect on the fit to the total cross section data. For weak resonances not visible in the total cross section, I used $\Gamma_{\gamma}=3.0$ eV and the corrected [25] capture kernels of Ref. [18] to calculate the neutron widths. I used $\Gamma_{\gamma}=3.0$ eV because it appears to be

TABLE I. ^{24}Mg+n resonance parameters.

E_n (keV)	l	$2J^\pi$	Γ_γ (eV)	$g\Gamma_n$ (eV)
46.347±0.016	(1)	(1^-)	1.83 [a]	1.556±0.089
68.529±0.024	(1)	(1^-)	3 [b]	5.60±0.22
83.924±0.031	1	3^-	4.7 [a]	8007.0±5.0
176.700 [c]	(1)	(1^-)	3 [b]	0.314 [d]
257.18±0.12	(2)	(3^+)	1.13 [a]	26.9±1.0
266.10±0.12	1	1^-	5.2 [a]	80216±41
431.07±0.23	1	3^-	7.0 [a]	30082±22
475.35±0.27	2	5^+	1.04 [a]	13.8±1.3
498.27±0.28	1	3^-	0.38 [a]	520.0±4.6

[a]Gamma width calculated to yield the corrected (Ref. [25]) capture kernel given in Ref. [18].
[b]Assumed gamma width. See text for details.
[c]From Ref. [18]. Not observed in this work. See text for details.
[d]Neutron width calculated to yield the corrected (Ref. [25]) capture kernel given in Ref. [18].

close to the average gamma width for these nuclides. In these cases, it is clear that the neutron widths are fairly small. I also used $\Gamma_\gamma=3.0$ eV for those cases where neither capture kernels nor Γ_γ values were given in Refs. [14,18]. Because the neutron widths for these resonances are large, any physically reasonable choice of Γ_γ could be used to fit the total cross section data. I also used $\Gamma_\gamma=3.0$ eV in those cases where resonances were visible only in the ^{25}Mg(n,γ)^{26}Mg data and fitted the data to obtain the neutron widths. In these cases, only the capture kernels are well determined, so the individual Γ_γ and $2g\Gamma_n$ values given in Table III are rather arbitrary. However, the widths of peaks in the neutron capture data and/or the total cross section data can be used to set limits on neutron, and hence the total, widths in these cases. For these cases, the tenth column in Table III lists the limits on the total widths rather than the actual total widths ($\Gamma_\gamma+\Gamma_n$) used to fit the data.

One-standard-deviation uncertainties in the partial widths determined in fitting the data are also given in Tables I–III. Uncertainties in the partial widths were added in quadrature to obtain uncertainties in the total widths. Uncertainties in the resonance energies are dominated by the flight path length uncertainty, $\Delta d\approx 3$ cm. Because the flight path length for neutron capture was shorter than that for the total cross section measurements, energy uncertainties for resonances observed only in the neutron capture data are correspondingly larger. Weak and very broad resonances can also have additional non-negligible uncertainties in their energy associated with the fitting process. The two uncertainties were added in quadrature to obtain the values given in Tables I–III.

TABLE II. ^{26}Mg+n resonance parameters.

E_n (keV)	l	$2J^\pi$	Γ_γ (eV)	$g\Gamma_n$ (eV)
68.7 [a]	(1)	(1^-)	3 [b]	0.070 [c]
219.39±0.11	2	3^+	1.78 [d]	101.5±4.0
295.91±0.15	1	3^-	3 [b]	66920±170
427.38±0.25	(0)	(1^+)	4.3 [d]	3170±160
430.88±0.33	(1)	(1^-)	4.2 [d]	25990±290

[a]From Ref. [18]. Not observed in this work. See text for details.
[b]Assumed gamma width. See text for details.
[c]Neutron width calculated to yield the corrected (Ref. [25]) capture kernel given in Ref. [18].
[d]Gamma width calculated to yield the corrected (Ref. [25]) capture kernel given in Ref. [18].

If the neutron width of a resonance is large enough, then it is possible to discern its spin and/or parity. For example, s-wave resonances have a characteristic asymmetric shape in the total cross section due to interference with potential scattering. On this basis, the ^{25}Mg+n resonances at E_n $=19.880$, 72.674, 79.30, 100.007, 188.334, and 261.00 keV definitely can be assigned as being s wave. Similarly, although it is not possible to discern the parity of the ^{25}Mg$+n$ resonances at $E_n=156.169$ and 211.20 keV, they are definitely not s wave. In addition, the spins of the ^{25}Mg+n resonances at $E_n=19.880$, 72.674, 79.30, 100.007, 156.169, 194.502, 200.285, 244.58, 261.90, 311.56, 361.88, and 387.35 keV definitely can be assigned by virtue of the heights of the peaks in the total cross section (depths of the dips in the transmission spectrum).

For the present application, it is important to identify natural-parity resonances in ^{25}Mg+n because only they can participate in the ^{22}Ne(α,n)^{25}Mg reaction. On the basis of the neutron data alone, there are at least 16 states in ^{26}Mg between threshold and the lowest observed ^{22}Ne(α,n)^{25}Mg resonance, two of which ($E_n=19.880$ and 72.674 keV) definitely have natural parity and two others ($E_n=79.30$ and 100.007 keV) definitely have non-natural parity. From the present analysis, together with information from ^{26}Mg(γ,n)^{25}Mg measurements [10], two more (E_n $=62.738$ and 200.285 keV) of the states in this region can be assigned as natural parity. In the next section, this and other issues arising from comparisons to previous work are discussed.

III. COMPARISON TO PREVIOUS WORK

The ^{24,26}Mg+n resonance parameters of the present work are, with a few notable exceptions, in agreement with those of Refs. [14,18,25] to within the experimental uncertainties. Exceptions include the ^{24}Mg+n resonance at 46.347 keV which was previously assigned as a definite $\frac{3}{2}^+$ [14]. This resonance is so weak in the total cross section that it was not possible to make a firm J^π assignment in the present work. In addition, I find that the width of the ^{24}Mg+n resonance at 498.27 keV is almost ten-standard-deviations larger than that given in Refs. [14,18]. Also, the neutron width (and hence the total width) of the ^{26}Mg+n resonance at 219.39 keV was found to be four times smaller in the present work than that given in Refs. [14,18]. Also, a broad $\frac{1}{2}^{(-)}$ ^{26}Mg+n resonance at $E_n=300\pm4$ keV is listed in Ref. [14] but not in Ref. [18]. I find that the fit to the total cross section data is much improved if a ^{26}Mg+n resonance is included with an energy and width in agreement with those given in Ref. [14], but only if $J^\pi=\frac{3}{2}^-$. In addition, the 68.529-keV resonance

TABLE III. ^{25}Mg+n resonance parameters.

E_n (keV)					l	J^{π}	Γ_{γ} (eV)	$2g\Gamma_n$ (eV)	Γ (eV)		
This work	Ref. [15]	Ref. [18]	Ref. [9]	Ref. [10]					This work	Ref. [18]	Ref. [9]
19.880±0.014	19.7±0.2	19.90 [a]			0	2^{+}	1.732±0.031	2148±20	2580±24		
	51±6										
62.738±0.023	62.5±0.2	62.88	60±10	62.4	1 [b]	1^{-} [b]	4.79±0.29	7.2±2.1	19.2±4.2	24.6±2.2	
72.674±0.042	73.1±0.5	73.3		72.3	0	2^{+}	4.56±0.29	3870±83	4650±100	7600±1100	
79.30±0.15	79.4±0.2	79.6			0	3^{+}	6.17±0.24	2700±180	2320±150	1910±140	
81.13±0.14	81.2±0.7	81.35			(2)	(2^{+})	3 [c]	1.20±0.13	<75	20.3±2.6	
93.61±0.17	93.6±0.2	93.8			(1)	(1^{-})	3 [c]	0.270±0.044	<77		
100.007±0.050	99.6±0.2	99.8			0	3^{+}	2.92±0.18	6074±85	5210±73		
	102±2										
	105.5±0.2	105.8									
156.169±0.076	156.3±0.2	156.5			(1) [f]	$2^{(-)}$	7.42±0.60	3759±89	4520±110		
188.334±0.081	188.6±0.2	188.9			0	$(2)^{+}$	3.24±0.35	450±43	543±52		
194.502±0.085	194.0±0.2	194.2			(1)	$4^{(-)}$	0.59±0.24	2270±51	1514±34		
200.285±0.097				204	1	1^{-} [d]	0.79±0.46	628±50	1257±100		
201.062±0.095	201.3±0.3	201.6			(2)	(2^{+}) [e]	4.26±0.60	10.7±5.0	17.1±6.0		
203.86±0.44	204.0±0.3	204.3			(1)	(2^{-})	3 [c]	1.28±0.38	<32		
211.20±0.11	209.8±0.5	210			(1) [f]	(3^{-})	3.31±0.73	9400±140	8060±120	2630±230	
226.19±0.50	226.7±0.5	227			(1)	(1^{-})	3 [c]	0.56±0.20	<56		
242.45±0.55					(1)	(1^{-})	3 [c]	0.30±0.16	<43		
244.58±0.12	244.7±0.5	245	235±2	250	1 [g]	1^{-}	3.63±0.47	212±43	428±86		250±170
245.57±0.56	245±2				(1)	(1^{-})	3 [c]	1.40±0.50	<34		
253.67±0.58					(1)	(1^{-})	3 [c]	0.71±0.28	<48		
261.00±0.14	260.7±0.5	261			0	(2^{+})	1.18±0.27	128±35	155±42		
261.9±0.14					(1)	$4^{(-)}$	1.82±0.38	6200±280	4140±190		
	279.8±0.6										
	282.8±0.6										
	290.7±0.6										
311.56±0.15	311.7±0.6				(2)	$5^{(+)}$	3 [c]	532±35	293±19		
	345.7±0.7										
361.88±0.19	360.7±0.7		362±2		2 [g]	4^{+}	3 [c]	2200±120	1470±80		2100±900
	379±2										
387.35±0.21	385.8±0.8		383±2		3 [g]	5^{-}	3 [c]	12000±160	6550±87		9300±2500

[a] Attributed to Ref. [17] in Ref. [18].
[b] Spin and parity assignment based on Ref. [10].
[c] Assumed gamma width. See text for details.
[d] Parity assignment based on Ref. [10].
[e] $J>1$.
[f] $l>0$.
[g] Assigned natural parity observed in ^{22}Ne(α,n)^{25}Mg.

listed in Table I has not been noted in any previous study but is clearly visible in the total cross section data. This resonance should be visible in the isotopic (n,γ) data, but the data are not available in this energy range for ^{25}Mg, or at all for ^{24,26}Mg, so I tentatively assign this resonance to ^{24}Mg $+n$. The neutron width is clearly too large to correspond to the 68.7-keV resonance attributed to ^{26}Mg+n in Ref. [18]. Finally, this latter resonance as well as the 176.7-keV resonance in ^{24}Mg+n were not visible in the total cross section, but they are included in Tables I and II in the interest of completeness.

The ^{25}Mg+n parameters extracted in the present work are compared to parameters resulting from a previous analysis of these same data [18] as well as to information from ^{26}Mg(γ,n)^{25}Mg [10] and ^{22}Ne(α,n)^{25}Mg [9] measurements and to a recent compilation [15] in Table III. Unless otherwise noted, the parameters in Table III are from the present work. To aid the comparison between the various experi-

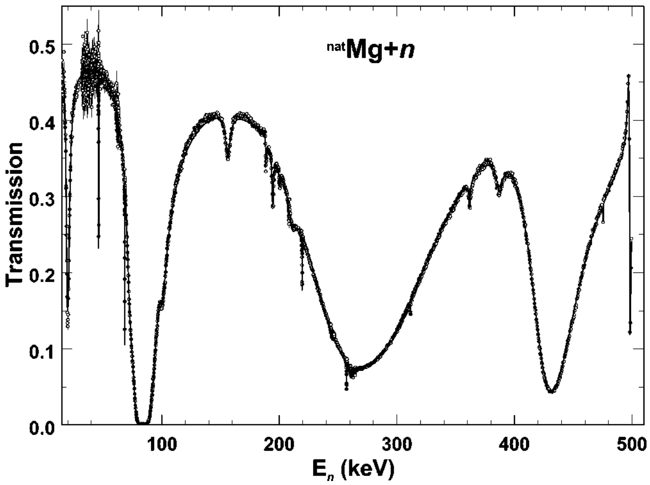

FIG. 1. $^{\mathrm{nat}}$Mg$+n$ total cross section data (points with error bars) from Ref. [18] (as transmissions) and SAMMY fit (solid curve).

ments, the energies of Refs. [9,10,15] have been converted to laboratory neutron energies using the Q values given in Ref. [15].

Overall, there is fairly good agreement between the results of the present work and previous studies although, except for excitation energies, there is sparse information about states in ^{26}Mg in this energy range from previous work. In order of increasing energy, important correspondences with and differences between the present and previous work are outlined in the next several paragraphs.

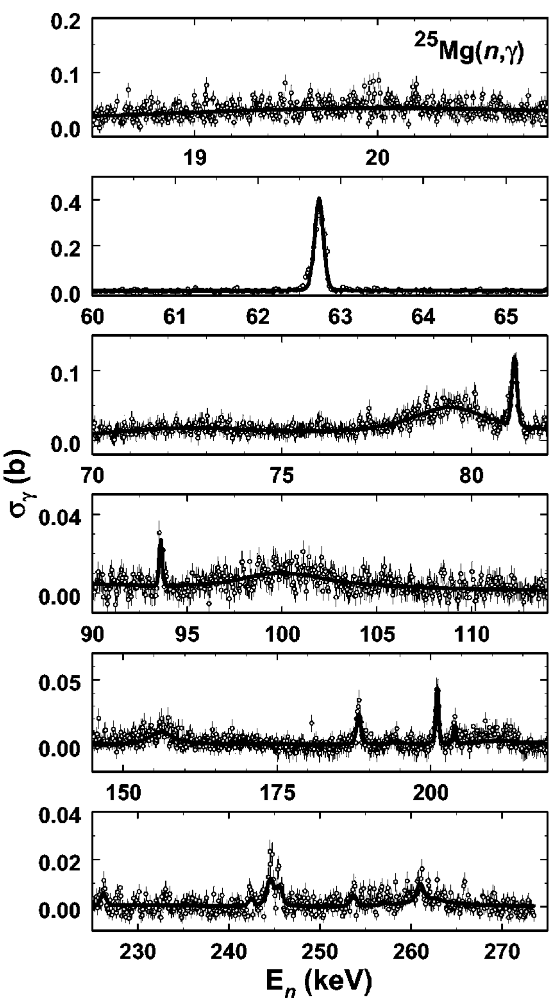

FIG. 2. ^{25}Mg(n,γ) cross section data (Ref. [18]) (points with error bars) and SAMMY fit (solid curves).

A. Neutron resonances below the lowest-energy ^{22}Ne$(\alpha,n)^{25}$Mg resonance

One of only two definite J^{π} assignments in this energy range was made in Ref. [17] at $E_n=19.9$ keV. This assignment is confirmed in the present work although the width needed to fit the data is considerably larger than that given in Ref. [17].

A natural-parity state at $E_x=11\,142$ keV ($E_n=51$ keV) tentatively assigned in Ref. [15] was not observed in this work. This state has been shown [7] to be an erroneous assignment [5,6] due to background from the ^{11}B$(\alpha,n)^{14}$N reaction.

Resonances at $E_n=62.738$ and 72.674 keV correspond well with the $E_L=54.3$- and 63.2-keV ($E_n=62.4$ and 72.3 keV according to Eqs. (7) and (8) in Ref. [26]) resonances observed in the ^{26}Mg$(\gamma,n)^{25}$Mg [10] reaction. Note that the neutron energies E_n, corresponding to the E_L values of Ref. [10], given in the footnote of Table 3 of Ref. [27] are incorrect. The former resonance was assigned as $J^{\pi}=1^-$ in Ref. [10] and is a strong resonance in ^{25}Mg$(n,\gamma)^{26}$Mg but because it is barely visible in the $^{\mathrm{nat}}$Mg$+n$ total cross section data, it is not possible to make a firm J^{π} assignment based on the data of Ref. [18]. The total width fitted in the present work is in agreement with Ref. [18] but the capture kernel I obtained is 30% smaller. The J^{π} value of the $E_L=63.2$-keV resonance is not discussed in Ref. [10], but the firm 2^+ assignment from the present work is consistent with the small size of the peak in the ^{26}Mg$(\gamma,n)^{25}$Mg data.

The precision of the width of the $E_n=81.13$-keV resonance given in Ref. [18] seems insupportable. This resonance could not be observed in the total cross section due to a nearby broad ^{24}Mg$+n$ resonance; hence, only the area and width of the peak in the ^{25}Mg$(n,\gamma)^{26}$Mg data can be used to determine the resonance parameters. The resolution of the experiment at this energy was 120 eV, or five times the width of the resonance assigned in Ref. [18]. I found that the data could be well fitted with widths as large as 75 eV. Because the data could be fitted by such a wide range of partial widths, I decided to hold Γ_{γ} fixed at 3 eV and vary only Γ_n while fitting the data.

The state in Ref. [15] at $E_x=11\,191$ keV ($E_n=102$ keV) was not observed in this work, but its existence cannot be ruled out due to the presence of the broad resonance at $E_n=100.007$ keV. A state at $E_x=11\,194.5$ keV ($E_n=105.5$ keV) is listed as a firm $J^{\pi}=2^+$ assignment having a fairly large width ($\Gamma=10\pm2$ keV) in Refs. [14,15] and apparently is based on the work of Ref. [18] in which a weak resonance was assigned at $E_n=105.8$ keV, although no width is given in this latter reference. Such a broad resonance easily would be visible in the total cross section data analyzed in this work, but there is no sign of it. Perhaps the compilers have confused it with the broad resonance at $E_n = 100.007$ keV. Although it is possible to add a small resonance at $E_n = 105.8$ keV, the fit to the data is not improved by its inclusion.

A doublet is required to fit the data near $E_n = 201$ keV rather than the single resonance listed in previous work. The lower resonance in this pair has a much larger neutron width than the upper one and definitely can be assigned as $J=1$. It appears to correspond to the $E_L = 182$ keV ($E_n = 204$ keV) resonance in $^{26}\mathrm{Mg}(\gamma,n)^{25}\mathrm{Mg}$ [10] and so is assigned natural parity in Table III.

The width of the resonance at $E_n = 211.20$ keV fitted in this work is three times larger than that determined in Ref. [18] and reported in Refs. [14,15]. Although it is clear that there is a broad $^{25}\mathrm{Mg}+n$ resonance at this energy, the data could not be fitted as well as one would like with any single resonance, although it is clear that a broad *s*-wave resonance is ruled out. There is also a fairly weak resonance just below the 211.20-keV resonance visible in the total cross section data. Because there is no sign of this resonance in the $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data, it is likely to be due to one of the other two Mg isotopes.

B. Which neutron resonance corresponds to the lowest-energy $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ resonance?

There are four neutron resonances ($E_n = 226.19$, 242.45, 244.58, and 245.57 keV) near the energy ($E_n = 235 \pm 2$ keV) corresponding to the lowest observed $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ resonance. None of these four resonances has an energy in agreement with the reported $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ resonance to within the experimental uncertainties, but only one ($E_n = 244.58$ keV) is broad enough to corresponed to the width reported in the latest $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ measurements [9]. It appears that either the width or the energy reported in Ref. [9] is in error, and if the reported width is correct, then the partial widths determined in this work indicate that different resonances near this energy have been observed in the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ and $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reactions.

The first two neutron resonances in this region ($E_n = 226.19$ and 242.45 keV) are visible only as small peaks in the $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data; hence, they have relatively small neutron widths. The higher-energy one has not been reported in any previous work. The upper two resonances in this region ($E_n = 244.58$, and 245.57 keV) appear as a partially resolved doublet in the $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data. Only the lower-energy one of this pair is visible in the $^{\mathrm{nat}}\mathrm{Mg}+n$ total cross section data, through which it definitely can be assigned $J=1$.

In addition to the previous analysis of these data [18] and the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ [5–7,9] work, resonances near this energy have been identified in $^{26}\mathrm{Mg}(\gamma,n)^{25}\mathrm{Mg}$ [10], $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ [27], and $^{22}\mathrm{Ne}(^{6}\mathrm{Li},d)^{26}\mathrm{Mg}$ [8] measurements. Data from the latter two and $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ reactions have been interpreted as having observed the same state in $^{26}\mathrm{Mg}$ corresponding to an $E_\alpha \approx 830$-keV resonance. If the fairly large width reported in Ref. [9] is correct, then the bulk of the width must be due to the neutron channel and a corresponding resonance easily would be visible in the data of Ref. [18]. In this case, the only possible corresponding resonance is at $E_n = 244.58$ keV. The energy of this resonance is almost five-standard-deviations higher than the energy determined in Ref. [9], but its width is in good agreement with Ref. [9] whereas all the other neutron resonances near this energy are too narrow. Given the much superior energy resolution of the data of Ref. [18], the excellent correspondence of the energies determined from the $^{\mathrm{nat}}\mathrm{Mg}+n$ total cross section and $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ data, and the vast quantity of data on other nuclides taken with this apparatus, it is extremely unlikely that the energy of the $E_n = 244.58$-keV resonance could be in error by such a large amount. Therefore, if the width in Ref. [9] is correct, then the reported energy must be almost 10-keV too low. Furthermore, if the width for the $E_\alpha = 832$-keV resonance reported in Ref. [9] is correct, then the parameters reported in that work and Ref. [27] indicate that different resonances were observed in the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ and $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ measurements, and the partial widths determined in this work indicate that the resonance observed in the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ measurements would not be seen in the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ measurements and vice versa.

The width ($\Gamma = 250 \pm 170$ eV) and strength $[\omega\gamma_{(\alpha,n)} = (2J+1)\Gamma_\alpha \Gamma_n/\Gamma = 118 \pm 11\ \mu\mathrm{eV}]$ for the $E_\alpha = 832 \pm 2$-keV resonance from the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ measurements [9], together with the strength $[\omega\gamma_{(\alpha,\gamma)} = (2J+1)\Gamma_\alpha \Gamma_\gamma/\Gamma = 36 \pm 4\ \mu\mathrm{eV}]$ of the $E_\alpha = 828 \pm 5$-keV resonance from the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ measurements [27] imply $\Gamma_\gamma = 58$ eV if the same resonance is being observed in both reactions. This is almost 20 times larger than the average radiation width for $^{26}\mathrm{Mg}$ and, although radiation widths vary more widely in this mass range than for heavier nuclides, it is considerably larger than any reported radiation width for nuclides in this mass range. Furthermore, the partial widths resulting from assuming the same resonance has been observed in both the (α,n) and (α,γ) channels imply a capture kernel $(g\Gamma_n \Gamma_\gamma/\Gamma)$ roughly ten times larger than observed for any of the four $^{25}\mathrm{Mg}(n,\gamma)^{26}\mathrm{Mg}$ resonances near this energy.

If instead different resonances were observed in the (α,n) and (α,γ) reactions, then the strength of the resonance observed in $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ together with the partial widths for the $E_n = 244.58$-keV resonance from the present work $(\Gamma_n/\Gamma_\gamma = 117)$ imply a resonance strength in the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reaction of $\omega\gamma_{(\alpha,\gamma)} = 1.0\ \mu\mathrm{eV}$, well below the sensitivity of the measurements of Ref. [27]. Similarly, if the $E_\alpha = 828$-keV resonance from $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ is identified with either the $E_n = 226.19$- or 242.45-keV resonance from the present work, then the strength from the $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ measurements together with the partial widths from the present work imply a strength in the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ reaction of about $\omega\gamma_{(\alpha,n)} = 10\ \mu\mathrm{eV}$. This is smaller than any resonance reported in Ref. [9], and in any case would have been obscured by the much stronger $E_\alpha = 832$-keV resonance if indeed different resonances near this energy were being observed in the $^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ and $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ reactions.

Alternatively, if the width reported in Ref. [9] for the $E_\alpha = 832 \pm 2$-keV resonance is too large, then it is possible that the same state in ^{26}Mg has been observed in the various reactions and the corresponding neutron resonance is at $E_n = 226.19$ or 242.45 keV. However, the energies still do not agree to within the reported experimental uncertainties.

Interestingly, a resonance at $E_L = 224$ keV, corresponding to $E_n = 250$ keV, was observed [10] in the ^{26}Mg$(\gamma,n)^{25}$Mg reaction and assigned $J=1$ in agreement with the $E_n = 244.58$-keV resonance of the present work, but it was tentatively assigned as being non-natural parity. Although no energy uncertainties were stated in Ref. [10], information given in Ref. [26] implies that the energy of the $E_L = 224$-keV resonance corresponds to the $E_n = 244.58$-keV resonance observed in this work to well within the experimental uncertainties. Also, a state in ^{26}Mg at $E_x = 11\,311 \pm 20$ keV (corresponding to $E_\alpha = 828$ or $E_n = 231$ keV), having a spectroscopic factor $S_\alpha = 0.04$, was observed in ^{22}Ne$(^6$Li$,d)^{26}$Mg measurements [8] and was assigned $J^\pi = 2^+$ although 1^- could not be ruled out. Because the energy resolution of the experiment was fairly broad ($\Delta E = 120$ keV), these measurements are not helpful in ascertaining whether there is more than one ^{22}Ne$+\alpha$ resonance near this energy.

C. Higher-energy resonances

The possible multiplet identified in Ref. [18] near $E_n = 261$ keV clearly shows up as a doublet in both the ^{25}Mg$(n,\gamma)^{26}$Mg and $^{\mathrm{nat}}$Mg$+n$ total cross section data. The lower-energy resonance of the pair is clearly *s* wave whereas the upper-energy one can be assigned as a definite $J=4$ resonance.

The lack of ^{25}Mg$(n,\gamma)^{26}$Mg data was a severe handicap to the analysis above this energy. However, the analysis was continued to $E_n = 500$ keV in an attempt to overlap with the ^{22}Ne$(\alpha,n)^{25}$Mg data as much as possible. Of the eight resonances listed in Ref. [15] in this region, three were observed, two of which correspond to ^{22}Ne$(\alpha,n)^{25}$Mg resonances.

The second and third lowest-energy ^{22}Ne$(\alpha,n)^{25}$Mg resonances [9] at $E_\alpha = 976$ and 1000 keV appear to correspond to the $E_n = 361.88$- and 387.35-keV resonances, respectively, observed in this work. There is fairly good agreement in the widths and energies between the neutron and ^{22}Ne$(\alpha,n)^{25}$Mg data. Curiously, the J values required to fit the neutron data imply rather high l_α values for these two resonances. Because the $E_n = 387.35$-keV resonance is also observed as a resonance at $E_\alpha = 1000$ keV in the ^{22}Ne$(\alpha,n)^{25}$Mg reaction, it is assigned as natural parity ($l_n = 3$) in Table III even though *f* waves were not included in the $\mathcal{R}$-matrix analysis. It should make little difference to the quality of the fit to the data that the fitted cross section was calculated with a *d*-wave rather than an *f*-wave resonance at this energy.

IV. IMPACT ON THE ^{22}Ne$(\alpha,n)^{25}$Mg ASTROPHYSICAL REACTION RATE

At *s*-process temperatures, the uncertainty in the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate is dominated by possible contributions from undetected resonances below the lowest observed resonance at $E_\alpha = 832$ keV. Most previous evaluations of this rate have assumed either that all the known states, or at most only a single state, in ^{26}Mg in this energy range can contribute to the reaction rate. To contribute to this reaction rate, the state must have natural parity. Two [14] or three [15] states in this region have been assigned natural parity in the compilations. As discussed above, two of these states do not even exist, let alone have natural parity. The third ($E_x = 11\,112.18$, $E_n = 19.880$ keV) was identified via the neutron total cross section measurements of Ref. [17] and this assignment was verified in the present work. In addition, another state ($E_x = 11\,162.95$, $E_n = 72.674$ keV) has been assigned definite natural parity ($J^\pi = 2^+$) in the present work, two others ($E_x = 11\,169.32$, 11 189.23, $E_n = 79.30$, 100.007 keV) have been assigned definite non-natural parity ($J^\pi = 3^+$), and together with information from ^{26}Mg$(\gamma,n)^{25}$Mg measurements [10], two more ($E_x = 11\,153.40$, 11 285.65, $E_n = 62.738$, 200.285 keV) can be assigned as very likely natural parity ($J^\pi = 1^-$). Therefore, at the very least four states of the 16 (17 if the $E_x = 11\,191$, $E_n = 102$ keV state of Ref. [15] is included) in this energy range should be included when estimating the contributions of possible low-energy resonances to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate, and two states definitely can be eliminated from consideration.

The yields below the lowest observed ^{22}Ne$(\alpha,n)^{25}$Mg resonance together with the quoted upper limit on the strength of the possible $E_\alpha = 635$-keV resonance from Ref. [9] can be used to estimate the contributions of this and other possible unobserved resonances to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate. Assuming that the thick target approximation applies [28], the upper limit on the resonance strength ($\omega\gamma_2$) of a possible resonance at energy E_2 having a yield Y_2 scales from the measured limits on the strength ($\omega\gamma_1$) and yield (Y_1) of the $E_\alpha = E_1 = 635$-keV resonance as

$$\omega\gamma_2 = \omega\gamma_1 \frac{Y_2 E_2}{Y_1 E_1}. \tag{1}$$

The yield limits of Ref. [9] in this energy are approximately constant, so I simply scaled the strengths of possible low-energy resonances from the measured limit for the $E_\alpha = 635$-keV resonance according to their energies. The contribution of these resonances to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate then can be estimated using the simple δ-resonance formula [29]:

$$N_A\langle\sigma v\rangle_r = 1.54\times 10^5 A^{-3/2} T_9^{-3/2} (\omega\gamma) e^{-11.605 E_r/T_9}. \tag{2}$$

Here A is the reduced mass, T_9 is the temperature in GK, $(\omega\gamma)_r$ is the resonance strength in eV, E_r is the center of mass resonance energy in MeV, and $N_A\langle\sigma v\rangle$ is the reaction rate in cm^3/s/mole. However, in some cases the widths of the resonances may be important, so I also calculated the reaction rate by numerically integrating the cross section calculated from the resonance parameters. To do this, I used the definitions of the resonance strength $[\omega\gamma_{(\alpha,n)} = (2J+1)\Gamma_\alpha \Gamma_n/\Gamma]$ and total width ($\Gamma = \Gamma_n + \Gamma_\gamma + \Gamma_\alpha$) to calculate the alpha widths $[\Gamma_\alpha = \omega\gamma(\Gamma_n + \Gamma_\gamma)/[(2J+1)\Gamma_n$

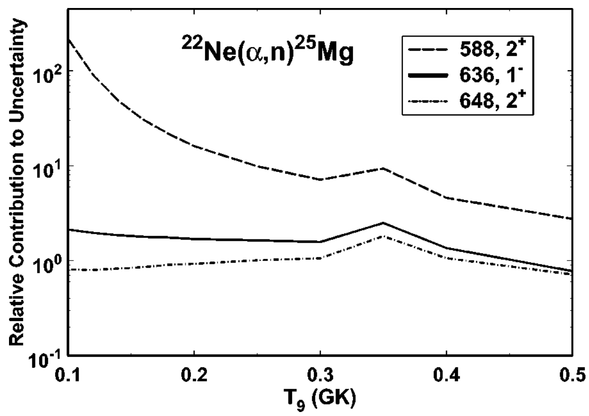

FIG. 3. Ratios of the individual contributions of three possible resonances (labeled by their laboratory alpha-particle energies and J^π values) to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate to the uncertainty (''high''-''recommended'') of Ref. [9] versus temperature.

$-\omega\gamma$]] from the scaled resonance strengths as well as the partial widths determined in the present work. Then, I used these partial widths in SAMMY to calculate the ^{25}Mg$(n,\alpha)^{22}$Ne cross section, from which the ^{22}Ne$(\alpha,n)^{25}$Mg cross section was calculated using detailed balance. The two approaches were in satisfactory agreement for the purposes of the present work. For example, using the measured [9] upper limit for the strength of the $E_\alpha=635$-keV resonance of 60 neV and the J^π, Γ_n, and Γ_γ values for the $E_n=62.738$-keV resonance in Table III leads to $\Gamma_\alpha<27$ neV, and a reaction rate at $T_9=0.1$ of 3.3×10^{-29} cm^3/s/mole from numerical integration and 3.4×10^{-29} cm^3/s/mole from the δ-resonance formula.

The contributions of the two definite natural-parity ($J^\pi=2^+$, $E_n=19.880$, and 72.674 keV) states and one very likely natural-parity state ($J^\pi=1^-$, $E_n=62.738$ keV) to the uncertainty in the reaction rate are shown in Fig. 3. Shown in this figure are the reaction rates due to each of the resonances divided by the difference between the ''high'' and ''recommended'' rates of Ref. [9]. The other very likely natural-parity state ($J^\pi=1^-$, $E_n=200.285$ keV) contributes much less to the uncertainty so it is not shown. As can be seen in Fig. 3, the present results indicate that the uncertainty in the reaction rate calculated in Ref. [9] is approximately a factor of 10 too small at s-process temperatures. Most of the increase in the uncertainty indicated by the present work results from inclusion of the $E_n=19.880$-keV resonance. The natural-parity nature of this state has been known for many years [17], but it often has been overlooked when estimating the uncertainty in the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate. Instead, most of the attention has been focused on the $E_n=62.738$-keV resonance since attention was first called to it in Ref. [10]. The contribution of the $E_n=62.738$-keV resonance to the reaction rate uncertainty appears to have been underestimated by a factor of 2 in Ref. [9]. Both the δ-resonance formula and numerical integration results using a resonance strength of 60 neV yield a reaction rate approximately twice as large as the ''high'' rate of Ref. [9] at the lower temperatures where their ''high'' rate is due mostly to this resonance. The reason for this difference is unknown, but the δ-resonance formula and numerical integration results were verified by a third technique [30] in which the reaction rate was calculated using a Breit-Wigner resonance shape.

Another effect that has been overlooked in previous evaluations of the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate is the uncertainty due to the resonance energy. As limits for resonance strengths are pushed lower and lower, the uncertainty in the energy of the resonance can become a significant effect. For example, in Ref. [9] the energy of the possible $E_\alpha=635$-keV resonance was estimated to be uncertain by ±10 keV. Using Eq. (2), this uncertainty in the resonance energy translates to a factor of 2.7 uncertainty in the reaction rate at $T_9=0.2$, which is comparable to the total uncertainty of a factor of 5.9 (''high''/''low'') at this temperature recommended in Ref. [9]. Although it is questionable that the energy of this state is so uncertain, the results of the present work should make it clear that energies resulting from analysis of the neutron data are so precise that this source of uncertainty now is practically eliminated.

V. SUMMARY AND CONCLUSIONS

I have analyzed previously reported ^{nat}Mg$+n$ total and ^{25}Mg(n,γ) cross sections to obtain parameters for resonances below $E_n=500$ keV. With a few notable exceptions, the obtained ^{24}Mg$+n$ and ^{26}Mg$+n$ parameters are in agreement with previous results to within the experimental uncertainties. The main focus of the present work has been to obtain an improved set of ^{25}Mg$+n$ parameters and hence an improved estimate of the uncertainty in the ^{22}Ne$(\alpha,n)^{25}$Mg astrophysical reaction rate. This reaction is the main neutron source during the weak component of the s-process nucleosynthesis as well as a secondary neutron source during the main component of the s process. The uncertainty in this rate at s-process temperatures is dominated by possible contributions from resonances between threshold and the lowest observed resonance.

The new ^{25}Mg$+n$ parameter set represents a substantial improvement over previous work. For example, several J^π assignments were made and the partial widths for most resonances were determined. In the previous analysis, no definite J^π assignments were made and very few partial widths were reported. Also, one previously reported [18] resonance was not observed and, if it does exist, has a width much smaller than reported in compilations [14,15]. In addition, four new resonances were observed in this energy range. Furthermore, corresponding resonances were found for all three of the ^{22}Ne$(\alpha,n)^{25}$Mg resonances as well as the four ^{26}Mg$(\gamma,n)^{25}$Mg resonances reported [9,10] in this energy range, although the energy or width of the lowest ^{22}Ne$(\alpha,n)^{25}$Mg resonances appears to be in error.

Only natural-parity states in ^{26}Mg can contribute to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate. Much attention has been focused on a ^{26}Mg$(\gamma,n)^{25}$Mg resonance at $E_L=54.3$ keV because it very likely has natural parity and therefore could correspond to a ^{22}Ne$(\alpha,n)^{25}$Mg resonance at $E_\alpha=636$ keV, nearly the optimal energy to make a large contribution to the reaction rate at s-process temperatures. The $\mathcal{R}$-matrix analysis of the present work revealed that of the 16 states observed, there are at least two, and very likely three, other definite natural-parity states in ^{26}Mg in this energy range and two definite non-natural-parity states. The parameters for these natural-parity states, together with yield limits from a recent ^{22}Ne$(\alpha,n)^{25}$Mg measurement [9], have been used to estimate the contributions of these states to this reaction rate. In a recent report [9], only one of these states ($E_{\alpha}=636$ keV) was considered, and it was concluded that the uncertainty in the reaction rate was much less than previously estimated. However, using the upper limit on the resonance strength of the possible $E_{\alpha}=636$-keV resonance reported in this reference, I calculate that they have underestimated the uncertainty due to this resonance alone by a factor of 2. More importantly, the definite natural-parity resonance at $E_n=19.880$ keV, which corresponds to a possible ^{22}Ne$(\alpha,n)^{25}$Mg resonance at $E_{\alpha}=588$ keV, contributes a ten times larger uncertainty to the rate at *s*-process temperatures.

There are still at least ten more states in ^{26}Mg observed in the neutron data that could contribute to the ^{22}Ne$(\alpha,n)^{25}$Mg reaction rate. It was not possible to make definite J^{π} assignments for these resonances because ^{25}Mg comprises only 10% of the ^{nat}Mg sample used in the total cross section measurements analyzed in this work. New high-resolution total cross section measurements on highly enriched ^{25}Mg samples could go a long way towards discerning how many of these states have natural parity. It may be that neutron elastic scattering measurements would also be needed in the more difficult cases. In addition, it would be useful to determine the energy and width of the lowest observed ^{22}Ne$(\alpha,n)^{25}$Mg resonance with improved precision. At present, the reported energy is not in good agreement with any observed neutron resonance, and the reported width implies that a different state at nearly the same energy has been observed in ^{22}Ne$(\alpha,\gamma)^{26}$Mg measurements.

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